Collective Effects in Relativistic Nuclear Physics: Historic Survey and Prospects

Anton Baldin

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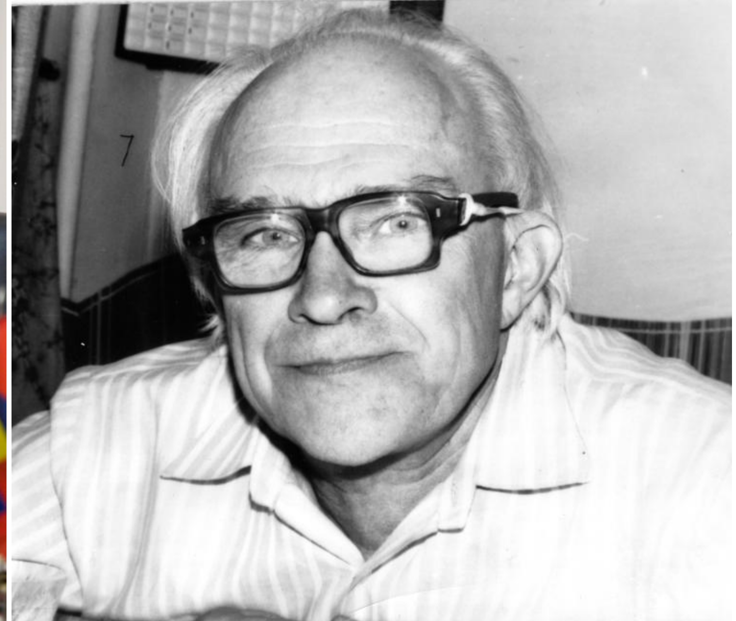

Алексей Норайрович
Сисакян
14.10.1944 -1.05.2010

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24.12.1929 – 27.06.2010

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SOVIET PHYSICS JETP VOLUME 6 (33), NUMBER 5 MAY, 1958

ON THE FLUCTUATIONS OF NUCLEAR MATTER

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J. Exptl. Theoret. Phys. (U.S.S.R.) 33, 1295-1299 (November, 1957)

It is shown that the production of energetic nuclear fragments in collisions with fast nucleons can be interpreted in terms of collisions of the incoming nucleon with the density fluctuations of the nuclear matter.

1. INTRODUCTION

THE motion of nucleons in nuclei can result in short-lived tight nucleon clusters, in other words, in density fluctuations of nuclear matter. Since such clusters are relatively far removed from the other nucleons of the nucleus, they become atomic nuclei of lower mass in a state of fluctuating compression.

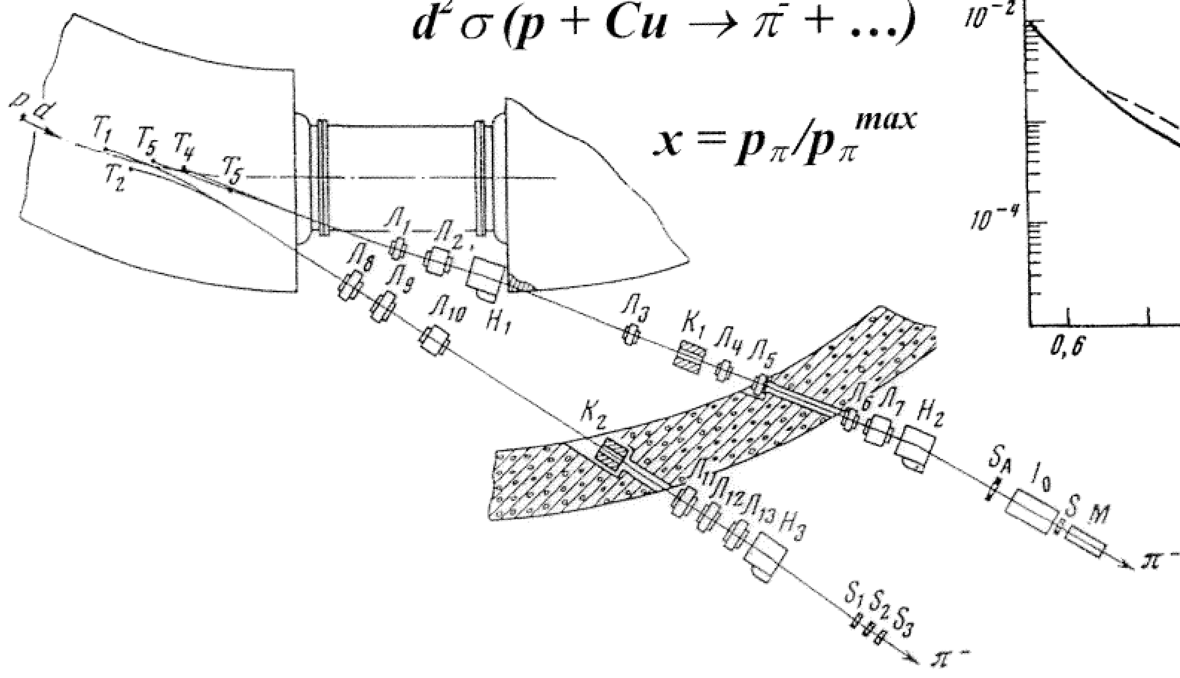
In their study of the scattering of 675-Mev protons by light nuclei, Meshcheriakov and coworkers[1,2] observed recently certain effects which confirm the existence of such fluctuations, at least for the simplest nucleon-pair fluctuations, which lead to the formation of a compressed deuteron.

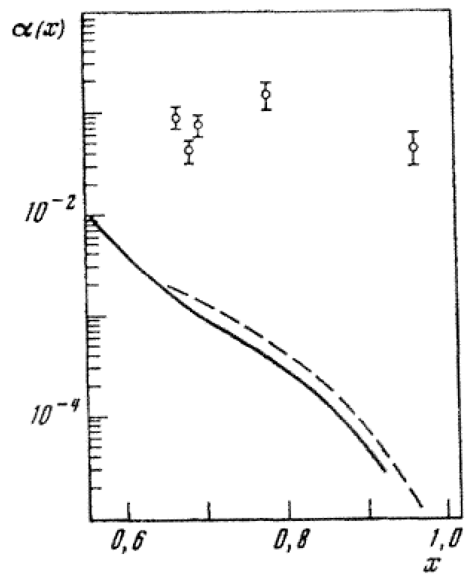
We recall in this connection reports in earlier works[3,4] that high-energy nucleons can split nuclei into "supra-barrier" fragments, i.e., fragments with an energy much larger than their binding energy and the energy of the Coulomb barrier. However, there was a lack of quantitative experimental data on which to base the theoretical analysis.

Some authors related this curious process, without foundation, to hypothetical long-range nuclear for-

$$\alpha(x) = \frac{d^2\sigma(d + Cu \to \pi^- + \ldots)}{d^2\sigma(p + Cu \to \pi^- + \ldots)}$$

$$x = p_\pi / p_\pi^{max}$$





ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
Дубна

Р1 - 5819

ЛАБОРАТОРИЯ ВЫСОКИХ ЭНЕРГИЙ

А.М. Балдин, Н. Гиордэнеску, В.Н. Зубарев,
А.Д. Кириллов, В.А. Кузнецов, Н.С. Мороз,
В.Б. Радоманов, В.Н. Рамжин, В.А. Свиридов,
В.С. Ставинский, М.И. Яцута

НАБЛЮДЕНИЕ ПИОНОВ ВЫСОКОЙ ЭНЕРГИИ ПРИ СТОЛКНОВЕНИИ РЕЛЯТИВИСТСКИХ ДЕЙТОНОВ С ЯДРАМИ

1971

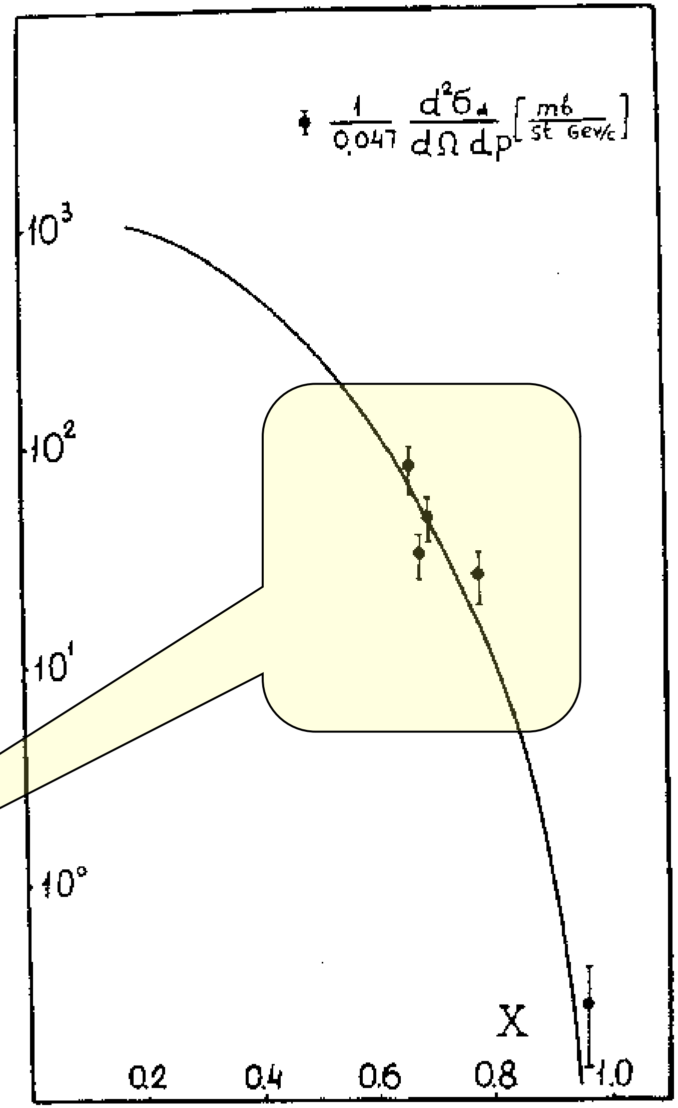


Рис. 3. Сравнение экспериментальных данных по сечению рождения пионов дейтронами с теоретической функцией, описывающей сечение рождения пионов протонами.

The first experimental data

LARGE MOMENTUM PION PRODUCTION IN PROTON NUCLEUS COLLISIONS AND THE IDEA OF "FLUCTUONS" IN NUCLEI

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Received 27 January 1977

It is shown that in proton-nucleus collisions, the production of pions with large momenta can be explained by the assumption of the existence of nuclear density fluctuations ("fluctuons") at short distances of the nucleon core radius order, with the mass of several nucleons.

The purpose of this note is to realize the idea [4] that the cumulative effect is connected largely with a suggestion on the existence in nuclei of the so-called fluctuons. Earlier fluctuons were proposed [7] in order to understand the nature of the "deuteron peak" in the pA-scattering cross section at large momentum transfers [8] and also to interpret the pd-scattering cross section [9]. Compressional fluctuations of mass $M_k = km_p$ of nucleons in the small volume $V_\xi = \frac{4}{3}\pi r_\xi^3$ where r_ξ is the fluctuon radius were assumed.

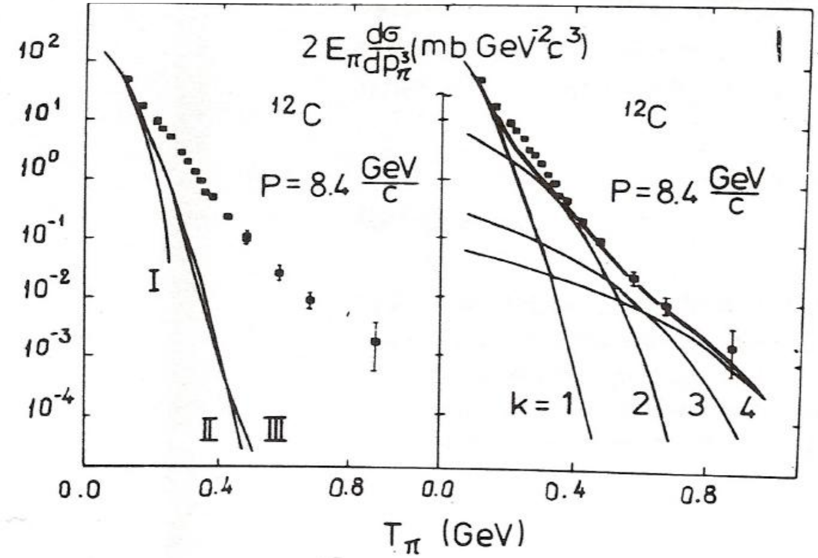

Fig. 1. (a) Calculations of the invariant pion production cross section for ^{12}C: I – for the free proton target; II – with fermi motion; III – the relativization effect. (b) The contributions of separate fluctuons with mass $M_k = km_p$ where k is the order of cumulativity.

«ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ И АТОМНОГО ЯДРА»,
1982, том 13, вып. 3

УДК 539.171.1

КВАРК-ПАРТОННАЯ КАРТИНА КУМУЛЯТИВНОГО РОЖДЕНИЯ

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Дается качественное сопоставление различных моделей кумулятивного рождения мезонов с экспериментальными данными.

вопросы. Мы в основном ограничились кумулятивным рождением мезонов, где ситуация, на наш взгляд, кажется несколько более простой и определенной, чем в рождении тяжелых частиц. В результате мы приходим к заключению, что флуктон является неким квазирезонансным образованием, существующим в ядре вне всякой связи с налетающей частицей, а кумулятивный мезон в исследованной сейчас области рождается в основном в результате диссоциации флуктона.

особенно в области малых p_T. Богатый материал для понимания механизма кумулятивного рождения могли бы дать поляризационные измерения и особенно рождение мезонов на поляризованных мишенях. Например, в картине жесткого рассеяния можно ожидать наличия сильной асимметрии [33], наподобие того, как это наблюдается в процессах с большими p_T [35].

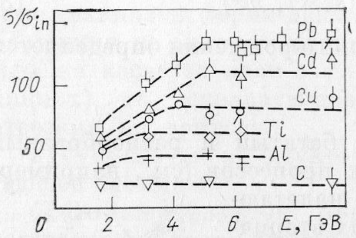

Рис. 2. Энергетическая зависимость сечения кумулятивного рождения протонов на разных ядрах

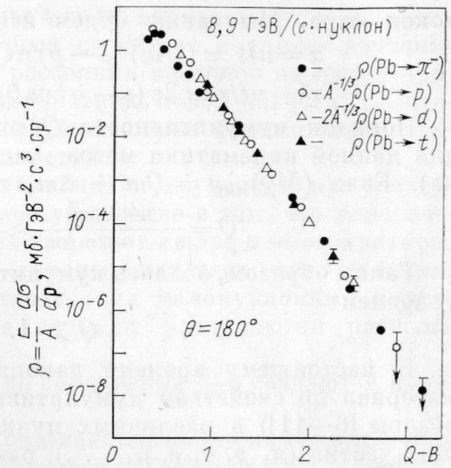

Рис. 3. Универсальность формы спектра кумулятивного процесса; B-барионное число кумулятивной частицы

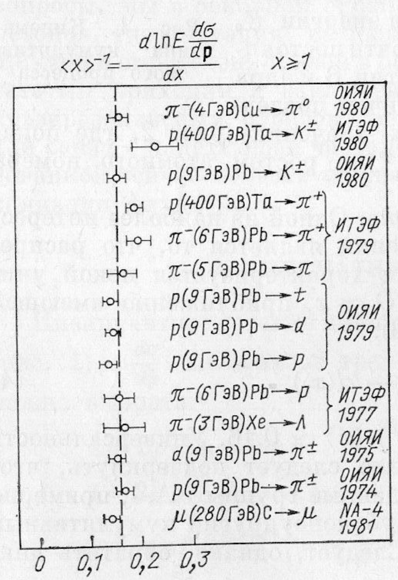

Рис. 4. Универсальность наклона спектра кумулятивного рождения по переменной x

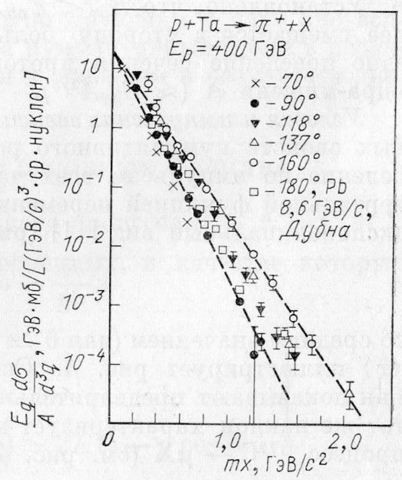

Рис. 5. Изменение наклона в зависимости от угла вылета

мание на то, что выражение (1) не передает всей угловой зависимости. При фиксированном значении x сечение с уменьшением угла падает [12] (рис. 5).

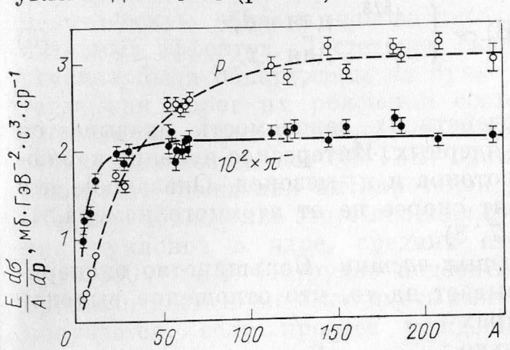

Рис. 6. Зависимость сечения кумулятивного рождения пионов и нуклонов от атомного номера, $p = 0{,}5$ ГэВ/c

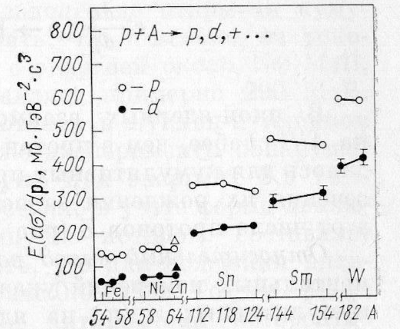

Рис. 7. Изотопический эффект сечения для кумулятивных протонов и дейтерия

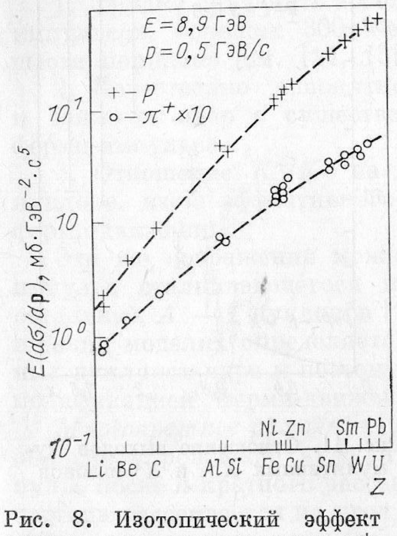

Рис. 8. Изотопический эффект сечения для кумулятивных π^+-мезонов

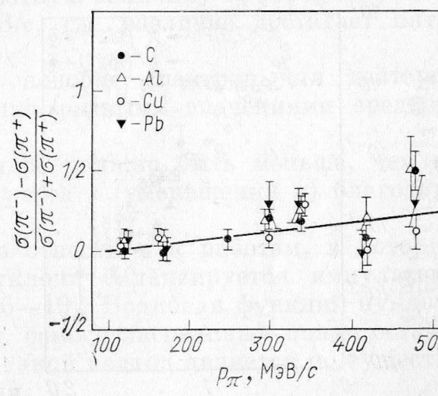

Рис. 9. Отношение выходов кумулятивных π^-- и π^+-мезонов

A-зависимость является наиболее специфической характеристикой кумулятивного процесса. Для точечных частиц (γ, e, μ) установлено, что $\varepsilon\, d\sigma/d\mathbf{p} \sim A$. Более сложная зависимость наблюдается для рождения адронов в адронных пучках (рис. 6):

$$\varepsilon \frac{d\sigma}{d\mathbf{p}} \sim \begin{cases} A & \text{для тяжелых ядер,} \\ A^{n>1} & \text{для легких ядер} \end{cases} \qquad (5)$$

IDENTIFICATION OF FLUCTON-FLUCTON INTERACTIONS AS AN APPROACH TO REGION OF HIGH TEMPERATURE AND DENSITY TYPICAL FOR QGP FORMATION

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A b s t r a c t

Based on the properties of cumulative particles, flucton charakteristics are derived as those of droplets of quark-gluon plasma (QGP) in the nuclear matter. A possibility is discussed to distinguish events of flucton-flucton interactions and to observe thereby a matter with an enchanced density corresponding to QGP.

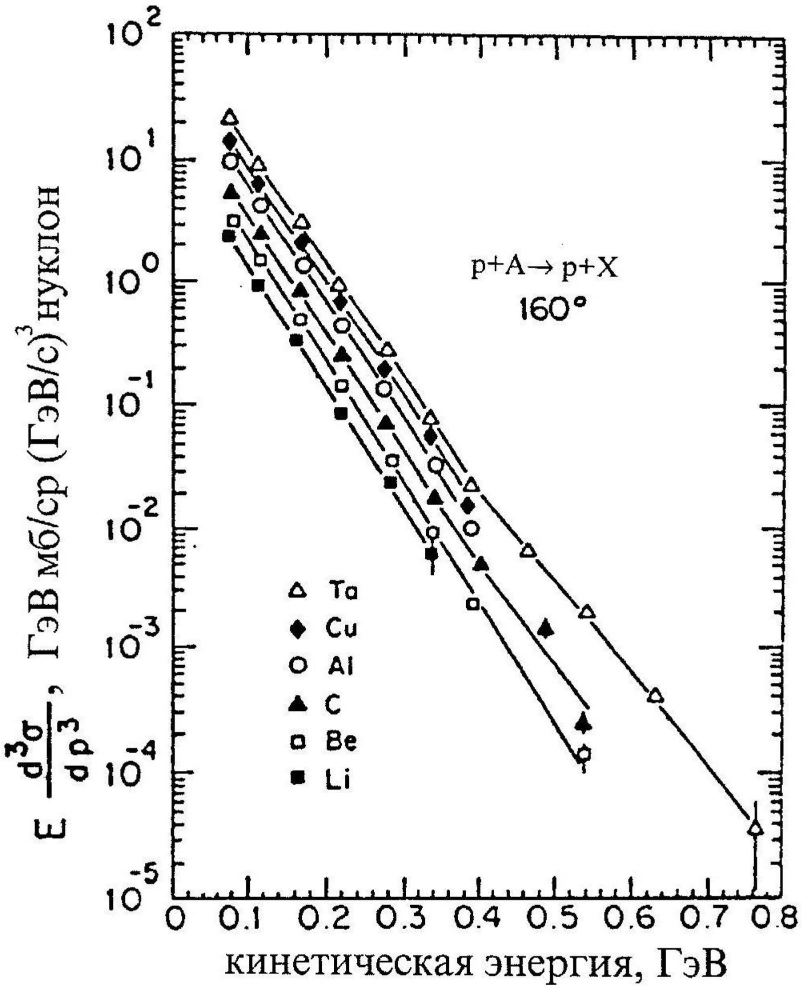
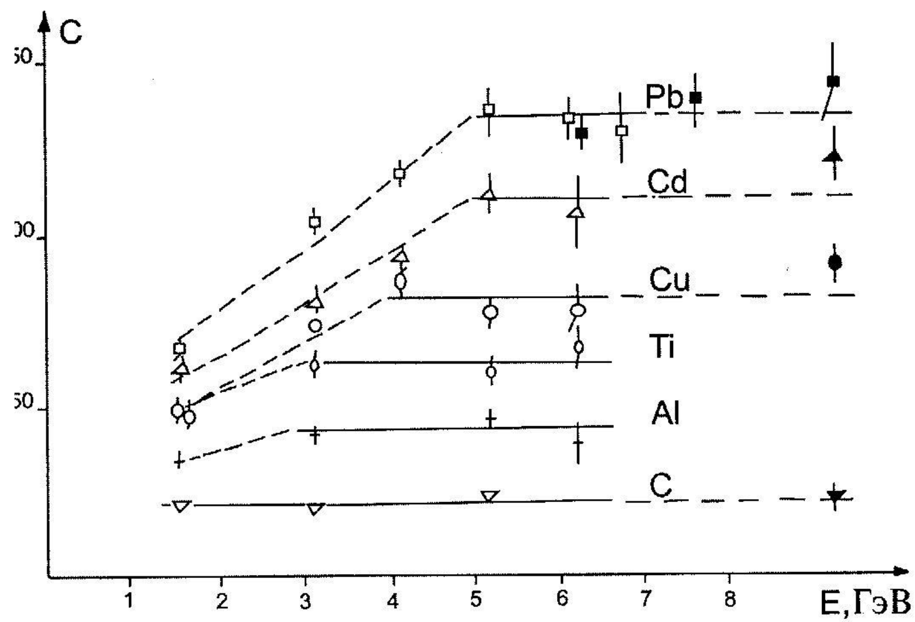


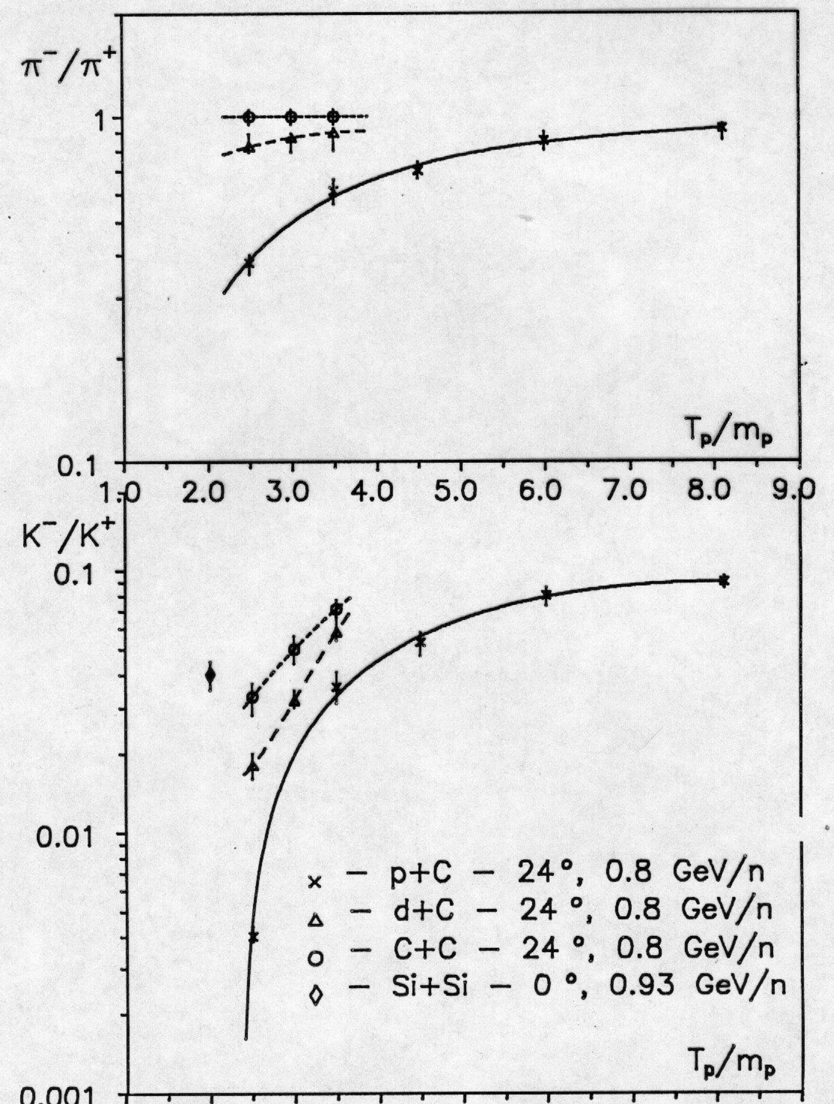
Рисунок 6: Инвариантные функции протонов, нормированные на число нуклонов в ядре мишени для разных ядер *(Li,Be,C,Al,Cu,Ta)*; протоны вылетали под углом 160^0 к направлению первичного пучка протонов с энергией 400 ГэВ



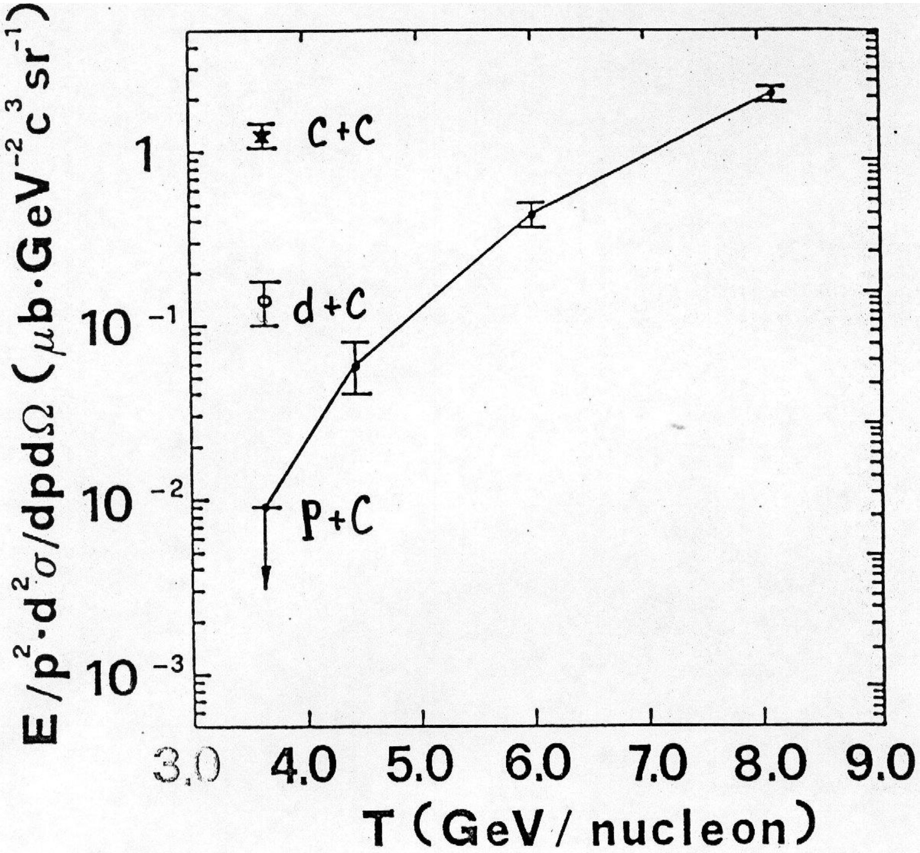
унок 3: Зависимость коэффициента C (T_0 =125 МэВ) в параметризации инвариантной кции $f=C\exp(-T/T_0)$ в реакции $pA(C,Al,Ti,Cu,Cd,Pb) \rightarrow pX$ для угла вылета протонов ^{0} в л.с. от импульса налетающих протонов. Правые точки относятся к начальной энер- 400 ГэВ

A.A.Baldin et.al Sov. JETP Lett.48 (1988)

A+A-> antiprotons



The ratio of invariant cross sections π^-/π^+ and k^-/k^+ as a function of projectile kinetic energy per nucleon.



Negative pion production in subthreshold heavy ion collisions

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Received 10 October 1990

Inclusive π^- spectra have been measured for ^{14}N+C collisions at 41*A*, 67*A*, 80*A* and 135*A* MeV, the lowest energies measured for the charged pion. The cross sections fall exponentially with T_π and the exponential slope factors at 90° in the nucleon–nucleon center of mass frame are determined. Energy distributions below a beam energy of 100*A* MeV are less steep than expected from the monotonic decrease of the slope factor down to 100*A* MeV. The production mechanism of energetic pions far below threshold is discussed for several models.

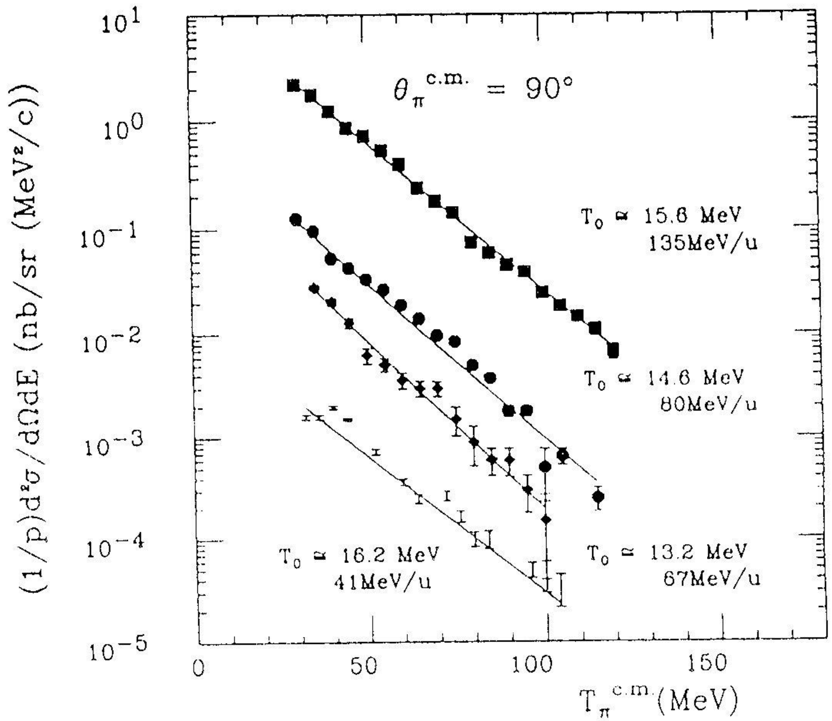

Fig. 2. The Lorentz-invariant cross sections, $(1/p)\mathrm{d}^2\sigma/\mathrm{d}\Omega\,\mathrm{d}E$, for inclusive π^- production in ^{14}N+C collisions, at the energies indicated. Only statistical errors are shown in the plot. T_0 is the slope factor when the cross sections are parameterized by $\exp(-T_\pi/T_0)$.

hep-ph/9710411

NUCLEAR STRUCTURE FUNCTIONS AND CUMULATIVE PROCESSES[1]

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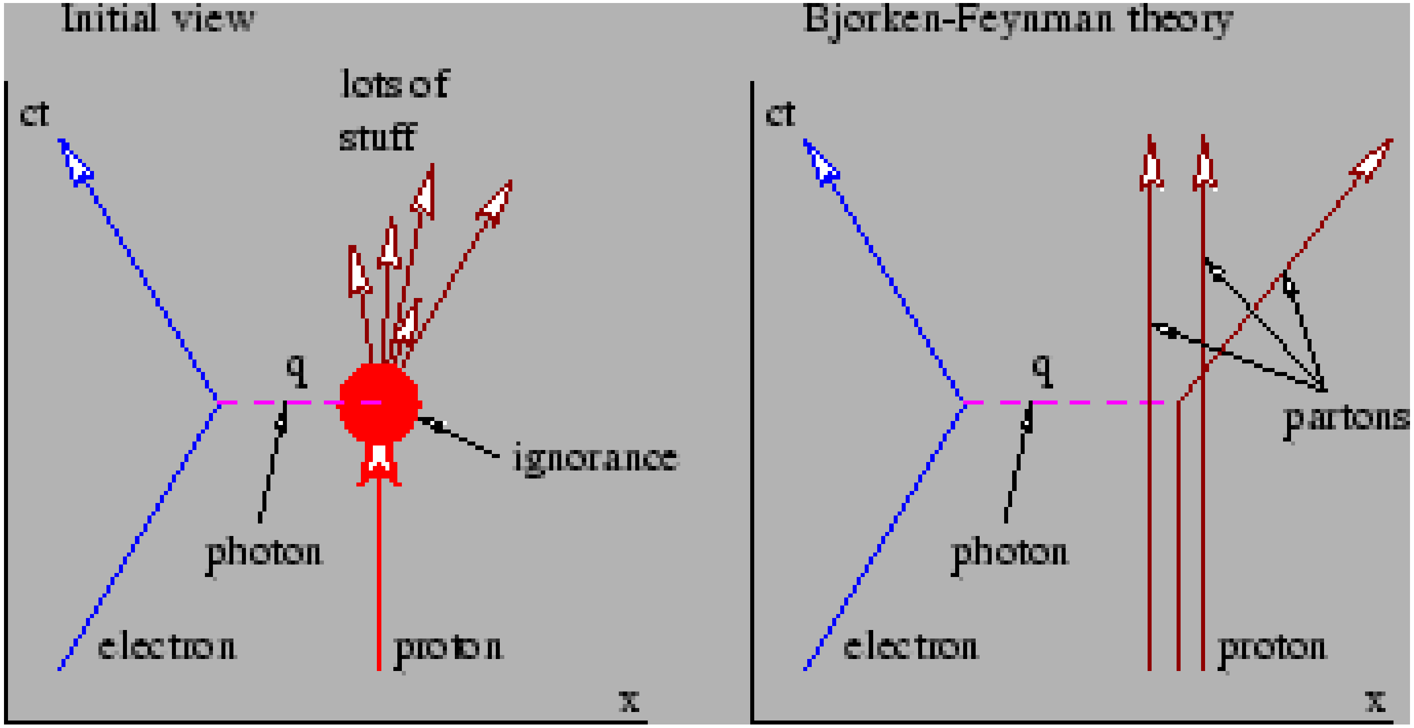
A question arises however: to what extent is the cumulative production cross section determined by the nuclear structure functions FA (x)? Until now there are no quite reliable data for nuclear deep inelastic scattering in the region x ≥1, though there are some indications of similarity of the cumulative meson spectra and structure function F2 (x) in this region [25].

Self-similarity in particle physics - history



$$x = -\frac{q^2}{2P_2 q}$$

$P^2 >> M^2$

Self-similarity following from dimensionality considerations

Bjorken self-similar solution

$$P_1 + xP_2 = P_1' + \sum P_i'$$

$$\left(P_1 + xP_2 - P_1' \right)^2 = \left(\sum P_i' \right)^2$$

$$P_1 - P_1' = q$$

$$\left(q + xP_2 \right)^2 = \left(\sum P_i' \right)^2$$

$$2\sum_{k,l} \left(\gamma_{kl} - 1 \right) M_k M_l$$

$$q^2 + 2xP_2 q + x^2 P_2^{\,2} = M^2$$

$$x = -\frac{q^2}{2P_2 q}$$

The cumulative effect

$\mathrm{I} + \mathrm{II} \rightarrow 1 + \ldots$

$$(U_1 U_{II}) > (U_I U_{II}) >> 1$$

$$X_I \geq \frac{m_1}{m_0} \cdot \frac{(U_1 U_{II})}{(U_I U_{II})} = \frac{m_1}{m_0} \cdot x_1 \geq 1$$

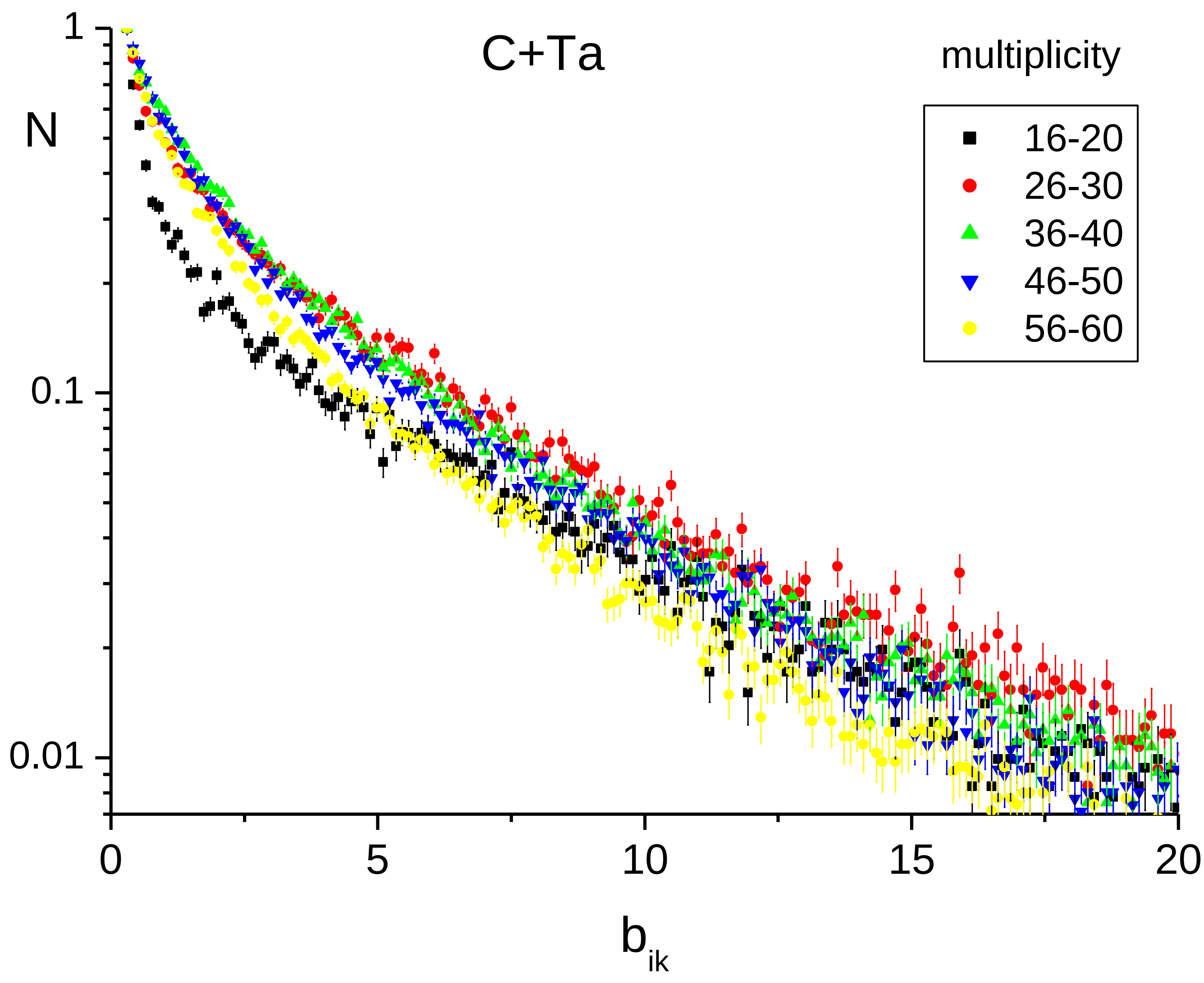
x_I – the light-cone variable.

X_I - the effective number of nucleons of nucleus I participating in the reaction.

$$W^I \propto A^{m(X_I')} \exp\left[\frac{X_I}{< X >}\right],$$

$$(X_I P_I + P_{II} - P_1)^2 = (\sum P_i)^2 = (\sum m_i)^2 + \sum_{i>j} m_i m_j b_{ij}$$

Hypothesis! The recoil is absorbed by the baryon cluster, for which $<b_{ij}> << 1$.



C+Ta
multiplicity
16-20
26-30
36-40
46-50
56-60
N
1
0.1
0.01
0
5
10
15
20
b_ik

Краткие сообщения ОИЯИ №18-86 *JINR Rapid Communications No.18-86*
УДК 539.12.01

ЕДИНЫЙ АЛГОРИТМ ВЫЧИСЛЕНИЯ ИНКЛЮЗИВНЫХ СЕЧЕНИЙ РОЖДЕНИЯ ЧАСТИЦ С БОЛЬШИМИ ПОПЕРЕЧНЫМИ ИМПУЛЬСАМИ И АДРОНОВ КУМУЛЯТИВНОГО ТИПА

В.С.Ставинский

Предложен единый алгоритм вычисления инклюзивных сечений рождения частиц с большими поперечными импульсами и адронов кумулятивного типа. Возможность единого описания этих процессов обусловлена введением нового аргумента – минимальной энергии сталкивающихся конституентов, необходимой для рождения наблюдаемой частицы. Проведено сравнение с экспериментальными данными.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Unique Algorithm for Calculation of Inclusive Cross Sections of Particle Production with Big Transverse Momenta and of Cumulative Type Hadrons

V.S.Stavinskij

Unique algorithm is proposed for calculating inclusive cross sections of particle production with big transverse momenta and cumulative type hadrons. A possibility of unique description of these processes is due to introduction of a new argument – of minimal energy of colliding constituents needed for the production of observed particle.

The investigation has been performed at the Laboratory of High Energies, JINR.

больших величинах $S_{min}^{1/2}$ сильно увеличиваются с ростом первичной энергии.

Как показал анализ, параметр, описывающий энергетическую зависимость,

$$G = S_{min}^{1/2} / (X_I \cdot M_I + X_{II} \cdot M_{II}) = S_{min}^{1/2} / (Q_I + Q_{II}) \qquad /5/$$

есть отношение минимальной энергии к сумме масс сталкивающихся конституентов, соответствующих этому минимуму.

Для процессов с большими $P_\perp$ этот параметр есть γ-фактор лоренцевского сжатия сталкивающихся нуклонов ($G \approx \approx \sqrt{s}/2M_N$).

Для процессов кумулятивного типа $G = 1,3 \div 2,5$ и очень слабо зависит от первичной энергии. Заметим, что такого порядка величины и γ-фактор фрагментирующего ядра.

3. *Сравнение с экспериментальными данными*

По первоначальному замыслу цель этой работы сводилась к нахождению аналитического вида функции регрессии для последующего фитирования и нахождения свободных параметров в описании сечений рождения кумулятивных пионов и π^0-мезонов с большими $P_\perp$. Однако оказалось, что введением небольших поправок удается воспроизвести нетривиальную и многогранную картину экспериментальных данных по кумулятивному рождению и большим $P_\perp$ для разных частиц.

С помощью единого алгоритма удалось описать выходы протонов, как кумулятивных, так и с большими $P_\perp$, и K^+-мезонов. Эти частицы составляют отдельный класс событий по А-зависимости сечений /сечения возрастают сильнее, чем $A^{4/3}$ /.

Инвариантные инклюзивные сечения рождения частиц $\frac{1}{A} E \frac{d\sigma}{d\bar{p}}$ имеют в первом приближении экспоненциальную зависимость

$$\frac{1}{A} E \frac{d\sigma}{d\bar{p}} = \sigma_0 F_1(G) \cdot F_2(A) \cdot \exp\{-(D_0 + D_1)(S_{min}^{1/2} - B)\}, \qquad /6/$$

где σ_0 - нормировка / σ_0 = 66 мб и для странных частиц 22 мб на единицу фонового объема/.

$$F_1(G) = 1 + |\ln(G - 0,9)|, \qquad /7/$$

$$F_2(A) = \left(\frac{1 - (C_1 \cdot \phi_1/M_{II})^{1/3}}{1 - (C_1 \cdot \phi_1/194)^{1/3}}\right)^3; \quad C_1 = 1 \text{ для } M_{II} \ge 10, \qquad /8/$$

$$\phi = \left(\frac{m_2}{m_2 + 10^{-3}}\right)\left(\frac{m_1 - m_2}{(m_1 - m_2) + 10^{-3}}\right); \qquad /9/$$

$$0,1 + \frac{Y_1 + Y_2 |S_{min}^{1/2} - 3|}{Y_3 \cdot Y_4};$$

$$C_2\left(1 + \frac{0,0513\,(G - 1,3)}{1 + 0,039 \cdot G^{1,23}}\right); \quad C_2 = 2,578; \qquad /10/$$

$$\frac{0,22\left(\frac{(Q_I/Q_{II})^2}{(Q_I/Q_{II})^2 + 10^{-4}}\right)}{1 + 133(1 + 3(m_1 - m_2)^5 (Q_I/Q_{II})^4} \cdot \exp(-25(G - 1,59)^2),$$

Q_{II} - массы сталкивающихся конституентов, соответст-

х минимуму энергии взаимодействия (S_{min})

$X_I \cdot M_I \quad Q_2 = X_{II} \cdot M_{II}$)

$$1 + C_3 \frac{S_{min}^{1/2}}{1 + 14/G + (6,4/G)^8} + \frac{1,73 \cdot 10^{-3} S_{min}}{1 + (6600/GS_{min})^6}; \quad C = 0,157;$$

$$= 1 - 0,26 \frac{S_{min}}{M_I^2 + M_{II}^2 + 2(E_I \cdot E_{II} + P_I P_{II})},$$

$$C_4\left(\frac{Y_5 \cdot Y_6}{Y_7} \cdot \frac{G - Y_8}{G^{1,5}} - \frac{0,087}{1 + 0,12(G - 5)}\right)\phi_2, \qquad /11/$$

$$= \left(\frac{m_2}{m_2 + 10^{-3}}\right) \cdot \frac{1}{1 + (m_1 - m_2)10^3}; \quad C_4 = 1,15, \qquad /12/$$

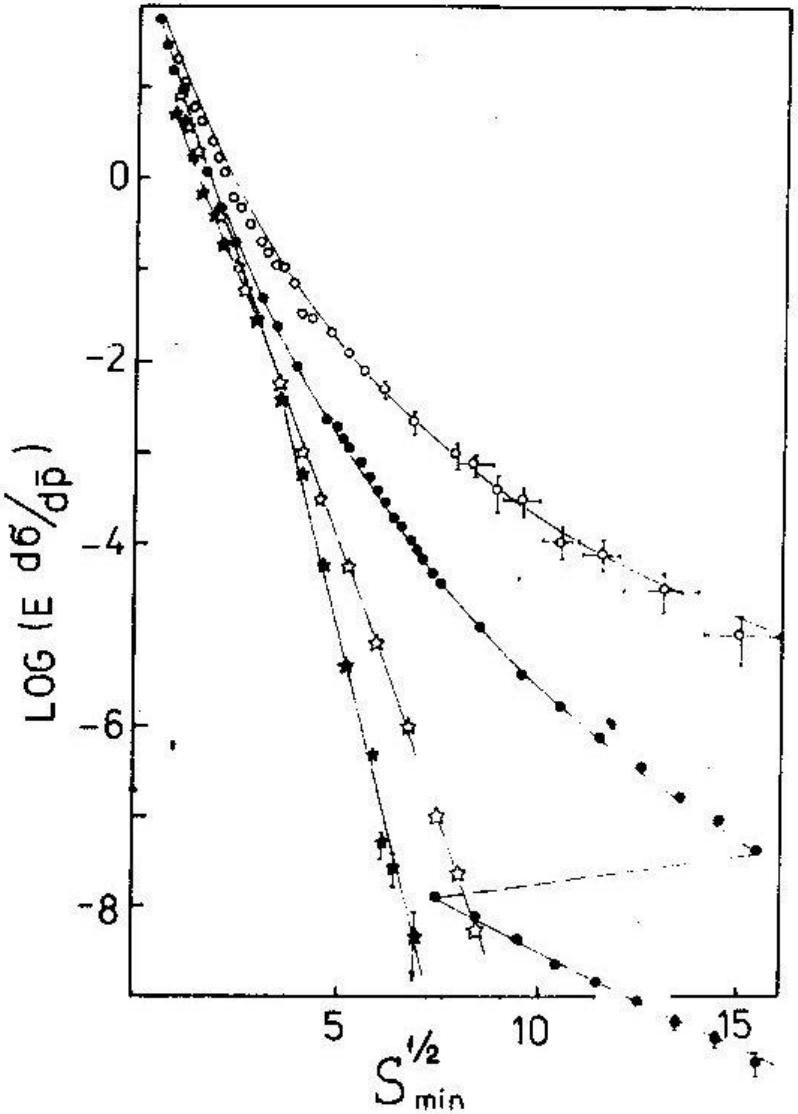
$$= (m_1 + m_2) + \frac{0,58}{1 + (m_1 + m_2)^4}\left(1 - \frac{(m_1 + m_2)}{0,273 + 13/G^2}\right);$$

$$= 1 + 4 \cdot 10^{-5} \frac{(m_1 + m_2)^2}{1 + 0,33(m_1 + m_2)^8}(S_{min}^{1/2} - (m_1 + m_2))^4,$$

$$= 1 + \left(\frac{1,56\,(1 + 0,001 \times G)^2}{S_{min}^{1/2} - (m_1 + m_2)}\right)^2 + \frac{0,5(m_1 + m_2)^2}{1 + 10^{-4}(m_1 + m_2)^4},$$

$$= \frac{1,6}{1 + C_5((m_1 + m_2)/G)^4}; \quad C_5 = 1,$$

Рис.1. Зависимость от минимальной энергии взаимодействующих конституентов инклюзивных сечений рождения как пионов кумулятивного типа (✶), так и пионов с большими $P_\perp$: (☆) – протон-протонные взаимодействия при энергии протонов 70 ГэВ, (●) – встречные протон-протонные взаимодействия при энергии пучков 31,5 ГэВ:, (○) – протон-антипротонные взаимодействия при энергии пучков 270 ГэВ. Кривые – расчет по формуле /6/.



THE UNIVERSITY OF CHICAGO
CHICAGO · ILLINOIS 60637
THE ENRICO FERMI INSTITUTE
5630 ELLIS AVENUE

November 25, 1974

Professor A. Baldin, Director
Laboratory of High Energies
Joint Institute for Nuclear Research (Dubna)
P. O. Box 79 Moscow
U.S.S.R.

Dear Professor Baldin:

Please excuse my delay in responding to your letter of October 14. We have been writing up the final version of our work at the Fermilab on hadron production at high transverse momentum, and I wanted to wait until that was ready before responding. I am sending you, under separate cover, a copy which is complete except that a few figures are not in final form, a fact I hope you will excuse.

I was pleased to receive your paper on backward pion production on nucleii. There are certainly some similarities in the two processes, in particular a comparison of your Fig. 14 with our Fig. 17.

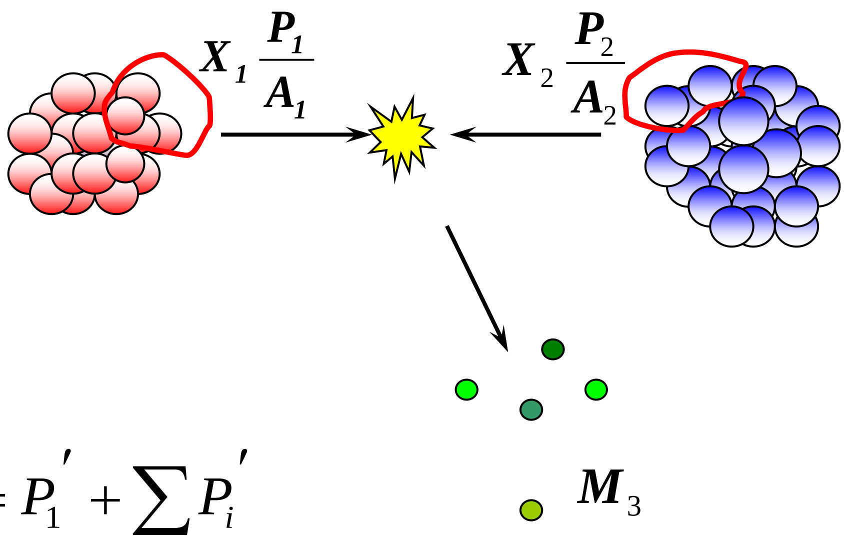
I look forward to seeing you again at a future conference.

Sincerely yours,

James W. Cronin

James W. Cronin

Self-similar solution for relativistic interacting particles



$$X_1 P_1 + X_2 P_2 = P_1' + \sum P_i'$$

$$\left(X_1 M_1 u_1 + X_2 M_2 u_2 - M_3 u_3\right)^2 = \left(M_1 X_1 u_1' + M_2 X_2 u_2' + \sum_{k=4} M_k u_k\right)^2$$

Correlation depletion principle in the relative four-velocity space enables us to neglect relative motion of not detected particles, namely $2\sum_{k,l}(\gamma_{kl} - 1)M_k M_l$ on the right-hand side of this equation.

Self-similar solution for relativistic interacting particles

$$X_1 X_2(\gamma_{12}-1) - X_1\left(\frac{M_3}{M_p}\gamma_{13} + \frac{M_4}{M_p}\right) - X_2\left(\frac{M_3}{M_p}\gamma_{23} + \frac{M_4}{M_p}\right) = \frac{M_4^2 - M_3^2}{2M_p}$$

In the case of production of an antiparticle with mass M_3, M_4 is equal to M_3 , due to conservation of quantum numbers.

X_1 and X_2 are obtained from the minimum Π , and are used to construct a universal description of A-dependencies.

$$\Pi = \frac{1}{2}\left(X_1^2 + X_2^2 + 2X_1X_2\gamma_{12}\right)^{1/2} \qquad S = (P_1 + P_2)^2$$

$$E\frac{d^3\sigma}{d^3p} = C_1 A_1^{\alpha(X_1)} A_2^{\alpha(X_2)} f(\Pi)$$

The relationship between X_1 and X_2 is described by the laws of conservation written in the form

$$\left(X_1 M_1 u_1 + X_2 M_2 u_2 - M_3 u_3\right)^2 = \left(M_n X_1 u_1' + M_n X_2 u_2' + \sum_{k=4} M_k u_k \right)^2$$

Here M_n is the nucleon mass, and M_3 the mass of an emitted particle. Essentially, we are using an experimentally proved correlation depletion principle in the relative four-velocity space which enables us to neglect the relative motion of not detected particles, namely the quantity $2\sum_{k>1}\left(\gamma_{kl} - 1\right) M_k M_l$ in the right-hand part of the above equation.

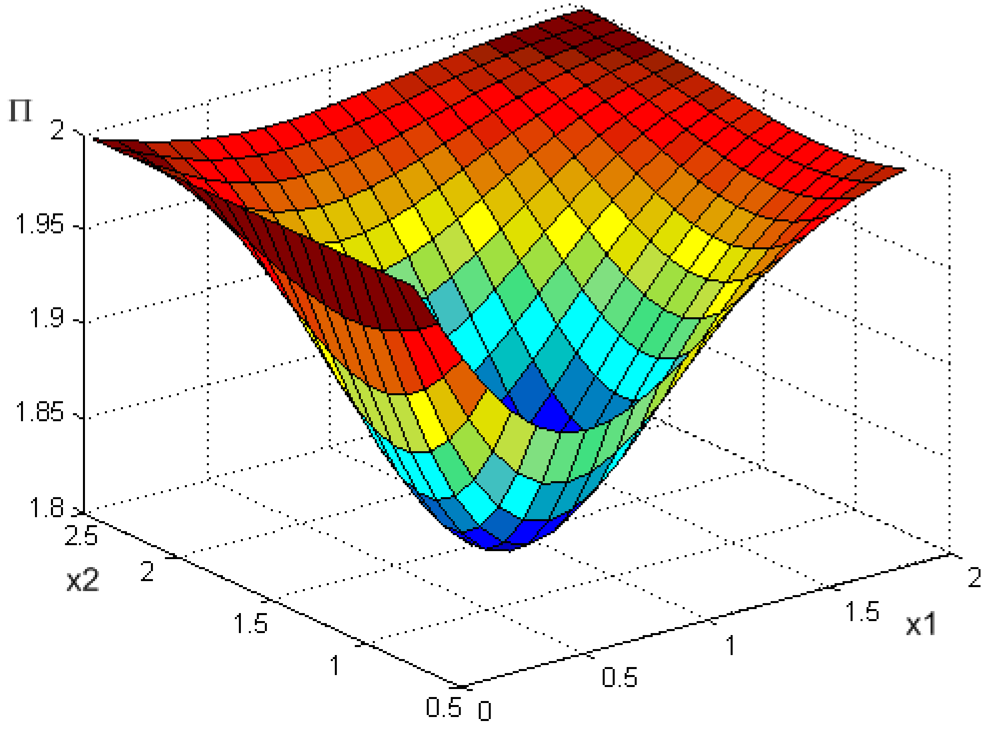
Employing this approximation, the correlation between X1 and X2 can conveniently be written in the form

$$X_1 X_2 \left(\gamma_{12} - 1\right) - X_1 \left(\frac{M_3}{M_p}\gamma_{13} + \frac{M_4}{M_p} \right) - X_2 \left(\frac{M_3}{M_p}\gamma_{23} + \frac{M_4}{M_p} \right) = \frac{M_4^2 - M_3^2}{2 M_p}$$

In the case of production of antiparticle with mass M_3, the mass M_4 is equal to M_3 as a consequence of conservation of quantum numbers. In studying the production of protons and nuclear fragments $M_4 = -M_3$ as far as minimal value of Π corresponds to the fact that any other additional particles are not produced. The X_1 and X_2 obtained from the minimum Π are used to construct an universal description of the A-dependencies.

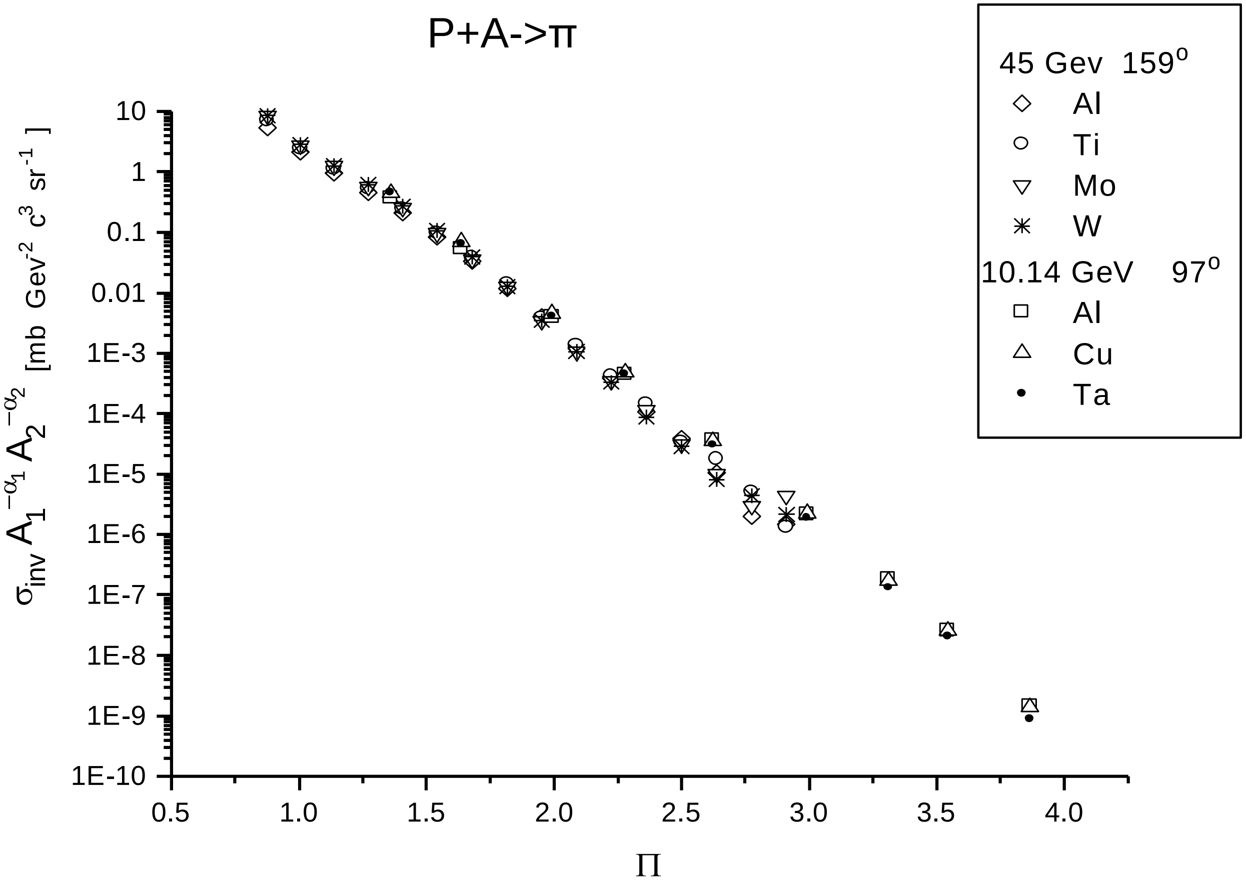
The analysis of the experimental data shows that the A-dependence of the inclusive production cross section can be parameterized by a universal function $\alpha = 1/3 + X/3$, were X is equal to X_1 and X_2 , respectively.

$$\Pi = \frac{1}{2}\left(X_1^2 + X_2^2 + 2X_1X_2\gamma_{12}\right)^{1/2}$$



$$E\frac{d^3\sigma}{d^3p} = C_1 A_1^{1/3 + X_1/3} A_2^{1/3 + X_2/3} \exp\left(-\Pi / C_2\right)$$

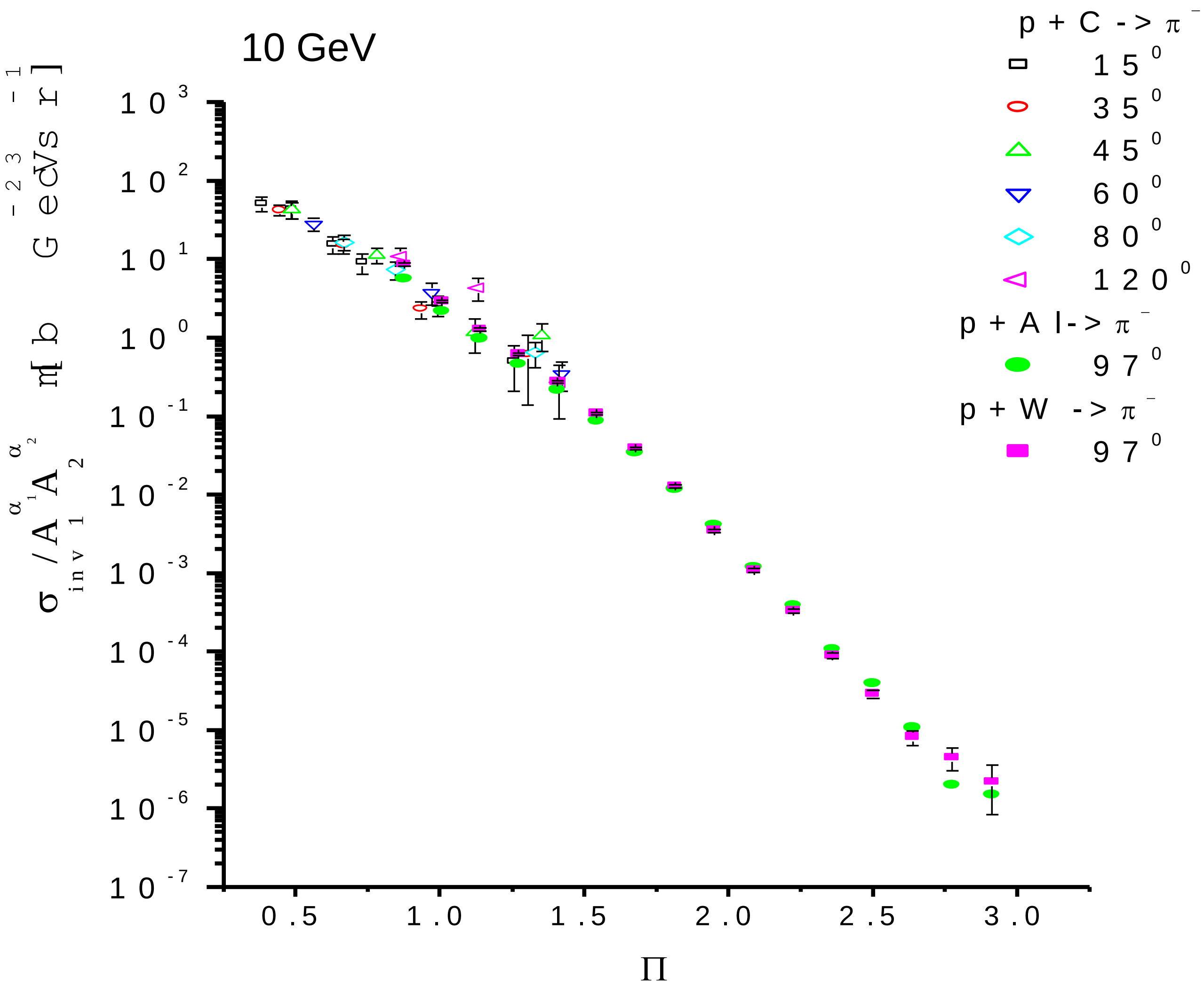
Cumulative processes



S.V.Boyarinov, et al. Yad. Fis. , v.57, N8, (1994) ,1452-1461.

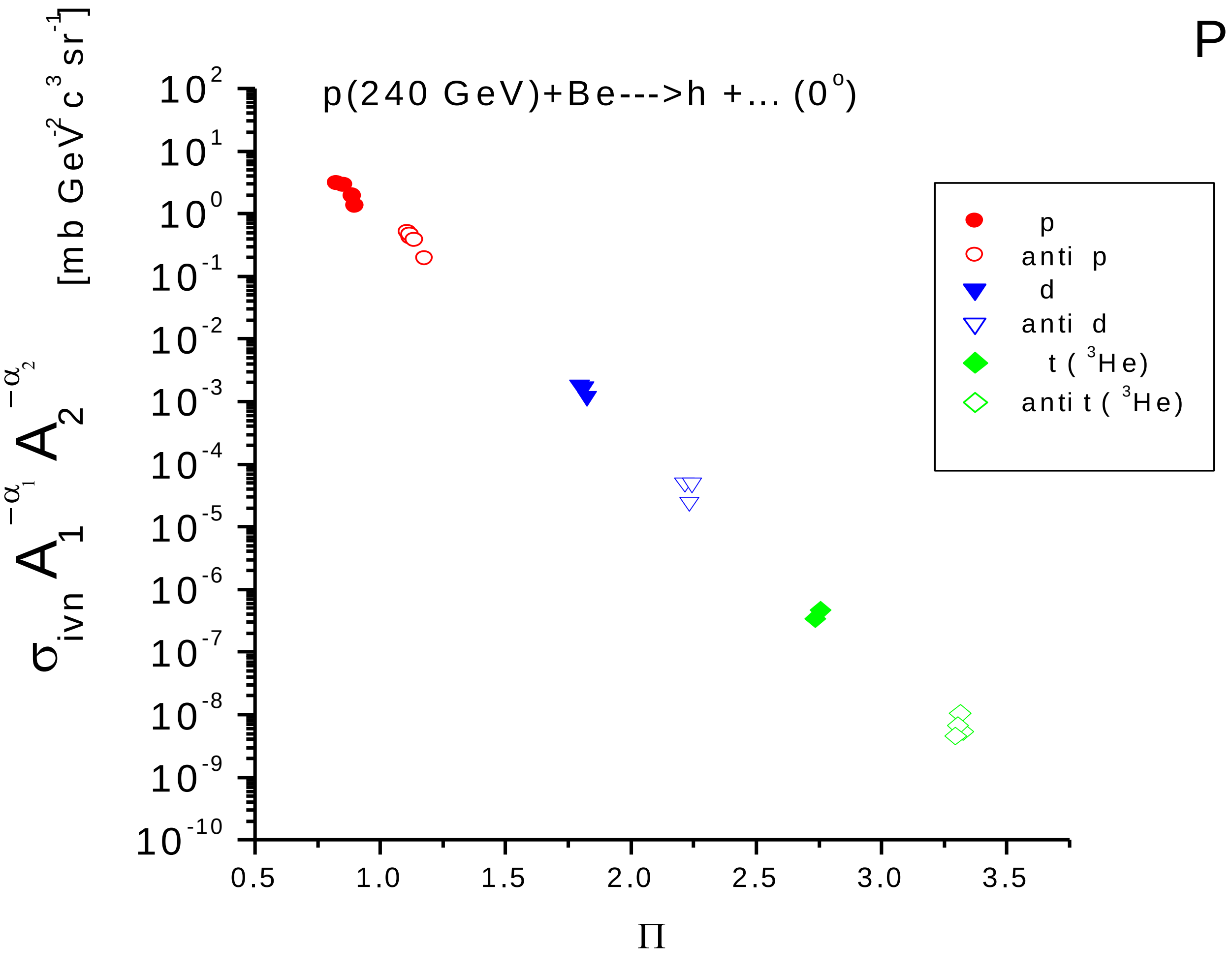
O.P.Gavrishchuk et al. Nucl. Phys., A523 (1991) 589.

Cumulative and non-cumulative processes

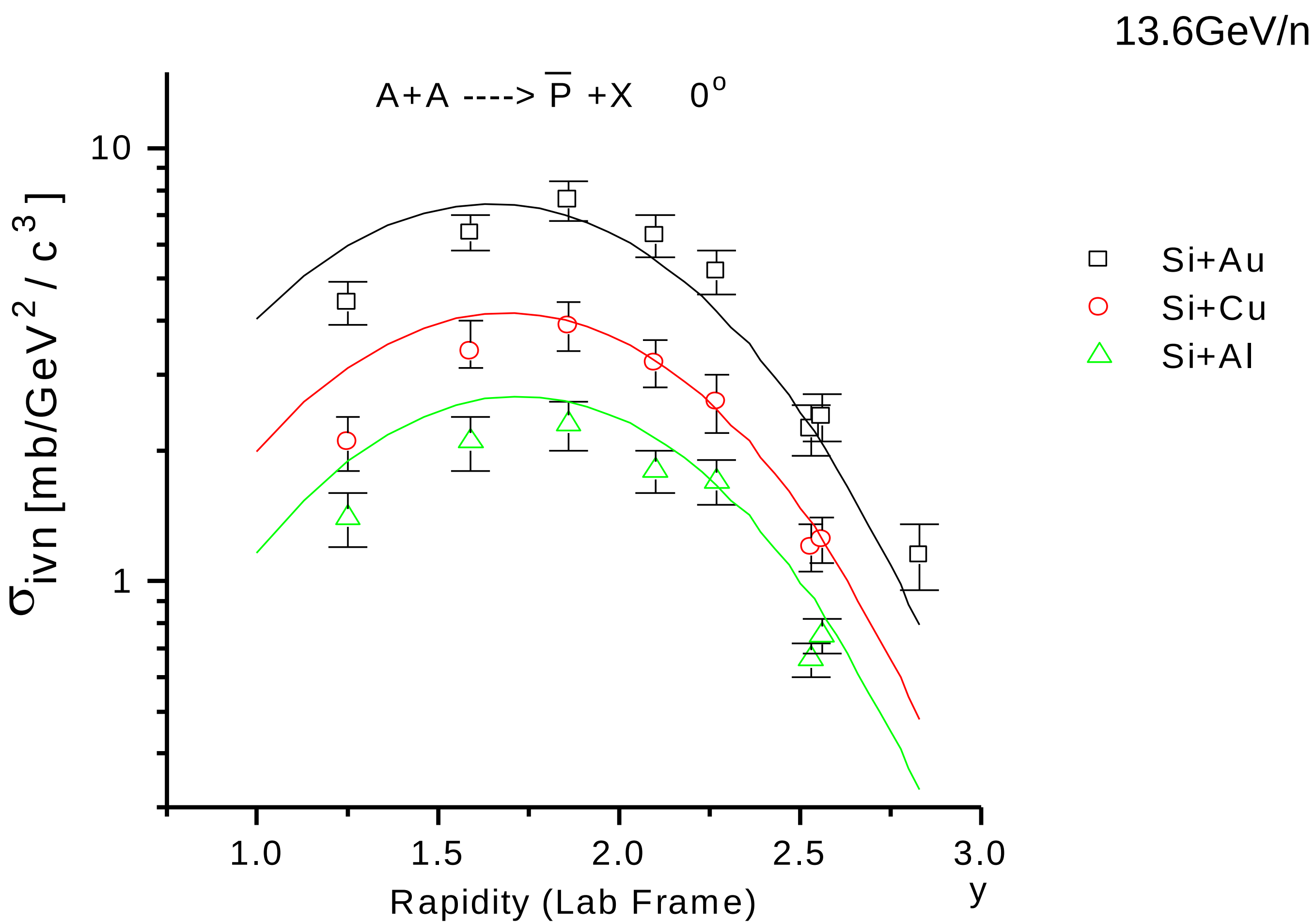


Antimatter production

P >> M !!!

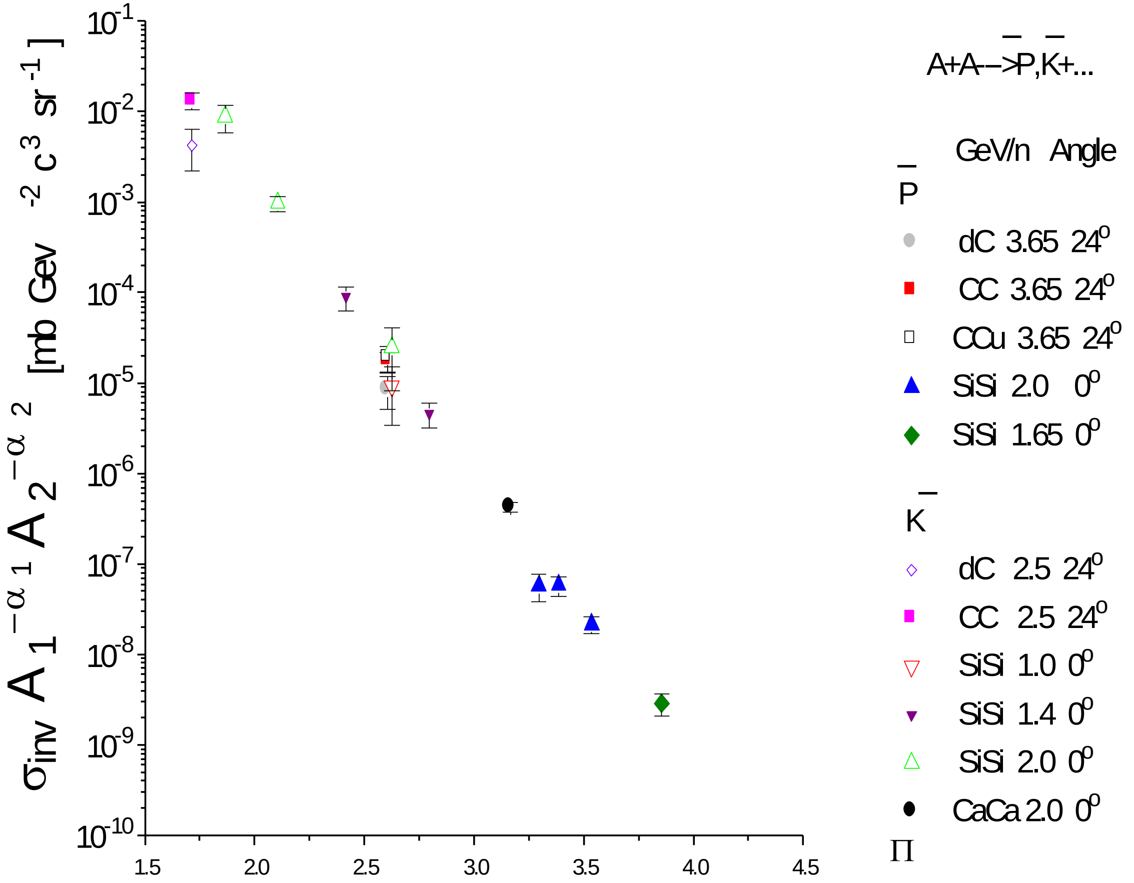


Near-threshold antimatter production



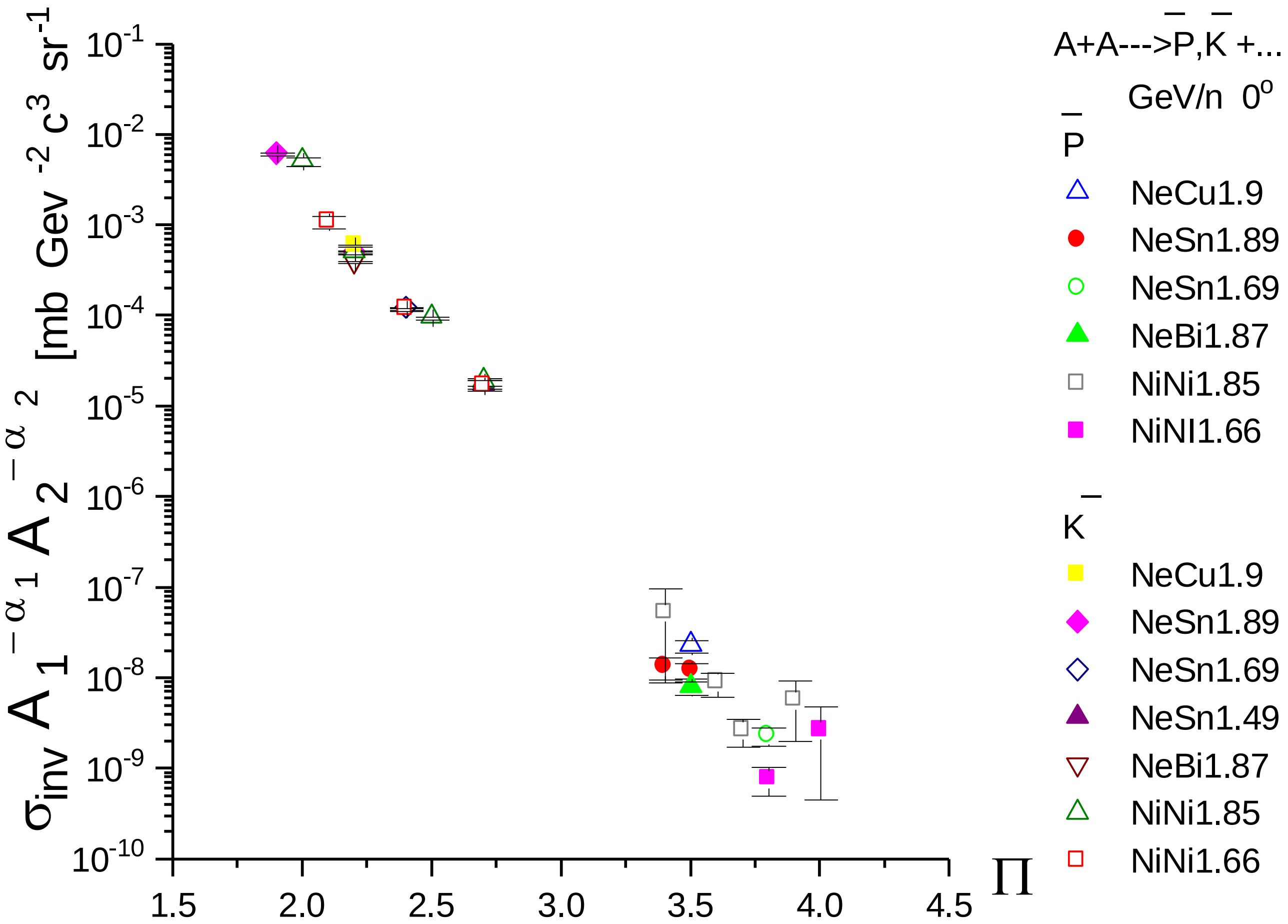
P.Stankus et al. Nucl. Phys. A544 (1992) p .603c-608c.

Twice cumulative deep subthreshold antimatter production



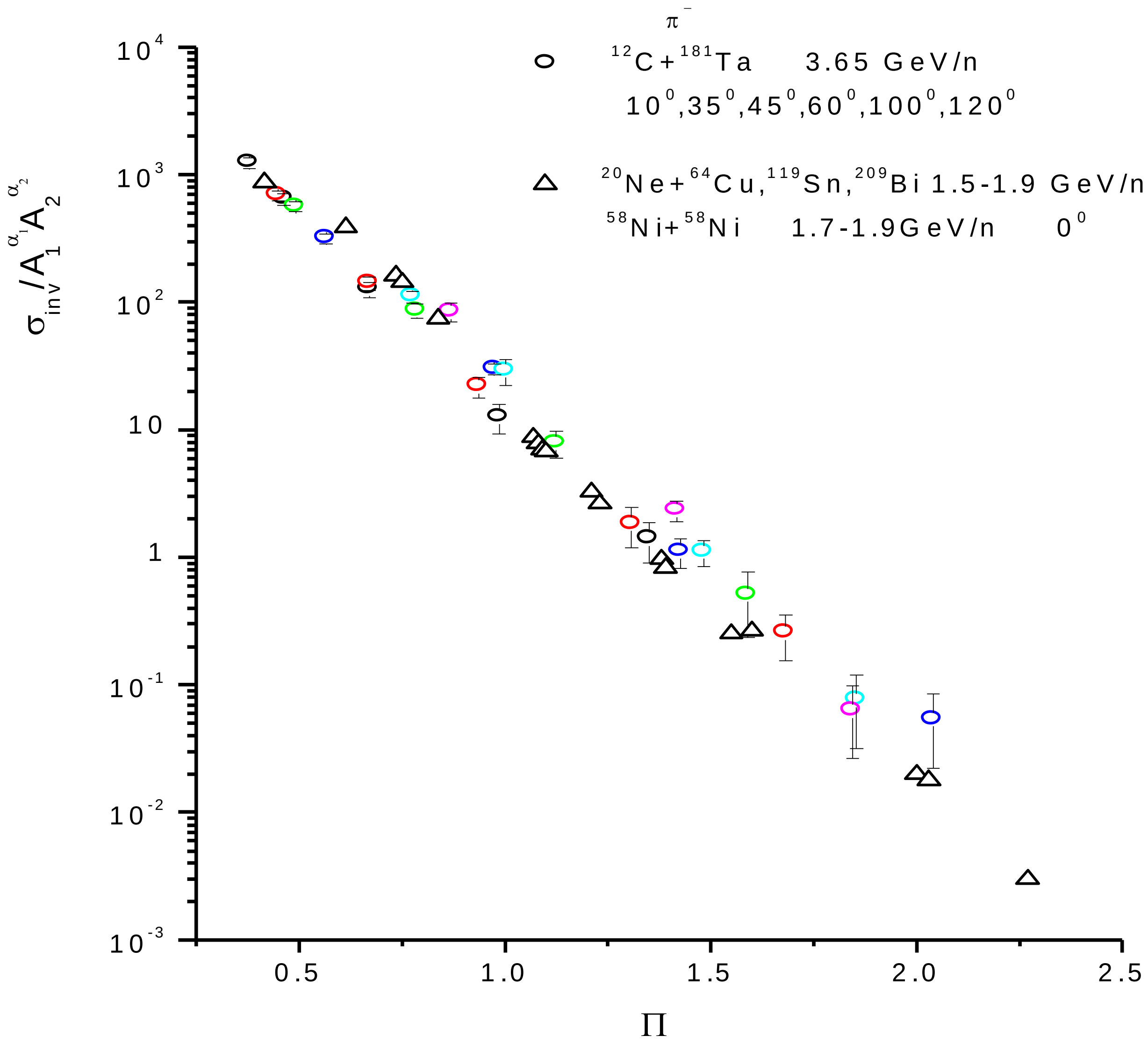
Jim Carroll Nucl. Phys. A488 (1989) 2192.
A.Shor et al. Phys. Rev. Lett. 62 (1989) 2192.
A.A.Baldin et al. Nucl. Phys., A519 (1990) 407.
A.A.Baldin et al. Rapid Communications JINR, 3-92 (1992) 20.

Twice cumulative deep subthreshold antimatter production with heavy nuclei

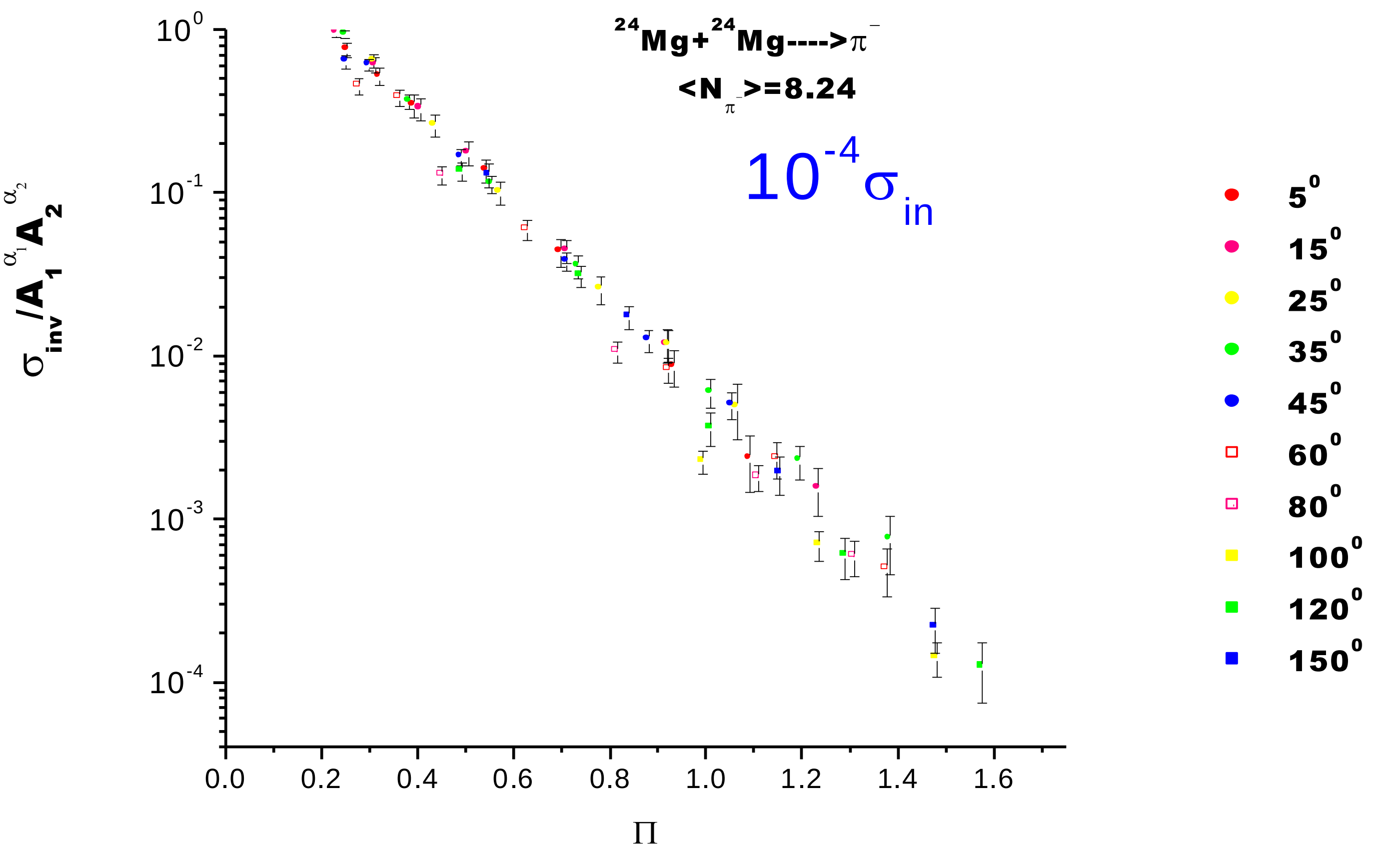


A.Schroter et al. Z.Phys. A350, (1994), 101-113.

Inclusive pion spectra (various experiment types)



Inclusive pion spectra in selected high-multiplicity events

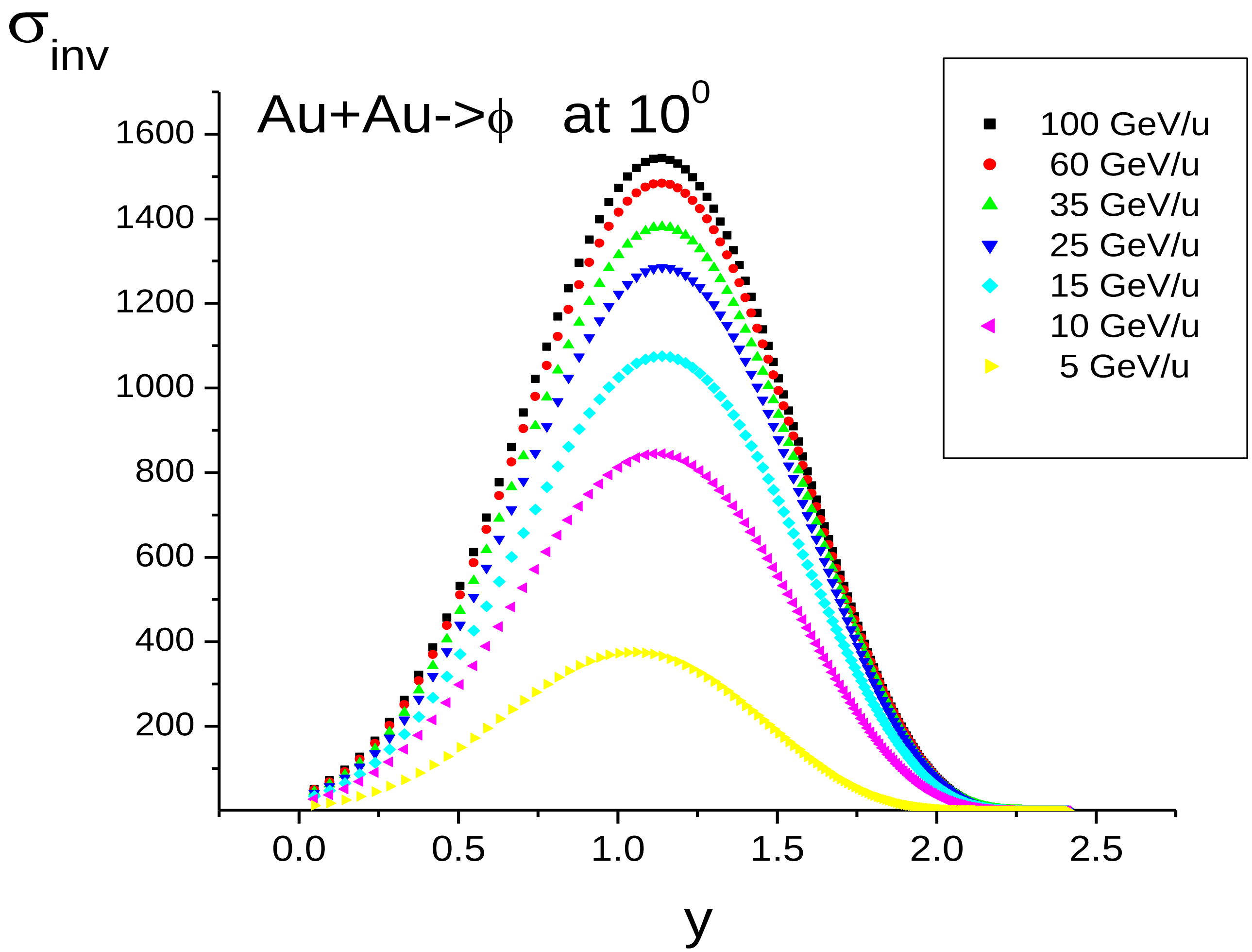


A.A.Baldin, E.N.Kladnitskaya, O.V. Rogachevsky, JINR Rapid Comm., (1999), N.2 [94]-99, p.20.
M.Kh.Anikina, et al., Phys. Lett. B., (1997), v.397, p.30.

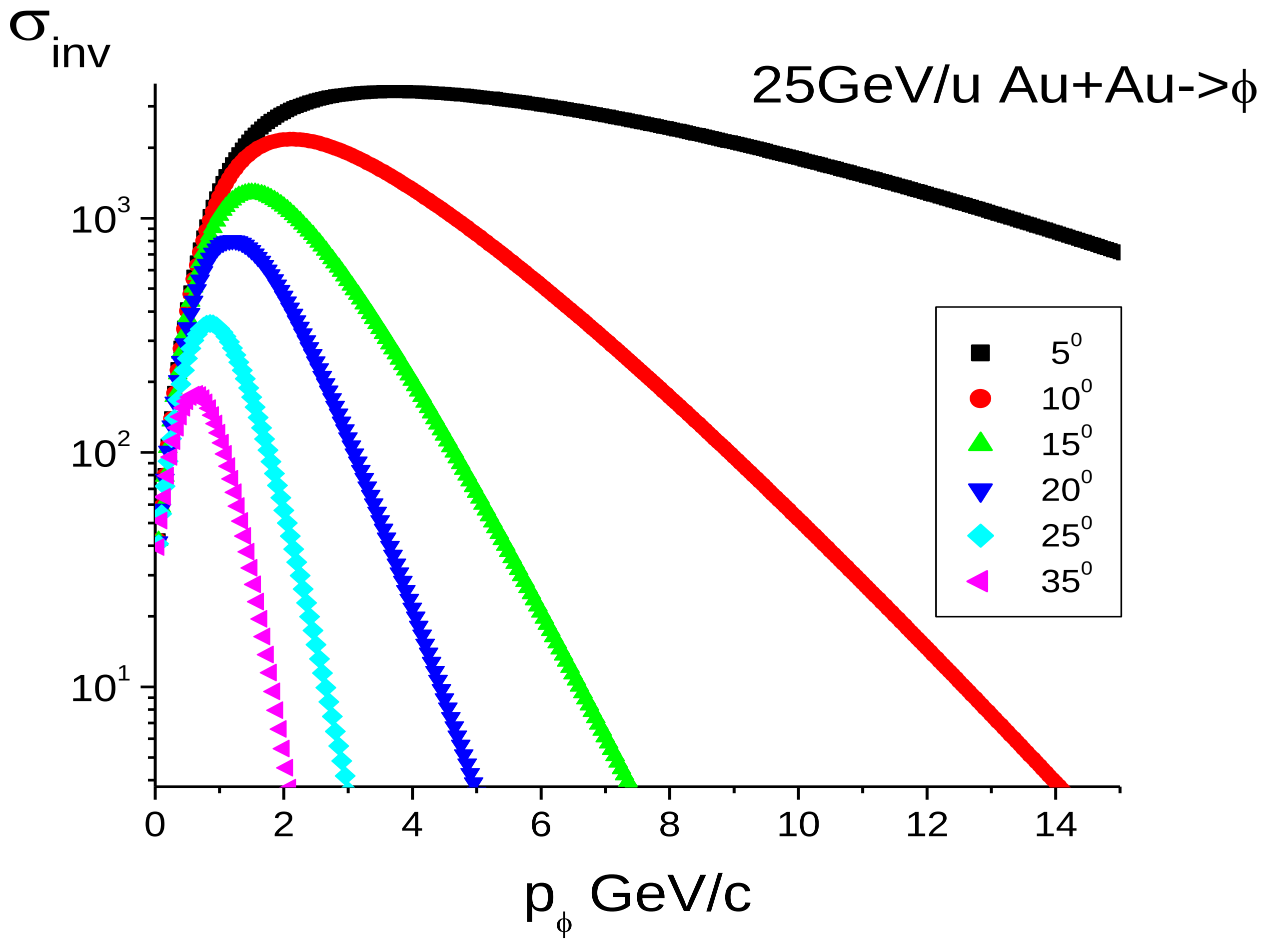
- The proposed self-similar solution quantitatively describes the angular, energy and A- dependences of inclusive production cross sections of all hadrons with transverse momentum up to 2GeV. For higher transverse momenta the A-dependence becomes a function not only of X_1, X_2, but also of P_t (or m_t).

$$E\frac{d^3\sigma}{d^3p} = C_1 A_1^{1/3 + X_1/3} A_2^{1/3 + X_2/3} \exp\left(-\Pi/C_2\right)$$

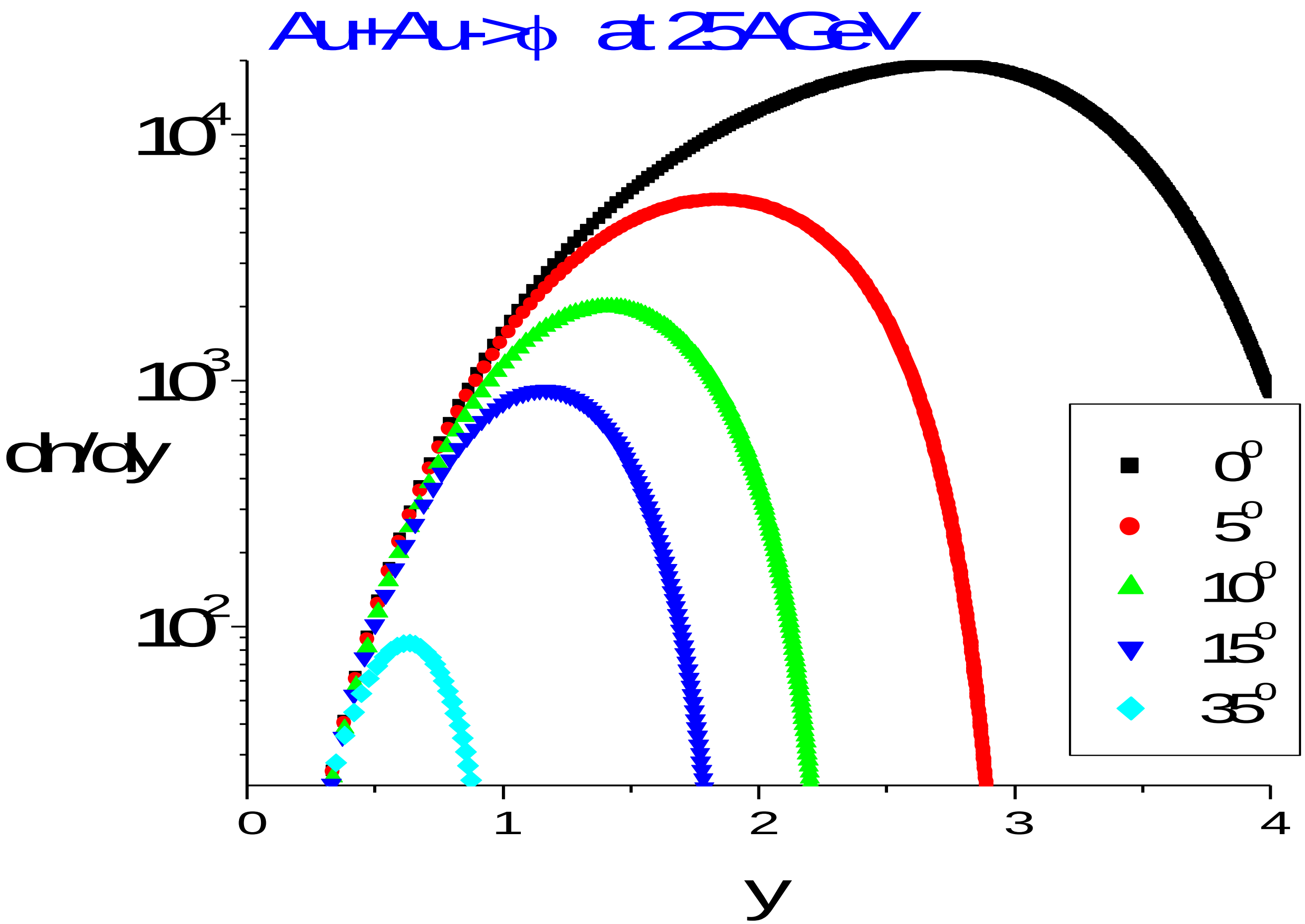
- The analysis of inclusive spectra for the data selected in different ways shows that multiplicity in relativistic nuclear collisions has its origin basically in independent nucleon-nucleon interactions. Thus, high multiplicity at interaction of heavy nuclei is not a satisfactory criterion for search and study of collective interactions, or detection of exotic states of nuclear matter (such as quark-gluon plasma).

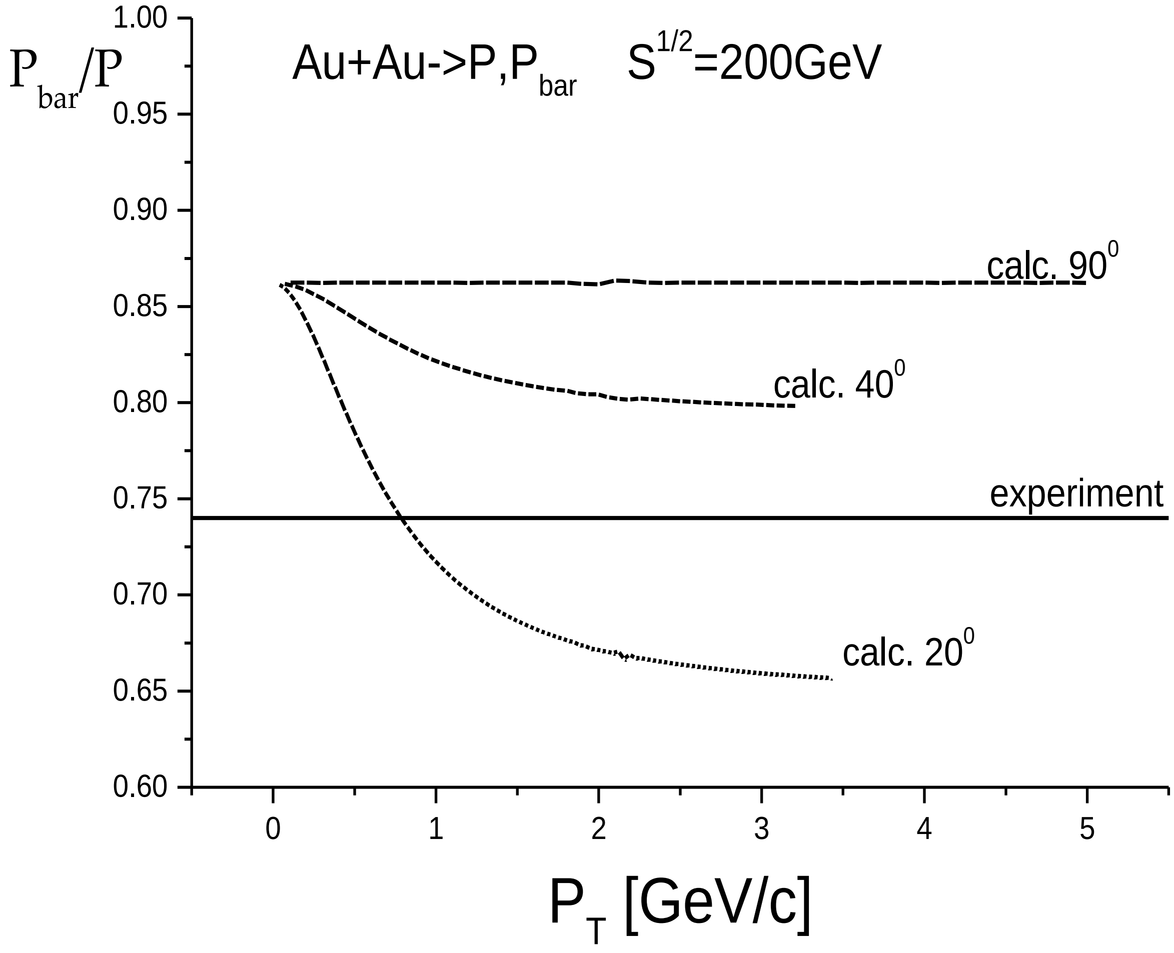


σ_{inv}
Au+Au->ϕ at 10⁰
100 GeV/u
60 GeV/u
35 GeV/u
25 GeV/u
15 GeV/u
10 GeV/u
5 GeV/u
1600
1400
1200
1000
800
600
400
200
0.0
0.5
1.0
1.5
2.0
2.5
y

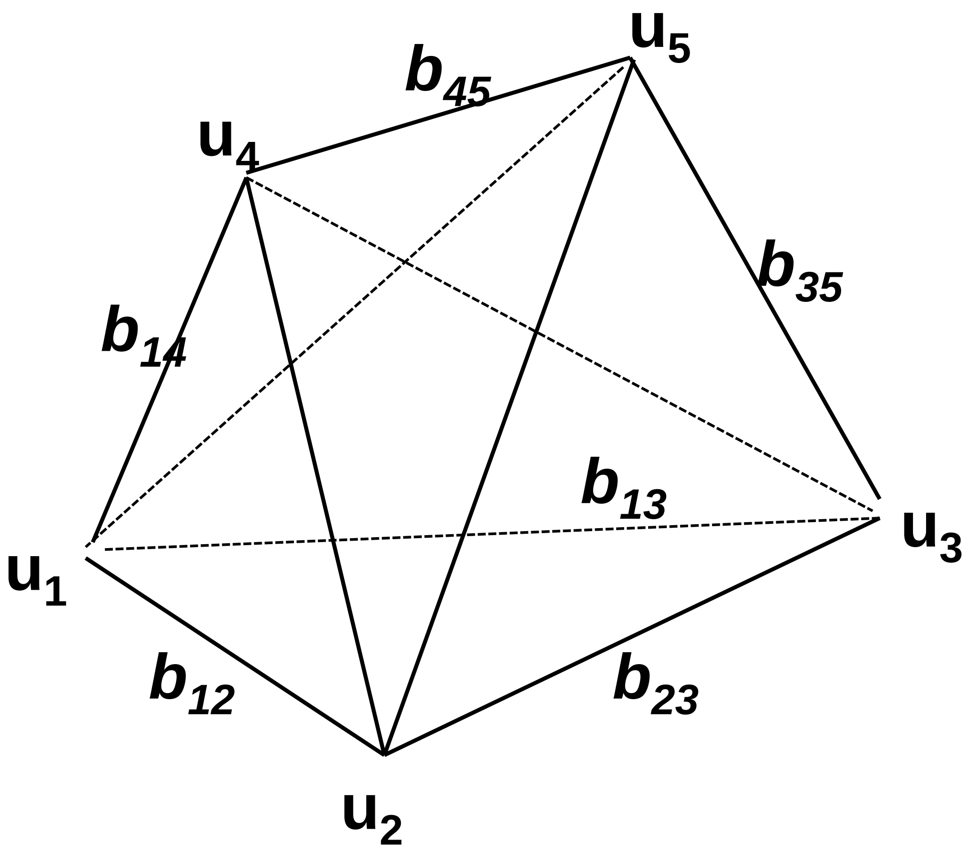


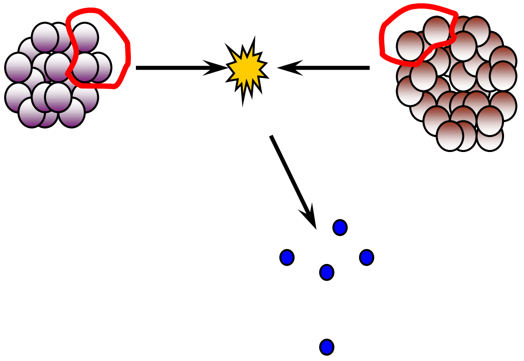
σinv
25GeV/u Au+Au->ϕ
10³
10²
10¹
0
2
4
6
8
10
12
14
pϕ GeV/c
5⁰
10⁰
15⁰
20⁰
25⁰
35⁰

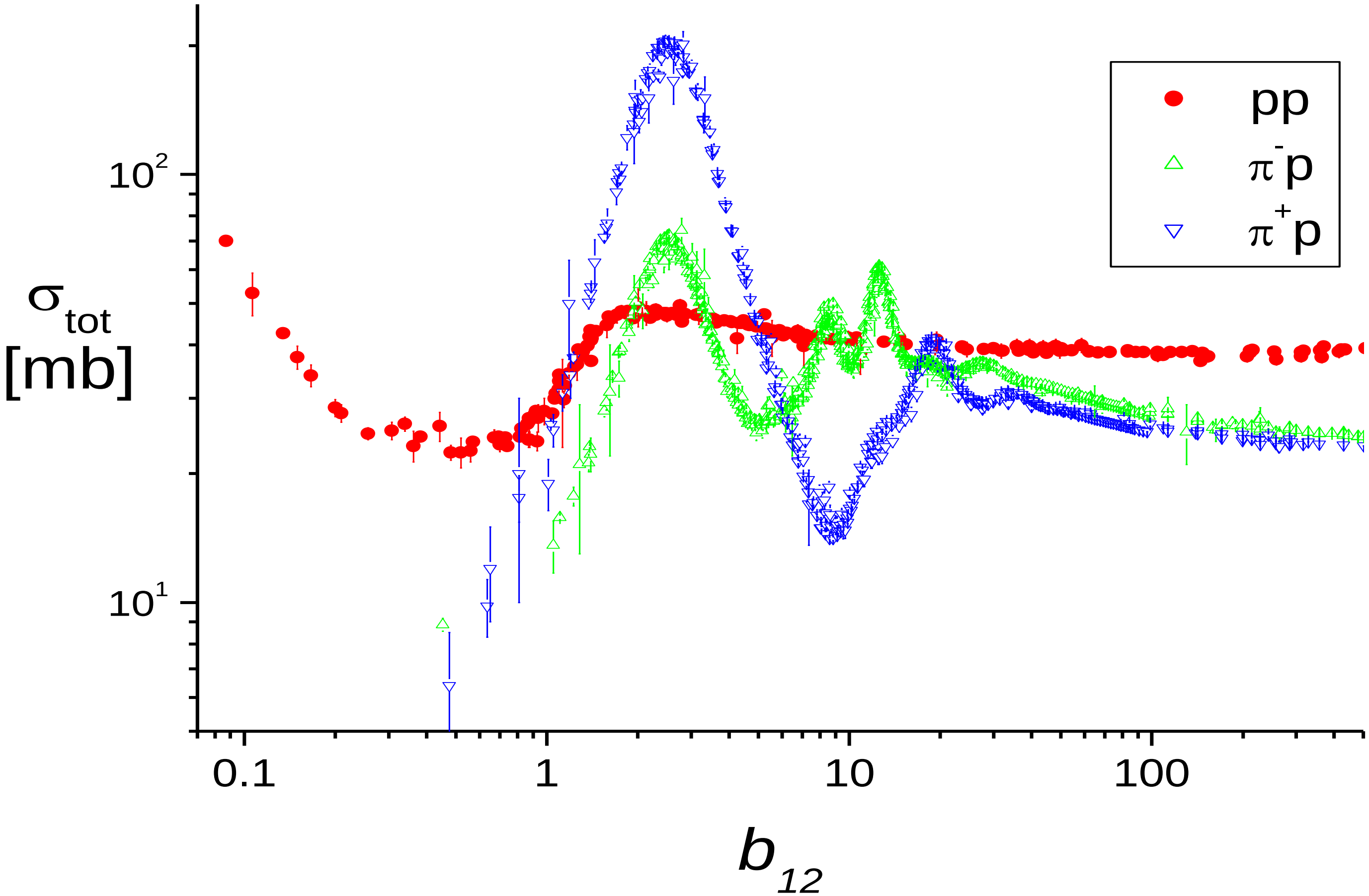

Au+Au->φ at 25AGeV
dn/dy
10^4
10^3
10^2
0
1
2
3
4
y
0°
5°
10°
15°
35°



Au+Au->P,P_bar S^1/2=200GeV
P_bar/P
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
calc. 90^0
calc. 40^0
experiment
calc. 20^0
0
1
2
3
4
5
P_T [GeV/c]


u5
b45
u4
b14
b35
b13
u3
u1
b12
b23
u2



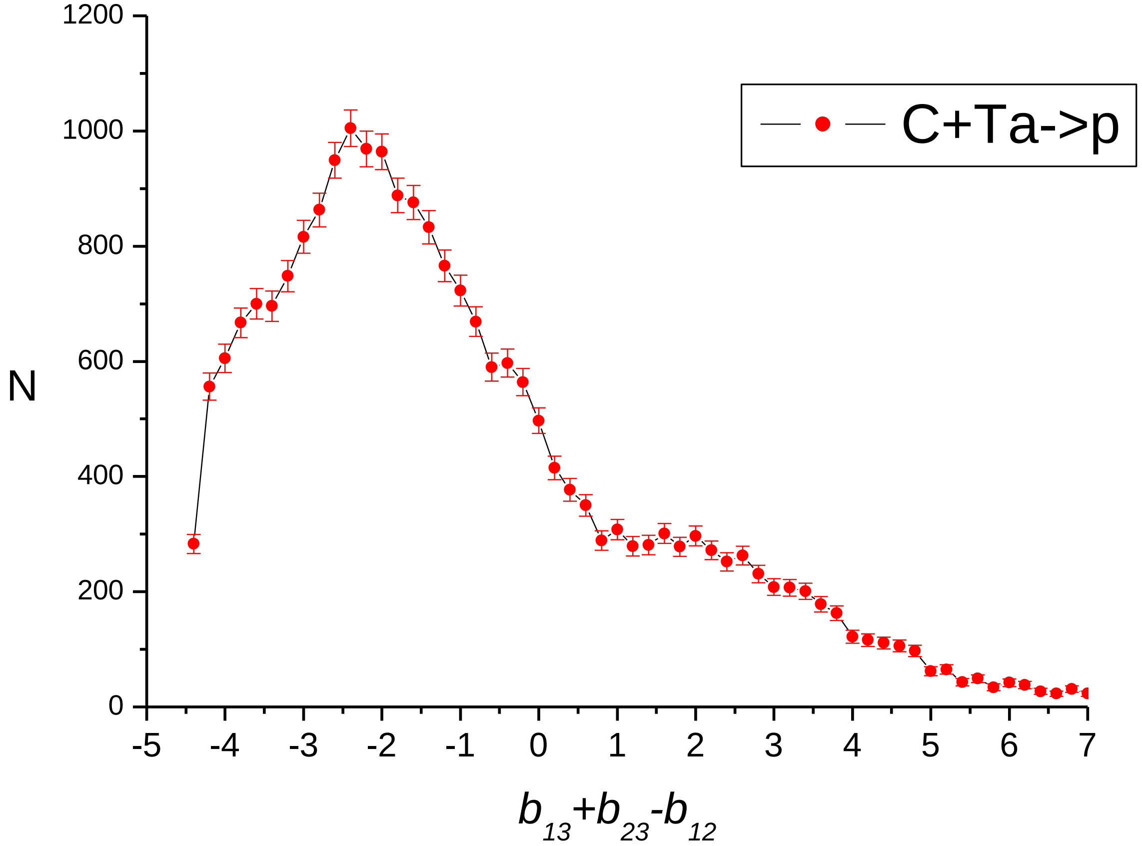


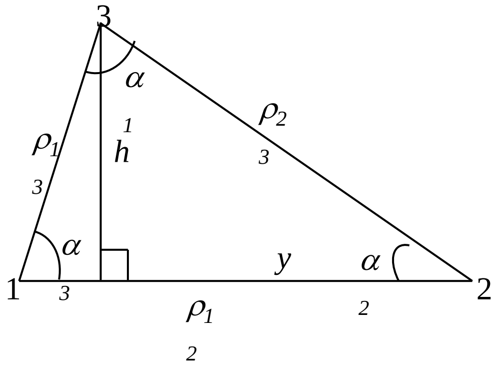
$$b_{ik} = 2\left[\left(U_i U_k\right) - 1\right] = 2\left[\frac{P_i P_k}{m_i m_k} - 1\right]$$

$$b_{12} = 2\left[\frac{E_{proj}}{m_{proj}} - 1\right]$$

PDG K. Hagiwara *et al.*, Phys. Rev. D **66**, 010001 (2002) (http://www-pdg.lbl.gov/)

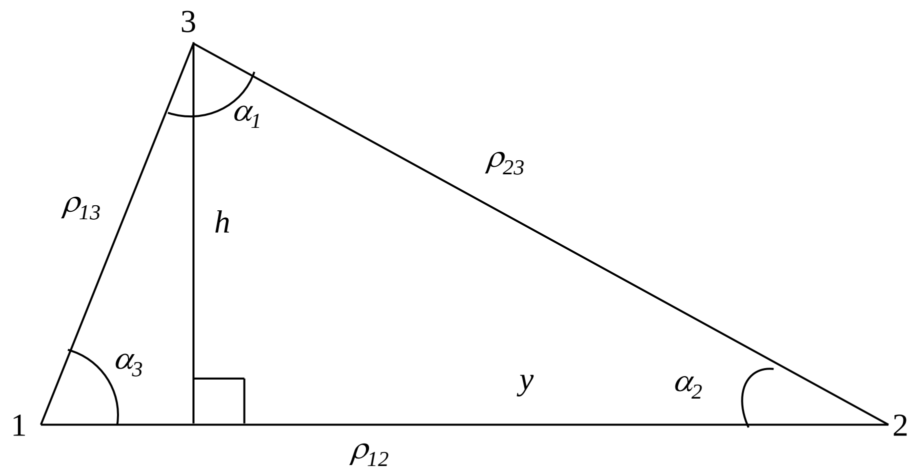
It should be noted that the variable b_{ik} does not form a metric space,
i.e. the relation $b_{12} + b_{13} \geq b_{23}$
is, generally speaking, wrong.





$$\min\left[-\sum_k \left(V_\alpha - u_k^{\ \alpha}\right)^2 - \sum_i \left(V_\beta - u_i^{\ \beta}\right)^2\right]$$

Lobachevsky Space



Longitudinal rapidity $$y = \frac{1}{2}\ln\frac{E + p_\parallel}{E - p_\parallel}$$

$$defect = \pi - \alpha_1 - \alpha_2 - \alpha_3$$

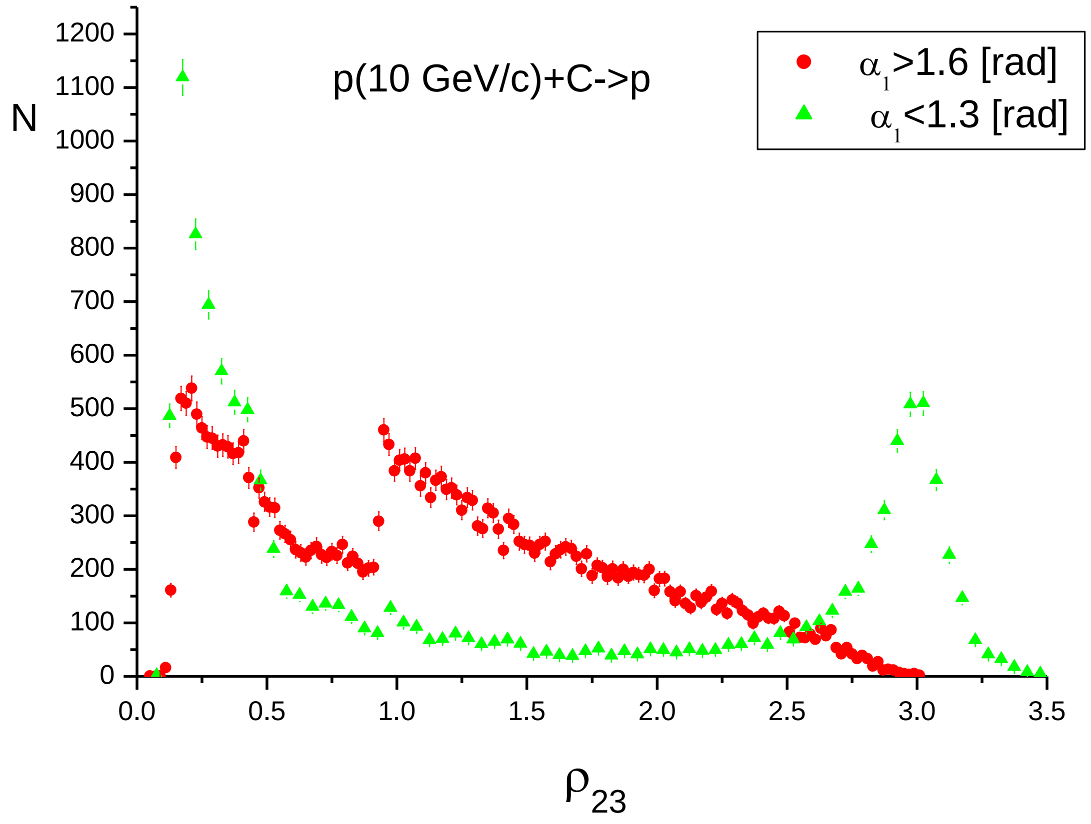
Transverse mass $$m_T = \sqrt{m^2 + p_T{}^2}$$

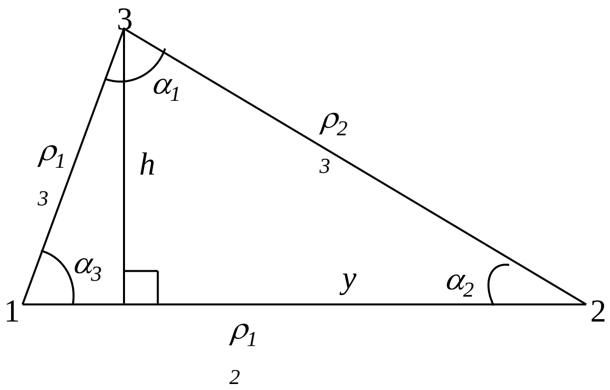
$$perimeter = \rho_1 + \rho_2 + \rho_3$$

Transverse rapidity $$\operatorname{ch} h = \frac{m_T}{m}$$

Angle of Parallelism $$\Pi_L(h) = 2 \cdot arctg\left(e^{-h}\right)$$

Proton distribution for two angular intervals in p(10GeV/c)+C

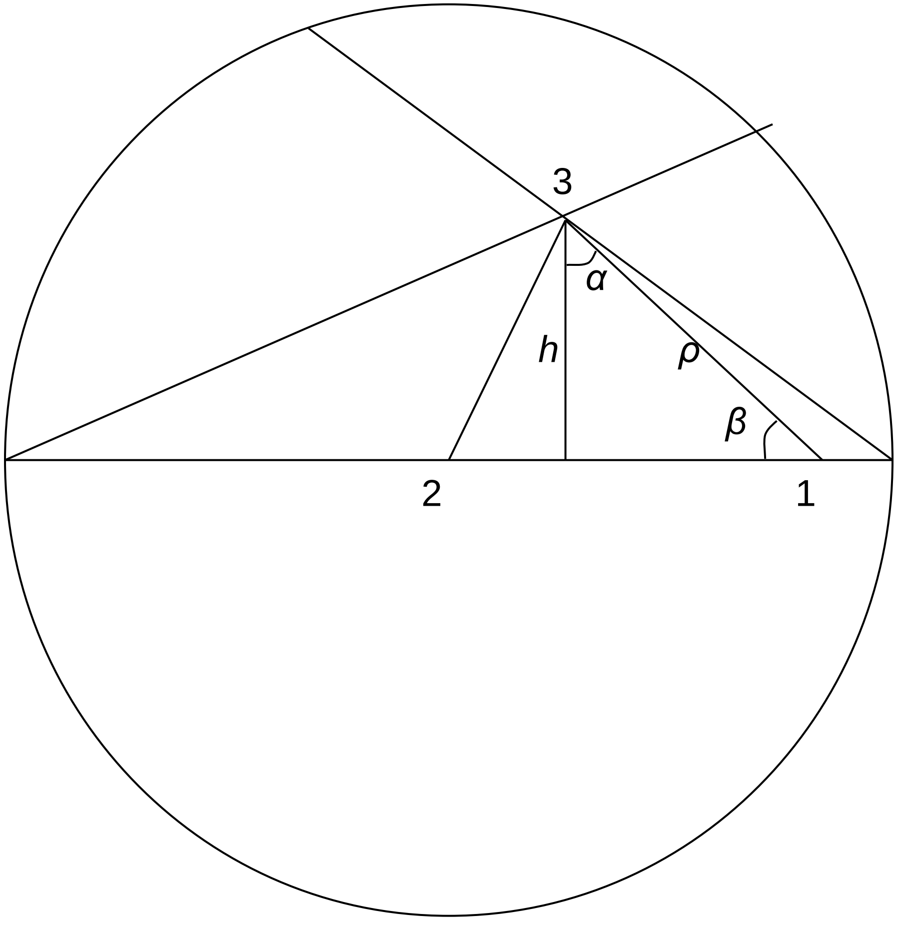




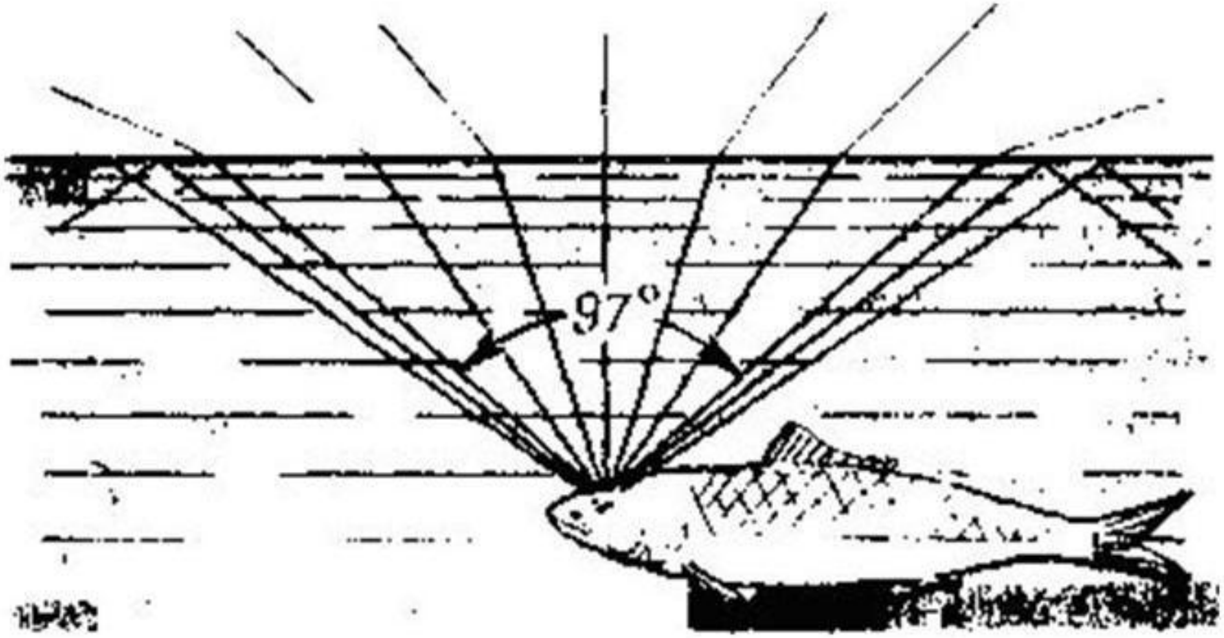
A. A. Baldin, E. G. Baldina, E. N. Kladnitskaya, O. V. Rogachevskii, Phys.Part.Nucl.Lett., vol. 1, no. 4, 7-16 (2004).

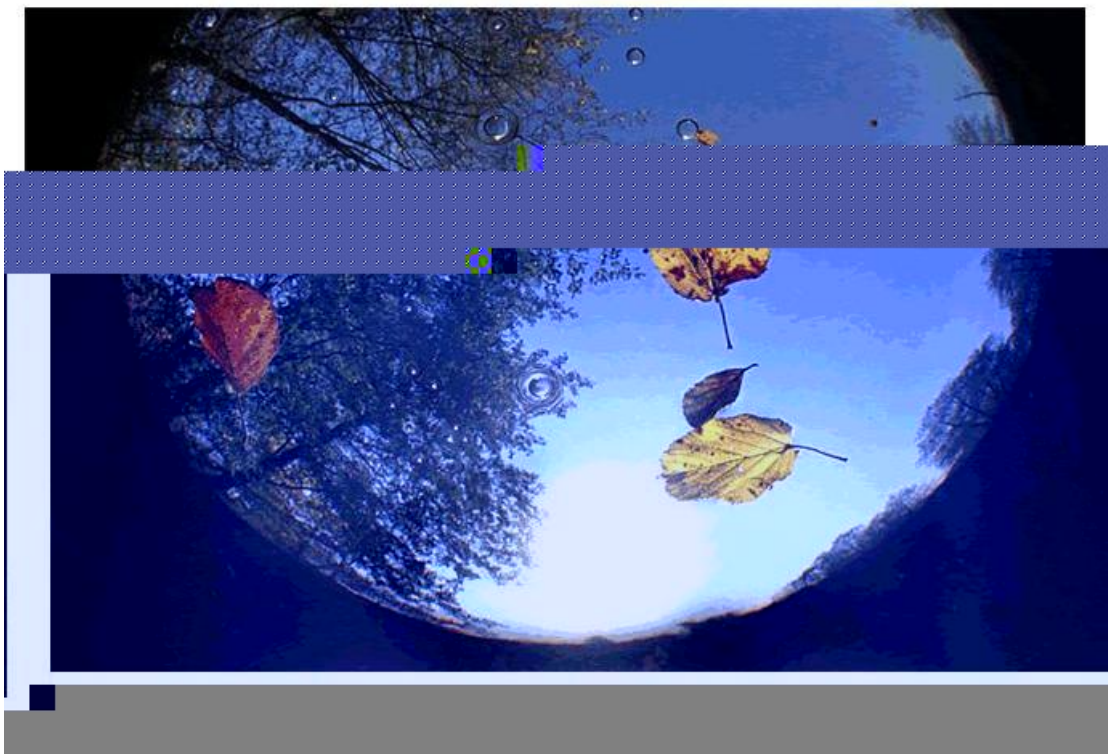
$$tg\,\frac{\Pi_L(h)}{2} = e^{-h}$$

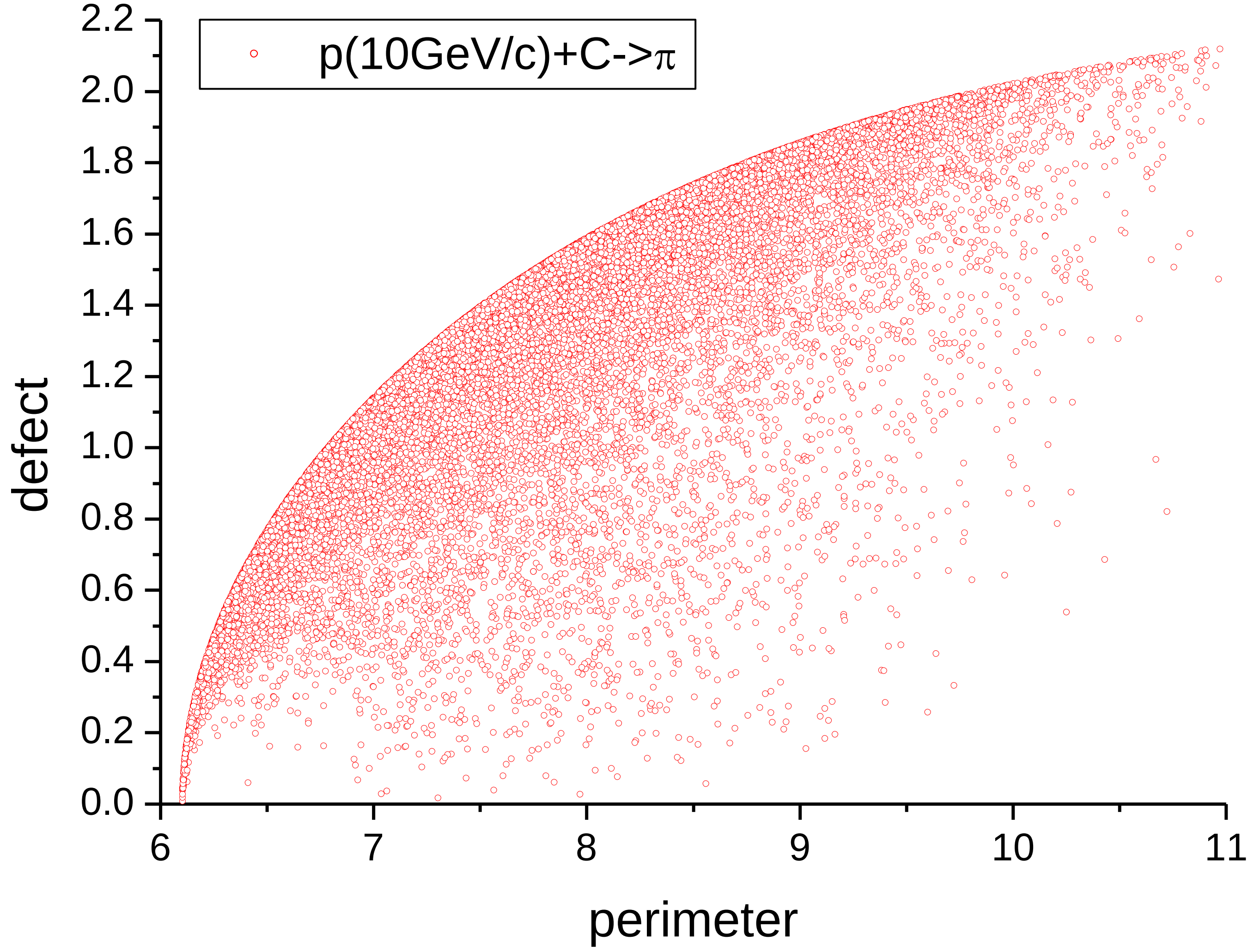
$$\Pi_L(h) = 2 \cdot arctg\left(e^{-h}\right)$$



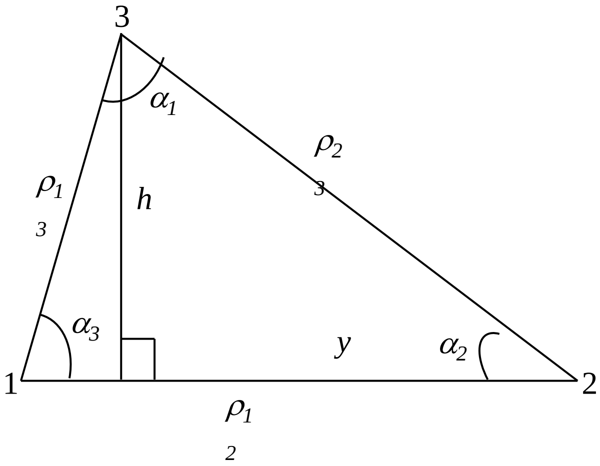
$$\Delta_{12}^{3} = 2\Pi_L\left(h_3\right) - \alpha_3$$

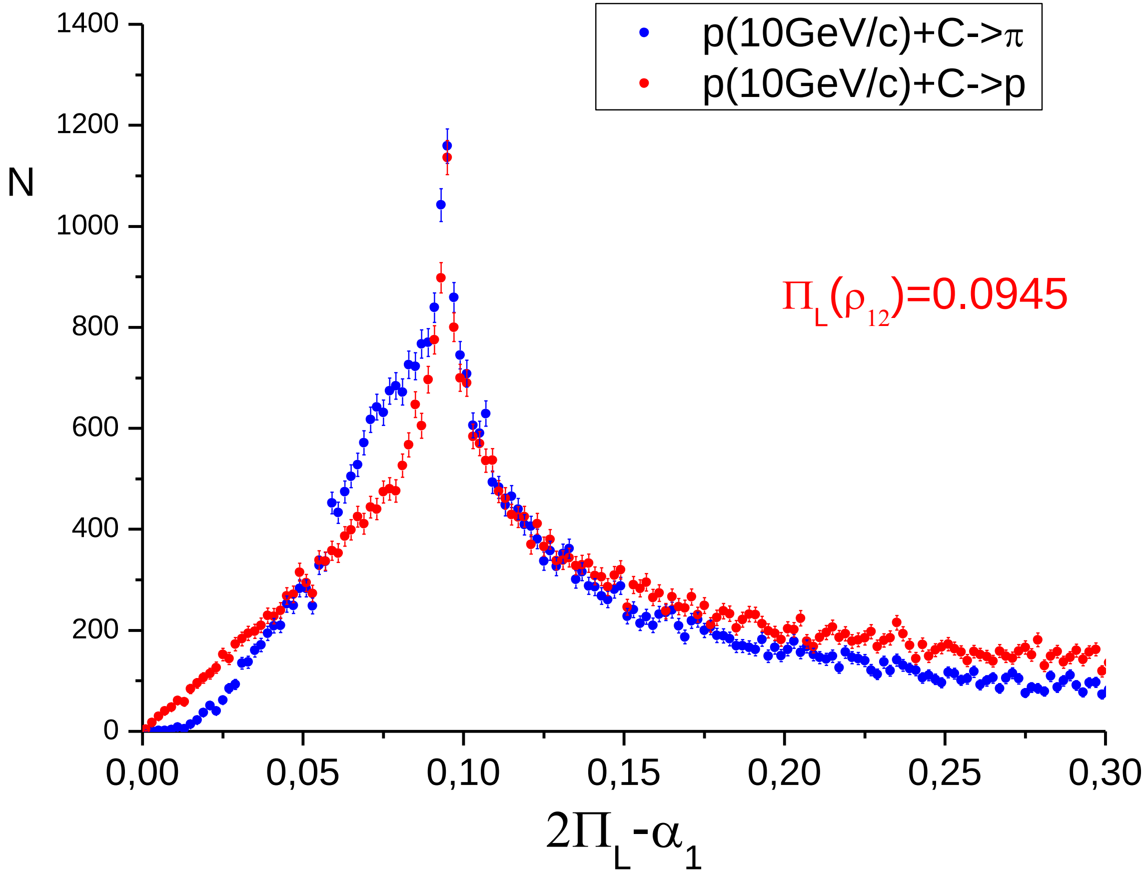

97°



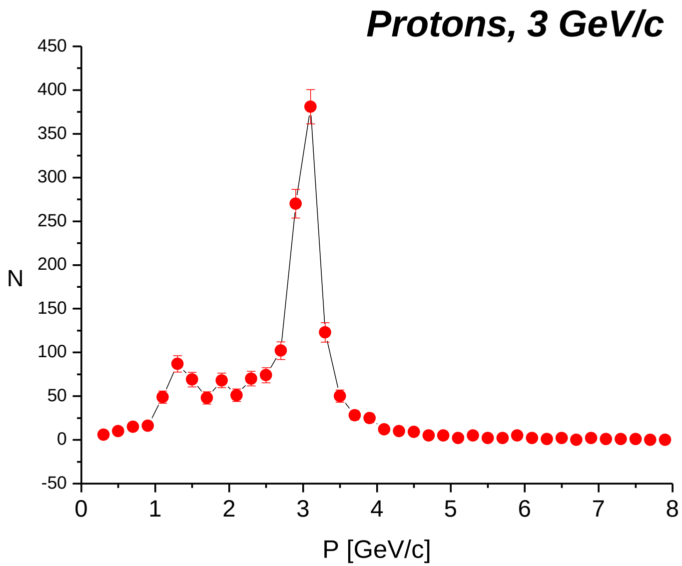


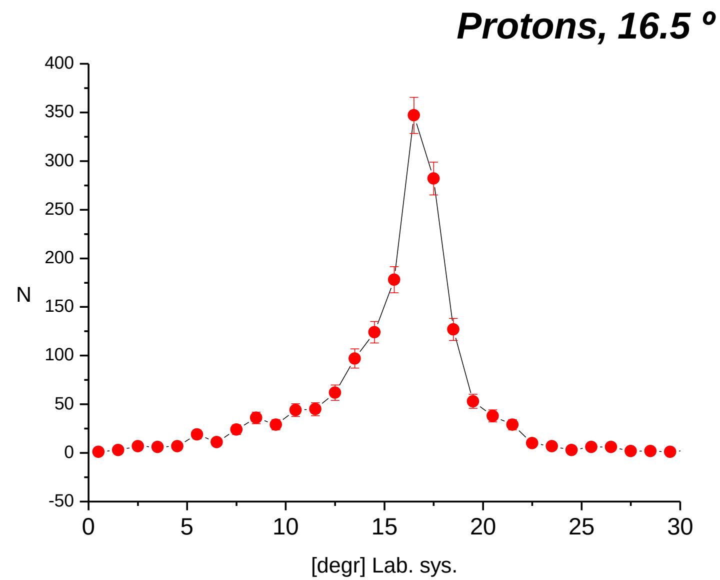
p(10GeV/c)+C->π
defect
perimeter
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
6
7
8
9
10
11

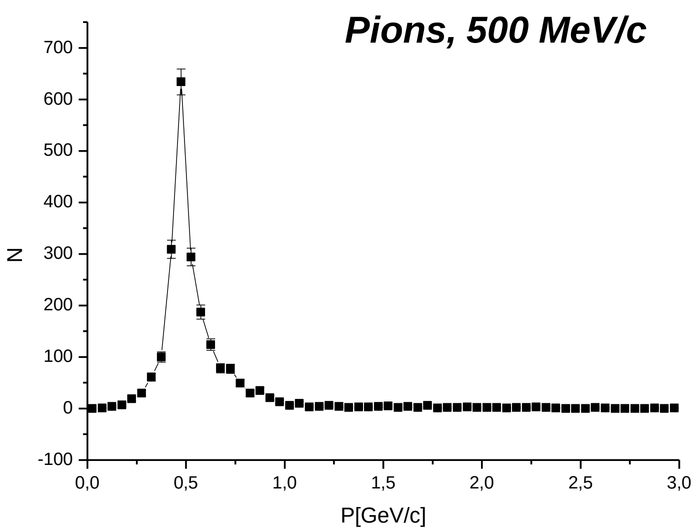

3
α1
ρ2
3
ρ1
3
h
α3
y
α2
1
2
ρ1
2

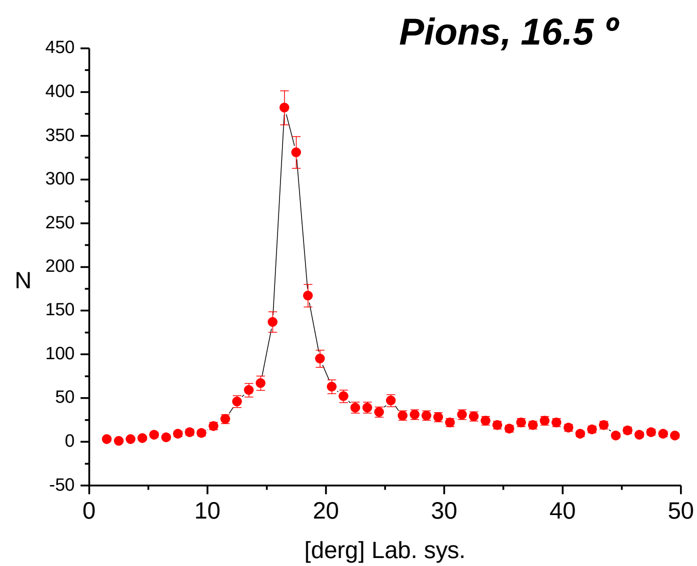

1400
1200
1000
800
600
400
200
0
N
p(10GeV/c)+C->π
p(10GeV/c)+C->p
Π L(ρ 12)=0.0945
0,00
0,05
0,10
0,15
0,20
0,25
0,30
2Π L-α 1

pC (10 GeV)

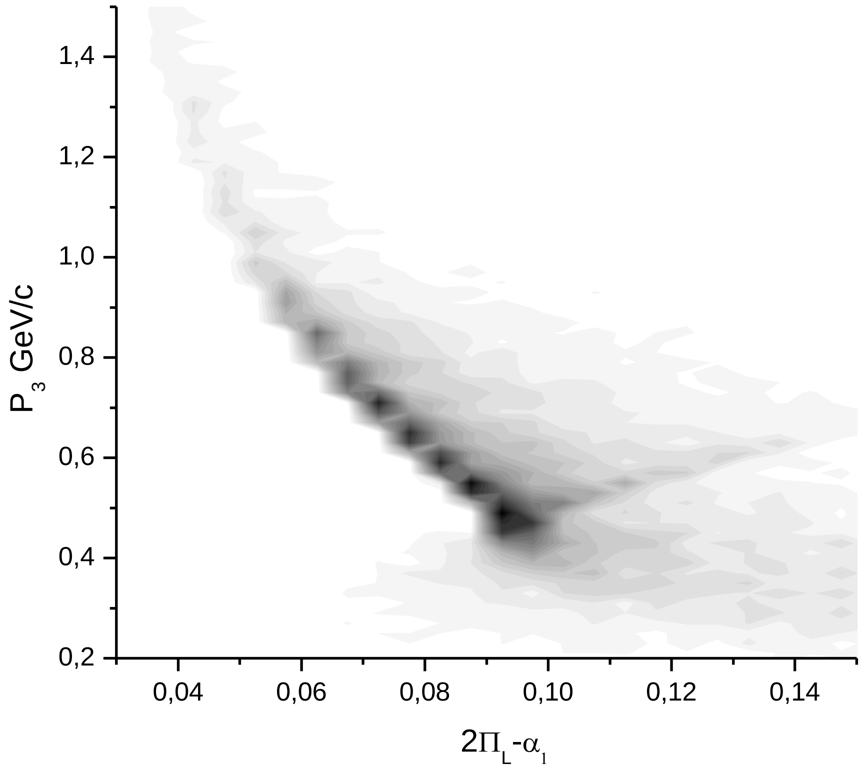

Protons, 3 GeV/c
N
P [GeV/c]
450
400
350
300
250
200
150
100
50
0
-50
0
1
2
3
4
5
6
7
8

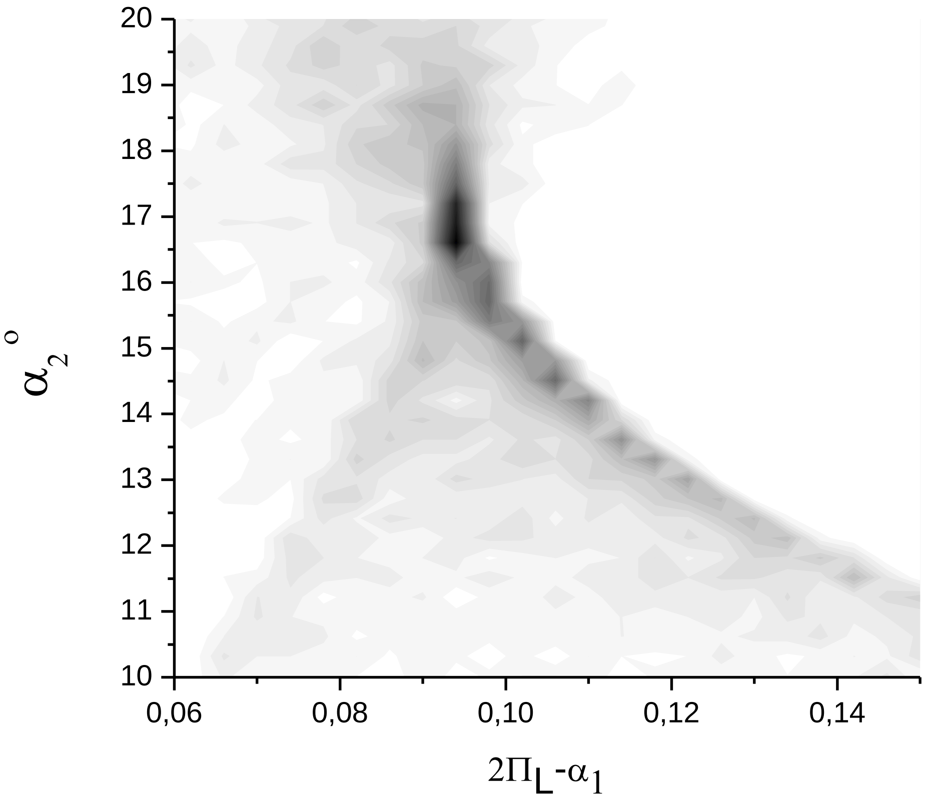

Protons, 16.5 º
N
[degr] Lab. sys.
400
350
300
250
200
150
100
50
0
-50
0
5
10
15
20
25
30


Pions, 500 MeV/c
N
P[GeV/c]
700
600
500
400
300
200
100
0
-100
0,0
0,5
1,0
1,5
2,0
2,5
3,0

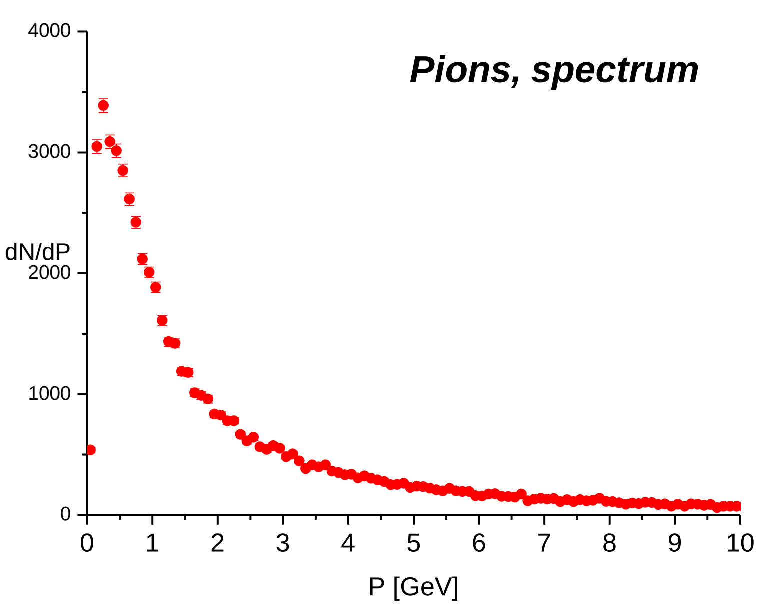

Pions, 16.5 º
N
[derg] Lab. sys.
450
400
350
300
250
200
150
100
50
0
-50
0
10
20
30
40
50

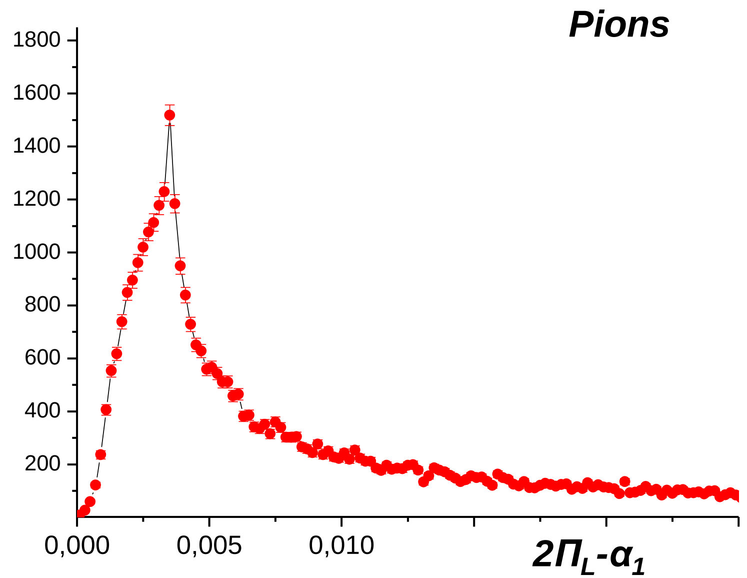
Directed Nuclear Radiation
P+C->pions at 10GeV

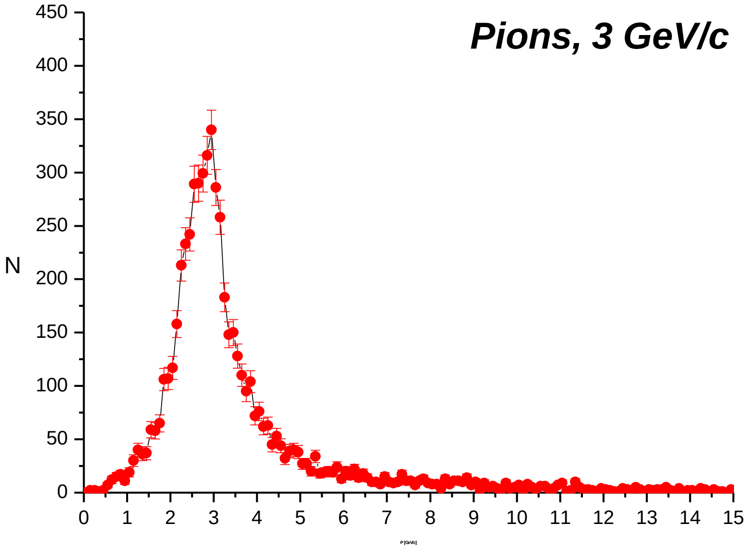


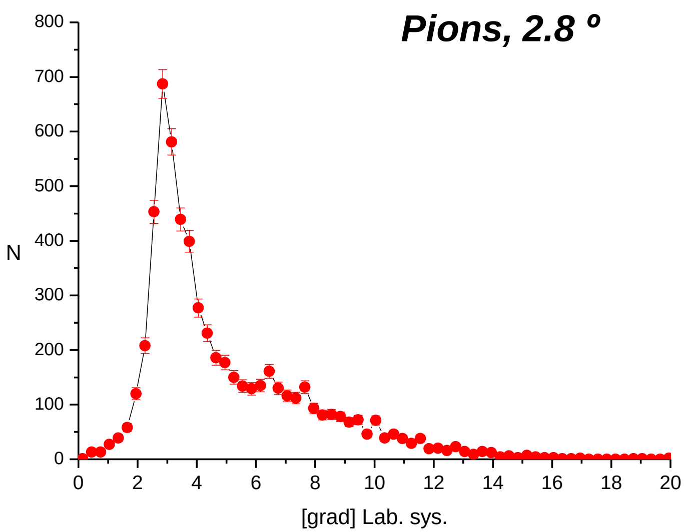


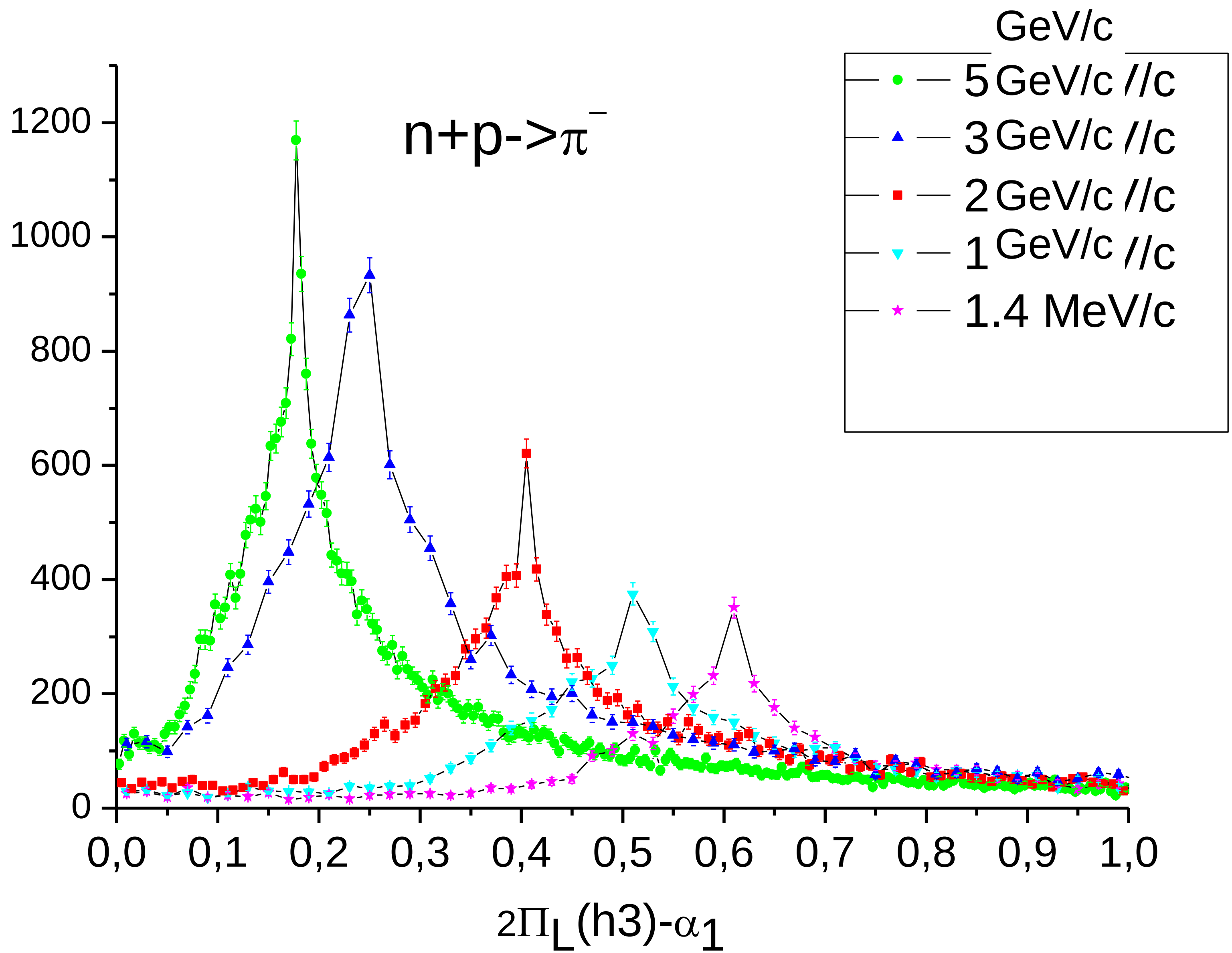
π^-C (40 GeV)


Pions, spectrum
dN/dP
0
1000
2000
3000
4000
0 1 2 3 4 5 6 7 8 9 10
P [GeV]

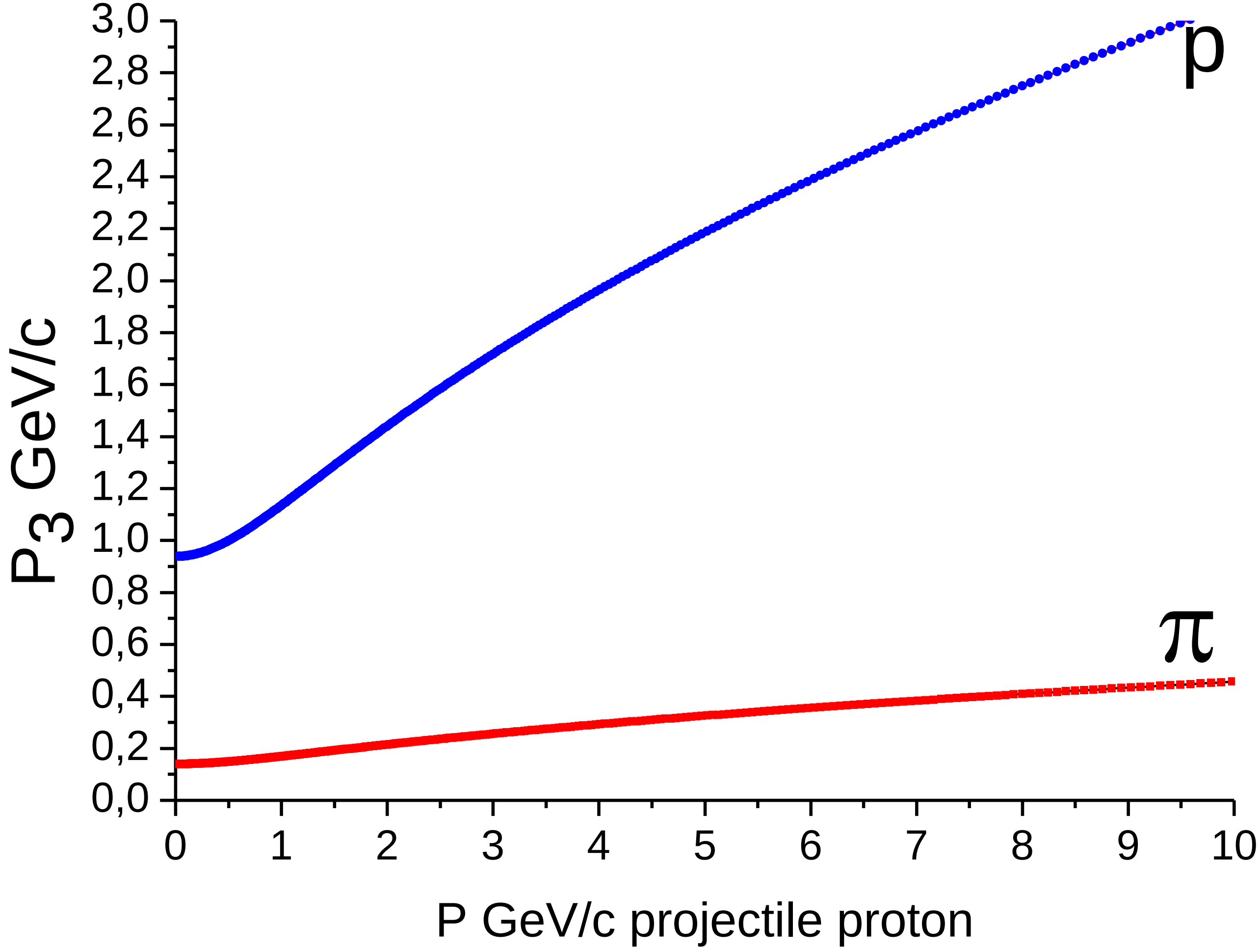

Pions
200
400
600
800
1000
1200
1400
1600
1800
0,000 0,005 0,010
2Π_L-α_1


Pions, 3 GeV/c
N
0
50
100
150
200
250
300
350
400
450
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15


Pions, 2.8 º
N
0
100
200
300
400
500
600
700
800
0 2 4 6 8 10 12 14 16 18 20
[grad] Lab. sys.



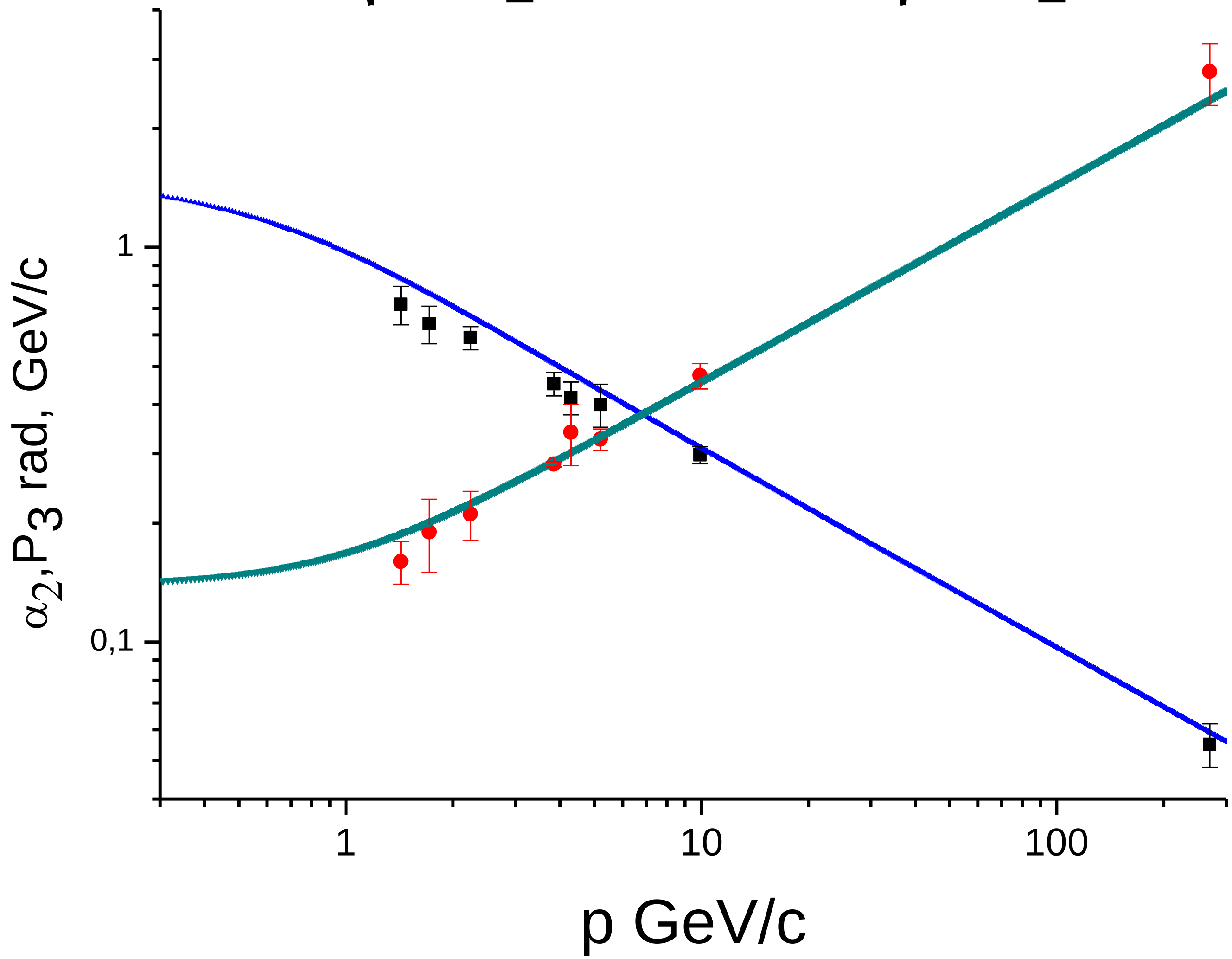
n+p->π⁻
GeV/c
5 GeV/c //c
3 GeV/c //c
2 GeV/c //c
1 GeV/c //c
1.4 MeV/c
0
200
400
600
800
1000
1200
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
2Π_L(h3)-α_1



3,0
2,8
2,6
2,4
2,2
2,0
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
P3 GeV/c
0
1
2
3
4
5
6
7
8
9
10
P GeV/c projectile proton
p
π

Directed Nuclear Radiation

$$\cos\alpha_2 = \sqrt{\frac{1+th(\rho_1)}{2}} - sh(h_3)\sqrt{\frac{1-th(\rho_1)}{2}}$$



ЯДЕРНАЯ ФИЗИКА, 2010, том 73, № 12, с. 1–10

ЭЛЕМЕНТАРНЫЕ ЧАСТИЦЫ И ПОЛЯ

SEARCH FOR COLLECTIVE PHENOMENA IN HADRON INTERACTIONS

© 2010 E. S. Kokoulina[1)*], V. A. Nikitin[1)**],
Y. P. Petukhov[1)***], A. V. Karpov[2)****], A. Ya. Kutov[2)*****]

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New results of the search for collective phenomena have been obtained and analyzed in the present report. The experimental studies are carried out on U-70 accelerator of IHEP in Protvino. It is suggested that these phenomena can be discovered at the energy range of 50–70 GeV in the extreme multiplicity region since the high-density matter can form in this very region. The collective behavior of secondary particles is considered to manifest itself in the Bose–Einstein condensation of pions, Vavilov–Cherenkov gluon radiation, excess of soft-photon yield, and other unique phenomena. The perceptible peak in the angular distribution has been revealed. It was interpreted as the gluon radiation and so the parton matter refraction index was determined. The new software was designed for the track reconstruction based on Kalman Filter technique. This algorithm allows one to estimate more precisely the track parameters (especially momentum). The search for Bose–Einstein condensation can be continued by using the selected events with the multiplicity of more than eight charged particles. The gluon dominance model predictions have shown good agreement with the multiplicity distribution at high multiplicity and confirmed the guark–gluon medium formation under these conditions.

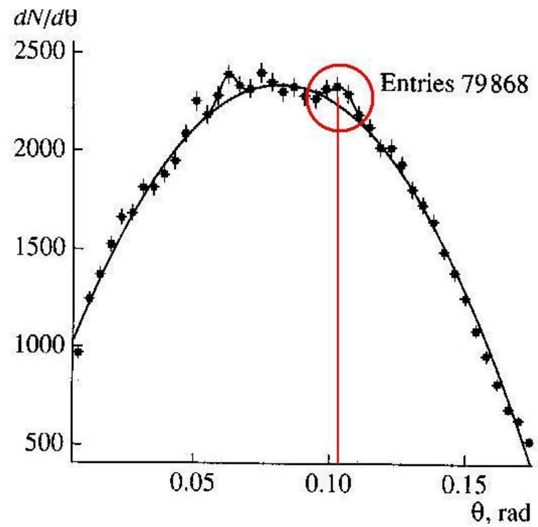
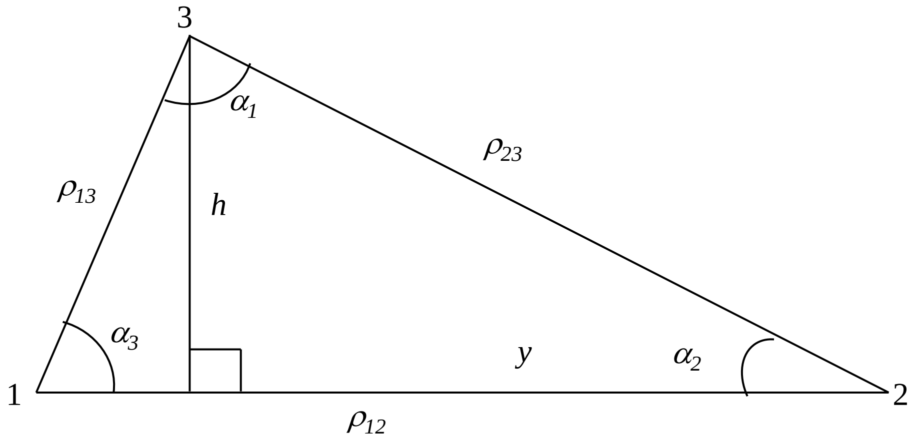


Fig. 7. The description of the θ distribution for the central region on the number of tracks (N) for events with multiplicity more than 8 charged particles by the third-order polynomial of background and two Gauss curves of two peaks (the same two-hump curve like in Fig. 6).



$$\cos\alpha_2 = \sqrt{\frac{1+th(\rho_1)}{2}} - sh(h_3)\sqrt{\frac{1-th(\rho_1)}{2}}$$

$$\alpha_1 = 2\arcsin\left\{\sqrt{\frac{1+th(\rho_1)}{2}}\sin(\Pi(h)) - \sqrt{\frac{1-th(\rho_1)}{2}}\cos(\Pi(h))\right\}$$

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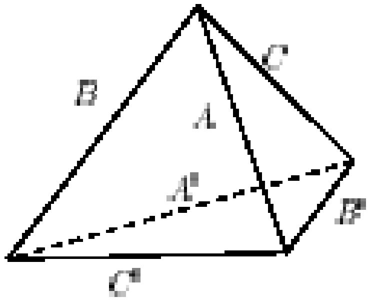
ATG



$$\begin{aligned} \alpha_1 &= \exp(i\overline{AB}); \quad \beta_1 = \exp(i\overline{BA}) \\ \alpha_2 &= \exp(i\overline{BC}); \quad \beta_2 = \exp(i\overline{CB}) \\ \alpha_3 &= \exp(i\overline{CD}); \quad \beta_3 = \exp(i\overline{DC}) \\ \alpha_4 &= \exp(i\overline{DA}); \quad \beta_4 = \exp(i\overline{AD}), \end{aligned} \tag{17}$$

we obtain

$$\begin{aligned} 0 = {} & \frac{1}{\alpha_1\alpha_2\alpha_3\alpha_4} - \beta_1\beta_2\beta_3\beta_4 + z^2\Big(-\frac{\alpha_1}{\alpha_2\alpha_3\alpha_4} - \frac{\alpha_2}{\alpha_1\alpha_3\alpha_4} - \frac{\alpha_3}{\alpha_1\alpha_2\alpha_4} - \frac{\alpha_4}{\alpha_1\alpha_2\alpha_3} \\ & + \frac{\beta_1\beta_2\beta_3}{\beta_4} + \frac{\beta_1\beta_2\beta_4}{\beta_3} + \frac{\beta_1\beta_3\beta_4}{\beta_2} + \frac{\beta_2\beta_3\beta_4}{\beta_1}\Big) \\ & + z^4\Big(\frac{\alpha_1\alpha_2}{\alpha_3\alpha_4} + \frac{\alpha_1\alpha_3}{\alpha_2\alpha_4} + \frac{\alpha_2\alpha_3}{\alpha_1\alpha_4} + \frac{\alpha_1\alpha_4}{\alpha_2\alpha_3} + \frac{\alpha_2\alpha_4}{\alpha_1\alpha_3} + \frac{\alpha_3\alpha_4}{\alpha_1\alpha_2} \\ & - \frac{\beta_1\beta_2}{\beta_3\beta_4} - \frac{\beta_1\beta_3}{\beta_2\beta_4} - \frac{\beta_2\beta_3}{\beta_1\beta_4} - \frac{\beta_1\beta_4}{\beta_2\beta_3} - \frac{\beta_2\beta_4}{\beta_1\beta_3} - \frac{\beta_3\beta_4}{\beta_1\beta_2}\Big) \\ & + z^6\Big(\frac{\beta_1}{\beta_2\beta_3\beta_4} + \frac{\beta_2}{\beta_1\beta_3\beta_4} + \frac{\beta_3}{\beta_1\beta_2\beta_4} + \frac{\beta_4}{\beta_1\beta_2\beta_3} \\ & - \frac{\alpha_1\alpha_2\alpha_3}{\alpha_4} - \frac{\alpha_1\alpha_2\alpha_4}{\alpha_3} - \frac{\alpha_1\alpha_3\alpha_4}{\alpha_2} - \frac{\alpha_2\alpha_3\alpha_4}{\alpha_1}\Big) + z^8\Big(\alpha_1\alpha_2\alpha_3\alpha_4 - \frac{1}{\beta_1\beta_2\beta_3\beta_4}\Big). \end{aligned} \tag{18}$$

The Regge symmetry is a scissors congruence in hyperbolic space

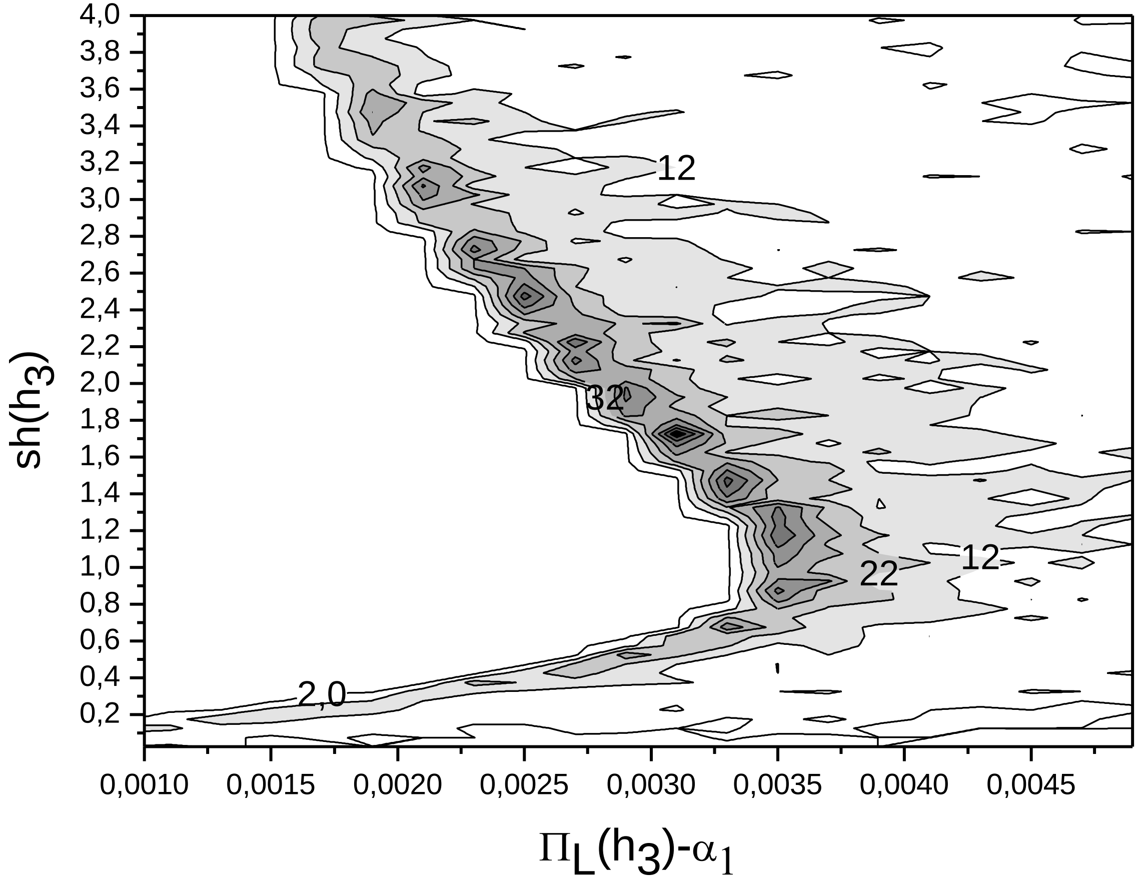
Yana Mohanty

$$\begin{aligned} \overline{BC} &= \frac{A + A' - 2B'}{4}; \quad \overline{CB} = \frac{2\pi - A + A' - 2C}{4} \\ \overline{CD} &= \frac{-A - A' - 2B}{4}; \quad \overline{DC} = \frac{2\pi - A + A' + 2C}{4} \\ \overline{DA} &= \frac{-A - A' + 2B}{4}; \quad \overline{AD} = \frac{2\pi + A - A' - 2C'}{4}. \end{aligned} \tag{21}$$

$$\begin{aligned} T) = {} & \text{Л}(\overline{AB} + \arg z_-) + \text{Л}(\overline{BA} - \arg z_-) + \text{Л}(\overline{BC} + \arg z_-) \\ & + \text{Л}(\overline{CB} - \arg z_-) + \text{Л}(\overline{CD} + \arg z_-) + \text{Л}(\overline{DC} - \arg z_-) \\ & + \text{Л}(\overline{DA} + \arg z_-) + \text{Л}(\overline{AD} - \arg z_-) + \frac{1}{2}\Big[\text{Л}\Big(\frac{\pi + A - B - C}{2}\Big) \\ & - \text{Л}\Big(\frac{\pi + B - A - C}{2}\Big) - \text{Л}\Big(\frac{\pi + C - A - B}{2}\Big) + \text{Л}\Big(\frac{\pi + B' - A' - C}{2}\Big) \\ & + \text{Л}\Big(\frac{\pi + A + B + C}{2}\Big) + \text{Л}\Big(\frac{\pi + C - A' - B'}{2}\Big) + \text{Л}\Big(\frac{\pi - A' + B' + C}{2}\Big) \\ & - \text{Л}\Big(\frac{\pi + A' + B' + C}{2}\Big) + \text{Л}\Big(\frac{\pi + A' - B - C'}{2}\Big) - \text{Л}\Big(\frac{\pi + A + B' + C'}{2}\Big) \\ & - \text{Л}\Big(\frac{\pi + A - B' - C'}{2}\Big) + \text{Л}\Big(\frac{\pi + B' - A - C'}{2}\Big) - \text{Л}\Big(\frac{\pi - A' - B + C'}{2}\Big) \\ & - \text{Л}\Big(\frac{\pi + A' - B + C'}{2}\Big) + \text{Л}\Big(\frac{\pi + A' + B + C'}{2}\Big) + \text{Л}\Big(\frac{\pi - A - B' + C'}{2}\Big)\Big], \end{aligned} \tag{23}$$

where the quantities with bars are given by (21), and z_- is the solution of the quadratic equation (18) with the negative square root.

π-C (40 GeV)



$$f(h)=2\left(\Pi_L(h)-arctg\,\frac{th\left(\frac{\rho_1}{2}\right)}{sh(h)}\right)=2arctg\left(\frac{\left(1-th\left(\frac{\rho_1}{2}\right)\right)\cdot sh(h)}{sh^2(h)+th\left(\frac{\rho_1}{2}\right)}\right)$$

Theory of Clustering Quark-Hadron Matter

1. A.M.Baldin, R. G. Nazmitdinov, A. V. Chizhov, A. S. Shumovsky, and Dokl.Phys. 29, 952 (1984).
2. V. I. Yukalov and E. P. Yukalova, Physica A 243, 382 (1997).
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5. V. I. Yukalov and E. P. Yukalova, Phys. Part.Nucl. 35, 348 (2004).

Theory of Clustering Quark-Hadron Matter

Prof. V.I.Yukalov:

"The theory of clustering quark-hadron matter is developed, where quarks are allowed to form different clusters that can coexist with unbound quark-gluon plasma. All calculated characteristics for pure gluodynamics and zero-barion density chromodynamics are in very good agreement with the known lattice simulations. For realistic parameters of matter with finite barion density, the deconfinement is predicted to be a gradual crossover, but not a sharp phase transition."

CONCLUSIONS

- **The developed functional self-similarity solution quantitatively describes angular, energy and A-dependences of inclusive production cross sections of all hadrons with transverse momentum up to 2GeV.**
- **The analysis of inclusive spectra for the data selected in different ways shows that multiplicity in relativistic nuclear collisions has its origin basically in independent nucleon-nucleon interactions. Thus, high multiplicity at interaction of heavy nuclei is not a satisfactory criterion for search and study of collective interactions, or detection of exotic states of nuclear matter (such as quark-gluon plasma).**
- **It is natural to consider two types of collectivity in nuclear-nuclear collisions: the first is related to production of particles in the region kinematically forbidden for single nucleon-nucleon interactions (X_1 or X_2 or both greater than unity); the second is a result of collectivity of the initial state in nucleus-nucleus collisions) – high probability of a large number of independent nucleon-nucleon interactions in the collision. The analysis of multiple experimental data on the basis of the proposed self-similarity approach allows to conclude that the effect of the collectivity of the first type drops drastically with increasing energy of colliding particles and increases with increasing mass of the produced particle.**
- **It seems reasonable to study specially selected events with at least one particle (or jet) for production of which X_1 or X_2 (or both) should be greater than unity for investigation of collective nuclear effects. For collider energies the suitable selection criterion may be a particle (or a jet) with high transverse mass. In the conditions of 4π geometry the statistics is usually insufficient for analysis of such processes. Therefore, in order to investigate the region $X_1>1$or $X_2>1$ (or both $X_1,X_2>1$) it is necessary to select the events at the first level trigger of the registration system.**
- **Interaction of very heavy nuclei (Au, Pb, …) may "entangle" experimental picture of the reaction and complicate theoretical interpretation. Collective effects can be observed already for light and intermediate nuclei, although with lower multiplicity and combinatorial background.**
- **Collective phenomena become extinct with increasing collision energy. Therefore, the energy range from hundreds MeV to tens of GeV is optimal for experimental observation of collective effects in nuclear collisions.**
- **The phenomenon of directed nuclear radiation predicted using the Lobachevsky geometry has received more experimental proof.**
- **The Lobachevsky space is an efficient tool for analysis of experimental data on multiparticle production at relativistic energies, finding new effects, and planning future experiments.**

1977 г. Апрель Том 121, вып. 4

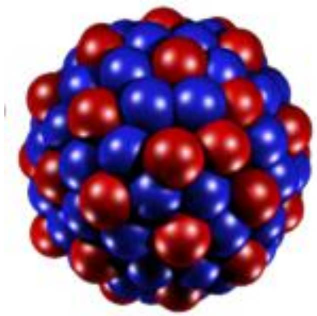
УСПЕХИ ФИЗИЧЕСКИХ НАУК

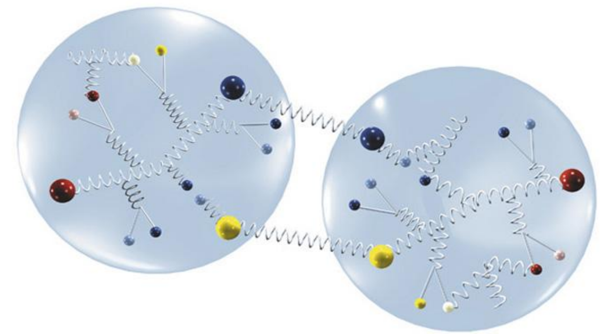
ПРИРОДА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ *)

В Гейзенберг

Поскольку при взаимодействиях частиц высоких энергий их число не сохраняется, вопрос о составных частях элементарных частиц может оказаться бессмысленным, и вполне возможно, динамика окажется центральной проблемой.

Ответ на вопрос «Что такое элементарная частица?» следует искать прежде всего в эксперименте, хотя вопрос этот требует также и философского рассмотрения. Поэтому я начну с краткого обзора важнейших экспериментальных результатов, полученных за последние пятьдесят лет. Из этого обзора будет видно, что беспристрастный анализ известных результатов уже дает определенный ответ на поставленный выше вопрос; теория же, как мы увидим дальше, не в состоянии добавить что-либо существенное к этому ответу.





НЕПРАВИЛЬНО ПОСТАВЛЕННЫЕ ВОПРОСЫ

Однако меня больше занимает физика, чем философия. Я начну с того, что, по моему убеждению, развитие теоретической физики частиц с самого начала ведется неверно; это обусловлено прежде всего неправильно поставленными вопросами.

Первым делом я упомяну о существовании тезиса о том, что наблюдаемые частицы, такие, как протон, пион и гиперон, состоят из еще более малых частиц: кварков, партонов, глюонов, очарованных частиц или чего-то еще, причем эти более малые частицы ненаблюдаемы. Совершенно очевидно, что здесь был задан вопрос: «Из чего состоит протон?», причем спрашивающий забыл о том, что сама фраза «состоит из» сохраняет достаточно ясный смысл только в том случае, если частицу можно раздробить на части малым количеством энергии — гораздо меньшим, чем масса покоя разрушаемой частицы.

*) Werner Heisenberg, The Nature of Elementary Particles, Phys. Today 29 (3), 32 (March 1976). Перевод В. А. Белоконя.

THANK YOU FOR YOUR ATTENTION!