Journal of Physical Mathematics
ISSN: 2090-0902

DOI: 10.4172/2090-0902.1000238

Research Article · Open Access

Study of the Cumulative Number Distribution of Charged Particles Produced in p12C-Interactions at 4.2 A GeV/c

Wazir Z[1]*, Aslam SM[1], Suleymanov MK[2] and Gilani AR[1]

[1]*Department of Physics, Riphah International University Islamabad, Pakistan*
[2]*Department of Physics, COMSATS Institute of Information Technology (CIIT), Islamabad, Pakistan*

Abstract

In this paper the behaviour of the cumulative number distribution and the maximum values of cumulative number in an event of all charged particles (protons,$\pi\pm$-mesons) produced in p12C-interctions at 4.2 A GeV/c from experimental and simulation data has been analysed. One could see four different regions in the cumulative number distributions for protons in which the last region has cumulative number greater than one which correspond to cumulative region. Similarly one could see two and three different regions for negative and positive pions respectively but there is totally absence of the cumulative area for negative pions but there are few positive pions in the cumulative area. The simulation data obtained from Cascade code cannot describe satisfactorily the distributions of the cumulative number for protons and positive and negative pions but in case of particles with maximum values of cumulative number cascade code can describe the behaviour of cumulative number distribution well.

Keywords: Cumulative number distribution; Protons; Mesons; Hadron-nucleus interactions

Introduction

The experimental results on ultra-relativistic heavy ion collisions have shown the collective behaviour for the partons in hot and dense matter [1-3]. The JINR Cumulative effect [4], CERN EMC (European Muon Collaboration) effect [4,5] at relativistic hadron-nuclear and nuclear- nuclear interactions could be considered as experimental evidence on nucleon collective phenomenon in the medium.

The JINR Cumulative effect [4] could be considered as a first signal on collective behaviour for inner nuclear nucleons. It led to the notion for production of particles with energies beyond the kinematic limit of free nucleon collisions [4]. The effect was deeply discussed in the paper [6] and one can extract some ideas from it. Few interesting points are: i) Observations of the pions with energies ~8 GeV in D+A reactions at 5 A GeV; ii) In the B+A ® C+X reactions, the particles C were produced with x>1 (Figure 1). The values of the x can be defined as $x=u/s$ »$(1/m)$ $(e-p \cos q)$, here u and s are the Mandelstam invariants, m, e, p and q are the mass of the C particle, its total energies, 3 momentum and emission angle respectively, in the lab frame. For free nucleon collisions the values of x must be limited by 1. But as we can see from Figure 2 [7] for hadron-nuclear interactions at JINR energies particles were emitted with x>1.

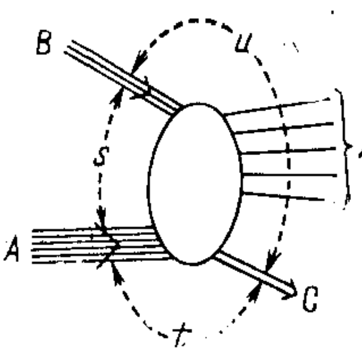

Figure 1: The kinematic picture of the cumulative particle production.

The JINR cumulative effect has very peculiar properties; some of them are: i) It has been observed for photon-nuclear; lepton-nuclear; hadron-nuclear and nuclear-nuclear interactions ii) The strong A-dependences were indicated for the invariant inclusive cross sections of the cumulative particles (f (p)=e ds/dp).

The theoretical interpretation of the effect proposed that it is a result of nucleon collective phenomena and the cumulative particles could be produced from the system of collected nucleons-coherent groups of nucleons. The latter could be formed as a result of fluctuations of nuclear density [8], the interaction of the projectile with target nucleons

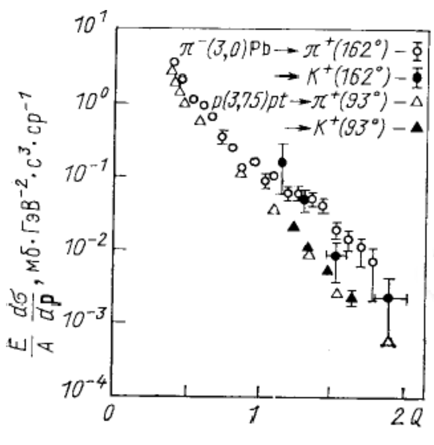

Figure 2: The inverse of the slope for ε *dσ/dp ~f*(-x/<x>) behaviour as a function of *x* has a universal value<*x*>≅0.16.

***Corresponding author:** Wazir Z, Professor, Department of Physics, Riphah International University Islamabad, Pakistan, Tel: 92 51 2891835; E-mail: zafar_wazir@yahoo.com

Received June 26, 2017; **Accepted** July 18, 2017; **Published** July 21, 2017

Citation: Wazir Z, Aslam SM, Suleymanov MK, Gilani AR (2017) Study of the Cumulative Number Distribution of Charged Particles Produced in p12C-Interactions at 4.2 A GeV/c. J Phys Math 8: 238. doi: 10.4172/2090-0902.1000238

(the possibility has a very small probability because the cumulative particles have been observed for photon and lepton interactions too), and nucleon percolation [9].

So we can say that JINR cumulative effect can be considered as a phenomenon with nucleons collective behaviour and coherent interactions.

The JINR cumulative effect has been confirmed by the CERN EMC effect [5]. European Muon Collaboration (EMC) investigated the muon deep inelastic scattering on iron and deuterium. They found the big disagreement between experimental result and theoretical expectations. The experimental result shown that the F2 and hence the quark and gluon distributions of a nucleon bound in a nucleus differ from those of a free nucleon. None of the popular models suggested to explain the EMC effect seem satisfactory and present a new point of view on the effect as a simple relativistic phenomenon [10]. The effect can also be considered as a result of nucleon collective phenomena.

These effects could be explained as a result of nucleon collective phenomena and coherent interactions. Coherent "Tube" Model (CTM) [11], which can give us even a clearer explanation for the energetic (cumulative) particle production. Here the interaction of a hadron with a target nucleus results from its simultaneous collision with the tube of nucleons of cross section s that lie along its path to the target nucleus. For the interaction of projectile with momentum plab the cumulative square of the center-of-mass energy is si @ $2imp_{lab}$ (i is a number of nucleons, m-a nucleon mass). The paper [12] quantitatively described unusually strong A dependence (stronger than the commonly assumed A or A2/3) of the cross section for p+A® J/Y+X reaction at incident energies below 30 GeV, using cumulative effects (via energy rescaling).

The CTM for high energy nucleus-nucleus collisions has been discussed in paper [13]. In this case two tubes have been considered: i1 nucleons in incident tube and i2 nucleons in the target tube. The c.m. energy squared for this tube-tube collision is approximately given by ~si1i2 @ $2i_1i_2mp_{lab}$. One can say that cumulative particles could give necessary information on collective phenomenon inside the nucleus and on dynamics of coherent particle productions. Though cumulative effect have been studied for many years there are only a few papers where the effect studied in case of 4p condition of measurement but in other hand the condition is necessary for get the information on the correlation in the cumulative events [14]. The main goal of the paper to study the cumulative effect in conditions of 4p geometry for measurements.

Method

To reach the goal of the investigation we have used the data obtained from 2 m propane (C3H8) bubble chamber, of the Laboratory of High Energy (LHE) of the JINR [15,16]. A magnetic field 1.5 Tesla has been applied around the chamber which was irradiated with the beams of protons and light nuclei accelerated to a momentum of 4.2 A GeV/c in the JINR Synchrophasotron [17]. In 4π geometry most of all charged particles were emerged, having energy larger than the threshold energy of track creation, were traced in the detector. Only charged particles are identified from their tracks, which are calculated by the momentums of produced particles and the magnetic field applied to the chamber [18]. Every particle entailed minimum momentum to form the track particular to its mass. The average minimum momentum for pion registration is set to about 70 MeV/c, below this pion cannot produce visible tracks. All negative particles, other than identified electrons, were classified as p-mesons. Positive pions were indentified if their momenta were less than 1.0 GeV/c [19]. The p^+ mesons are recognized and differentiated from protons by ionization produced in chamber in the momentum region less than 0.5 GeV/c. The protons are identified well within the momentum interval 0.15-0.5 GeV/c and above this momentum the p^+ mesons has contamination with protons [20,21]. We have created the cumulative number spectrum for the secondary charged particles. For the cumulative number we have used the variable 'x'. The charged particles include the identified protons, p^+ and p^--mesons. The x spectrum of the protons and positive and negative pions were created separately too. The x-distribution of the charged particles with maximum values of the x in an event is also considered. All the experimental data were compared with ones coming from the Dubna version of the cascade model and were fitted using the exponential function y=ax+b (a and b are free parameters of fitting) [22].

Cascade Evaporation Model (CEM)

As we have mentioned above that all the experimental data have been compared with ones coming from the Dubna version of the cascade model [22]. The model was described in somewhere else [21,23], based on Monte-Carlo simulation, used to explain the common prospects of nucleus-nucleus and hadron-nucleus collisions at relativistic energies. In this model, the system of colliding nuclei is acted as gas of nucleon bound in a potential well. It employs for nucleus-nucleus and hadron-nucleus collisions with multiple scattering. During interaction, particles are produced when conditions for production are satisfied, after momentum transfer; these further interact elastically or in-elastically with the nucleons [24]. The newly produced particles coming from the interaction of secondary particles may produce further particles. The process continues either absorption of particles in the target medium or leaving the target medium. A diffused distribution is considered for the potential and density of nucleus where correlation exists between nucleons in the normal state. The time evolution Monte-Carlo study of two interacting nuclei, the inter dependence of target and cascade are consummate through nucleons density correlations from intra nuclear collisions. All conservation laws and invariance principles are obeyed including the Pauli Exclusion Principle and the energy-momentum conservation in each intra nuclear interaction. The nuclei that are excited and are unable to produce new particles after the cascade stage are then described by the statistical theory in the evaporation approximation. The basic assumptions and procedures of the cascade model are given in papers [23,24].

Results and Discussion

Figure 3a-d show the x distribution of protons, p^+- and p^--mesons, produced in $P^{12}C$-interctions at 4.2 A GeV/c. One can see (Figure 3a, all charged particles: protons, p^+- and p^--mesons together) four different regions in the distribution: $0.02<x<0.18$(first region); $0.26<x<0.66$(second region); $0.74<x<0.90$ (third region); $x>1.0$ (fourth region) which were compared with data generated through simulation by using the Cascaded Model. To get quantitative results the distributions in the different regions were fitted by using function y (see above). The results of the fitting are shown in Table 1 of both experimental and model data. The vertical lines in the figures fix the boundary for the cumulative particles (particles with x>1) [25-27]. One can see that for all charged particles (Figure 3a) and protons (Figure 3b) in the area of x<1 the number of particles (Ni) almost doesn't depend on x and it decreases exponentially with x in the area of x>1 (area of the cumulative particles). As we can see from the Figure 3b, cascade cannot describe satisfactorily the behavior of the x-distribution for the proton in I and IV regions. The code gives systematically decreased

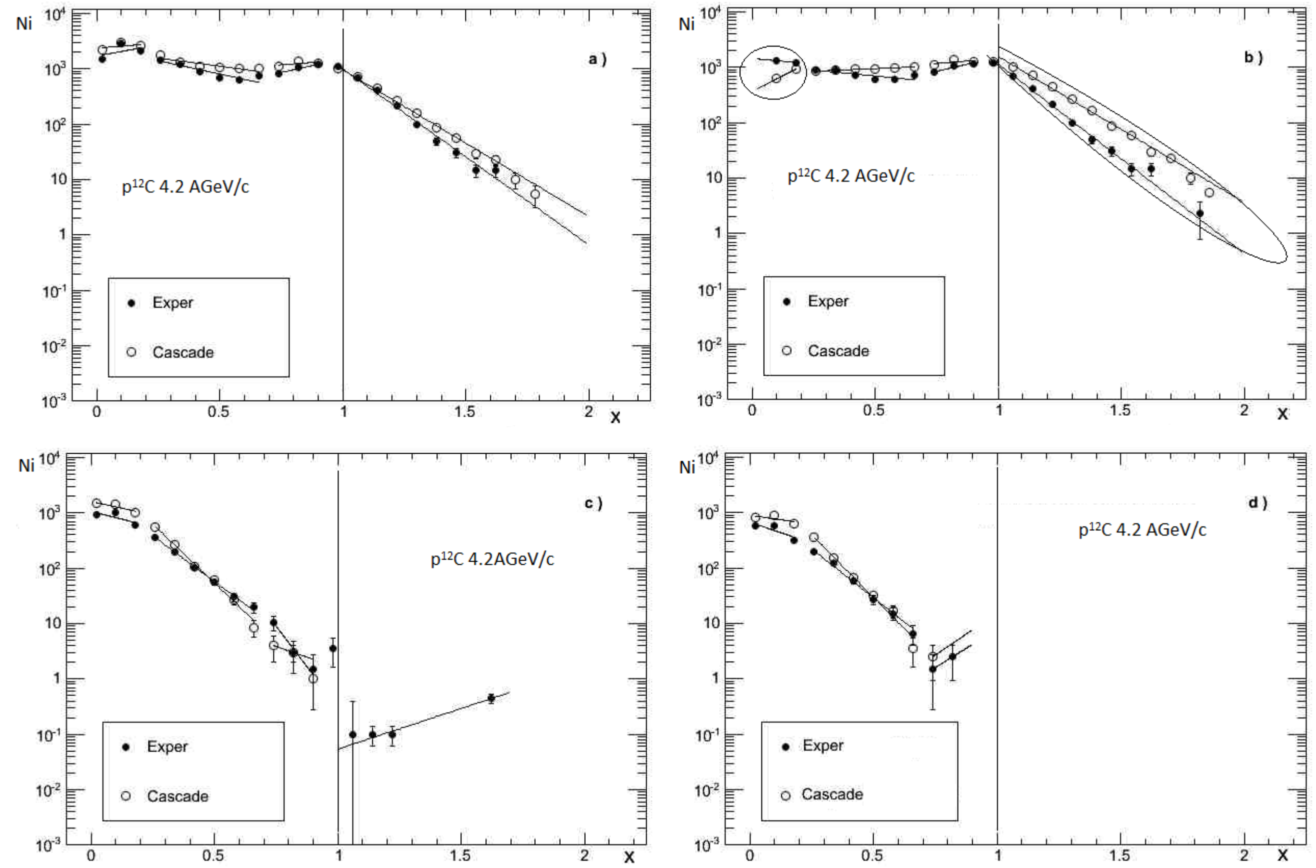

Figure 3a-d: x-Distribution for the a) all charged particles; b) protons; c) π^+-mesons; d) π^--mesons produced in the p¹²C-interactions at 4.2 A GeV/c.

Charged Particles	Region		Parameter 1	Parameter II	χ^2	No of points
All charged Particles	IV(x>1.0)	E	$3.2 \times 10^6 \pm 8.0 \times 10^5$	7.9 ± 0.2	7.192	8
	IV (x>1)	M	$3.4 \times 10^5 \pm 1.0 \times 10^5$	6.5 ± 0.2	2.11	10
Proton	IV(x>1.0)	E	$5.0 \times 10^6 \pm 2.0 \times 10^6$	8.3 ± 0.4	4.94	9
	IV (x>1)	M	$6.7 \times 10^5 \pm 7.0 \times 10^4$	6.06 ± 0.09	27.32	11
Pion Plus	IV(x>1.0)	E	1.5 ± 3.7	0.8 ±1.6	0.16	4
	IV(x>1.0)	M	Nil	Nil	Nil	Nil

Table 1: The result of the fitting for total charged particles/proton/pion plus in experimental and cascaded model.

values for protons in the last area. Figure 3c and 3d show number of regions decreased to 2 for negative pions because in 3rd region we can see only two points with huge error. Similarly one can see 3 numbers of regions for positive pions because in this case the 4th region has also only few points with huge error. So we cannot say that we observed 3 and 4 regions for negative and positive pions, respectively. There were not observed any negative pions in the area of x>1 and one could see several positive pions in the cumulative area. The result is in good agreement with one obtained in the paper [28]. In this paper, the authors have reported that number of cumulative p^+-mesons several times greater than number for the cumulative p^--mesons produced in the $p^{-12}C$-interaction at 40 GeV/c. The last result could be considered as a signal that observed cumulative p^+-mesons produced in the area very close to the surface of the carbon nucleus where the number of protons is greater than number of neutrons due to repulsive force between positively charged protons. To understand the result we have studied the characteristics of the particles with maximum values of the x. We have defined a particle with maximum values for x (xL-particles) in each event.

Figure4a shows the x distribution for the xL-particles produced in $P^{12}C$-interctions at 4.2 A GeV/c. The xL-particles could be proton, p^+- or p^--mesons. The data coming from the cascade model are also shown in the same figure. All the data were fitted using the exponential function. The results of the fitting are shown in Tables 1 and 2 from of experimental and model data [24-27].

One can see four different regions in the distribution: 0.02<x<0.18(first region); 0.26<x<0.66(second region); 0.74<x<0.90 (third region); x>1.0 (fourth region-cumulative region). It is evident that simulation data coming from the cascade code can describe satisfactorily the experimental data. Figure 4b shows the x distribution for the xL-particles in cases of they are the protons. The behaviour of the distribution is almost same with ones what we could observe from Figure 4a. The same results for the behaviour of the xL-particles distributions in case of $p^{\pm}$-mesons (Figure 4c and Figure 4b) are particles with maximum x in an event.

Charged Particles	Region		Parameter 1	Parameter II	χ^2	No of points
All charged particles	IV (x> 1.0)	E	$7.3 \times 10^5 \pm 1.0 \times 10^5$	6.9 ± 0.2	16.17	12
	IV(x> 1.0)	M	$2.1 \times 10^5 \pm 2.0 \times 10^4$	5.8 ± 0.1	88.31	10
Proton	IV (x> 1.0)	E	$7.5 \times 10^5 \pm 1.2 \times 10^5$	6.9 ± 0.1	18.73	12
	IV (x> 1.0)	M	$2.1 \times 10^5 \pm 2.0 \times 10^4$	5.7 ± 0.1	88.98	12

Table 2: The result of the fitting for total charged particles/proton having max Cumulative number in experimental and cascaded model.

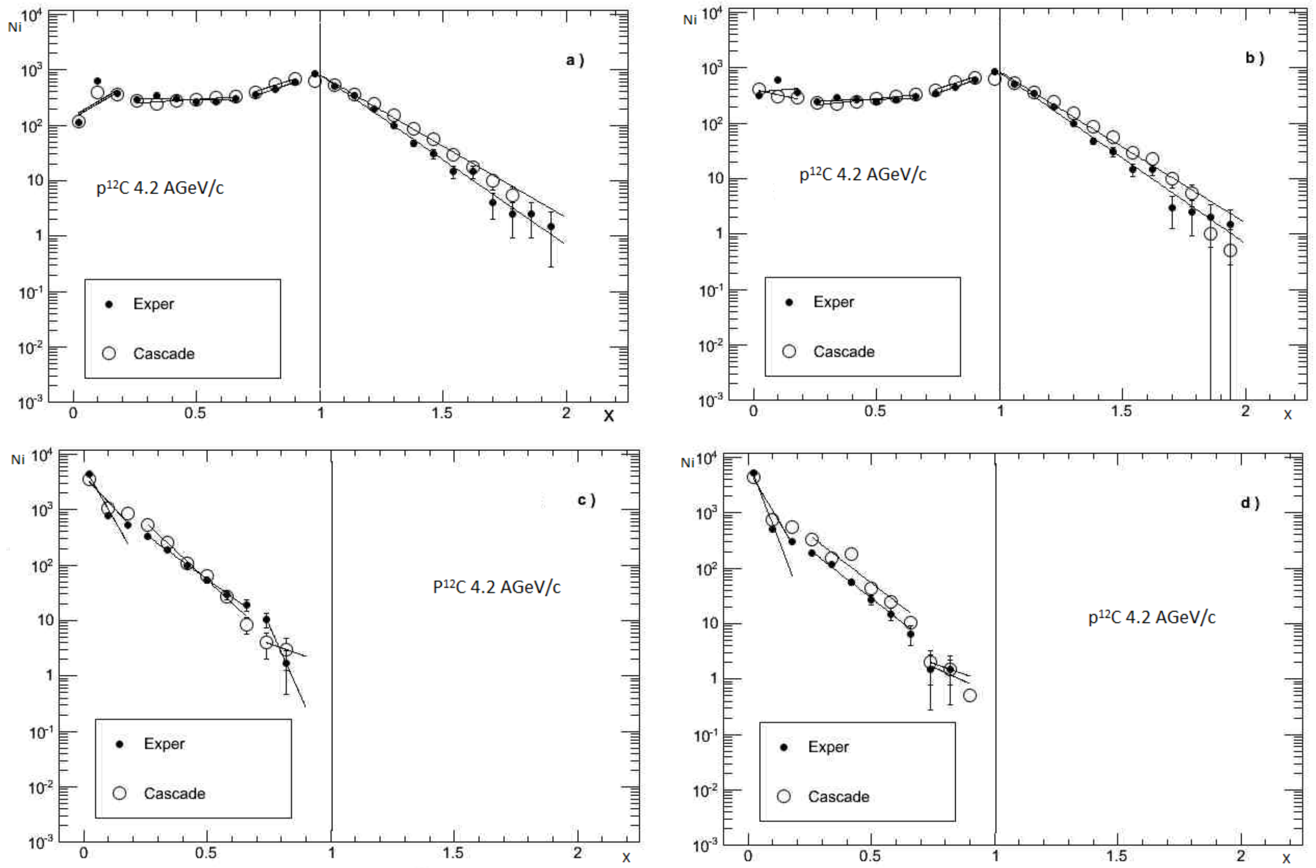

Figure 4: *x*-Distribution for the xL-particles: a) all charged particles; b) protons; c) π^+-mesons; d) π^--mesons.

Conclusion

The behaviour of the cumulative number distribution for the charged particles produced in the $P^{12}C$-interactions at 4.2 GeV/c has been studied. We have also analysed the behaviour of the cumulative number distribution for the particles with maximum values of the cumulative number in an event too. One has got: i) There are four different regions in the cumulative number distributions for protons and positive pions and the last region is correspond to values of cumulative number great than one; ii) In case of negative pions, number of regions decreased to three; iii) There is absent the cumulative area for p^--mesons but there are a few p^+-mesons in the cumulative area, the result is in good agreement with one obtained for the charged cumulative particles produced in the $p^{-12}C$-interaction at 40 GeV/c, they obtained that a number of cumulative p^+-mesons greater than number for the cumulative p^--mesons; iv) Cascade cannot describe satisfactorily the distributions of the cumulative protons and cumulative p^{-+}-mesons, it gives less number for the mentioned particles. But in case of particles with maximum values of cumulative number cascade can describe the behaviour of cumulative number distribution well for protons and positive pions too, there is absent the cumulative regions for positive pions. The last two results point out that there exist some events with two cumulative particles which could not describe by the cascade dynamics. May be collective nucleon effect could be reasons of the observation two cumulative particles events.

References

1. Okorokov VA (2009) Slope analysis for elastic nucleon-nucleon scattering. Corenll University Library.

2. Adams J, Aggarwal MM, Ahammed Z, Amonett J, Anderson BD (2005) Experimental and theoretical challenges in the search for the quark–gluon plasma: The STAR Collaboration's critical assessment of the evidence from RHIC collisions.Nuclear Physics A 757: 102-183.

3. Adare A, Afanasiev S, Aidala C, Ajitanand NN, Akiba Y (2007) Production versus Centrality, Transverse Momentum, and Rapidity in Au+Au Collisions. Phys Rev Lett 98: 162301.

4. Baldin AM (1977) Short Commun Phys. Part Nucl 8: 429.

5. AubertJJ, Becker U, Biggs PJ, Burger J, Chen M, et al. (1974) Experimental observation of a heavy particle. J Physical Review Letters 33: 1404.

6. Efremov AV (1982) Asymptotical behaviour of pion electromagnetic form factor in QCD. Joint Inst for Nuclear Research Dubna (USSR).

7. Efremov AV, Radyushkin (1982) Field theoretic treatment of high momentum transfer processes. 3. Gauge theories. Theoretical and Mathematical Physics 44: 774.

8. Stavinskii VS(1973) MI Strikman For experimental and theoretical reviews of the cumulative effect. Sov J Part Nucl 10: 373.

9. Blokhintsev DI (1956) Acoustics of a Nonhomogeneous Moving Medium. Washington DC: National Advisory Committee for Aeronautics.

10. Baldin AM, Giordenesku N, Zubarev VN, Ivanova LK, Moroz NS, et al .(1977) Experimental investigation of cumulative meson production. Joint Inst for Nuclear Research, Dubna, USSR.

11. Efremov AV, Radyushkin AV (1980) Factorization and asymptotic behaviour of pion form factor in QCD. Physics Letters B 94: 245-250.

12. Berlad G, Dar A, Eilam G (1976) Multi particle production in particle-nucleus collisions at high energies. Phys Rev D 13: 161.

13. Afek Y, Berlad G, Eilam G, Darf A (1976) Cumulative Enhancement of J/ψ Production in Hadron-Nucleus Collisions. Phys Rev Lett 37: 947.

14. Afek Y, Berlad G, Dar A, Eilam G (1978) Multipion Production in Relativistic Heavy-Ion Collisions. Physics Review Letters 41: 849.

15. Baldin AM (1971) Polarizability of nucleons. Nuclear Physics 18: 310-317.

16. Bergstrom L, Frederiksson S (1977) High-energy collisions with atomic nuclei: The experimental results. Physics Reports.

17. Baldin AM, Kovalenko AD (1993) STAR detector overview. Creighton University

18. Frederiksson S (1976) Many Degrees of Freedom in Particle Theory. Nucl Phys 167.

19. Bradner H (1957) Catalysis of Nuclear Reactions by μ Mesons. Physical review journals.

20. Gilani AR (1993) Study of the pT-distributions of secondary charged particles produced in p12C interactions at 4.2 A GeV/c . Indian Journal of Physics 8: 933-938.

21. Armutliysky D (1989) Analyzing the features of π− mesons and protons from AC interactions at a momentum of p=4.2 GeV/c per projectile nucleon on the basis of the FRITIOF model. Yad Fiz 49: 839-844.

22. Agakishiyev HNN, Akhababian D, Armutlijsky AM, Baldin J, Bartke R, et al. (1985) Multiplicity, momentum and angular characteristics of π− mesons forpC, dC, αC and CC interactions at 4.2 GeV/c per nucleon. Zeitschrift für Physik C Particles.

23. Adamovich MI, Aggarwal MM, Alexandrov YA, Ameeva ZV, Andreeva NP, et al. (1990) Scaled-factorial-moment analysis of 200A-GeV sulfur+ gold interactions. Physical review letters 65: 412.

24. Boudard A, Cugnon J, Leray S, Volant C (2002) Intranuclear cascade model for a comprehensive description of spallation reaction data. Physical Review C 66: 044615.

25. Baldin AM (1973) On excitation of isomeric nuclear states in a crystal by synchrotron radiation. Phys Nucl 18: 53.

26. Baldin AM (1985) Nuclear reactions with large momentum transfers as a source of information about multiquark states in nuclei. Nuclear Physics A 434: 695-704.

27. Stavinskii VS (1978) For experimental and theoretical reviews of the cumulative effect. Sov J Part Nucl 10: 373.

28. Anoshin AL, Suleymanov MK (1980) Searching for the properties of nuclear matter using proton–carbon and deuteron–carbon collisions AT 4.2A GeV/c. International Journal of Modern Physics.