Angular Distributions of Target Fragments Emitted in 14.6 A GeV Silicon-Emulsion Interactions

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Abstract

Many results obtained from studying the angular distributions of heavy fragments emitted from interaction of silicon nucleus with composite target nuclei of emulsion at collision energy 14.6 A GeV per nucleon. The angular distributions of grey and black secondary charged produced fragments are well described through statistical model. The average emission angle is 64° for grey particles and 82° for black particles that are nearly constant for different projectiles in range of collision energy 2.2 to 14.6 A GeV. The predicted rational velocity by statistical model χ_o which describe the system responsible for production of secondary particle is nearly equal to 0.5 for grey particles and tends to be ~0.13 for black particles. The velocity of the emitting system described by parameter $\beta_{//,}$ where the emitting system for grey particles is fast with typical longitudinal velocities $\beta_{//}^{g}$ ~ 0.13-0.20 while it slow for emission black particle in the range $\beta_{//}^{b}$~0.008-0.019. The temperatures of the system responsible for emission of secondary slow fragments are found to be 58 and 6 MeV for fast grey and slow heavy fragments respectively. The angular distributions of slow fragments, grey and black particles show clear dependence on size of target nucleus. Most probable emission angles are in forward direction for interactions with light nuclei while it becomes symmetry around the middle angle for interactions with heavy nuclei. The emission system of these particles becomes slower and low temperature with increasing mass number of the interacting target nucleus.

1. Introduction

Hadron-nucleus and nucleus-nucleus collisions with sufficient energy above two GeV per nucleon are allowed to study some of the nuclear properties in terms of the experimental data analysis. Many experimental and theoretical efforts are investigate different properties of the possible new states of nuclear matter by the so known quark gluon plasma [1]. Experiments of nucleus-nucleus collisions with high-energy study the kinematic of the collisions to give complete concepts on the nuclear properties and check the assumed theoretical models which are based on new properties of nucleus constituents. In this work we will study angular distribution of slow fragments and their dependence on projectile energy, projectile mass number and on the target size. This parameter is one of the important parameters which give valuable information on the dynamical system responsible for production of secondary slow fragments. This research will display the experimental angular distributions for slow charged fragments recorded for collisions of ^{28}Si nucleus with compound nucleus of emulsion at collision energy 14.6A GeV. The experimental data is compared with statistical theoretical model [2,3] which are based on the mathematical relationship between collections of variables, each variable being a vector of readings of a specific trait on the samples in an experiment. It explains in what way a variable depends on other variables in the study. Statistical model gives mathematical formulation, which embodies a set of assumptions concerning the generation of some sample data. This formulation correlates some of expected and other random variables. The distribution of emitted secondary particles as a function of the emission angle θ, which are measured from direction of incident projectile, is one of important experimental parameter that describe the temperature and mechanical mechanism responsible for particle emission. To study this mechanism we will use statistical model for Maxwell distribution [2] for secondary emitted particle and their multiplicities according to their momentum as (let c=1)

$$\frac{d^2N}{dP\,d\mu} \propto P^2\, exp\left\{-\frac{\left(P^2-2M\overline{\beta_{\|}}\;P_{\mu}\right)}{P_O^2}\right\} \tag{1}$$

where $\beta_{\|}$, is the longitudinal velocity of the particle-emitting system. $\mu = \cos\theta$, where θ is the laboratory angle between the momentum of the fragment of mass M and the momentum of the initial projectile, and $P_o = \sqrt{2ME_o}$, where E_o is the characteristic energy per particle in the hypothetical moving system. Eq. (1) would be modified

$$\frac{d^2N}{d\beta\,d\mu} \propto \beta^2\, exp\left\{-\frac{\left(\beta^2-2\overline{\beta_{\|}}\;\beta_{\mu}\right)}{\overline{\beta}_{\circ}^2}\right\} \tag{2}$$

where $\bar{\beta}_o = \sqrt{2ME_o}$. It follows that the parameter $\chi_\circ$ denoted as

$$\chi_o = \frac{\beta_{\|}}{\beta_o} = \frac{\overline{\beta_{\|}}}{\overline{\beta_o}} \tag{3}$$

which is the ratio of the longitudinal velocity of the center of mass, β_{II}, to the characteristic spectral velocity β_o, of the fragmenting system fitting parameter $\chi_\circ = \beta_{\|}/\beta_o$ only. With

$$\frac{dN}{d\theta} \approx sin\theta\left(\frac{F}{B}\right)^{cos\theta} \tag{4}$$

The values of *F/B* obtained in experiment.

2. Experimental Details

The experimental technique, method of measurements and primary results of the experiment are explained in details in refs. [4-6]. When charged particle is passing through the photographic nuclear emulsion, it will slow down via losing its kinetic energy due to its inelastic interactions with the nuclear emulsion atoms along its path trails of ionized silver halides along its path. The grain density defined as the number of developed grains of silver halides per unit path length of the particle's track. It is denoted by (g) and sensitivity of the used emulsion for minimum relativistic charge is

g_o where g_o =30 grains per 100 μm. Secondary charged particles classified according the grain densities into shower tack producing particles and multiplicity N_s where $g/g_o \leq 1.4$. Most of the shower particles are mesons with energy >50 MeV contaminated with small fraction of fast protons with energy >400 MeV, charged K-mesons, antiprotons, and hyperons. The second type of particles are grey tack producing particles with $1.4 < g/g_o \leq 10$ corresponds to proton energies in the range from 26 MeV up to 400 MeV. Some of the grey tracks may be due to emitted deuterons, tritons, helium nuclei and nearly about (5%) due to slow π-mesons. The grey tracks multiplicity denoted by (N_g). The third type is the black track producing particles with $g/g_o \geq 10$ correspond to proton energies < 26 MeV. The black tracks may be also due to deuterons, α-particles, and heavy fragments. The black tracks multiplicity denoted by (N_b). The heavily ionizing particles multiplicity is denoted by N_h, where $N_h = N_g + N_b$.

3. Experimental Results

3.1. Angular distribution of grey particles

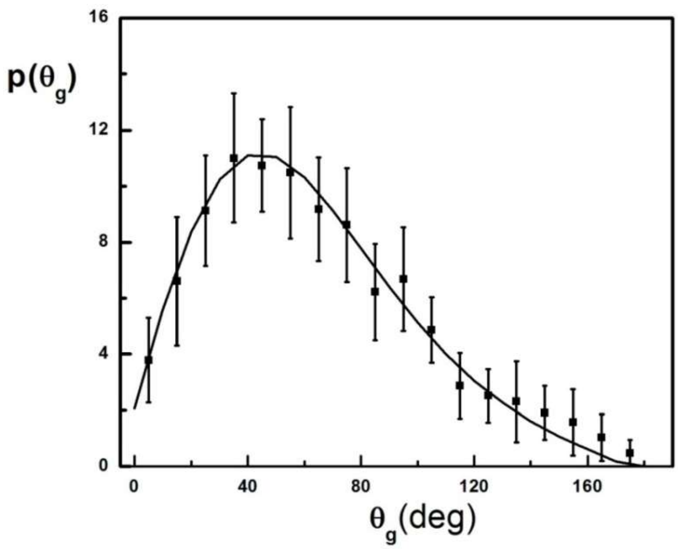

Fig.1 The angular distribution of grey particle emitted in ^{28}Si-Em interactions at 14.6A GeV. Smooth curve represents the corresponding prediction of the statistical model using from Eq. (4).

Figure 1 shows the experimental angular distribution for grey particles emitted from ^{28}Si-Em at 14.6A GeV collisions. The smooth line represents the predictions for statistical model according to the Gaussian fitting shape from Eq. (4) when applied for grey particles. The predicted rational velocity χ_o^g, is calculated from statistical model by using the following equation,

$$\chi_o^g = \frac{\beta_{\parallel g}}{\beta_\circ} = cos(< \theta_g >) \quad (5)$$

It is noticed that within experimental errors the two distributions are in good agreement. The mean value of the emission angles $< \theta_g >$ for grey particles is defined as the medium angle i.e. the angle at which half of the number of the specified particles is emitted. It is compared with the different projectiles in the range of energy 3.7-14.6 A GeV and magnitudes of the parameter χ_o^g and $\beta_{\parallel g}$ are given in table 1. This caparison shows that this parameters are nearly constant and independent on projectile mass number which reflect the constancy of the mechanism which responsible for emission of this particles. Also from figure 1 it can be noticed that, the distribution shows a peaking shape with peak positioned nearly at $\theta = < \theta_g >$. The number of the backward emitted particles (i.e. $\theta \geq 90^o$) decreases with increasing θ. The distribution of such backward angles follows an exponential decay and studied before in ref. [7]. From table 1 and fig.1 it is noticed that, the constancy in the values of $< \theta_g > \sim 64$, independent of the variation of projectile mass number as well as incident energy. The rational velocity for the system of grey particle emission χ_o^g is nearly equal 0.5 for different interactions studied here. The emitting system of the g-particles is fast and with typical longitudinal velocities $\beta_{//}^g \approx 0.13$-$0.20$. The anisotropic ratio $(F/B)_g$ is the ratio of the number of forward fragments of grey particles to that emitted in the backward for different projectiles are given in table 1. This ratio is appear constant and ranged between two and three. It proves that all predictions of statistical models for all given projectiles are similar and controlled by a fixed mechanism for grey particle productions.

Table 1 The average values of the emission angles of the grey particles $< \theta_g >$ in different interactions at (3.7-14.6A GeV), in addition to the rational velocity of the system χ_o^g, ratio $(F/B)_g$ and longitudinal velocity $\beta_{\parallel g}$ based on statistical model

Projectile	Energy A GeV	$< \theta_g >$	χ_o^g	$(F/B)_g$	$\beta_{\parallel g}$	Ref.
^{6}Li+Em	3.7	64.90 ± 2.20	0.33	2.12±0.13	0.11	8-10
^{12}C+Em	3.7	64.00 ± 1.90	0.52	3.51±0.20	0.18	11-17
^{22}Ne+Em	3.3	63.70 ± 1.60	0.54	3.38±0.28	0.19	12-18
^{28}Si+Em	3.7	63.30 ± 1.44	0.55	3.38±0.28	0.19	12-14,17,18
^{28}Si+Em	14.6	64.76 ± 2.06	0.49	3.05±0.27	0.17	Present work
^{28}Si+CNO	14.6	62.44 ±5.18	0.46	2.84±0.24	0.16	Present work
^{28}Si+AgBr	14.6	65.56 ±3.51	0.41	2.54±0.25	0.14	Present work

Now we will explain the effect of target size on the angular distribution of secondary charged and slow particles grey and black. In this experiment, target is compound nucleus and easy classified into three main groups of interactions. Experimentally, classification of these interactions is characterized by multiplicity of heavily ionizing secondary charged particle N_h. These particles are pure target fragments and are an experimental parameter, which describe the degree of overlapping of projectile and target nuclei. Experimental tools for separation of interactions is explained in details in Ref. [19,20]. First group with multiplicity $N_h \leq 1$ is the interactions with hydrogen and are low statistics to exclude from this consideration. Second group is the interactions with light emulsion components CNO, where $2 \leq N_h \leq 7$ and consider as gentle interactions. Third group is the interactions of ^{28}Si with heavy emulsion nuclei AgBr. It considers as hard interactions and characterize by $N_h \geq 8$. Figure 2 shows the angular distributions of grey particles for interactions of ^{28}Si with CNO and AgBr nuclei at collision energy 14.6 A GeV. In this figure, the angular distribution for both target components are different where most of probable angles for gentle interactions are for angles in the forward hemisphere ($\theta \leq 90^{o}$) and minimum probability for angles in backward hemisphere. In hard interactions in forward hemisphere the probability gradually small increases and most values of probability is observed in the backward hemisphere and it uniformly distributed in wide range of angles to reach the backward directions (θ=180^{o}). This is observed from the ratio $(F/B)_g$ in table 1 where their values for gentle interactions 2.84±0.24 while it 2.54±0.25 for hard interactions. In addition, the average angle of emission for gentle interactions is 62.44^{o} ±5.18 and it increases to 65.56^{o} ±3.51 for hard interactions. The rational parameter χ_o^g decreases with target mass number i.e. the system of emission of grey particles becomes slower of emission with target mass number. This could explain if we consider the increasing in the number of target nucleons increases the number of binary collisions. This become sufficient for projectile nucleons to lost most of momentum up to emitted recoil fragments in wide range of angles, and reach maximum angles opposite to original direction of incident projectile.

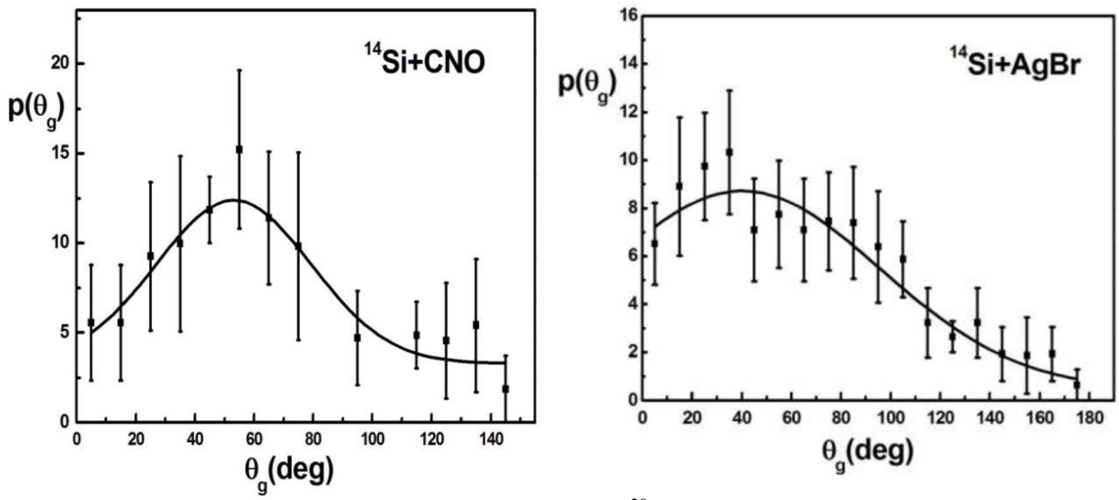

Fig.2 The angular distribution of grey particle emitted ^{28}Si interactions at 14.6A GeV with light emulsion component CNO and heavy component AgBr. Smooth curve represents the corresponding prediction of the statistical model using Gaussian-fitting shape.

3.2 Angular distribution of black particles

Second, in this section we will study the angular distributions and properties of the collisions responsible for production of slow particles, which appear as black tracks in emulsion experiments. These particles play an important role to describe the mechanism of the interactions between projectile and target nuclei. It's mainly target fragments and emitted during the last stage of interactions as an evaporated particle from residual target nucleus. It contains massive particles with minimum energy emitted in a wide range of angles, which are independent on direction of the incident projectile especially more heavy black fragments. The experimental data for angular distribution of the emitted black particle from ^{28}Si-Em interactions at energy 14.6 A GeV with the corresponding prediction of the statistical model are shown in fig. 3.

The mean value for this distribution is compared with other projectiles and is given in table 2. It is noticed that the spectrum seems to be symmetric about the peak position, which is near from the mean value $\langle\theta_b\rangle$. The feature of this spectrum implies that, the emission of black particles, in forward and backward hemispheres tends to be symmetric in both directions, where the particle multiplicity increases in the vicinity region of $\theta_{lab} \sim 90^o$.

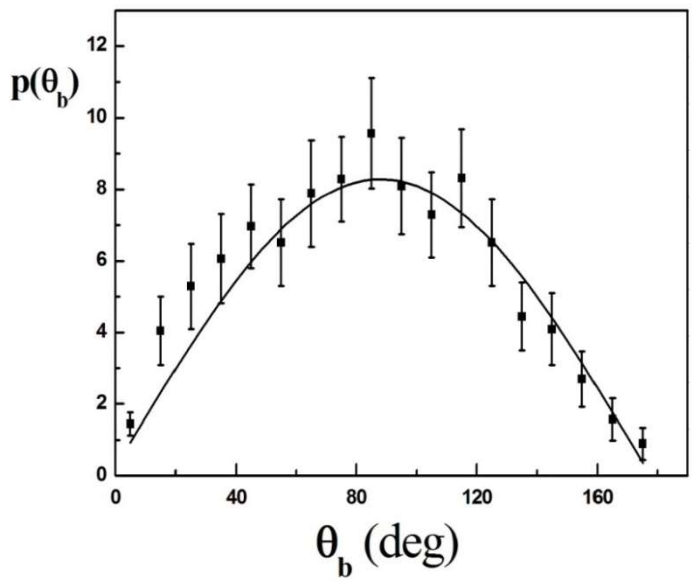

Fig.3 The angular distribution of black particle emitted ^{28}Si-Em interactions at 14.6A GeV. Smooth curve represents the corresponding prediction of the statistical model using Gaussian fitting shape from Eq. (4).

Table 2 The average values of the emission angles of the black particles $<\boldsymbol{\theta_b}>$ in different interactions at 2.2 -14.6A GeV, in addition to the rational $\boldsymbol{\chi_o^b}$ velocity of the system, the ratio $(F/B)_b$ and longitudinal velocity $\boldsymbol{\beta_{\parallel_b}}$ of black particle emission, on the basis of statistical model.

projectile	Energy A GeV	$<\theta_b>$	χ_o^b	$(F/B)_b$	$\beta_{\parallel_b}$	Ref.
^{4}He+Em	3.7	83.00±3.80	0.13	1.33±0.07	0.014	11,21
^{6}Li+Em	3.7	82.20±2.60	0.12	1.29±0.06	0.013	16,22
^{7}Li+Em	2.2	81.30±2.30	0.17	1.48±0.07	0.018	16,22
^{12}C+Em	3.7	79.50±2.10	0.18	1.27±0.10	0.019	11
^{28}Si+Em	3.7	83.30±1.18	0.17	1.59±0.07	0.018	12-14
^{28}Si+Em	14.6	83.54±1.89	0.11	1.26±0.08	0.012	Present work
^{28}Si+CNO	14.6	79.98 ±3.70	0.17	1.48±0.08	0.019	Present work
^{28}Si+AgBr	14.6	84.96 ±2.18	0.09	1.22±0.07	0.010	Present work

If predictions of statistical model are applied for black particles it gives the values of the rational velocity χ_o^b and longitudinal velocity $\beta_{\parallel_b}$ and are given in table 2. The value of $\beta_o^b \sim 0.115$ is taken from ref. [3]. It can conclude that the constancy in the values of $<\theta_b> \sim 83^\circ$, independent of the variation of projectile mass number as well as incident energy. The predicted rational velocity χ_o^b according to statistical model tends to be ~0.13 for the system, which is responsible for black particle emission. The ratio $(F/B)_b$ for black particles is more concise for different projectiles in small range 1.2-1.6 describe a fixed mechanics of black particle production and different that for grey system. The emitting system of the b-particles is slow and has a typical longitudinal velocities $\beta_{//}^b$ lie in the range $\beta_{//}^b$~ 0.008-0.019. The temperature of the emitting system of black particle can calculate using $T = \frac{1}{2} M\beta_\circ^2$ where M is the nucleon mass. It value is found to be for black particle is equal to 6 MeV per nucleon which is approximately equal to the binding energy per nucleon for in normal state of nucleus. The corresponding temperature for the system responsible for grey particle production is calculated by using the magnitude of $\beta_o^g \sim 0.35$ (ref.[3]) is found to be 58 MeV which is much sufficient for protons to make cascading of secondary interactions before emitted from hot size of interactions.

The interesting observations are the effect of target mass on the angular distributions of black particles. This effect for both two-target components is shown in figure 4. The studied experimental parameter is shown in table 2. It is clear that for gentle interactions the emission of evaporated black particles begins from angles 20^o and most probabilities equal distributed to reach 90^o and begins in fast decreasing with lower probability in backward directions. This means that the distribution is not homogenous about any specific angle. The corresponding distribution for hard interactions with AgBr nuclei shows a uniform distribution in all possible range of emission angles and there is a similarity of emission angles on forward and backward hemispheres of emission angles. The mean value of emission angles is about 85^o, which reflect the symmetry of distribution in the middle angles of the range of emissions. This symmetry is deviated for CNO interactions. The ratio $(F/B)_b$ and rational parameter χ_o^b decreases from 1.48±0.08 and 0.17 in gentle interactions to 1.22±0.07 and 0.09 for hard interactions respectively. It proves that the system of emission black particles becomes slower and low temperature with increasing mass number of the interacting target nucleus.

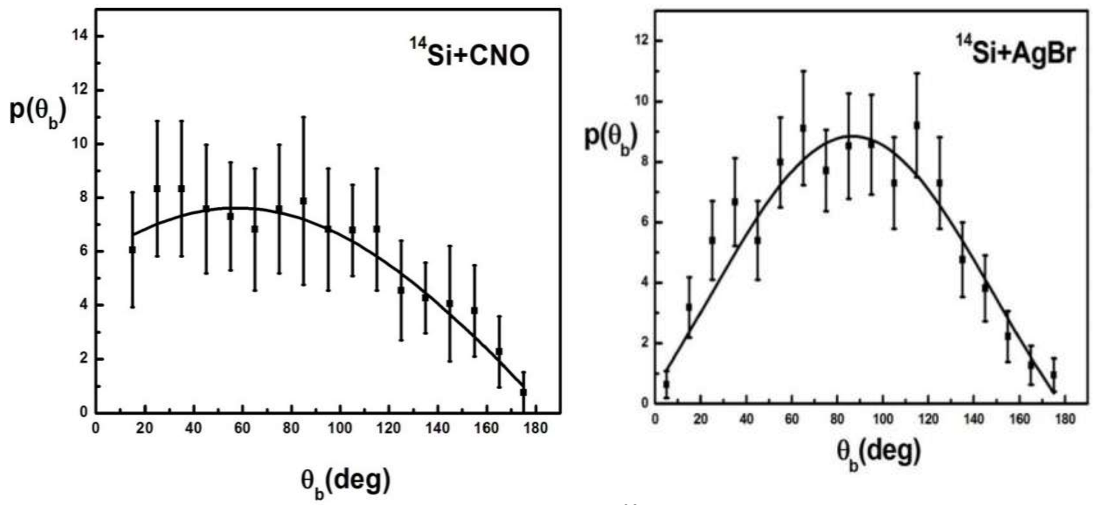

Fig.4 The angular distribution of black particle emitted ^{28}Si interactions at 14.6A GeV with light emulsion component CNO and heavy component AgBr. Smooth curve represents the corresponding prediction of the statistical model using Gaussian-fitting shape.

Conclusions

- The angular distribution of grey and black particles emitted from ^{28}Si-Em interactions at energy 14.6 A GeV are well described by statistical model
- The experimental parameters such as mean values of the emission angles of grey $< \theta_g > \sim 64^\circ$ and black $< \theta_b > \sim 83^\circ$ are nearly constant with the corresponding

collisions with different projectiles within range of collision energy 2.2-14.6 A GeV.

- The predicted rational velocity χ_o by statistical model which characterize the system responsible for secondary particle emissions is nearly equal 0.5 for grey particles and tends to be ~ 0.13 for black particles.
- The velocity of emitting system is describe by the parameter $\beta_{//}$, where the emitting system for g-particles is fast and with typical longitudinal velocities $\beta_{//}{}^{g}$ ~ 0.13-0.20 while it slow for emission of black particle in the range $\beta_{//}{}^{b}$ ~ 0.008-0.019
- The anisotropic ratio (F/B) is found to be 2-3 for system responsible for grey particle productions while it is 1.2-1.6 for system of black particle production.
- The temperatures of the system responsible for emission of secondary slow fragments are found to be 58 MeV for grey particle productions while 6 MeV for black and slow heavy fragments.
- The angular distributions for both grey and black particles depend on the size of the target nucleus where most of emission angles for grey particles are mainly in forward angles for small target nuclei CNO, while it in symmetry distributions between forward and backward hemispheres for heavy target AgBr.
- The system responsible for grey and black particle productions becomes slower and low temperature with increasing target mass.

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References

[1] S. K. Karn, R.S. Kaashal, and Y.K. Mathur, Z Phys. C, 72, 297 (1996). doi:10. 1007/s 002880050249
[2] H. H. Hackmann, H. J. Crawford, D. E. Greiner, P. J. Lindstrom and W. Wilson Lamce, Phys. Rev. C17, 1651 (1978).
[3] A. Abdelsalam, Phys. Scr., 47,124 (1993).
[4] M. El-Nadi, M. S. El-Nagdy, N. Ali-Mossa, A. Abdelsalam, A. M. Abdalla and A. A. Hamed, J. Phys. G: Nucl. Phys. 25, 1169-1178 (1999).
[5] M. El-Nadi, et. al., The European Physical Journal A-Hadrons and Nuclei 10 (2), 177-181 (2001).
[6] M. El-Nadi, et. al., Journal of Physics G: Nuclear and Particle Physics 28 (6), 1251 (2002).
[7] A. Abdelsalam, M. S. El-Nagdy, A. M. Abdalla and A. Saber, International Journal of Modern Physics E Vol. 24, No. 11, 1550084 (2015)
[8] M. I. Adamovich; et al. LUND Report LUIP 8906 (1989).
[9] M. El-Nadi, A. Abdelsalam, N. Ali-Moussa, Z. Abou-Moussa, S. Kamel, K. Abdel Waged, W. Osman and Badawy, Eur. Phys. J. A 3, 183 (1998).
[10] M. El-Nadi, A. Abdelsalam, N. Ali-Moussa, Z. Abou-Moussa, S. Kamel, Kh. Abdel Waged, W. Osman and B. M. Badawy, IL Nuovo Cimento A 111, 1243 (1998).
[11] A. Abdelsalam, Phys. Scr., 47, 124 (1993).

[12] M. El-Nadi, A. Abdelsalam and N. Ali-Moussa, Int. J. Mod. Phys. E. 3, 811 (1994).
[13] M. El-Nadi, A. Abdelsalam and N. Ali-Moussa, Radiat. Phys. Chem. 47, 681 (1996).
[14] M. El-Nadi, A. Abdelsalam and N. Ali-Moussa, IL Nuovo Cimento A 110, 1255 (1998).
[15] A. Abdelsalam, E. A. Shaat, N. Ali Mossa, Z. Abou-Moussa, O. M. Osman, N. Rashed, W. Osman, B. M. Badawy and E. El-Falaky, J. Phys. G 28, 1375 (2002).
[16] LI. Hui-Ling, Z. Dong-Hai and LI. Jun-Sheng, Chin. J. Phys. C (HEP&NP) 33, 521(2009).
[17] A. Abdelsalam, B. M. Badawy and E. El-Falaky, Can. J. Phys. 85, 837 (2007).
[18] M. M. Sherif, Il Nuovo Cimento Vol. 109A, 1135 (1996).
[19] J.R. Florian et al; Report submitted to the meeting of Division of particles and fields, Berely, California (1973).
[20] A. Abdelsalam, JINR Report (Dubna) El-81-623(1981).
[21] A. Abdelsalam, M. S. El-Nagdy, N. Rashed, B. M. Badawy and E. El-Falaky, J. Nucl. Radiat. Phys. 2, 49 (2007).
[22] M. El-Nadi, A. Abdelsalam, N. Ali-Moussa, Z. Abou-Moussa, Kh. Abdel-Waged, W. Osman, and Badawy, IL Nuovo Cimento A111, 1243 (1998).