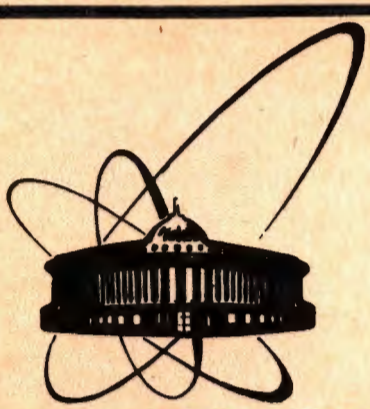

объединенный
институт
ядерных
исследований
дубна

E1-92-286

A.P.Cheplakov, N.G.Fadeev, A.P.Nagaitsev,
M.I.Soloviev, N.M.Viryasov

π^- MESON PRODUCTION IN INTERACTIONS OF DEUTERONS AND α-PARTICLES WITH THE EXTENDED CARBON AND BERYLLIUM TARGETS AT 1.0, 2.0 AND 3.3 GeV/NUCLEON

Submitted to "Muon Catalyzed Fusion"

1992

Introduction

The investigation of π^- generation processes in interactions of the lightest nuclei with extended targets is important to determine the optimal conditions of negative muon beam production available for application to the muon catalysis of nuclear fusion [1].

The results of investigating the π^--mesons production process in D- and α- interactions at 1.0 ,2.0 and 3.3 GeV with extended targets (propane,Be,graphite) are presented.

In comparison with the published data [2], new results are based on larger statistics on spectral distributions for the DBe data at 1.0 GeV/nucleon and the αBe data at 2.0 GeV/nucleon are presented for the first time. The investigation was supported by the I.V. Kurchatov Institute of Atomic Energy in the framework of the muon catalysis of nuclear fusion problems.

The experimental data have been obtained by means of the 2-metre propane bubble chamber in a magnetic field exposed to beams of light relativistic nuclei from the Dubna synchrophasotron. An extended cylinder target was placed along the beam inside the sensitive volume of the propane bubble chamber, and the beam cross section was practically covered by the target. The carbon extended target was made of graphite in cylinder form (length 30 cm, diameter 10 cm and density 1,73 g/cm^3). For the beryllium target the corresponding values were 28 cm, 6 cm and 1.848 g/cm^3.In the case of the propane target two effective volumes with different lengths were chosen and used both as a target and as a detector. The density of propane was 0.43 g/cm^3.

The methodic aspects were published in our previos papers [2-4] and also in the 2-m propane collaboration ones [5-8].

I. Inelastic Cross Section of Deuteron Interactions

The results of measuring the inelastic cross sections and the mean values of π^-- meson multiplicity produced in DBe , DC, αBe, αC interactions at 1.0 , 2.0 , 3.3 GeV/nucleon are presented in Table I. The values of σ_{apr} in the table are an empirical approximation of the cross section $\sigma_{AlAt}=78*(A_l^{1/3} + A_t^{1/3} - 1.25)^2$ mb obtained in the Berkeley experiment [9] for inelastic D, He and C interactions with P, D ,He and C targets for beam energies of 0.87 and 2.1 Gev/nucleon which are close to our primary energies.

The values of σ_{in} are corrected due to the contribution of the diffractive dissociation process for projectile nuclei and due to the quasi-elastic scatterihg of deuterons on target

TABLE 1

Reaction	T_k[Gev/]	$\langle N_\pi \rangle$	σ [mb]	σ_{apr} [mb]	$E/1\pi^-$[Gev]
DC (graphite)	1	0.17 ± 0.01	459 ± 19[2]	412	17.0 ± 1.0
DC (propane)	1	0.16 ± 0.01	425 ± 21[5-8]	412	24.0 ± 1.7
DBe	1	0.19 ± 0.02	363 ± 13[2]	340	14.7 ± 1.6
DBe	2	0.50 ± 0.03	340 ± 18	340	11.6 ± 1.0
αBe	2	0.73 ± 0.05	360 ± 30	456	15.4 ± 1.1
DC (propane)	3.3	0.62 ± 0.03	413 ± 20[5-8]	412	21.3 ± 1.2
αC (propane)	3.3	1.07 ± 0.05	445 ± 22[5-8]	540	23.0 ± 1.3

nucleons.The propane target data in Table I corresponds to a 80 cm lengths of the chosen effective volume.

The use of propane as a target was caused by the following two factors :

1) to estimate the contribution of absorption and secondary π^--meson production in a thick target. Both processes were found to compensate each other: the total contribution of additional processes to primary interaction was near zero : (1.6±2.1) %.

2) to determine the change of energy quantity for the production of one negative pion in DC interactions for the propane target of different size.

It is seen from Table I that the DC data at 1.0 GeV are close for different targets. The mean value of pion multiplicity increases with increasing beam energy and with increasing the A-number of beam nuclei.

The values of energy amount needed for the production of one pion in different reactions are listed in the last column of the table. It is seen that DBe interactions at 2.0 Gev/nucleon are more preferable for π^-- meson production .

II. Momentum and Angular Distributions of π^- Mesons

For further practical use of experimental data , it is important to measure the two-dimensional distribution of π^--mesons. The momentum - angular correlations for DBe , DC ,αC interactions at 1.0 GeV and 2.0 GeV are summarized in Table II.

MOMENTUM-ANGLE TABLE 2

DBe-1 Gev/N

Nch theta:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Nch mom																
1	4	9	28	25	33	27	23	33	21	20	18	21	12	11	13	6
2	29	80	137	157	182	169	149	141	148	147	101	88	72	51	43	9
3	36	97	144	160	139	161	127	74	60	35	33	27	16	8	5	7
4	41	102	153	148	131	72	53	39	15	8	5	2	2	3	3	1
5	38	110	160	96	64	33	14	14	7	3	1	4	2	3	2	6
6	28	67	83	33	13	12	6	3	1	2	0	1	1	0	3	2
7	18	41	30	19	5	2	2	0	2	0	0	0	1	0	1	1
8	6	10	16	2	3	1	0	4	0	0	0	0	1	1	0	1
9	3	5	3	1	0	1	0	0	0	0	0	1	0	1	0	0

D+C(extended)-1 Gev/N

Nch theta:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Nch mom																
1	0	3	5	4	9	10	13	8	7	12	6	5	5	1	0	0
2	4	22	41	51	55	56	59	40	41	35	31	30	15	15	0	0
3	6	26	42	50	50	41	35	40	20	3	10	9	6	4	0	0
4	4	30	51	44	42	26	25	10	7	3	3	5	0	1	0	0
5	7	20	25	35	15	16	5	8	1	1	1	1	0	0	0	0
6	4	13	23	17	6	2	4	1	0	0	0	0	0	0	0	0
7	2	9	11	3	4	2	1	0	1	0	0	0	0	0	0	0
8	1	2	3	0	2	0	0	0	0	0	0	0	1	1	0	0
9	0	1	2	1	0	0	1	0	0	0	0	0	0	0	0	0

D+C(propane)-1 Gev/N

Nch theta:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Nch mom																
1	0	0	4	0	4	1	3	1	3	0	1	0	0	1	1	0
2	4	19	20	26	25	31	30	40	25	24	24	11	26	13	7	5
3	6	21	28	48	47	44	32	22	11	20	9	9	0	0	1	0
4	7	19	44	44	32	33	11	10	9	0	0	3	0	1	0	0
5	7	41	34	49	22	14	8	5	3	1	0	0	0	0	0	0
6	4	12	27	10	11	6	4	0	0	0	0	0	0	0	0	0
7	9	14	11	6	4	1	0	1	0	0	0	0	0	0	0	0
8	1	1	6	2	2	0	1	0	0	0	0	0	0	0	0	0
9	4	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0

MOMENTUM-ANGLE TABLE 2 (continued)

D+Be-2 Gev/N

Nch theta:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Nch mom																
1	3	3	20	26	30	30	31	20	22	21	26	19	17	19	11	4
2	40	122	218	254	278	243	253	245	214	198	155	144	114	94	67	40
3	37	155	251	244	286	242	185	136	125	86	57	56	47	28	16	4
4	49	176	247	255	211	153	111	86	49	26	23	14	6	3	3	2
5	55	163	266	221	181	86	63	44	17	14	7	5	1	1	1	2
6	63	163	179	159	99	53	35	28	9	5	1	3	0	0	0	1
7	50	137	156	114	62	27	17	5	3	2	2	1	0	1	0	0
8	40	128	115	63	26	18	8	3	1	1	2	0	0	0	0	0
9	44	100	84	26	15	9	4	2	0	1	0	0	0	0	1	0
10	27	69	44	19	5	5	1	1	0	0	0	0	0	0	0	0
11	26	46	32	16	5	0	0	0	0	0	0	0	0	0	0	0
12	13	32	20	12	1	0	4	0	0	0	0	0	0	0	0	0
13	9	21	8	6	2	0	1	0	1	0	0	0	0	0	0	0
14	5	11	7	2	1	0	1	0	0	0	0	0	0	0	0	0
15	5	12	1	0	0	0	0	0	0	0	0	0	0	0	0	0
16	1	7	1	1	0	0	0	0	0	0	0	0	0	0	0	0

ALFA+Be-2 Gev/N MOMENTUM-THETA TABLE

Nch theta:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Nch mom																
1	3	2	14	7	10	13	5	3	7	1	4	2	4	0	2	1
2	15	35	53	56	79	72	70	51	50	30	37	34	17	8	10	9
3	17	25	52	78	60	39	45	23	19	18	16	6	5	3	4	3
4	20	46	59	47	35	32	30	16	5	7	1	2	2	0	1	0
5	15	45	38	52	19	23	12	8	0	1	0	1	1	1	0	0
6	12	39	50	27	18	16	5	3	2	0	0	1	0	1	0	0
7	12	34	30	22	10	4	1	0	0	0	0	0	0	0	0	0
8	9	23	25	7	4	1	2	0	0	0	0	1	0	0	0	0
9	8	8	10	7	6	1	0	0	0	0	0	0	0	1	0	0
10	5	17	6	8	1	1	0	0	0	0	0	0	0	0	0	0
11	2	7	12	1	1	1	0	0	0	0	0	0	0	0	0	0
12	4	4	4	3	0	0	0	0	0	0	0	0	0	0	0	0
13	1	1	3	3	1	0	0	0	0	0	0	0	0	0	0	0
14	4	3	1	0	0	0	0	1	0	0	0	0	0	0	0	0
15	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The momentum and emission angle intervals in this table are uniform (ΔP=.1 GeV/c,$\Delta\theta$=10 degrees) and both variables start from zero.

The two-dimensional momentum - angular distributions for DC and αC at 3.3 Gev are published in [3].

Table III presents the average kinematic characteristics of π^-- mesons as well as the number of events used for different reactions.

As mentioned in [2] the fraction of π^- - mesons was emitted from the side of the target invisible with objectives or had a

short track for measurement and identification. These tracks and those with a small angle to the objective axes were considered as bad reconstructed tracks. The weight for each π^- meson was introduced to remove distribution distortions due to the lost part of events. The weights were experimentally determined from uniform requirements of the azimuthal distribution of π^-. The weights as a function of polar angles are listed in Table IV. As one could expect, the weights are close to unity at a small π^- emission angle and reach the highest value at $\theta_{\pi^-} \sim 90^\circ$.

It is also important to note that a reliable momentum measurement in a propane bubble chamber starts from the value greater than 0.07 GeV/c. Thus, the first momentum interval includes the largest systematic error.

In Figs. 1- 3 the inclusive spectra of π^-- mesons for the kinematic variables (P_{π^-}, θ_{π^-}, P_t^2, T_{π^-} -kinetic energy) and the dependences of $\langle P_{\pi^-}\rangle$ on θ_{π^-} and $\langle\theta_{\pi^-}\rangle$ on P_{π^-} are compared for DBe, DC, αBe, αC interactions at 1.0 GeV/nucleon and 2.0 GeV/nucleon. The errors are statistical only ; all the distributions are weighted. The largest statistics is for the DBe at 2.0 Gev/nucleon.

The comparison of the data shows:

- the corresponding spectra have the same shape for different targets and primary energies;
- the momentum distributions for the DC extended target are lower than those for DC interactions in propane;
- no significant effect of the thick target is seen in the angular distributions;
- the π^- transverse monentum squared distributions could not be fitted analytically by one exponential;
- there is no hamp in the kinetic energy spectra.

Summarizing , the comparison of the data for different targets has shown an insignificant influence of the longitudinal size of the target on the angular distributions, and the energy spectra have become "softer".

TABLE 3

Reaction	DBe	DBe	αBe	DC(extended)	DC(propane)
T_{beam} [Gev]	1	2	2	1	1
$\langle P_{\pi^-}\rangle$ [Gev/c]	.274±0.002	.379±.003	.363±.006	.270±.004	.314±.005
$\langle\theta_{\pi^-}\rangle$ [deg.]	54.±.5	49.±.3	47.±.7	54.±.1	51.±.1
$\langle P_t^2\rangle$[(Gev/c)^2]	.033±.001	.053±.001	.048±.001	.038±.001	.043±.001
$\langle T_k\rangle$ [Gev]	.175±.002	.268±.002	.250±.005	.172±.004	.209±.004
Nb of events	4800	9800	2100	1200	1000

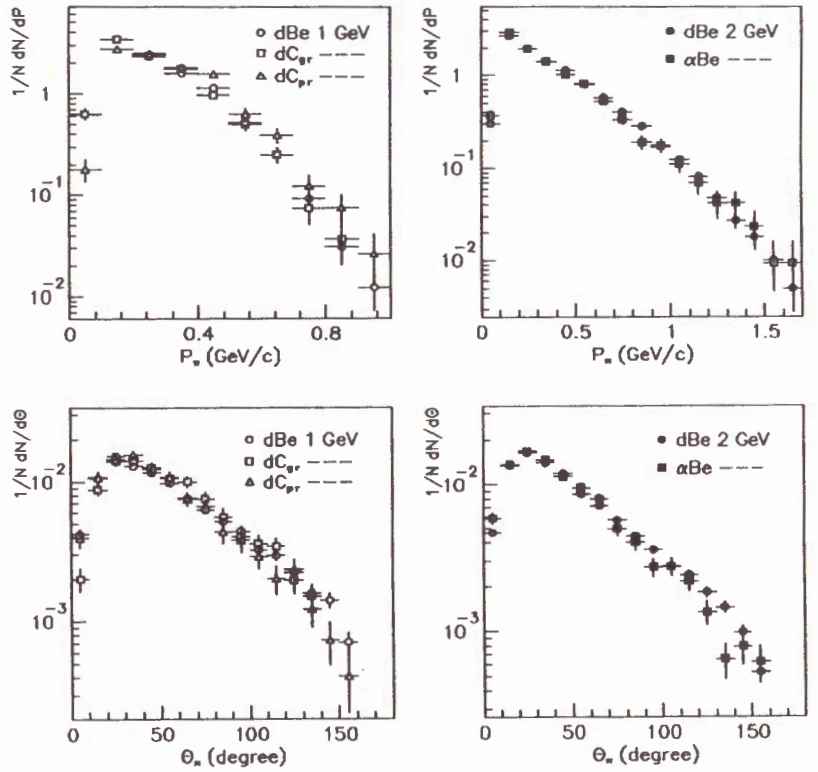

Fig.1. Momentum P_{π^-} and angular θ_{π^-} distributions of π^--mesons:
○ - DBe interactions at 1 GeV/n ,
□ - DC interactions at 1 GeV/n in graphite,
Δ - DC interactions at 1 GeV/n in propane,
● - DBe interactions at 2 GeV/n ,
■ - αBe interactions at 2 GeV/n .

TABLE 4

θ_{π^-} [deg.]	0-60	60-70	70-80	80-90	90-100	100-110	110-180
WEIGHT	1.00	1.04	1.07	1.30	1.17	1.09	1.00

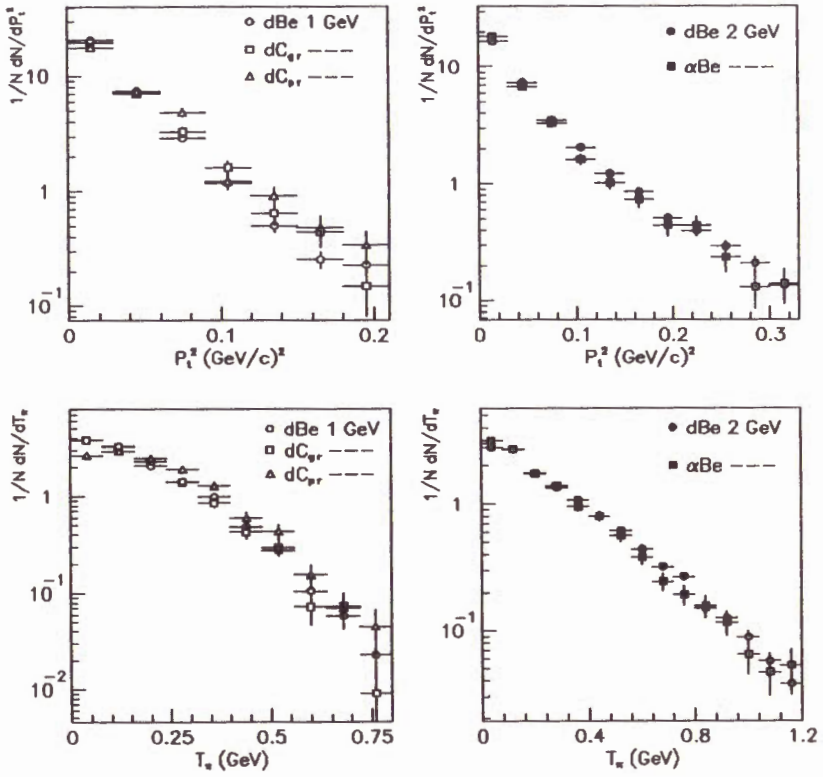

Fig.2. Transverse momentum squared P_t^2 and kinetic energy distributions of π^- (designation as in Fig. 1).

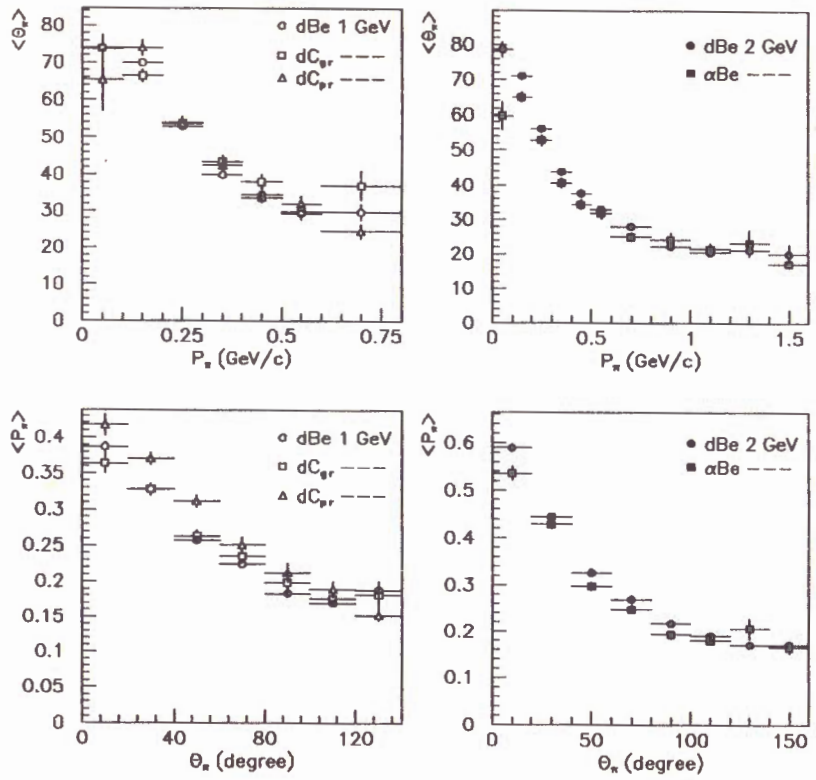

Fig.3. Dependence of the average values of π^- meson emission angle $\langle\theta_{\pi^-}\rangle$ on momentum P_{π^-} and dependence of the average values of π^- meson momentum $\langle P_{\pi^-}\rangle$ on emission angle (designation as in Fig. 1).

Conclusions

The cross sections of inelactic interactions of projectile deuterons and α - particles with different targets (Be,C-extended, propane), the multiplicity of π^- mesons and their kinematic distributions have been measured at beam energies of 1.0, 2.0, 3.3 GeV/nucleon.

1. With increasing deuteron primary energy from 1.0 to 3.3 GeV/nucleon, the energy required for production one negative pion in the propane target decreases only from 24.0 to 21.3 GeV, although the yield of π^- mesons increases from 0.16 up to 0.62. Also there is no energy gain for αC interactions.

2. The DBe reaction at 2 GeV/nucleon is the most preferable one of all the considered reactions.

3. The production energy of one pion decreases with increasing target longitudial size. Thus, for DC interactions at 1.0 Gev/nucleon in propane the increase of the effective volume from 40 cm to 80 cm leads to decreasing the production energy of one pion from 41 GeV to 24 GeV.

4. The present data make it possible to estimate the appropriate length of a target with A-number close to Be or C and indicate that the beam particle should be a deuteron and the beam energy approximately 1.0 - 2.0 GeV/nucleon.

ACKNOWLEDGEMENT

We are very grateful to the personnel of the 2-metre propane bubble chamber and to G.S.Lomachenkova for successful organization of the track measurements. We wish to express our gratitude to the Yerevan group for their participation in data analysis at 1.0 GeV/nucleon and to H.N.Agakishiev, N.S.Grigalashvili, D.Salihagic for their assistance in data handling and to L.N.Barabash for her help in translation.

REFERENCES

1. Gerstein S.S., Petrov Yu.V., Ponomarev L.I., Somov L.N. and Faifman H.P. JETP 51(1981) 1053
   Ponomarev L.I. and Fiorentini G. Muon Catalyzed Fusion 1(1988)3.
2. Viryasov N.M. et al. JINR Communication P1-91-455, Dubna, 1991.
   Cheplakov A.P. et al. Muon Catalyzed Fusion (to be published).
3. Cheplakov A.P. et al. Muon Catalyzed Fusion 4(1989)399.
4. Bekmirzaev R.N. et al. Muon Catalyzed Fusion 3(1988)537.
5. Angelov N. et al. Yad. Fiz. 33(1981) 1046.
6. Akhababyan N. et al. JINR Communication 1-12114, Dubna, 1979.
7. Agakishiev H.N. et al. Yad. Fiz. 40(1984) 1209.
8. Angelov N. et al. JINR Communication 1-2424, Dubna, 1979.
9. Jaros J. et al. Phys.Rev.C (1978) 18, p.2273.

Received by Publishing Department
on July 6, 1992.

Чеплаков А.П. и др.

E1-92-286

Образование π^--мезонов во взаимодействиях дейтронов и α-частиц с углеродной и бериллиевой протяженными мишенями при энергиях 1,0; 2,0 и 3,3 ГэВ на нуклон

Измерены выходы, импульсные и угловые распределения π^--мезонов, образующихся во взаимодействиях дейтронов и α-частиц с энергией 1,0, 2,0 и 3,3 ГэВ на нуклон с углеродной и бериллиевой мишенями длиной около 30 см, помещенными в пропановую пузырьковую камеру. Проводится сравнение в аналогичными данными, полученными на пропановой мишени при энергиях 1,0 и 3,3 ГэВ на нуклон. Определены энергетические затраты на рождение одного π^--мезона в DBe, DC, αBe, αC-взаимодействиях при энергиях 1,0, 2.0 и 3,3 ГэВ на нуклон.

Работа выполнена в Лаборатории сверхвысоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1992

Cheplakov A.P. et al.

E1-92-286

π^- Meson Production in Interactions of Deuterons and α-Particles with the Extended Carbon and Beryllium Targets at 1.0, 2.0 and 3.3 GeV/Nucleon

The yields, momentum and angular distributions of π^- mesons produced in the interaction of deuterons and α-particles at 1.0 and 2.0 GeV/nucleon with thick carbon and beryllium targets have been obtained. The targets (about 30 cm along the beam direction) were placed inside a two-metre propane bubble chamber. The data were compared with those obtained for a propane target at 1.0 and 3.3 GeV/nucleon. The estimate of energy amount needed to produce one negative pion in DBe, Dc, αBe, αC interactions at 1.0, 2.0, 3.3 GeV/nucleon is presented.

The investigation has been performed at the Particle Physics Laboratory, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1992