“Cold Superdense Baryonic Component of Nuclear Matter”

S.S. Shimanskiy (JINR, Dubna)

OUTLINE

1. The Phase Diagram of Nuclear Matter and Cold Dense Baryonic Matter at Stars
2. New component of Nuclear Matter

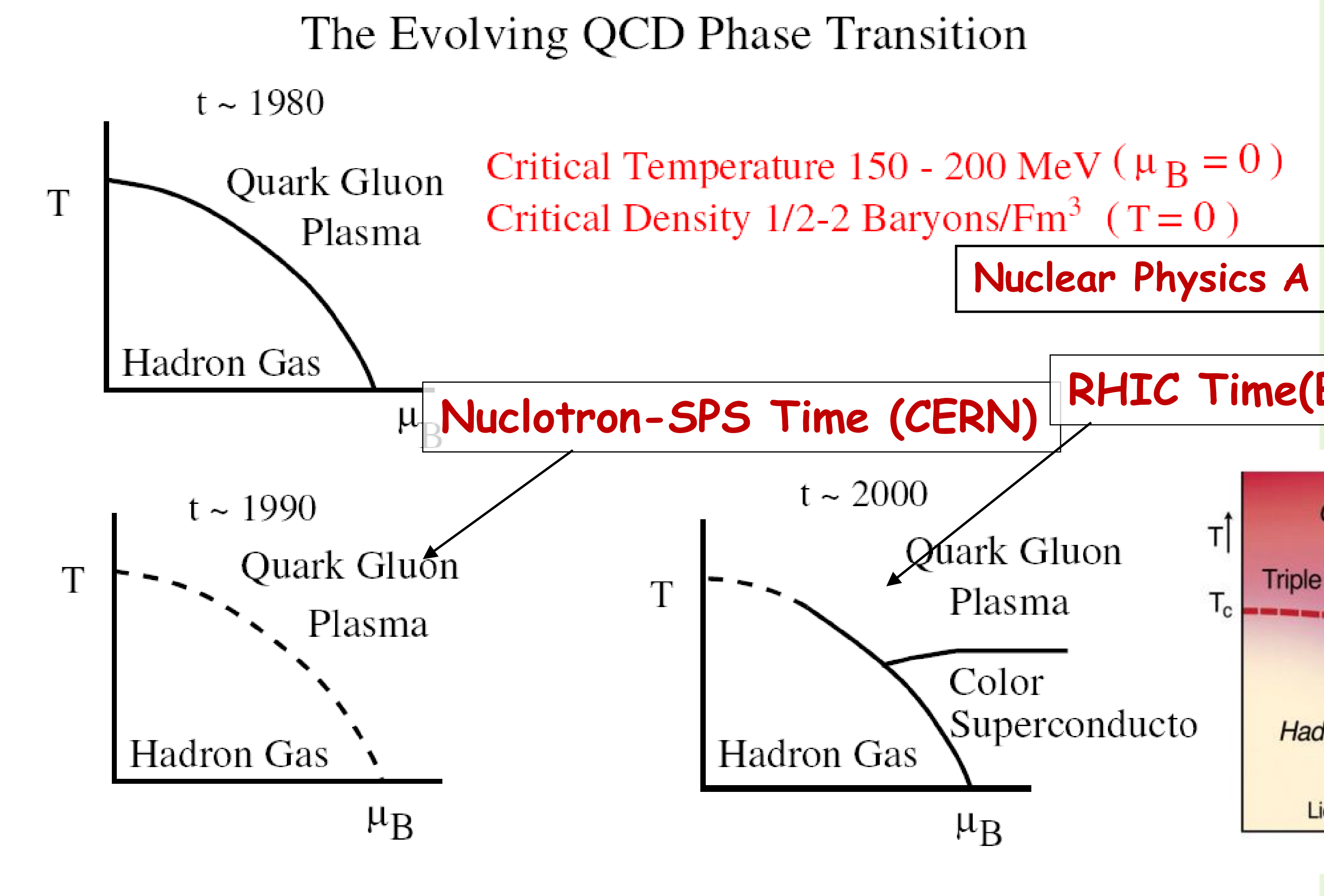
   Discovery and Investigation with Different Probes
3. High p_T probes and SPIN data
4. CsDBM

RHIC Physics: 3 Lectures*

Larry McLerran
Physics Department PO Box 5000 Brookhaven National Laboratory Upton, NY 11973 USA

September 13, 2003

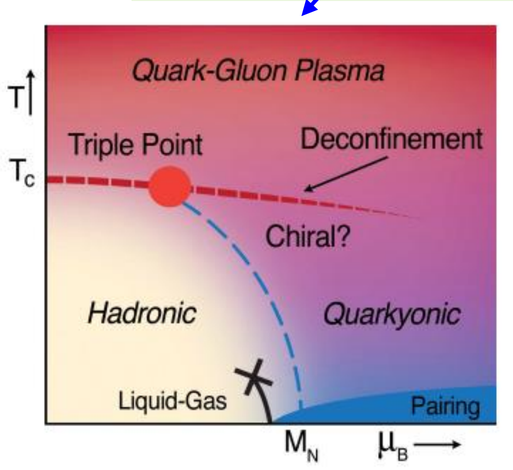
+ CERN Yellow Report
2007-005, p.75
2008-005



Nuclear Physics A 837 (2010) 65-86

RHIC Time(BNL)

Nuclotron-SPS Time (CERN)



Strangeness in Neutron Stars

FRIDOLIN WEBER[*], ALEXANDER HO[†], RODRIGO P. NEGREIROS[‡], PHILIP ROSENFIELD[§]

astro-ph/0604422 v1 20 Apr 2006

$H \sim 10^{17}$ Gs

$E \sim 10^{19}$ V/cm

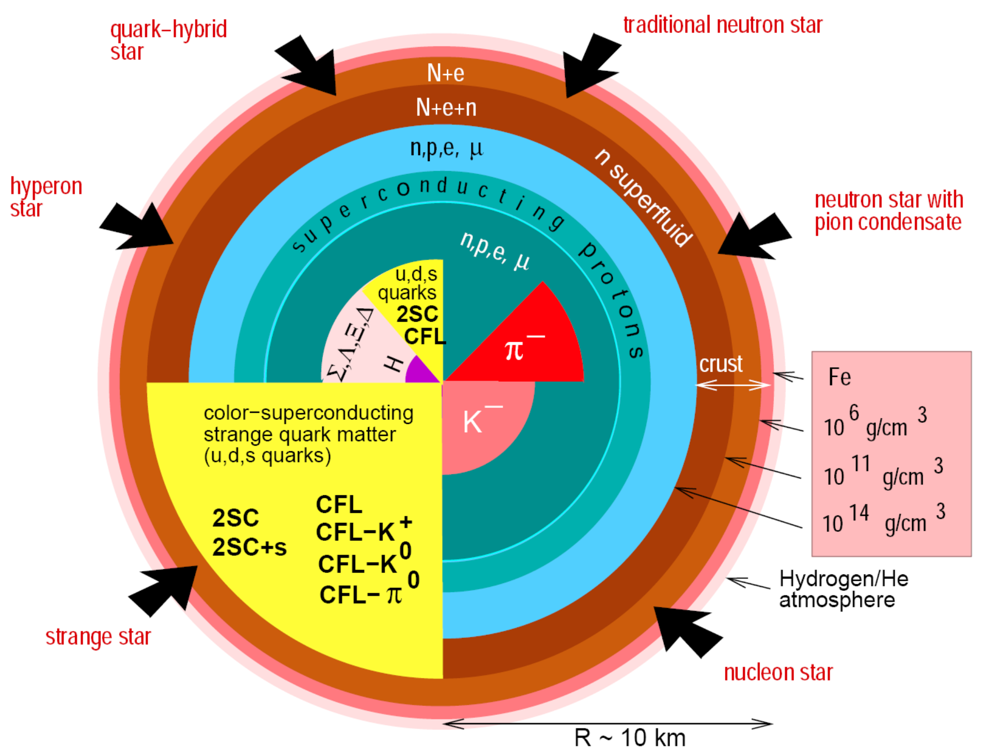


Fig. 1. Competing structures and novel phases of subatomic matter predicted by theory to make their appearances in the cores ($R \lesssim 8$ km) of neutron stars[4].

significant range of chemical potentials and strange quark masses[51]. If the strange quark mass is heavy enough to be ignored, then up and down quarks may pair in the two-flavor superconducting (2SC) phase. Other possible condensation patters

color−superconducting strange quark matter (u,d,s quarks)

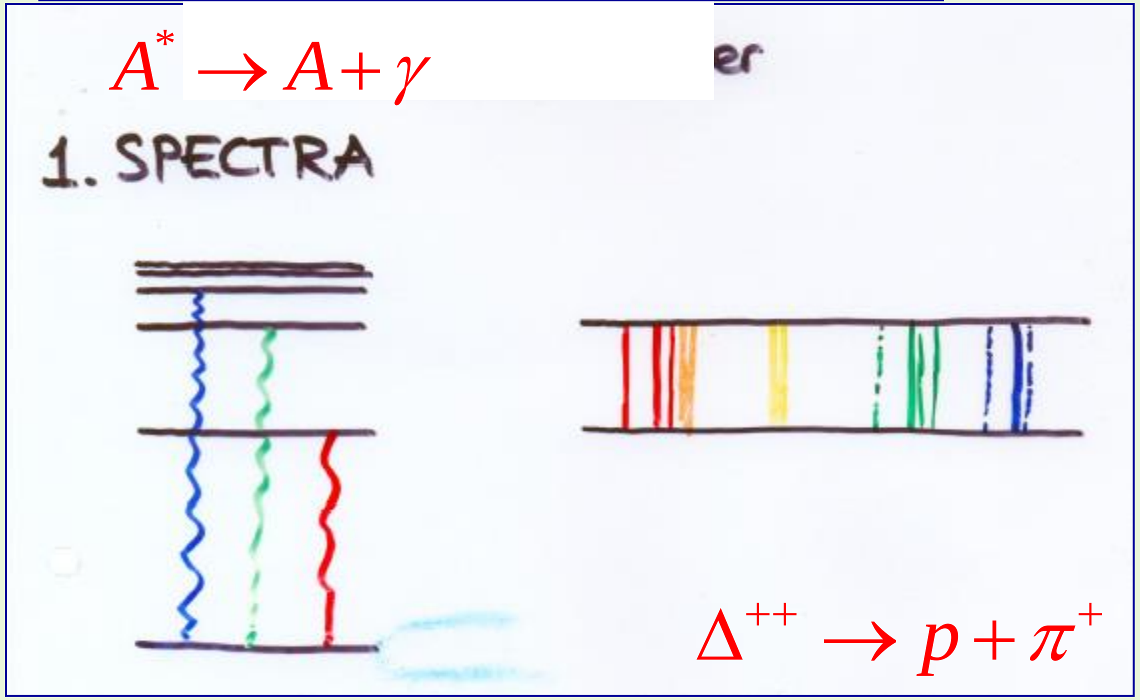
K. Rajagopal and F. Wilczek, *The Condensed Matter Physics of QCD*, At the Frontier of Particle Physics / Handbook of QCD, ed. M. Shifman, (World Scientific) (2001).
M. Alford, Ann. Rev. Nucl. Part. Sci. **51** (2001) 131.

New component of Nuclear Matter
Discovery and Investigation with Different Probes

F. Close

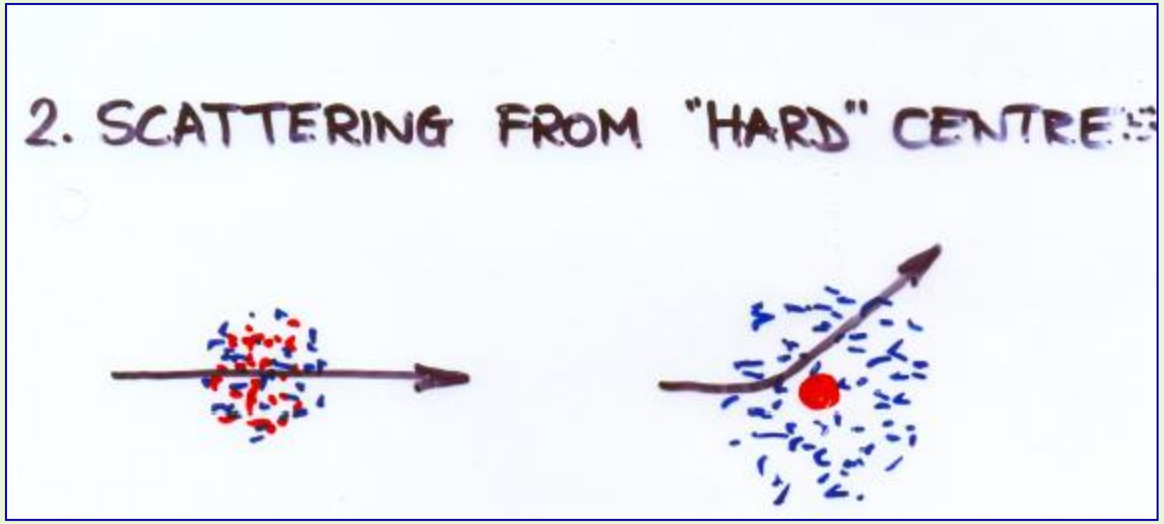
Structure of Matter

Two ways that structure is revealed:



$$A^* \rightarrow A + \gamma$$

$$\Delta^{++} \rightarrow p + \pi^+$$



True from atoms to particles…..

Volume 67B, number 1 PHYSICS LETTERS 14 March 1977

ТЕОРИЯ

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

V.V. BUROV
The Moscow State University, Moscow, USSR

and

V.K. LUKYANOV and A.I. TITOV
Joint Institute for Nuclear Research, Dubna, USSR

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 ma
$M_k = km_p$ of nucleons in the small volume $V_\xi = \frac{4}{3}\pi r$
where r_ξ is the fluctuon radius were assumed.

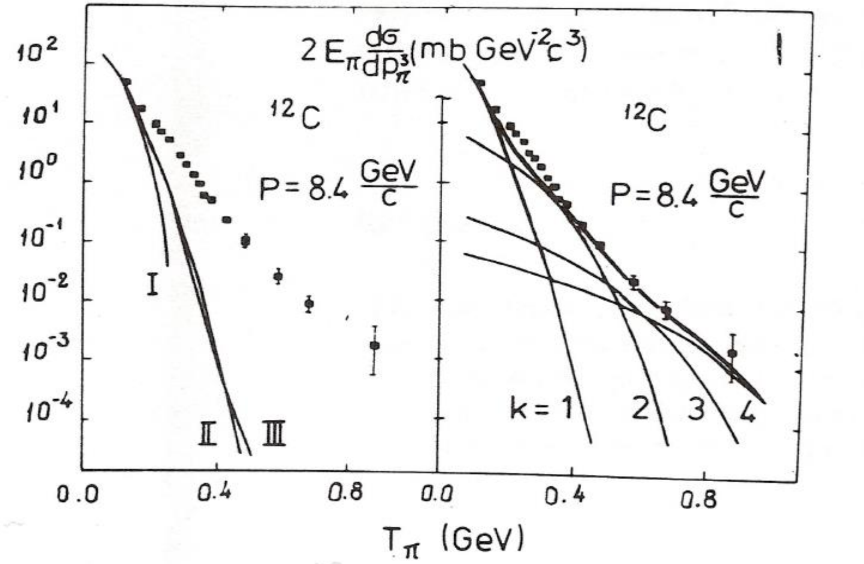


Fig. 1. (a) Calculations of the invariant pion production cross section for ^{12}C: I – for the free proton target; II – with fermi motion; III – the relativization effect. (b) The contributions of separate fluctuons with mass $M_k = km_p$ where k is the order of cumulativity.

A - dependence (1974-...)

$$\varepsilon \frac{d\sigma}{dp}(p + A \to \pi) \sim \begin{cases} A - heavy\_nuclei \\ A^{n>1} - light\_nuclei \end{cases}$$

$$\varepsilon \frac{d\sigma}{dp}(p + A \to B) \sim \begin{cases} A^{5|/3} - for\_d \\ A^{2} - for\_t \end{cases}$$

The same time Cronin team at FNAL have seen about the same A-dependence for pA(for 200, 300, 400 GeV protons) high p_T Particle production

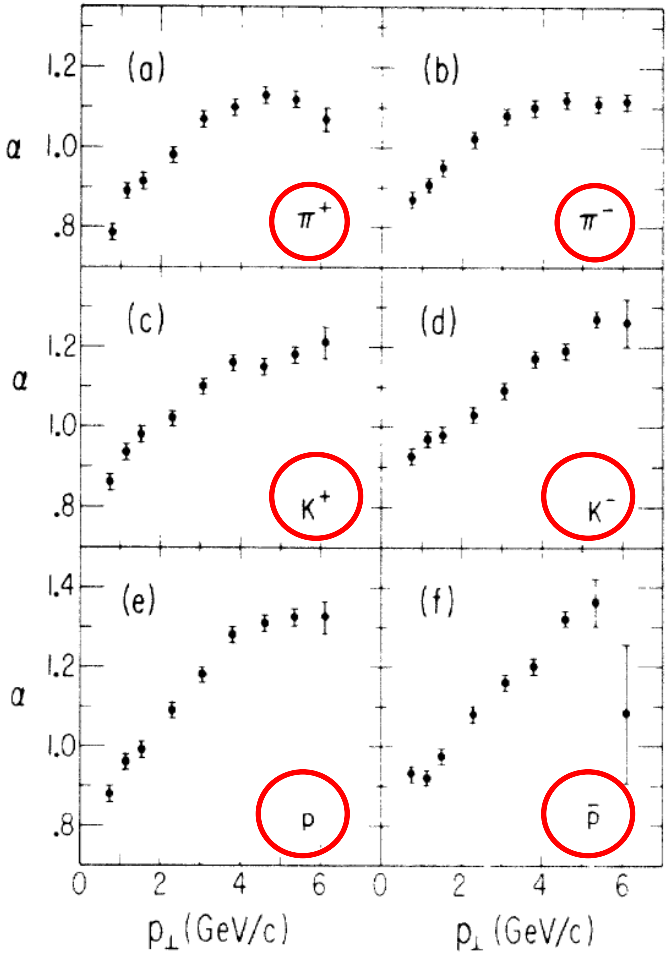


FIG. 17. Plots of the power α of the A dependence versus $p_\perp$ for the production of hadrons by 300-GeV protons; (a) π^+, (b) π^-, (c) K^+, (d) K^-, (e) p, and (f) $\bar{p}$.

Other processes to investigate the high dense state of the cold nuclear matter – high p_T physics. Stavinsky tried to describe by the same way as cumulative processes.

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.

Common case for AA-collisions

V.S. Stavinsky JINR Rapid Communications N18-86, p.5 (1986)

$(X_I \cdot M_I) + (X_{II} \cdot M_{II}) \rightarrow m_c + [X_I \cdot M_I + X_{II} \cdot M_{II} + m_2]$

$$S_{\min}^{1/2} = \min(S^{1/2}) = \min[(X_I \cdot P_I + X_{\mathrm{II}} \cdot P_{II})^{1/2}]$$

A.A. Baldin's parameterization

Phys. At. Nucl. 56(3), p.385(1993)

$$\Pi = \frac{1}{2}(X_I^2 + X_{II}^2 + 2 \cdot X_I \cdot X_{II} \cdot \gamma_{I,II})^{\frac{1}{2}} = \frac{1}{2 \cdot m} \cdot S_{\min}^{\frac{1}{2}}$$

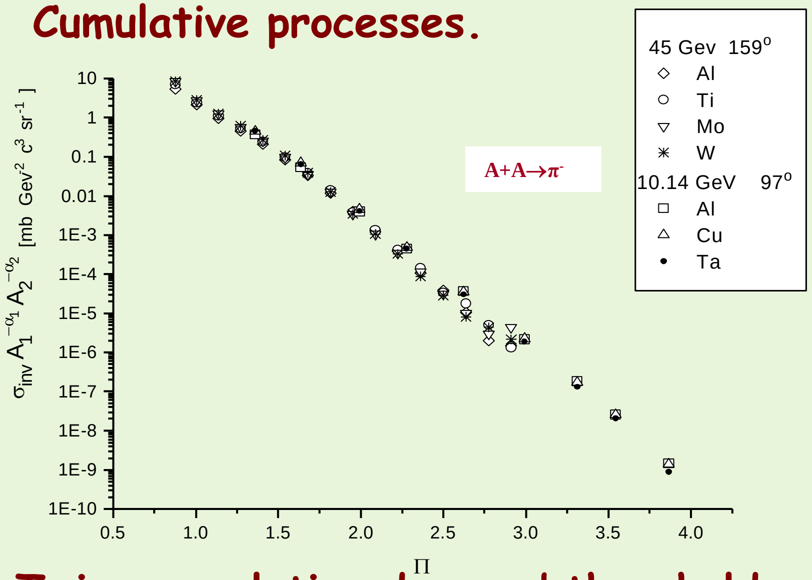
$$\gamma_{I,II} = \frac{(P_I \cdot P_{II})}{M_I \cdot M_{II}}$$

Inclusive data parameterization

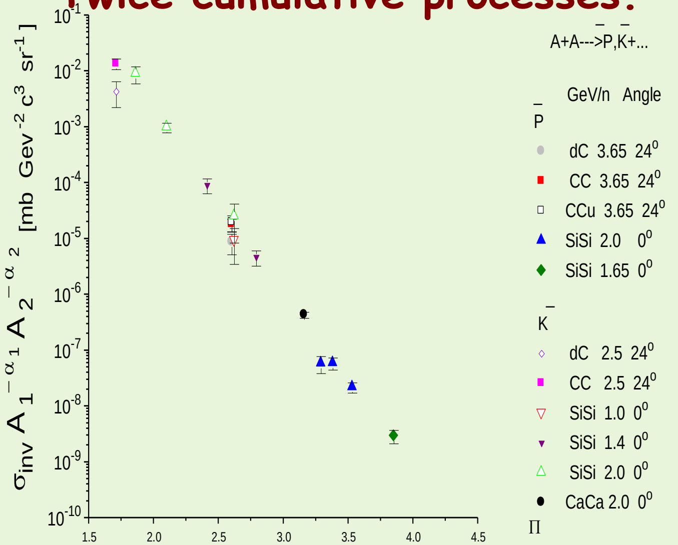
$$E \cdot \frac{d^3\sigma}{dp^3} = C_1 \cdot A_I^{\frac{1}{3}+\frac{X_I}{3}} \cdot A_{II}^{\frac{1}{3}+\frac{X_{II}}{3}} \cdot \exp(-\frac{\Pi}{C_2}),$$

$$C_1 = 2200[mb \cdot GeV^{-2} \cdot c^3 \cdot sr^{-1}], C_2 = 0.127$$

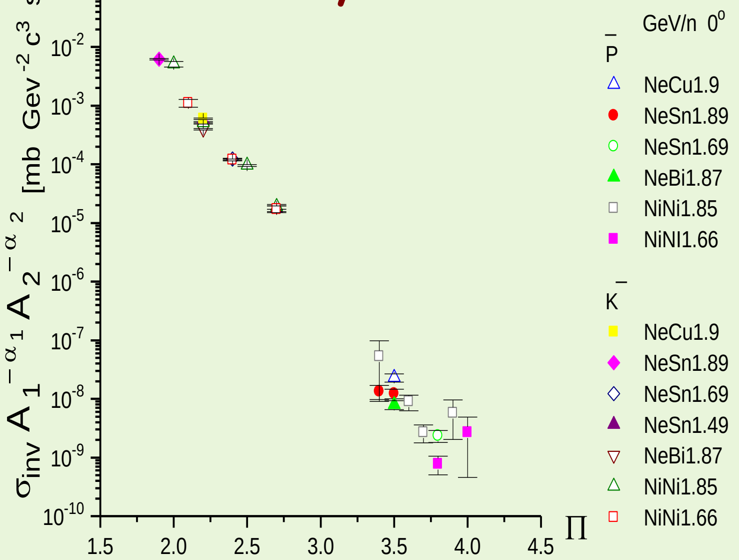
Cumulative processes.



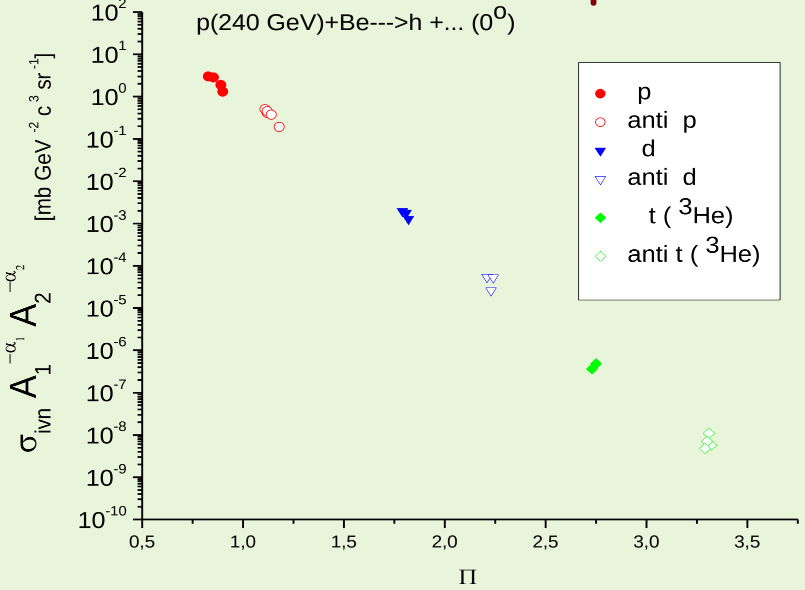
Twice cumulative processes.



Twice cumulative deep subthreshold processes with heavy nuclei.



Antimatter production.



DIS in the cumulative region.

PHYSICAL REVIEW C VOLUME 45, NUMBER 4 APRIL 1992

Nuclear structure functions at $x > 1$

B. W. Filippone, R. D. McKeown, R. G. Milner,* and D. H. Potterveld†
Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California 91125

D. B. Day, J. S. McCarthy, Z. Meziani,‡ R. Minehardt, R. Sealock, and S. T. Thornton
Institute of Nuclear and Particle Physics and Department of Physics, University of Virginia, Charlottesville, Virginia 22901

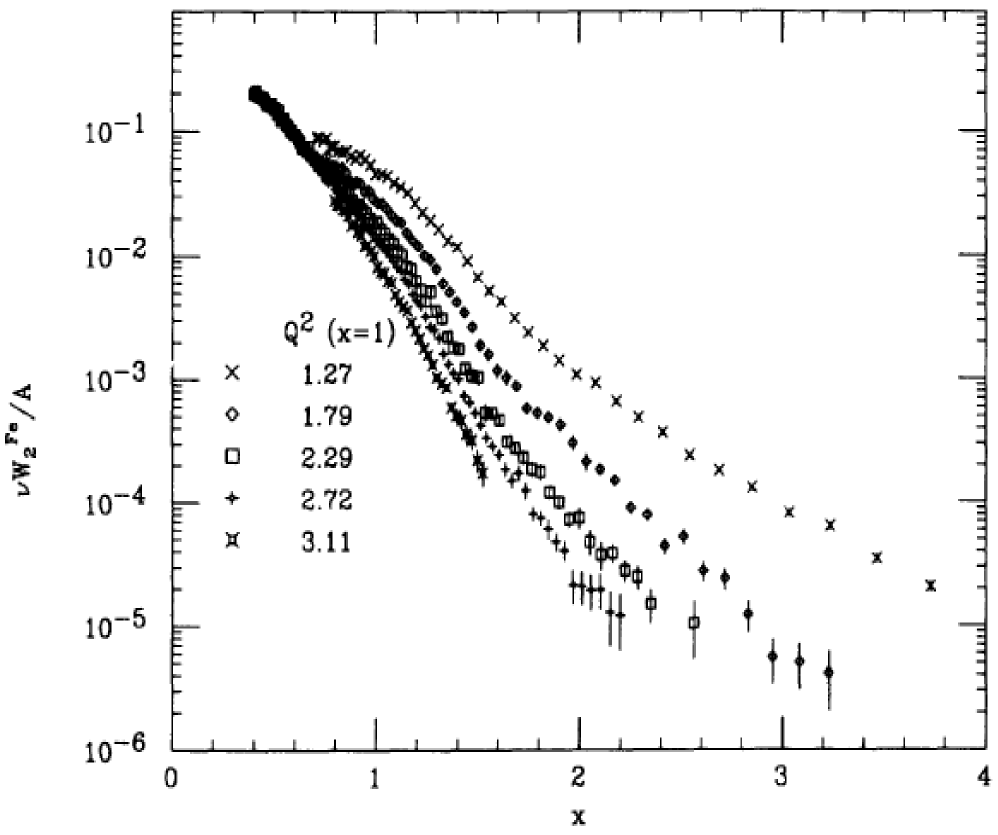


FIG. 1. Measured structure function per nucleon for Fe vs x. The Q^2 value at $x=1$ is also listed for the different kinematics.

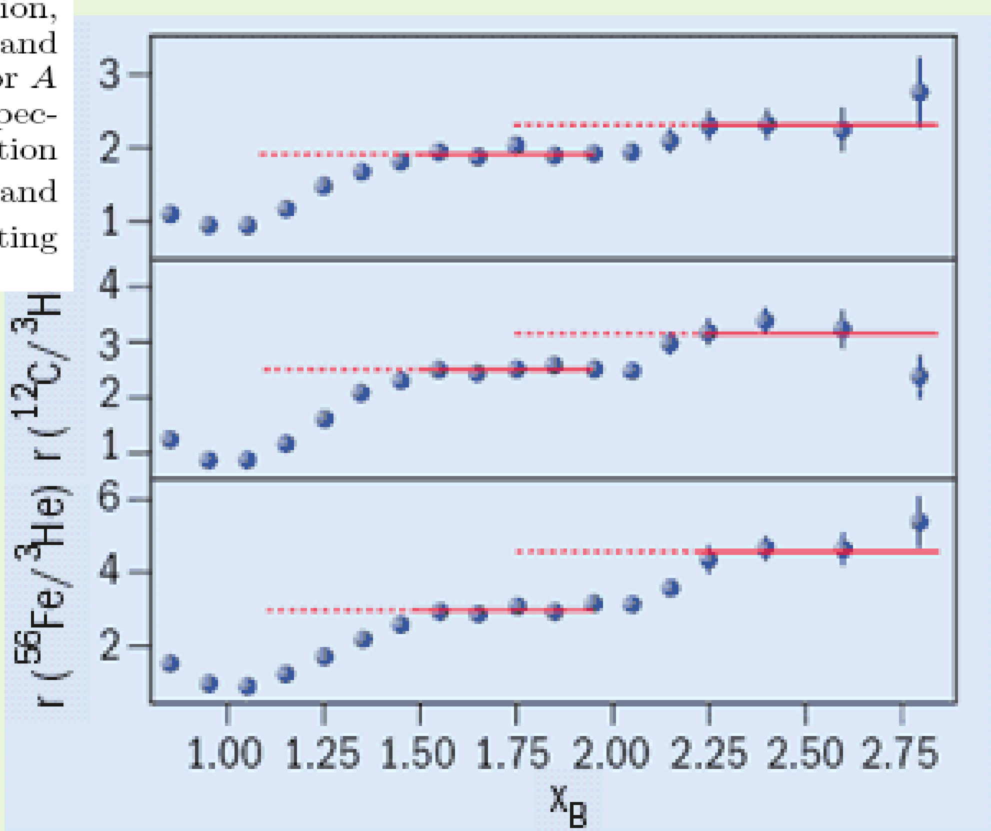
Phys.Rev.Lett. 96 (2006) 082501

Measurement of 2- and 3-Nucleon Short Range Correlation Probabilities in Nuclei

K.S. Egiyan,[1] N.B. Dashyan,[1] M.M. Sargsian,[10] M.I. Strikman,[28] L.B. Weinstein,[27] G. Adams,[30] P. Ambrozewicz,[10] M. Anghinolfi,[16] B. Asavapibhop,[22] G. Asryan,[1] H. Avakian,[34] H. Baghdasaryan,[27] N. Baillie,[38] J.P. Ball,[2]

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

where Z and N are the number of protons and neutrons in nucleus A, σ_{eN} is the electron-nucleon cross section, $\mathcal{Y}$ is the normalized yield in a given (Q^2, x_B) bin [30] and C^A_{rad} is the ratio of the radiative correction factors for A and ^{3}He ($C^A_{\text{rad}} = 0.95$ and 0.92 for ^{12}C and ^{56}Fe respectively). In our Q^2 range, the elementary cross section correction factor $\frac{A(2\sigma_{ep}+\sigma_{en})}{3(Z\sigma_{ep}+N\sigma_{en})}$ is 1.14 ± 0.02 for C and ^{4}He and 1.18 ± 0.02 for ^{56}Fe. Fig. 1 shows the resulting ratios integrated over $1.4 < Q^2 < 2.6$ GeV^2.



Having these data, we know almost full (≈99%) nucleonic picture of nuclei with $A \leq 56$

Fractions / Nucleus	Single particle (%)	2N SRC (%)	3N SRC (%)
^{56}Fe	**76** ± 0.2 ± 4.7	**23.0** ± 0.2 ± 4.7	**0.79** ± 0.03 ± 0.25
^{12}C	**80** ± 02 ± 4.1	**19.3** ± 0.2 ± 4.1	**0.55** ± 0.03 ± 0.18
^{4}He	**86** ± 0.2 ± 3.3	**15.4** ± 0.2 ± 3.3	**0.42** ± 0.02 ± 0.14
^{3}He	**92** ± 1.6	**8.0** ± 1.6	**0.18** ± 0.06
^{2}H	**96** ± 0.8	**4.0** ± 0.8	-----

Using the published data on (p,2p+n) [PRL,90 (2003) 042301] estimate the isotopic composition of 2N SRC in ^{12}C

$a_{2N}(^{12}C) \approx$ **20** ± 0.2 ± 4.1 % →

$a_{pp}(^{12}C) \approx$ **4** ± **2** %

$a_{pn}(^{12}C) \approx$ **12** ± 4 %

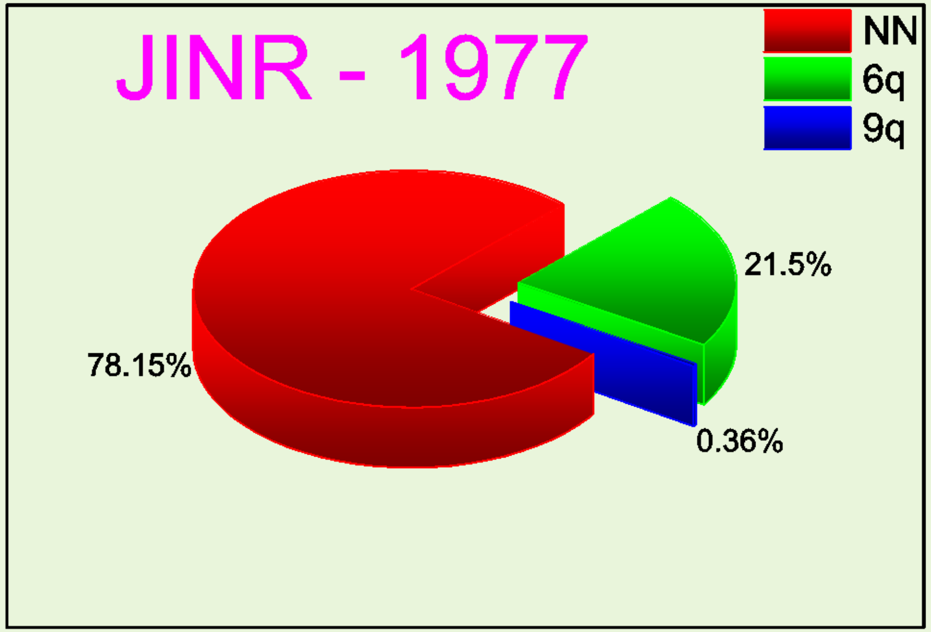
$a_{nn}(^{12}C) \approx$ **4** ± **2** %

17

^{12}C - structure

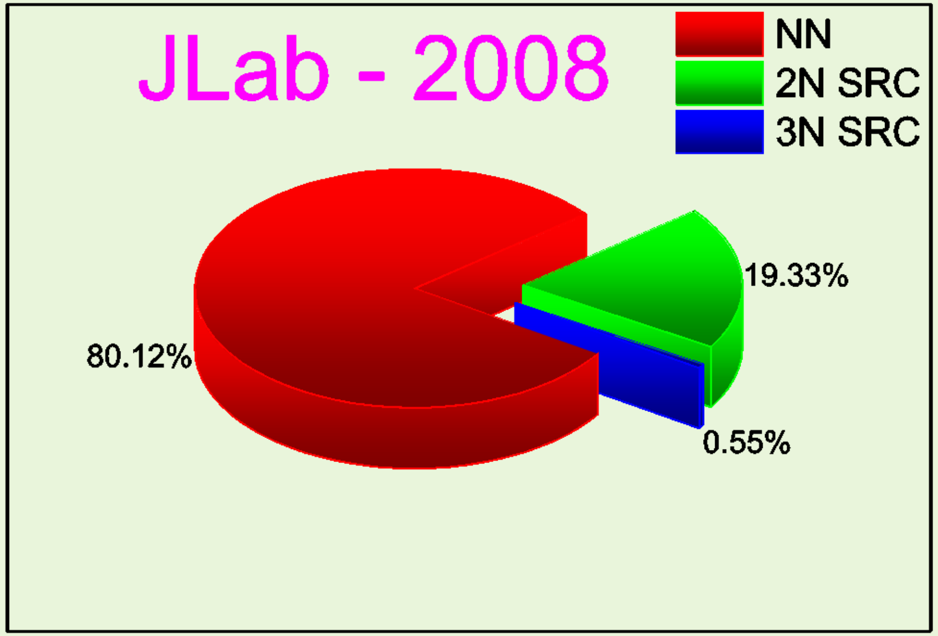
RNP – program at JINR

V.V.B., V.K.Lukyanov, A.I.Titov, PLB, 67, 46(1977)



eA – program at JLab

R.Subedi et al., Science 320 (2008) 1476-1478
e-Print: arXiv:0908.1514 [nucl-ex]



Т. 32. Журнал экспериментальной и теоретической физики. Вып. 3

1957

G.A. Leksin, Elastic and quasielastic scattering of 660-MeV protons by deuterons
Published in: Sov.Phys.JETP 5 (1957) 371-377, Zh.Eksp.Teor.Fiz. 32 (1957) 440-444

УПРУГОЕ И КВАЗИУПРУГОЕ РАССЕЯНИЕ ПРОТОНОВ С ЭНЕРГИЕЙ 660 MeV НА ДЕЙТОНАХ[1]

Г. А. Лексин

При энергии падающих протонов 660 MeV методом сопряженных телескопов измерены дифференциальные сечения упругого $(p-d)$-рассеяния в диапазоне углов 40—150° в с. ц. и. и квазиупругого $(p-p)$-рассеяния в диапазоне углов 50—90° в с. ц. и. двух нуклонов. Экспериментальные данные указывают как на преимущественное взаимодействие налетающего протона с отдельным нуклоном в дейтоне, так и на существование коллективного взаимодействия трех нуклонов. Измерена также энергетическая зависимость дифференциального сечения квазиупругого $(p-n)$-рассеяния на угол 90° в с. ц. и. двух нуклонов в области энергий 460—660 MeV.

Т. 33. Журнал экспериментальной и теоретической физики. Вып. 5(11)

1957

L.S. Azhgirei et al., Sov. Phys. JETP 5, 911–919 (1957).

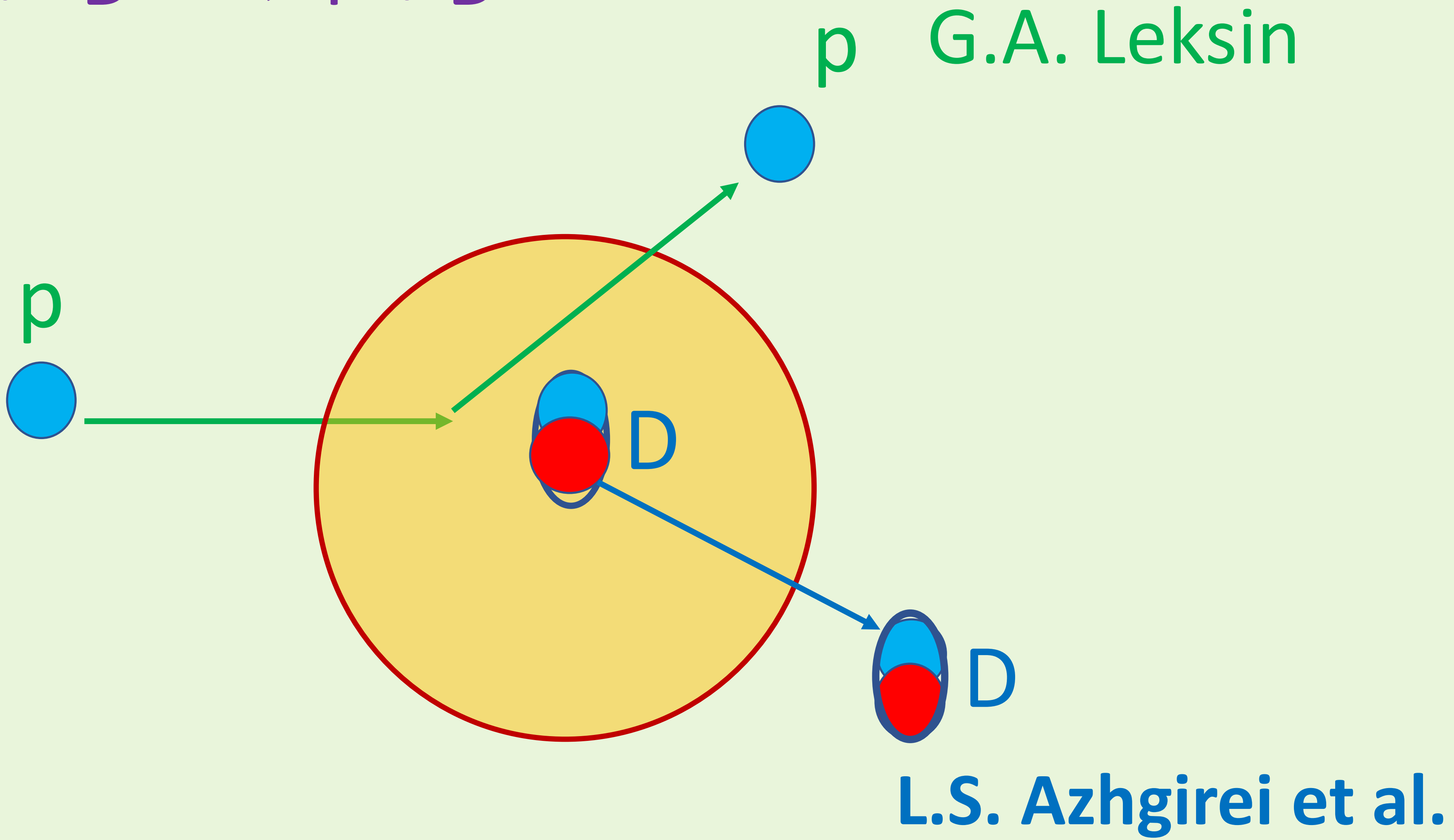
ВЫБИВАНИЕ ДЕЙТРОНОВ ИЗ ЯДЕР Li, Be, C и O ПРОТОНАМИ С ЭНЕРГИЕЙ 675 MeV [1]

Л. С. Ажгирей, И. К. Взоров, В. П. Зрелов, М. Г. Мещеряков, Б. С. Неганов, А. Ф. Шабудин

Изучены импульсные спектры заряженных частиц, испускаемых при бомбардировке дейтерия, лития, бериллия, углерода и кислорода протонами с энергией 675 MeV. Исследование производилось методом магнитного анализа под углом 7,6° относительно пучка протонов. Для всех элементов обнаружено испускание группы дейтронов с энергией около 600 MeV. В случае дейтерия источником быстрых дейтронов является упругое $(p-d)$-рассеяние; в остальных случаях испускание дейтронов происходит в реакции $p+(Z, A)\rightarrow d+p+(Z-1, A-2)$, представляющей собой рассеяние протонов на квазидейтронных группах внутри ядер. С точностью около 20% дифференциальные сечения этой реакции составляют 2,9, 2,2, 3,7 и $4{,}6\cdot10^{-27}$ *см²/стерад* соответственно для Li, Be, C и O. Для тех же ядер средняя энергия движения квазидейтронных групп оценена равной примерно 8, 11, 14 и 14 MeV. В высокоимпульсной части спектров не обнаружено в заметных количествах выбитых ядер трития.

Выполненные эксперименты показывают, что в соударениях нуклонов данной энергии с легкими ядрами имеют место процессы трехчастичного взаимодействия, сопровождающиеся передачей больших импульсов. Полученные результаты согласуются с представлениями, лежащими в основе высокоимпульсной модели ядра.

P + “D” ---> P + D



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

ON THE FLUCTUATIONS OF NUCLEAR MATTER

D. I. BLOKHINTSEV

Joint Institute for Nuclear Research

Submitted to JETP editor July 1, 1957

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.

Beck(Editor), Clusters in Nuclei Volume 1,2010

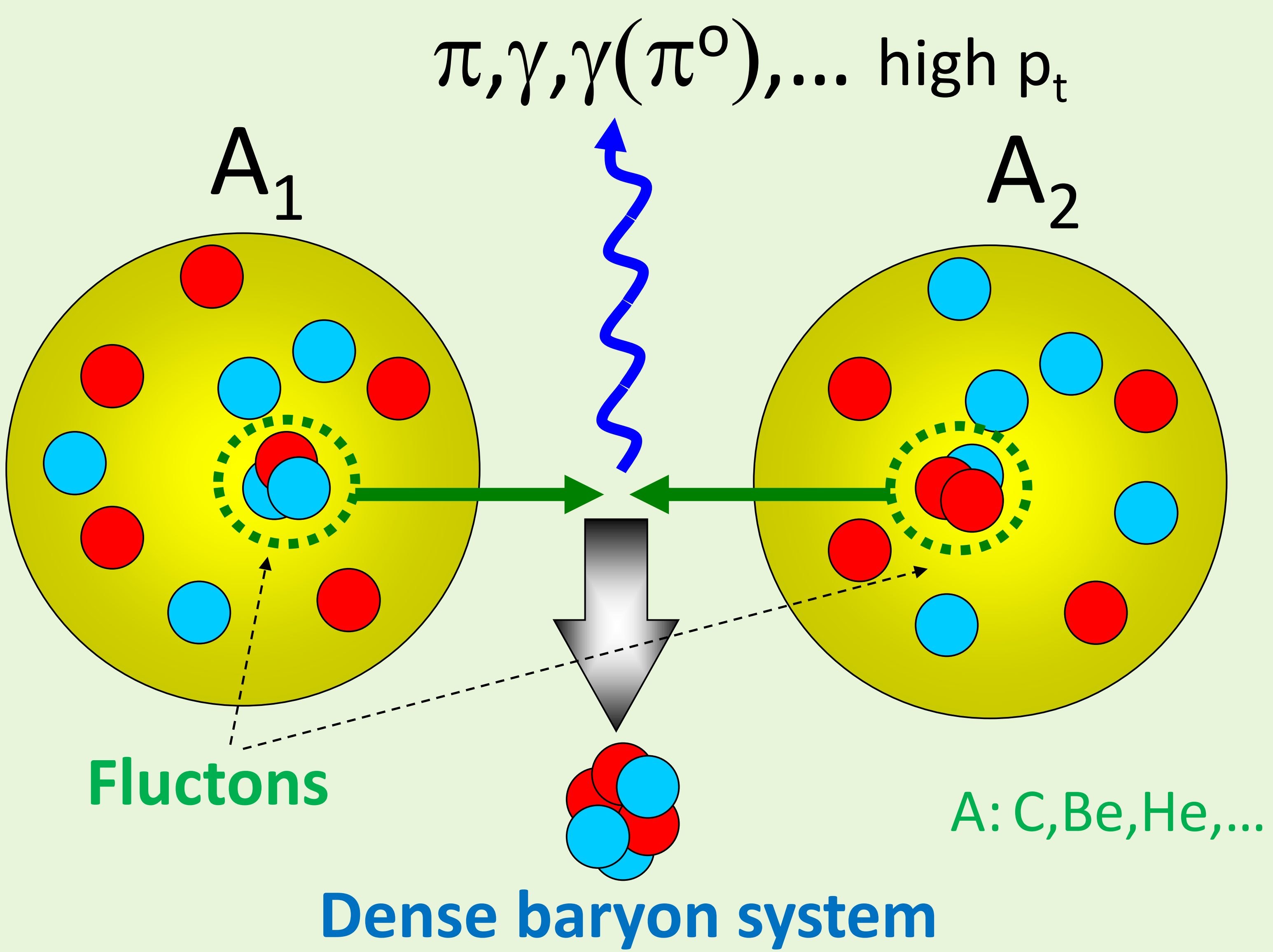
p.v

A great deal of research work has been performed in the field of alpha clustering since the pioneering discovery, by D. A. Bromley and co-workers half a century ago, of molecular resonances in the excitation functions for 12C + 12C scattering. The aim of this new series of Lecture Notes in Physics entitled Clusters in Nuclei is to deepen our knowledge of this field of nuclear molecular physics whose history was so well recounted in 1995 by W. Greiner, J. Y. Park and W. Scheid in their famous book on Nuclear Molecules (World Scientific Publishing Co.).

Nuclear clustering remains, however, one of the most fruitful domains of nuclear physics, and faces some of the greatest challenges and opportunities in the years ahead.

High p_T processes

FLINT@ITEP: ^{12}C + Be $\rightarrow$ γ + X



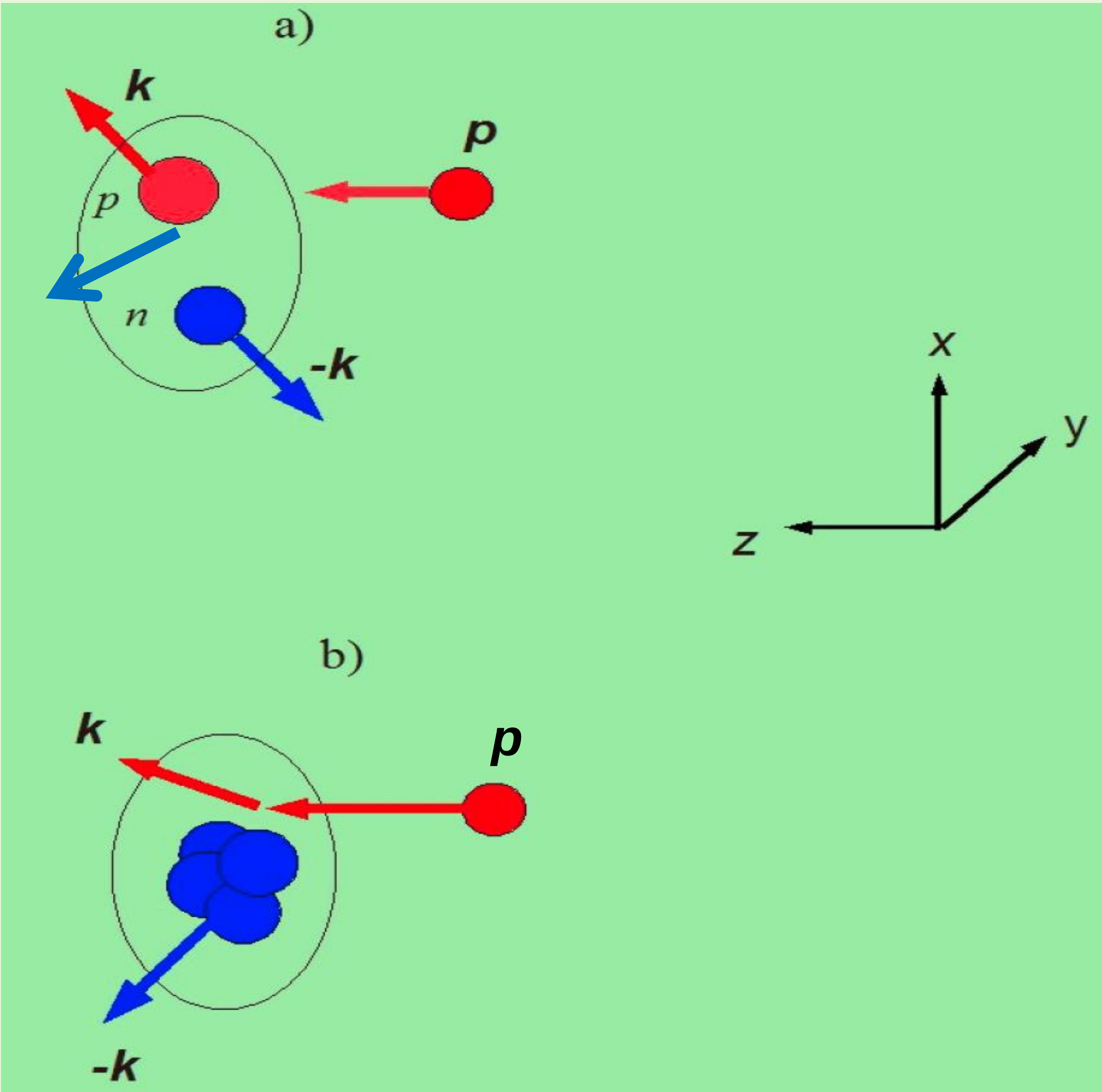
Knot out cold dense nuclear configurations

SRC configuration

<B> ~ 1

<B> ?

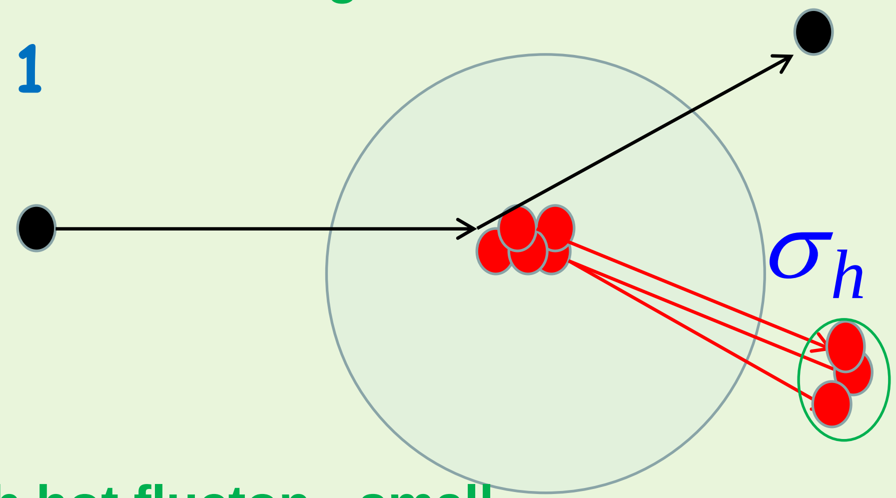
Multiquark configuration



Flucton case

Knock out of a nuclear fragments

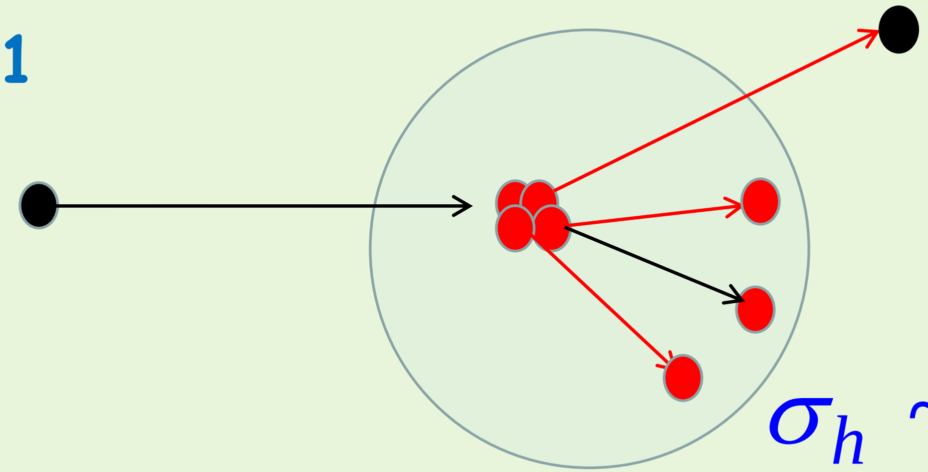
$\langle B \rangle > 1$



$$\sigma_h \sim P_K \cdot \frac{d\sigma_{"el"}(K)}{dt}$$

Collision with hot flucton - small explosion

$\langle B \rangle < 1$

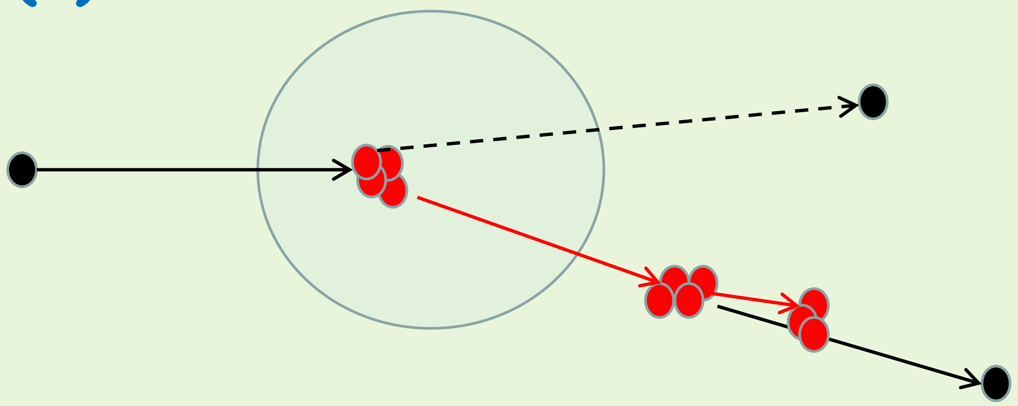


$$\sigma_h \sim P_K \cdot \frac{d\sigma_{inel}(K)}{dt}$$

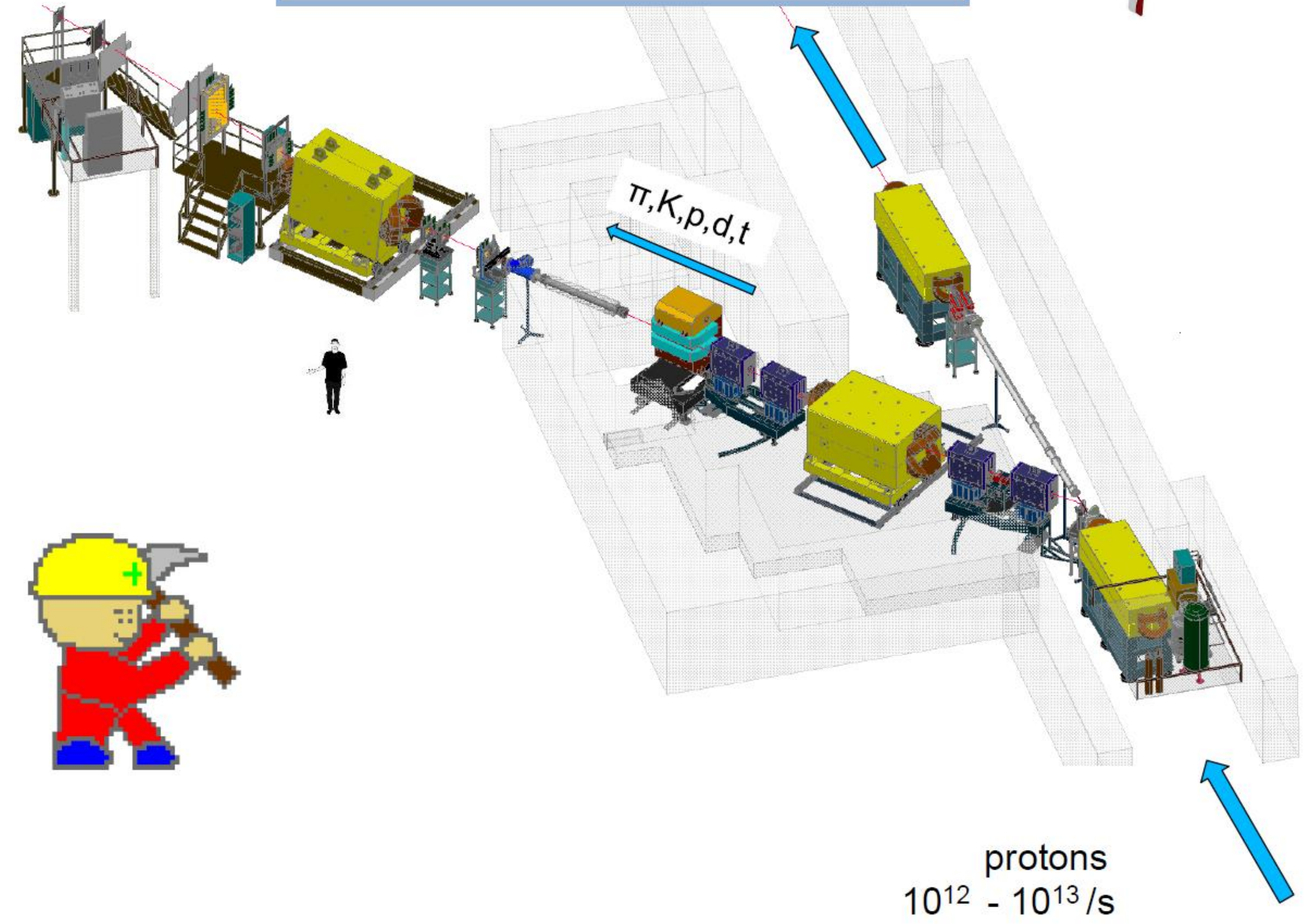
Flucton case

The fluctons Knock out of in an excited state

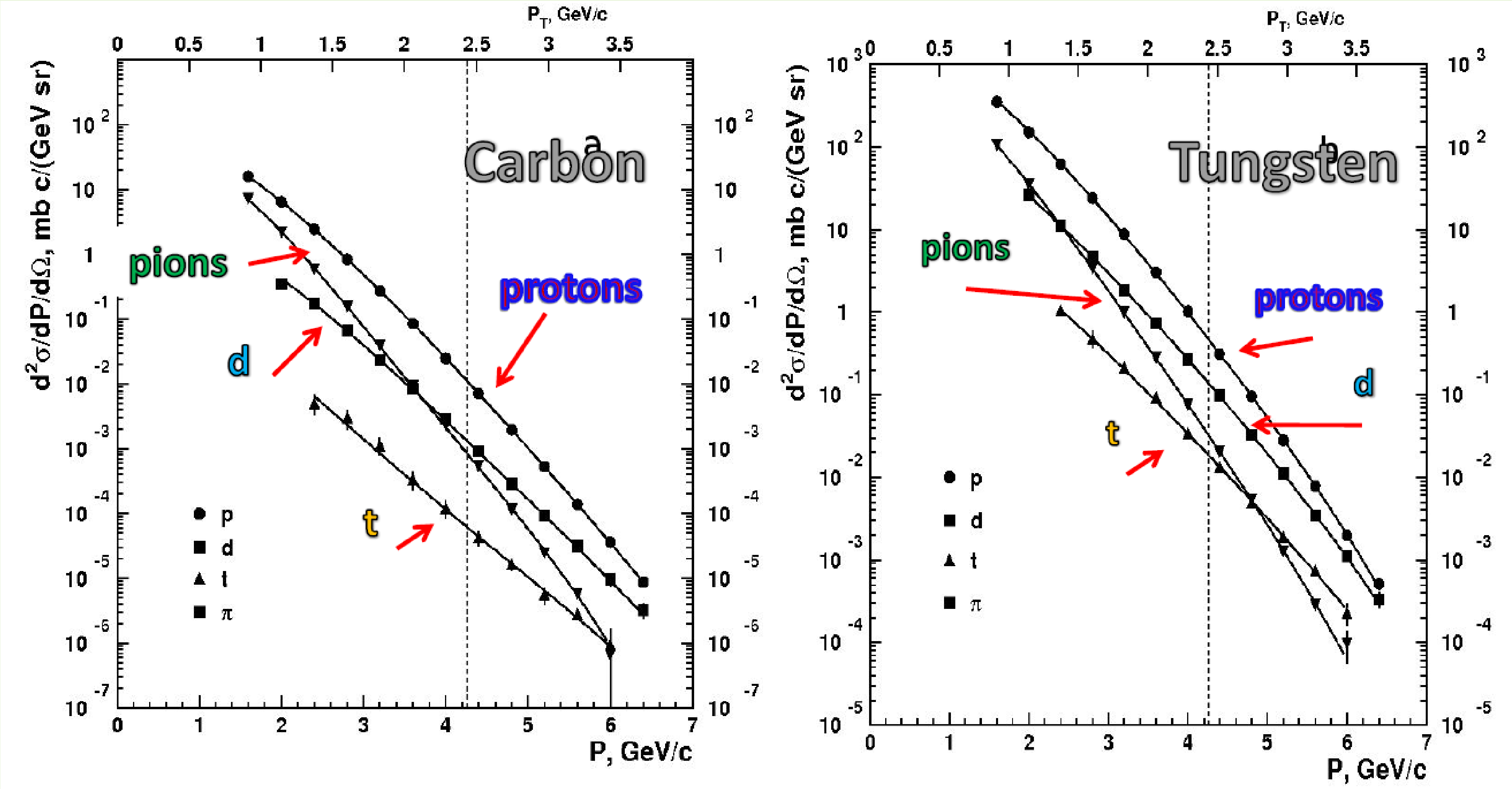
<B> > 1 (?)



SPIN – narrow acceptance spectrometer, beam line #8



N.N. Antonov et al., *JETP Letters*, Vol.101, No.10, pp.670-673(2015)



Invariant function found for positive pion, proton, deuteron and triton.
The vertical dashed lines indicate the kinematical limit for elastic nucleon–nucleon scattering. The upper horizontal scale shows values of the transverse momentum p_T *.*

PHYSICAL REVIEW VOLUME 126, NUMBER 5 JUNE 1, 1962

Particle Production at Large Angles by 30- and 33-Bev Protons Incident on Aluminum and Beryllium*

V. L. FITCH, S. L. MEYER,† AND P. A. PIROUÉ
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey

(Received February 12, 1962)

A mass analysis has been made of the relatively low momentum particles emitted from Al and Be targets when struck by 30- and 33-Bev protons. Measurements were made at 90°, 45°, and 13¼° relative to the direction of the Brookhaven AGS proton beam. Magnetic deflection and time-of-flight technique were used to determine the mass of the particles.

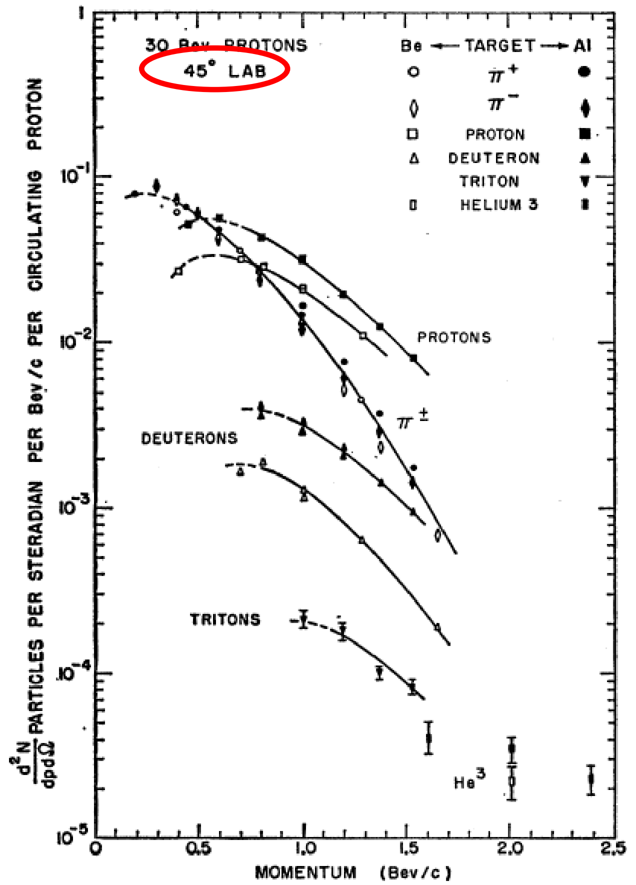


FIG. 3. Momentum spectra of particles emitted at 45° from aluminum and beryllium targets when struck by 30-Bev protons. Tritons from Be were not measured. For general remarks refer to Fig. 2 caption.

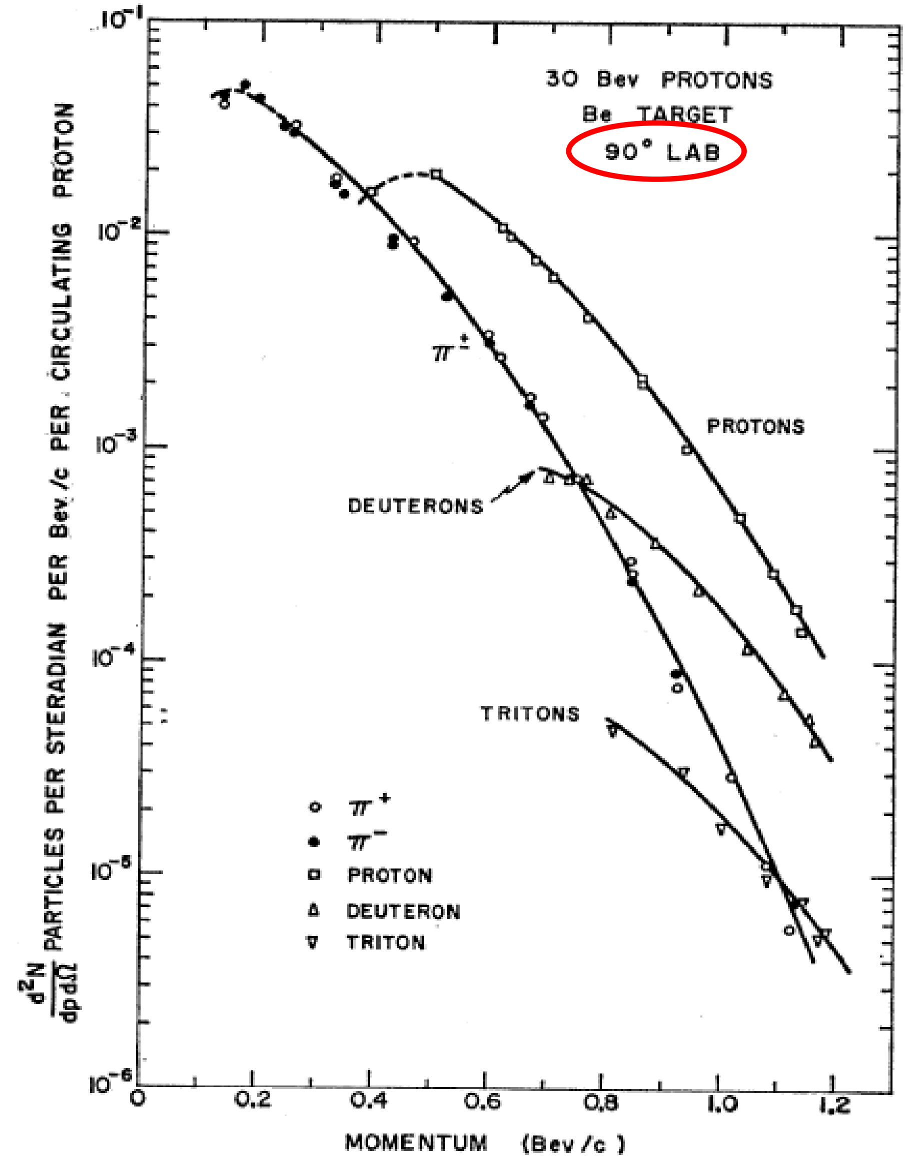
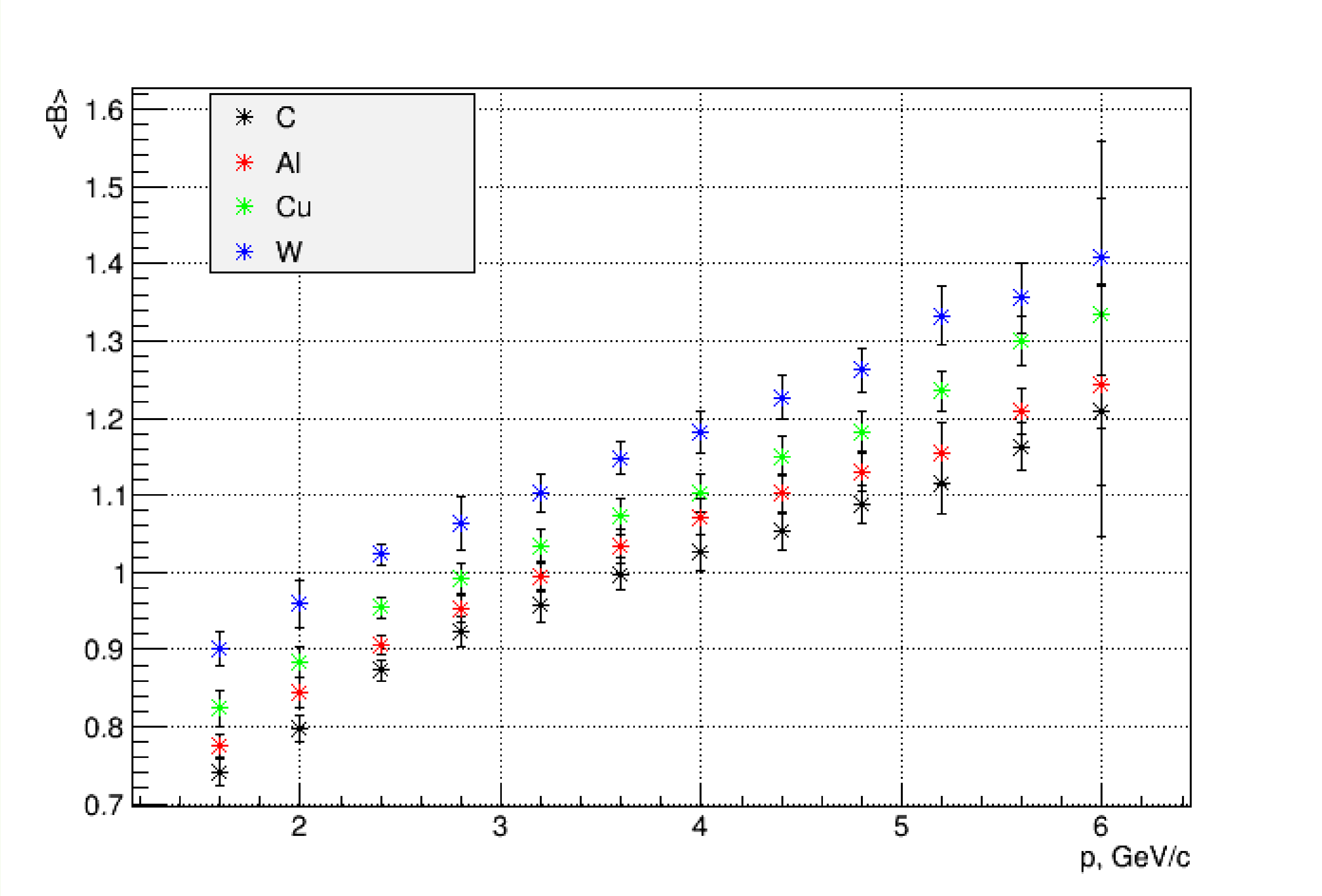


FIG. 2. Momentum spectrum of particles emitted at 90° from a beryllium target struck by 30-Bev protons. The ordinate is the number of particles produced at the target per steradian per Bev/c per circulating proton. The dashed portions of the curves indicate regions where the corrections due to multiple scattering exceed 15%. At the time these data were taken no effort was made to detect He³.

N.N. Antonov et al., JETP Letters, Vol.101, No.10, pp.670-673(2015)

Average baryon number <B>



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FIELDS, PARTICLES, AND NUCLEI

Knockout of Deuterons and Tritons with Large Transverse Momenta in *pA* Collisions Involving 50-GeV Protons

N. N. Antonov[a], A. A. Baldin[b], V. A. Viktorov[a], V. A. Gapienko[a, *], G. S. Gapienko[a], V. N. Gres'[a], M. A. Ilyushin [a], V. A. Korotkov[a], A. I. Mysnik[a], A. F. Prudkoglyad[a], A. A. Semak[a], V. I. Terekhov[a], V. Ya. Uglekov[a], M. N. Ukhanov[a], B. V. Chuiko[a†], and S. S. Shimanskii[b]

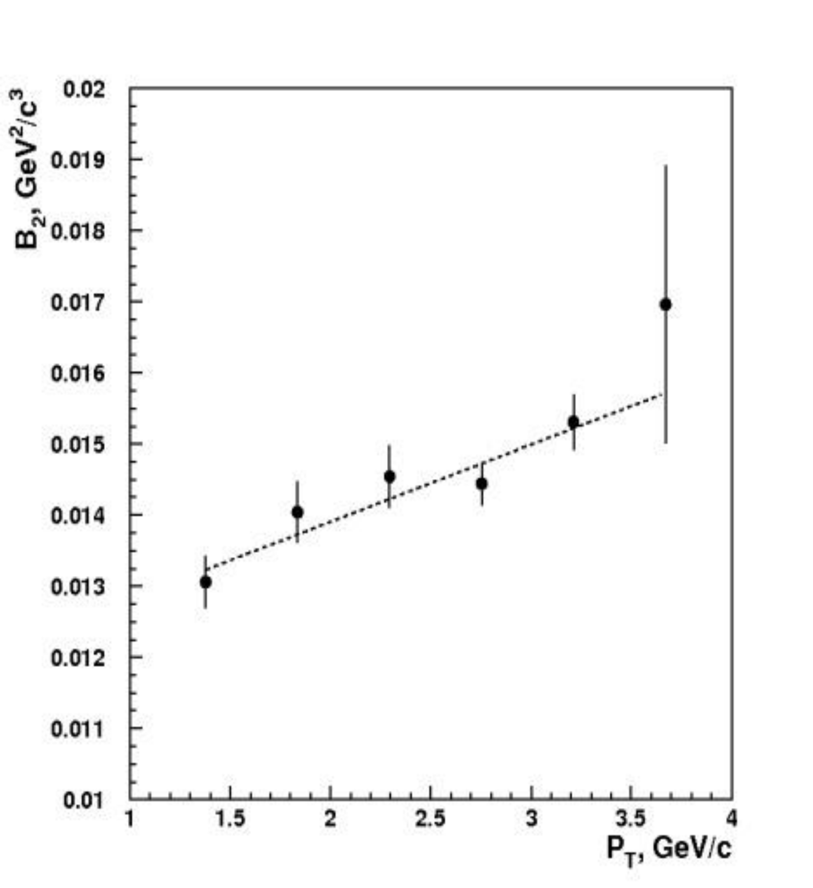
$$\frac{E_d}{\sigma_{inel}} \frac{d^3\sigma_A}{dp_A^3} = B_A \times \left(\frac{E_p}{\sigma_{inel}} \frac{d^3\sigma_p}{dp_p^3} \right)^A$$

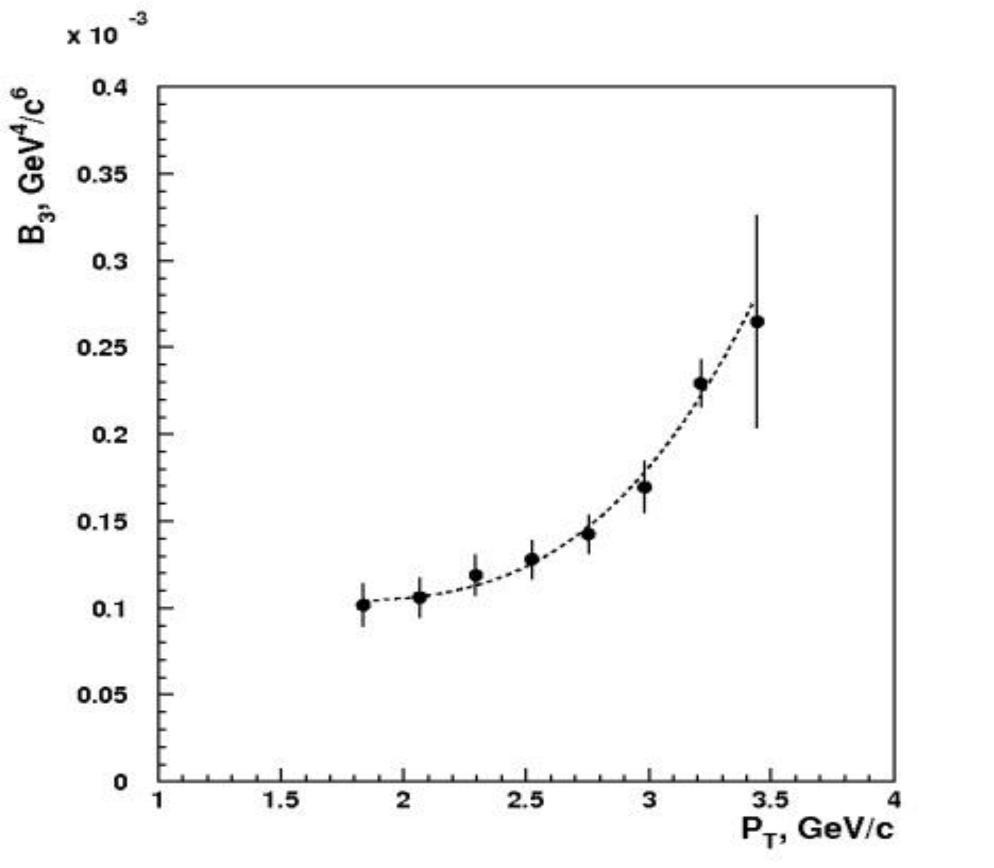
Mean values of the B_2 parameter

Target	C	Al	Cu	W
$B_2 \times 10^2$, GeV$^2/c^3$	1.41 ± 0.10	1.56 ± 0.08	1.51 ± 0.07	1.41 ± 0.06

$B_2 \sim V^{-1}$

$B_3 \sim V^{-2}$)





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Russian Text © The Author(s), 2020, published in Pis'ma v Zhurnal Eksperimental'noi i Teoreticheskoi Fiziki, 2020, Vol. 111, No. 5, pp. 291–294.

Scaling Behavior of Spectra of Protons, Deuterons, and Tritons Produced with High Transverse Momenta in *pA* and ^{12}C*A* Collisions

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The first data on the yield of the lightest nuclear fragments (protons p, deuterons d, and tritons t) with high transverse momenta p_T at an angle of 40° in the laboratory reference frame from nuclear targets bombarded by 50-GeV/c protons and 20A-GeV/c carbon nuclei obtained in the SPIN experiment (IHEP, Protvino, Russia) have been reported. It has been shown that the pA and CA data can be described within a common scaling approach, which possibly indicates that the mechanism of formation of high-p_T nuclear fragments is common for these reactions.

$$g(\Pi) = E\frac{d^3\sigma}{dp^3} / \left(C_1 A_1^{\alpha(X_1)} A_2^{\alpha(X_2)}\right)$$

$$f_{A_1+A_2} = E\frac{d^3\sigma}{dp^3} = C_1 A_1^{\alpha(X_1)} A_2^{\alpha(X_2)} \exp(-\Pi/C_2),$$

$$R = \frac{f_{p+A_{2a}}}{f_{p+A_{2b}}}\left(\frac{A_{2b}}{A_{2a}}\right)^{\alpha(X_2)} = 1$$

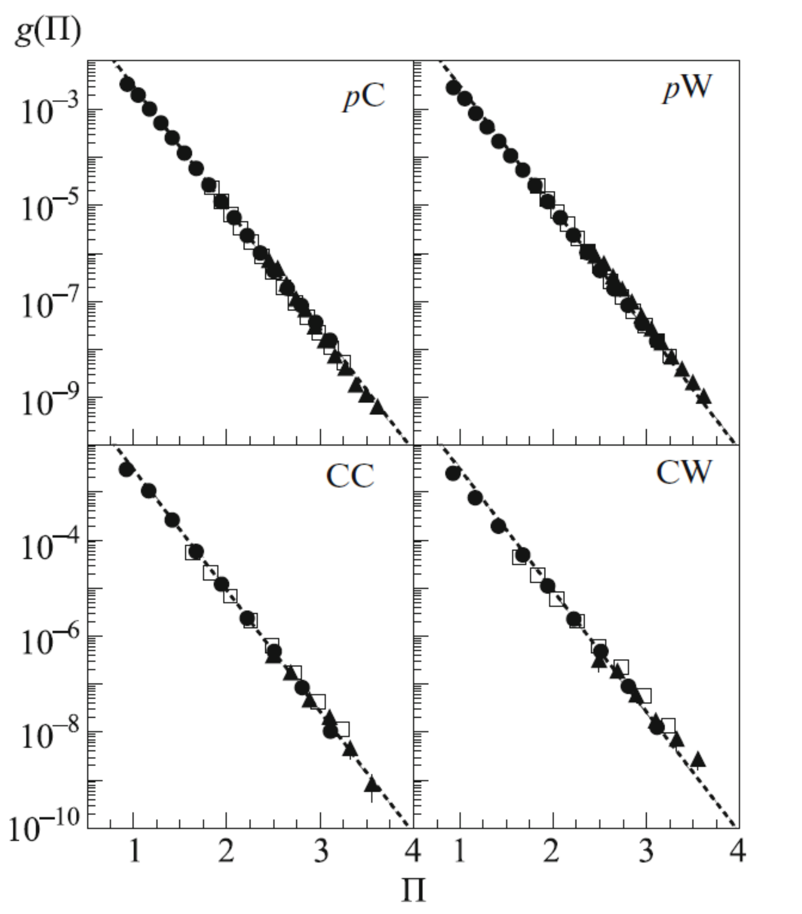

Fig. 4. Exponential dependence of the cross sections on Π for (circles) protons, (squares) deuterons, and (triangles) tritons. The dashed lines represent the function exp(–Π/0.172).

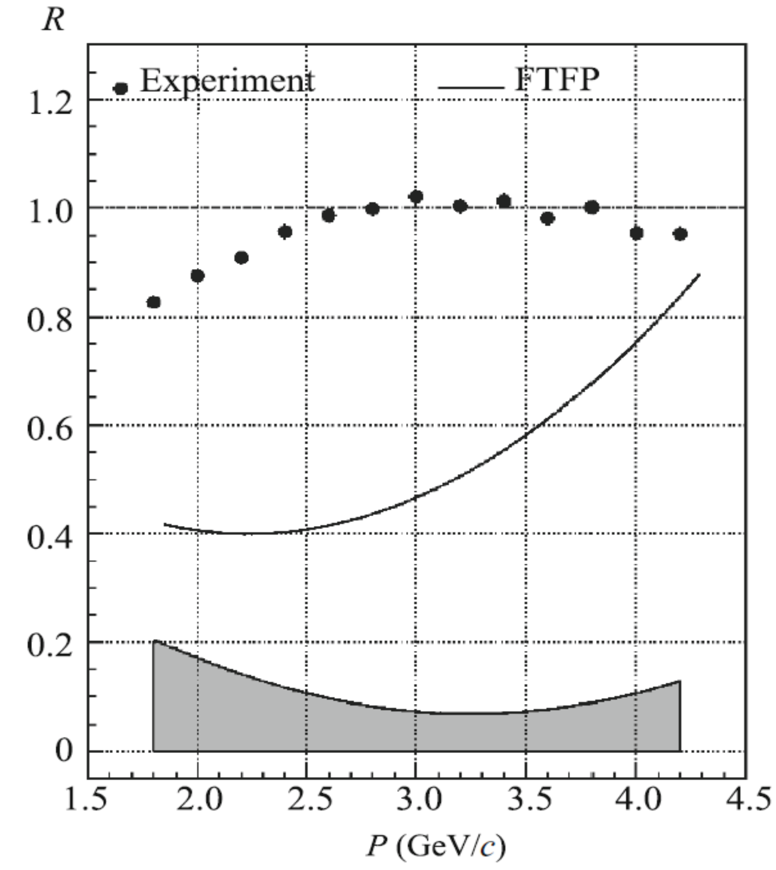

Fig. 3. Ratios R calculated for (points) experimental data and (line) values simulated by the FTFP algorithm [8]. The width of the gray band at the bottom represents the possible systematic error in the measured R values.

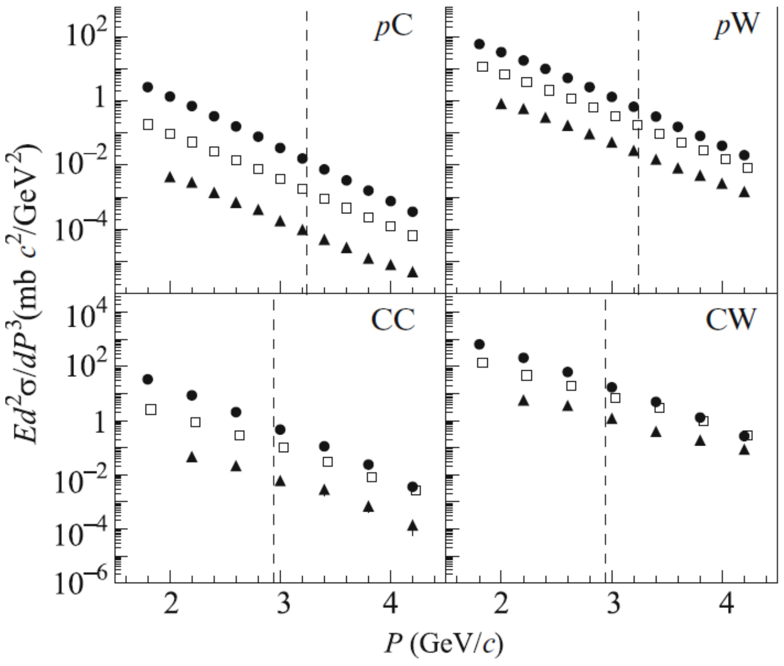

Fig. 1. Spectra of (circles) protons, (rectangles) deuterons, and (triangles) tritons in four different collisions. The vertical dashed straight lines indicate the kinematic limit of elastic nucleon–nucleon scattering at 40°.

CsDBM

1. Cold - exists inside ordinary nuclear matter as a quantum component of the wave function (with some probability and life time).

2. superDense - several nucleons can be in a volume less than the nucleon volume. The mass will be several nucleon masses. The small size means that the multinucleon(multiquark) configuration seeing as point like objects in processes with high transfer energy.

3. Baryonic Matter – enhancement of baryonic states and suppression of sea and gluon degrees of freedom (mesons and antiparticles production).

Тема	Re: Cumulative at high p_T
От	Boris Kopeliovich
Кому	Stepan
Ответить	bzk@mpi-hd.mpg.de
Дата	23.01.2012 7:42

«I think that the main problem in understanding of high pT hadrons at the energies of Serpukhov is why you see more protons than pions. This was claimed long time ago by the Sulyaev's group and I remember hot debates in that back in the 80s. Those debated ended up with no clear conclusion. Much later an excess of baryons was observed by the STAR at RHIC and was called "baryon anomaly". Again, no good explanation has been proposed so far. I might have my own explanation, but haven't written anything so far. Anyway, my point is, if we do not understand the mechanism of production of baryons dominating at high pT, we should not make any certain conclusions about the cumulative mechanisms.»

END