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Missing energy within helium emitted in AA collisions at high energies

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Abstract- Using the multiplicity characteristics of the final state hadron, the shower particles emitted in the 4–pspace through 4He interactions with emulsion nuclei are studied in a few A GeV region. Basing on a universality of state, the multiplicity distributions, in the backward hemisphere of the space, are determined as a function of the target size. The shower particle multiplicity, while found to depend only on the target size in the backward hemisphere, depends on both the energy and system size in the forward hemisphere. It is seen that the shower particles are originated from two emission sources. One of both emits pion in the backward hemisphere, beyond the kinematic limits, as a target source particle regarding the limiting fragmentation hypothesis. The other is the main source which emits pion in the forward hemisphere as a result of a particle creation system. The results are analyzed in the framework of the Lund Monte–Carlo program code–events generating FRITIOF model.

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Keywords- Pions; Projectile fragmentation; Nuclear emulsion.

1. INTRODUCTION

In nucleus-nucleus experiments where emulsion is used simultaneously as target and track detectors, one can qualitatively classify the observed reactions, depending upon their visual characteristics into central or peripheral collisions. Central events exhibit no visible forward cone fragments of charge Z≥2 from the projectile, such events are mostly due to the destruction of the projectile and target nuclei at small values of the impact parameter (b) of collision i.e., $b = r_1 + r_2$ (r_1,r_2 are radii of target and projectile nuclei, respectively). In peripheral collision, a little excitation of the target nucleus may occur, at the same time the primary beam may be fragmented into a number of charge components, the observed fragments has no interactions with the target. The process involves a virtual break up of the projectile in which $Z_{beam} = \sum Z_{PF}$ where Z_{PF} is the charge of a projectile fragment. Emulsion detector is an ideal one for such events when observed at high magnifications. Emulsion is a unique detector to distinguish between centers of successive interactions and neighboring [1]tracks of very small separation. A study of secondary helium projectile fragments produced in high energy relativistic and ultra-relativistic heavy-ion collision has been regarded as a potentially useful source of information about the underlying production processes. Consequently helium emission in heavy-ion reaction has been carefully studied previously [2].

In this paper, the data reported from different laboratories for nucleus-nucleus interactions at energy range from 1.4A GeV to 200A GeV, concerning the average multiplicities of shower particles $<n_s>$. These are assumed to be mostly produced pions π^+ and π^- having relativistic velocity $\beta > 0.7$ and non-interacting protons (p, d,t) produced from the inelastic nuclear reactions[3]. Also included in the $<n_s>$ those produced from the interactions of secondary projectile fragments of Z=2 (mainly α-particles). The helium fragments produced from parent stars of heavy-ions beams were easily identified in all laboratories by different methods which include grain density, gap density and δ-ray counting[4]. In general the detection of helium fragments is quite definite due to their distinctive grain density. The momenta of projectile fragments are generated within their moving system with isotropically distributed directions according to known P_1 spectra. The projectile spectator fragmentation is done using experimental multiplicities. Pions are generated out of available energy. Their numbers are fixed in the following way. After the baryons are provided with their kinetic energy, pion is produced preliminarily. This means, as will be clear later, the

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pion gets a momentum according to a given P_1 which determines also its total energy E_{meson}[5]. For E_{av} - E_{meson} > 0 (where E_{av} is equal to the total energy in CMS " $\sqrt{s}$ " minus the rest mass of participant nucleon "m_o"), pion is taken as a real particle and E_{av} is reduced by E_{meson}. Therefor one can say that multiplicity of pions n_s plus other neutral mesons directly results out of the energy conservation. Neutral pions π^o are identified by their decay photons ($\pi^o > 2\gamma$).

The aim of this work is to compare <n_s> produced from the primary α-particle interactions with those of secondary helium interactions at similar energies.

2.Experimental Results

To see the dependence of the shower particle multiplicity n_s on the beam mass number A and total kinetic energy E_T, we show in table 1 the average multiplicities <n_s> from ^{4}He at 2A and 3.66A GeV [6] and 12A GeV [7], 3.66 A GeV ^{12}C[8], ^{16}O(60A GeV and 200 A GeV[9]), and 200 A GeV ^{32}S[10].

Table 1. The experimental average multiplicities of shower particles < n_s>with the corresponding energies.

Beam	Energy A (GeV)	Total kinetic energy E_T (TeV)	<$\pi^+ + \pi^-$>	Ref.
^{4}He	3.66	0.015	4.4±0.1	5
^{12}C	3.66	0.044	7.8±0.2	7
^{4}He	12.0	0.048	8.33±0.27	6
^{16}O	60.0	0.96	34.12±2.30	8
^{16}O	200.0	3.2	57.3±3.1	8
^{32}S	200.0	6.4	79.9±4.1	9

In Fig.1, a linear relation is shown to be valid in the energy range 2A GeV – 200 A GeV for the average multiplicity of shower particles produced in the interaction of the primary beams given in table 1.

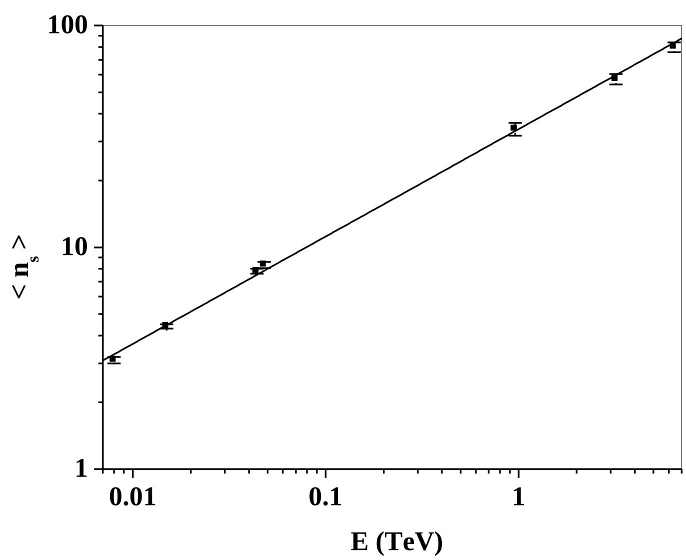

Fig. 1. The average values of shower tracks < n_s> produced from the interactions of different primary beams as a function of the total beams energy of the beams. The solid line is the best fit to the data points.

The results have been fitted with the expressions <n_s>=a E_T^b where a = 33.88±1.56, b=0.48±0.01 and correlation coefficient r =0.9996. Now it is interesting to check this universal relation by applying the values of <n_s>produced in the interaction of secondary helium fragments produced from parent stars of heavy-ion beams to deduce the kinetic energy of such helium fragments. We use universal relation to deduce the average energy corresponding to $<n_s>$=13.59±0.18 of ^{4}He (daughter 60A GeV^{16}Obeam [11]. From Fig.1, the corresponding energy is found to be equal =40 A GeV. For helium (daughter 200A GeV^{16}O and ^{32}S beams) $<n_s>$=23.59±0.18, the corresponding average kienitic energy is ~140 A GeV[12]. For helium (daughter 3.66A GeV^{12}C beam)[13]$<n_s>$=3.16±0.12, the energy is ~2.5 A GeV. Jain mentioned [14] that the energy of ^{4}He (daughter of 14.5 AGeV^{28}Si beam) is equal to 11 AGeV. Thus , the observed decrease for the multiplicity of charged Pions (n_s) according to the energy conservation is about 30% less than the energy of the parent beam this missing energy may due to creation of unknown neutral source namely bosons can not be observed in emulsion which will conserve the energy or momentum in the interaction of helium fragments.Heavy neutral mesons may also be produced in the primary interaction but the probability of its production is more in the interactions of the second generation. The analysis of the NA35 streamer films allow to study the production of Δ ,$Δ^-$, K_S° and $K^\pm$[17]. NA38 studies inclusive production of muon pairs in^{16}O– U, ^{16}O- Cu and ^{32}S+ U interactions at 200 A GeV[18].

The observed decrease in < ns > for secondary helium intersections is about 20 % as compared to the primary ^{4}He interactions at similar energy. Production of neutral boson would imply a source to that decrease in addition to the expected decrease due to the existence of ^{3}He species among the Z = 2 fragments. Thus, it is important now to evaluate the effect of the contamination of ^{3}He among ^{4}He. It is given in ref. [14] for primary ^{3}He $<n_s>$ = 4.0±0.1 and for ^{4}He$<n_s>$ = 4.5±0.1 at the same energy 3.7A GeV. By assuming 100 % ^{3}He in secondary helium fragment, this will lead to decrease not more than 11 %. However, a mixture of equal amount of ^{3}He and ^{4}He will make a decrease of ~ 5.5 %. Keeping in mind that the ratios of ^{3}He to ^{4}He produced from ^{6}Li is 30/68 and ^{7}Li is 22/72 [16] at 3.7A GeV.

On the other hand, in our opinion, $<n_s>$ is introduced where the onset of meson production is important related to or strongly dependent on both the energy and atomic mass number of the projectile beam. We show in Table (2) the average multiplicities from ^{4}He beams at (1.4, 3.7, and 12.0A GeV) [19–21] as well as those produced from secondary helium fragments emitted from 1.8A GeV ^{56}Fe [22], 3.7A GeV ^{12}C [23] and ^{6}Li [19], and 14.6A GeV^{28}Si [24] 60A GeVand 200A GeV ^{16}O and ^{32}S In particular, we know that fragments produced from break up of projectile nuclei at a given energy continue with about the same velocity (and energy) as the parent nuclei [25]. So it is meaningless to say that He fragments have energy less than parent beam by about 1/3 (~30 %). In particular, the depressions of $<n_s>$ and kinetic energy in the interactions of secondary helium projectile fragments as relative to the corresponding primary ^{4}He beams has been put forward as a possible signature of formation of a neutral boson through a decay of the excited α fragments.

Table2. Average values of shower track multiplicities produced from the interactions of primary and secondary projectile helium nuclei in emulsion from different experiments.

Energy of Primary ^{4}HeGeV/A	$<n_s>_{primary}$	Parent Nuclei Producing Secondaryα Particle	$<n_s>_{secondary}$	$\frac{<n_s>_{secondary}}{<n_s>_{primary}}$	Ref.
1.4	3.36±0.05	^{56}Fe (1.8)	2.66±0.07	0.79±0.03	19, 22
3.7	4.54±0.11	^{12}C (3.7)	3.61±0.12	0.80±0.03	20, 23
		^{6}Li (3.7)	3.65±0.22	0.80±0.06	20
		^{16}O (60)	13.60±0.20		24
		^{16}O (200)	23.60±1.20		26
12.0	8.33±0.27	^{28}Si (14.6)	6.80±0.30	0.82±0.05	21, 24
		^{32}S (200)	23.60±1.20		26

In order to see the development of average shower particle multiplicities in helium beam and helium projectile fragment interactions with emulsion target, it is given in Table 2$<n_s>$ for primary ^{4}He beam at energies 1.4, 3.7, 12A

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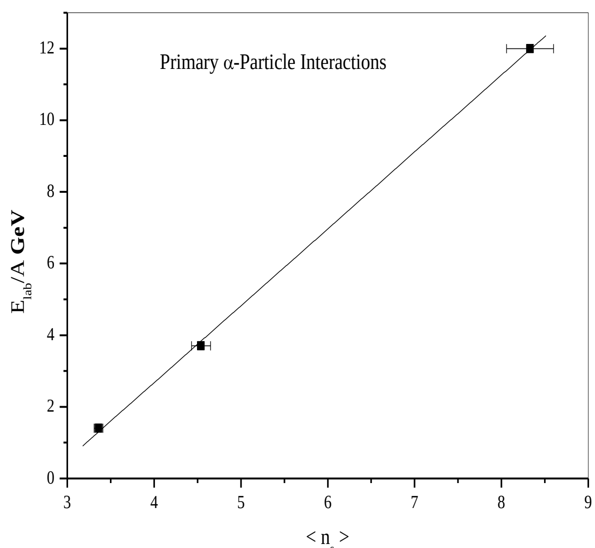
GeV and those for secondary helium projectile helium daughters of 1.8 ^{56}Fe, 3.7 ^{12}C and ^{6}Li, 14.6 ^{28}Si, 60 ^{16}O and 200A GeV (^{16}O and ^{32}S). On the other hand, figure (2, 3) show $< n_s >_{prim}$ and $< n_s >_{second}$ as a function incident energies per nucleon. Fits to beam data using a linear dependence of form $E_{lab} = c < n_s >^d$ where c = 0.21±0.01 and d = 2.17±0.02. The dash line represents the expected data for the primary α-particle interaction with the scale of secondary helium interactions. Such curve is similar to what is called Segre chart. This is due to the observed decrease in $< n_s >$ for secondary helium interactions. In Fig. (4), it is shown the $\Delta < n_s >$between primary and secondary helium as a function of energy. The plotted points fall along two straight line segments with distinctive break at about

10 GeV corresponding to two ranges of energy (4 - < 10) and (10 – 40) GeV with sharply different slope. It is fitted with expression $E = e + f \Delta < n_s >$ where e = -2.76±0.67, f = 9.66±0.69 for the first segment and e =5.47±0.58, f = 3.41±0.11 for the second segment. The first class segment may characterized by relativistic energy while the other ≥ 10 GeV may due to ultra-relativistic energy. It is given inCERN – SPS and AGS in Brookhaven that ultrarelativistic energy up to $\sqrt{S_{NN}}$ = 17.4 GeV.

Fig. 2.The energy as a function of the charged pion multiplicity in the interactions of the primary α-particle with emulsion nuclei.



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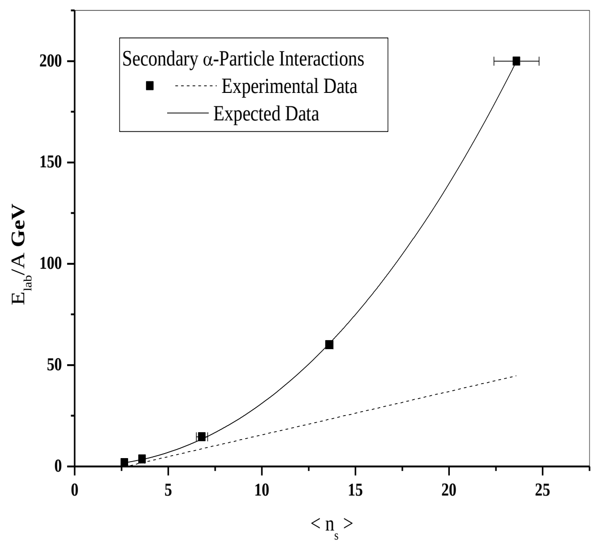

Fig. 3.The energy as a function of the charged pion multiplicity in the interactions of the secondary α-particle with emulsion nuclei.

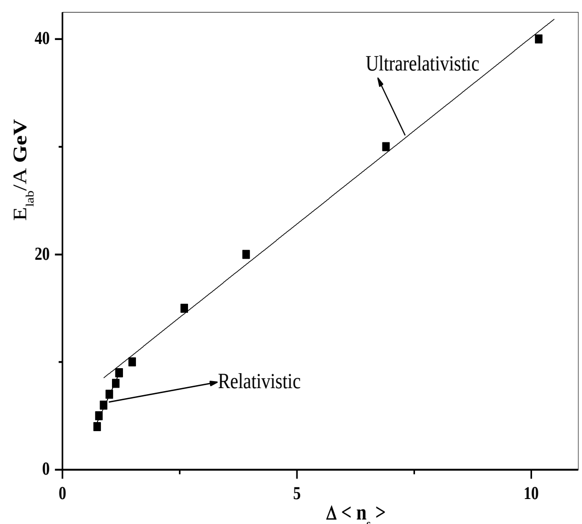

Fig. 4.The energy correlation with the pion multiplicity deficient in α-particle with emulsion nuclei.

3. Balancing of Missing Energy with π^0 Emission

Most of the particles produced in inelastic collisions arepions (π^0,π^-, π^+). They are produced in equalabundance. The charged pions (π^+,π^-), N_{ch}, are measured. The total number, N_{tot}, of pions can be estimated from $<N_{tot}> = 3/2 <N_{ch}>$. In this setting, the missing energy observed due to depression of $< n_s >$ for secondary $< n_s >$ helium interactions can be

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blanked by the sum of many neutral bosons through the decay of the excited helium fragments. It could be determined the number of neutral pions π^0 which conserve the missing energy by taking the lowest energy ($\frac{5.6\text{ GeV}}{3.36\times3/2}$= 1.11 GeV) for one pion emitted in 1.4A GeV ^{4}He as follows:

Number of π^0 = [< n_s>$_{prim}$ - < n_s>$_{second}$)/1.11

Table (3) includes the number of neutral pions which can balance with the missing energy for each of the present helium data. Figure (5) shows the relation between the number of neutral pions balanced the missing energy versus helium energy.

Table 3. The average number of produced neutral pions and the corresponding to the energy missed in α-particle interactions.

α-Beam Energy A GeV	No. of π^0 Corresponding to Missing Energy A GeV
1.4→1.8	0.78
3.6	0.84
12→14.6	1.38
60	15.86
200	65.23

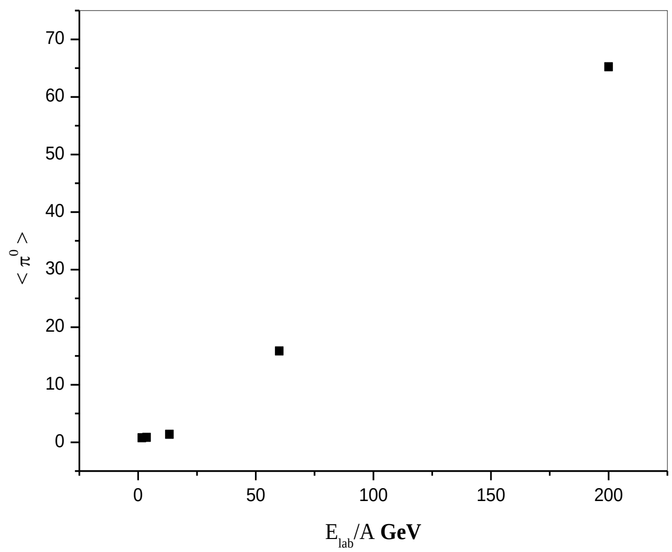

Fig. 5. The average number of produced neutral pions and the corresponding to the energy missed in α-particle interactions.

They concluded that the dimuons can either have a mass in the continuum of the spectrum or be decay product of J/ψ. In general, many experiments have now measured the yield of several particle species containing one or more strange mesons (K^+,K°,Δ, Ξ and their anti-particles [27], strangeness enhancement is now seen more as a characteristic feature of a system approaching chemical equilibrium rather than as a unique signal for QGP formation.

4. Conclusion

1- From the universal linear relation between the average multiplicity of shower particles and the kinetic energy of the projectile beams at energy range 3.66A GeV -200 A GeV. It is found that< n_s> of secondary ^{4}He(daughter from mother nuclei) interaction corresponds to an kinetic energy per nucleon less than the mother beam by about 1/3 which suggest the production of other neutral mesons to satisfy the conversation laws.
2- The differences in< n_s> between ^{4}He beam and ^{4}He fragments is found to increase with energy of incident in which heavier neutral mesons production are probable at ultrarelativstic energy.

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3- Balancing of missing energy is estimated by producing π^0 emission increased with α beam energy (1.4-200 AGeV) by 0.78 $\pi^0$to 65.23 π^0.
4- The difference $\Delta< n_s>$ falls along two straight line segments with distinctive break at 10 GeV may characterized by the separation between relativistic energy < 10 GeV&ultra relativistic≥ 10 GeV.

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REFERENCES

[1] E.M Friedlander et al., phys. Rev. Lett. 45, 1084 (1980).
[2] A.S.Goldhaber, phys. Lett. B 53,306(1974), H.G. Baumgert et al.,Z. Phys. Rev. A237, 359(1975),D.E. Greiner et al., Phys. Rev.Lett.35,152(1975), M.El-Nadi, O.E.Badawy,M.S. El-Nady, N.M Sadek, A.A. El-Sourogy, M.M. Mosaad, M.N. El-Bakry and A.El-Hamalawy, Nucl. Phys. G 13,1173(1987), K. Sengupta, G. Singh and P.L. Jain, Phys. Lett. B 222,301 (1989).
[3]A. Abdelsalam, M. S. El–Nagdy and B.M.Badawy,Can.J.Phys,89,261,(2011).
[4] A.Z.M Ismail, M.S. El-Nagdy, K.L. Gomber, M.M. Aggarwal, and P.L. Jain, Phys. Rev. lett. 52, 1280 (1984).
[5]W.Schulz and E. Ganssauge, J.Phys. G.Part. Phys. 18, 1491 (1992).
[6]M.I. Adamovich et al., Preprint JINR, E1-10838, Dubna (1977).
[7] Banaras – Cairo – Chandigarh – Jainpur – Jammu – Lund Collaboration 7th High Energy Heavy Ion Study, GSI Darmstadt, October, 8-12 (1984).
[8]A.Marin et al., Sov. J. Nucl. Phys. 29 (1),52 (1979).
[9] P.L. Jain, G. Singh and K.Sengupta, Phys. Rev. C.43 R2027 (1991).
[10] EMUOI Collaboration, M.I. Adamvich et al., Phys. Lett, B, 262,369(1991).
[11] M.EL-Nadi, N.M. Mettwalli, O.E.Badawy, M.S. EL-Nagdy, and L. kelany, IL NuovoCimento 107 A (1), 1(1994).
[12] P.L. Jain, G. Singh, J. Sengupta and N.Kim, Intern. J. Mod. Phys. A7, 1907 (1992), Phys. Rev. c 44, 844 (1991).
[13] M.EL-Nagdy, O.E. Badawy, A.M. Moussa, E.I. Khalil, and A.A. EL-Hamalawy, Phys. Rev. Lett. 52, 1971(1984).
[14] P.L. Jain, A. Mulkhopadhyay and G.Singh, Phys. Lett. B 294 27 (1992).
[15] A. Abdelsalam, M. S. El–Nagdy et al, Egypt. J. Phys., 36, 257 (2005).
[16] M. S. El–Nagdy, M. M. Sherif, O. Whaba and F. A. Abdelwahed, Mod. Phys. Lett., A 20, 1513 (2005).
[17] NA 35 Collaboration G. Odyniec et al., Proc. Int. Worleshop on relativistic Aspects of Nuclear Physics, Rio de janeiro, Brazil, August,1989. LBL-27926 (1989).
[18]NA 38 Collaboration C. Baglin et al., Phys. Lett. B220 471(1989), B251.465 and 472 (1990).
[19] O. E. Badawy, M. El–Nadi, S. A. El–Sharkawy, M. K. Hegab, and M. M. Sherif , Z. Phys.A 311, 105 (1983).
[20] M. El–Nadi, M. S. El–Nagdy, A. Abdelsalm, E. A. Shaat, N. Ali–Mossa, Z. Abou–Moussa, N. Rashed, S. Kamel, and M. A. Fayed, Egypt. J. Phys. 33, 229 (2002).
[21] Banaras, Cairo, Chandigarh, Jammu, Lund Collaboration, 7th High Energy Heavy Ion Study, GSI Darmstadt, October 8 – 12(1984).
[22] E. M. Friedlander et al., 6th High Energy Heavy Ion Study and 2nd Workshop on Anomalons, LBL, June 28 – 1 July(1983).
[23] Abdel–Moniem M. M. Moussa, Ph. D. Thesis Submitted to Faculty of Science, Cairo. University, (1984).
[24] P. L. Jain, A. Mukhopadhyay, and G. Singh, Phys. Lett. B 294, 27 (1992).
[25] H. H. Heckman, D. E. Greiner, P. J. Lindstrom, and H. Shwe, Phys. Rev. C 17, 1735 (1978).
[26] P. L. Jain. G. Singh, K. Sengupta, and S. N. Kim, Int. J. Mod. Phys. A 7, 1907(1992); P. L. Jain, G. Singh, and K. Sengupta, Phys. Rev. C 43, R2027 (1991); P. L. Jain, K. Sengupta, and G. Singh, Phys. Rev. C 44, 844 (1991).
[27] J. Schukraft, European Organization for Nuclear Reserch Report CERN PPE/92-92 May 18 th (1992).