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# THE DISCOVERY OF RESONANCES IN MULTIBARYON SYSTEMS.

## Part II. $\Lambda\Lambda$ AND $\Lambda\Lambda P$ RESONANCES

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# THE DISCOVERY OF RESONANCES IN MULTIBARYON SYSTEMS.

## Part II. $\Lambda\Lambda$ AND $\Lambda\Lambda P$ RESONANCES

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## Обнаружение резонансов в мультибарионных системах. Часть II . ΛΛ и ΛΛp резонансы

Исследованы спектры эффективности масс ΛΛ и ΛΛp систем при помощи пропановой пузырьковой камеры, облученной $\pi^-$-мезонами при 4,0 ГэВ/с и нейтронами со среднням импульсом 7,0 ГэВ/с.

Обнаружены мультибарионные резонансы ΛΛ и ΛΛp с массами и ширинами $M_{\Lambda\Lambda}$= (2365,3±9,6) МэВ/с$^2$ , $\Gamma$ = (47,2±15,1) МэВ/с$^2$ и $M_{\Lambda\Lambda p}$= = 3568,3 МэВ/с$^2$ , $\Gamma_{\Lambda\Lambda p} <$ 60 МэВ/с$^2$ . Эффективные сечения образования равны соответственно $\sigma_{\Lambda\Lambda}$ (2365)=(24,2±7,0) мкб и $\sigma_{\Lambda\Lambda p}$(3568)=(16,1± ±5,2) мкбн. Обсуждаются возможные механизмы образовання мультибарионных резонансов.

Показано также, что согласно правилу отбора по гиперзаряду $Y \leq 1$ мультибарионные резонансы являются также и сверхплотными, сверхстранными объектами. Спектры эффективных масс ΛΛ и ΛΛp проявляют особенности вблизи масс большинства двух- и трехбарионных резонансов.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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## The Discovery of Resonances in Multibaryon Systems. Part II . ΛΛ and ΛΛp Resonances

The ΛΛ and ΛΛp effective mass spectra reveal enhancements near the most of the resonance masses predicted by MIT Bag Model. Among them strong resonance-like peaks at $M_{\Lambda\Lambda}$ = (2365.3 ± ± 9.6) MeV/c$^2$, $\Gamma$ = (47.2 15.1) MeV/c$^2$ and $M_{\Lambda\Lambda p}$=3568.3 MeV/c$^2$, $\Gamma <$ 60 MeV/c$^2$ have been observed. Possible mechanisms of these di- and tribaryon resonance formation and the statistical significance of the observed peaks have been discussed. The production effective cross sections are estimated to be $\sigma_{pr}$ (2365) = (24.2±7.0)μb and $\sigma_{pr}$ (3568) = (16.1±5.2) μb . According to the hypercharge selection rule multibaryon resonances are shown to be ultra-high density superstrange objects.

The investigation has been performed at the Laboratory of High Energies, JINR.

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## ΛΛ system (Y = 0, I = 0, B = 2, S = -2)

First the ΛΛ system was studied in 1969-1970[1e-j] in events with two Λ- hyperons found in interactions of 4.0 GeV/c negative pions and neutrons of average momentum $\langle p_n \rangle$ = 7.0 GeV/c with carbon $^{12}C$ nuclei. The ΛΛ effective mass spectrum of 57 events is shown in fig.1. The concentration of events near the $2M_\Lambda$ mass changes by a peak at (2291.2 - 2411.2) MeV/c$^2$.

The fitted Breit-Wigner curve has its maximum at the resonance mass of 2365.3 MeV/c$^2$ and a width of $\Gamma$ = (47.2±15.1) MeV/c$^2$. The ΛΛ effective mass resolution in the peak region is equal to $\Delta M$ = (10.0±2.4) MeV/c$^2$, wherease the one averaged over the whole ΛΛ effective mass spectrum is $\langle \Delta M \rangle$ = (22.0±4.0) MeV/c$^2$.

The mass of the presumed ΛΛ resonance, 2365.3 MeV/c$^2$ is very close to the predictions of the MIT Bag Model[2,3], especially to the mass of $J^P = 2^+$, M = 2357 MeV/c$^2$ ΛΛ resonance, predicted by R.L.Jaffe[2].

The maximum of the histogram peak is at 2335.5 MeV/c$^2$. Two main mechanisms, in our opinion, could contribute to the ΛΛ resonance creation.

A. Hyperon-nucleon interactions in the final state $\Lambda N \to \Lambda\Lambda K m\pi$ $\Sigma N \to \Lambda\Lambda K m\pi$ , $\Xi N \to \Lambda\Lambda m\pi$ , m = 0,1,2,... are considered to be a probable source of possible ΛΛ resonances.

Since the lowest threshold for the above three reactions is equal to 2.6 GeV/c, hypothetical resonance systems may have rather large momenta to escape the decay inside the nucleus with subsequent rescattering of decay Λ - hyperons. We tried to imitate the ΛΛ effective mass spectrum by a series of effective mass distributions from the following processes: 1) production of two lambdas in n $^{12}C$ collisions imitated by a sum of phase space volume distributions for several tens of possible reaction channels (dotted histogram in fig.1 normalized to the total weight of the experimental histogram); 2) intranuclear cascade, resulting in different stage two lambdas escaping the nucleus without interaction with nucleons, was imitated by chance combinations of $\Lambda$- hyperons coming from n $^{12}C$ and $\pi\,^{12}C$ interactions, 3) intranuclear cascade resulting in different stage two lambdas or one $\Lambda$ and one $\Sigma$. One of $\Lambda$ or $\Sigma$ is rescattered via the reactions $\Lambda N \to \Lambda N$, $\Lambda N \to \Sigma^o N$, $\Sigma^o \to \Lambda\gamma$, $\Sigma N \to \Lambda p$; 4) direct two $\Lambda$ - production via the reactions $nN \to \Lambda\Lambda KKm\pi$, $m = 1,2,\ldots,6$. The phase space volume histogram of the six last reactions weighted over relative pion multiplicities taken from 57 $\Lambda\Lambda$- events and normalized to the total weight of the $\Lambda\Lambda$ histogram is shown by open circles in fig.1. The intermediate distributions (2) and (3) appeared to be smooth curves of broad maxima far from the peak and also cannot imitate the peak. As was shown earlier/1f-j/, the $\Lambda\Lambda$ peak cannot be imitated by the $\Lambda$p-peaks. The events from the $\Lambda\Lambda$p peak at 3568 MeV/$c^2$ are hatched in fig.1.

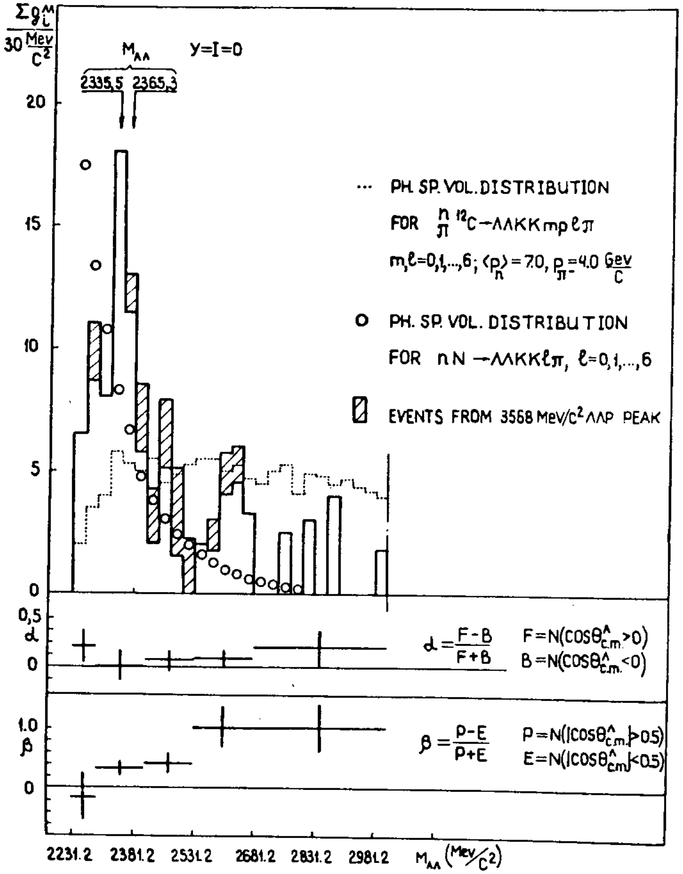

Fig. 1.

The estimation of the statistical significance of the $\Lambda\Lambda$ peak as in the case of $\Lambda$p peaks meets difficulties due to a possible presence of other resonances of close masses predicted by J.J. de Swart and his colleagues/3/. Neglecting them for the present and accepting the dotted histogram as a background, we have for the significance 4.0 s.d. with CL = $2.75 \cdot 10^{-4}$ /4/. But taking into account other possible backgrounds, one can come to 2.2 s.d. According to our estimates, a possible background, due to the intranuclear cascade production of dilambda events, cannot exceed 50% of the whole statistics. This means that for this background the lower limit of the peak significance (four 30 MeV/$c^2$ bins, 2291.2- 2411.2 MeV/$c^2$) is 3.5 s.d. with CL=$1.75 \cdot 10^{-3}$.

In the $K^-$-experiments performed using heavy nuclei/6-8/ according to the mechanism in question $\Xi$ - hyperons may serve as the unique source of the $\Lambda\Lambda$ resonance because the maximal $\Lambda$ - and $\Sigma$ - hyperon momenta appear to be lower than the $\Lambda,\Sigma N \to \Lambda\Lambda Km\pi$ thresholds. Because of the strongly asymmetric emission of $\Xi$ hyperons in the $K^-N$ c.m.s., predominantly in the backward hemisphere with a peak at cos $\theta^* = -1$, they will be rather slow in the laboratory system. This means that a predominant part of $\Lambda\Lambda$ resonances with a high probability will decay inside the heavy nucleus with the following rescattering of at least one of the decay $\Lambda$- hyperons. The failure of observing the $\Lambda\Lambda$ peak in the experiments/6,7,8/ can be thus explained.

Meanwhile, one can notice a concentration of events in a region of (2531.2 - 2681.2) MeV/$c^2$, where two more resonances are predicted/3/: $J^P=2^+$ at 2630 MeV/$c^2$ and $J^P=0^+$ at 2540 MeV/$c^2$.

Thus the $\Lambda\Lambda$ effective mass spectrum in fig.1 reveals enhancements at three of the four predicted/3/ resonance mass values.

B. There should exist a second mechanism which can be either complementary or alternative to the first one depending on experimental conditions. We mean the hyperonization of highly compressed nuclear matter. Such phase transitions are possible in collisions of relativistic particles and nuclei with nuclei. The form and the contribution of the background in this case will substantially differ from the ones estimated above. This means that all above estimates of statistical significance are very conventional and even perhaps incorrect because of our ignorance of the strong interaction theory and the mechanism of multibaryon resonance production. It is more expedient to discuss the details of the compression mechanism in the last subsection.

It is noteworthy that the asymmetry coefficient of $\Lambda$-hyperon emission in the $\Lambda\Lambda$ rest system in the peak region is equal to zero (lower part of fig.1).

We can state that a strong evidence for a $\Lambda\Lambda$ resonance with a mass of $M_{\Lambda\Lambda} = (2365.3 \pm 9.6)$ MeV/$c^2$ and a width of $\Gamma_{\Lambda\Lambda} = (47.2 \pm 15.1)$ MeV/$c^2$ has been found. The production effective cross section of this resonance in $n^{12}C$ collisions at $\langle P_n \rangle = 7.0$ GeV/c is of the same order of magnitude as that of the $\Lambda p$ resonace ( $\sigma_{pr}(2256) = (85.3 \pm 20.0)\ \mu b$ ), namely $\sigma_{pr}(2365) = (24.2 \pm 7.0)\ \mu b$.

## $\Lambda\Lambda p$ system ($Y=1$, $I=\frac{1}{2}$, $B=3$, $S=-2$)

Fifty events from the $\Lambda\Lambda$ statistics, except pions and kaons, contain also from one to four protons giving altogether 79 $\Lambda\Lambda p$ combinations. The $\Lambda\Lambda p$ effective mass spectrum is shown in fig.2.

The hatched area contains the events from the 2365.3 MeV/$c^2$ $\Lambda\Lambda$ peak. The final $\Lambda\Lambda p$ effective mass spectrum without these events is shown on the right-hand side of fig.2. A peak at 3568.3 MeV/$c^2$ of $\Gamma < 60$ MeV/$c^2$ width is observed. We consider this peak as an evidence for a possible tribaryon $\Lambda\Lambda p$ resonance. Its mass is very close to the mass of the predicted at 3570 MeV/$c^2$ tribaryon resonance of $J^P = \frac{5}{2}^+$ spin - parity assignement/3/.

The estimated production effective cross section is of the same order of magnitude as those for $\Lambda p$ and $\Lambda\Lambda$ resonances, $\sigma_{pr}(3568) = (16.1 \pm 5.2)\ \mu b$.

Besides, the spike in the (3369.5-3489.5) MeV/$c^2$ mass region

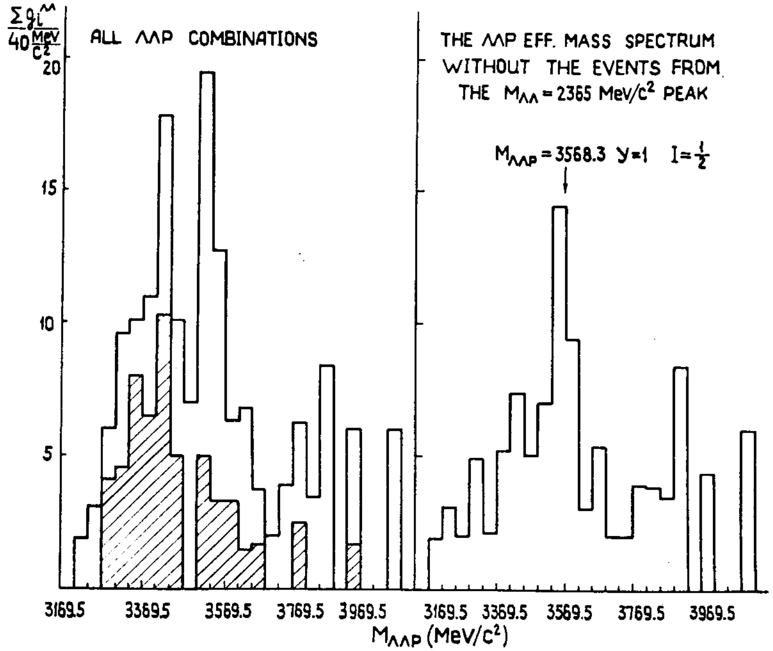

Fig. 2.

perhaps corresponds to the $J^P = \frac{1}{2}^+$ , M=3460 MeV/$c^2$ resonance, the spike in the (3649.5-3689.5) MeV/$c^2$ interval is due to the $J^P = \frac{7}{2}^+$, M=3670 MeV/$c^2$ and $J^P = \frac{3}{2}^+$, M=3680 MeV/$c^2$ resonances and finally the spikes in the (3729.5-3969.5) MeV/$c^2$ region are due to the $J^P = \frac{5}{2}^+$, M= 3750 MeV/$c^2$, $J^P = \frac{1}{2}^+$, M = 3780 MeV/$c^2$ and $J^P = \frac{3}{2}^+$, M = 3930 MeV/$c^2$ resonances/3/.

Thus the $\Lambda\Lambda p$ effective mass spectrum in fig.2 reveals enhancements at seven of the ten predicted/3/ resonance mass values.

## Multibaryon Resonances are Ultra High Density, Superstrange Objects

For the following it is important to clear up possible mechanisms of creation of these resonances. It has been already shown/11/ that adopting the Fermi gas model of the $^{12}C$ nucleus, the 2256 MeV/$c^2$ $\Lambda p$-resonance may be produced in the final state elastic scattering $\Lambda p \rightarrow \Lambda p$. Though the effective cross section of its formation via this channel $\sigma_f(2256) = 5.3\ (2J_{\Lambda p}+1)$ mb/11/ can attain rather high values depending on the resonance spin $J_{\Lambda p}$, its production cross section via $n\,^{12}C$ interactions at $\langle p_n \rangle = 7.0$ GeV/c is only $\sigma_{pr}(2256) = (85.3 \pm 20.0)\ \mu b$.

The 2365 MeV/$c^2$ $\Lambda\Lambda$ - resonance in the frame of the same model may arise in final state inelastic hyperon-nucleon interactions: $\Lambda N \rightarrow \Lambda\Lambda K^{\pm}_{0}\ (m\pi)$, $\Sigma N \rightarrow \Lambda\Lambda K^{\pm}_{0}(m\pi)$, $\Xi^{-} N \rightarrow \Lambda\Lambda(m\pi)$, m = 0, 1, 2, ..., the lowest threshold momentum for incident lambdas being 2.6 GeV/c. The production of this resonance via $n\,^{12}C$ interactions at $\langle p_n \rangle = 7.0$ GeV/c proceeds with an effective cross section of $\sigma_{pr}(2365) = (24.2 \pm 7.0)\ \mu b$.

Finally, the $\Lambda\Lambda p$ production effective cross section in $n\,^{12}C$ collisions at $\langle p_n \rangle = 7.0$ GeV/c is estimated to be $\sigma_{pr}(3568) = (16.1 \pm 5.2)\ \mu b$. Thus, we can state that the $\Lambda p$, $\Lambda\Lambda$ dibaryon and $\Lambda\Lambda p$ tribaryon resonance production effective cross sections via $n\,^{12}C$ collisions at $\langle p_n \rangle = 7.0$ GeV/c differ by less than one order of magnitude.

The Fermi gas model of nuclei cannot ensure the creation of multibaryon resonances with sensible probabilities. Hence a new mechanism should be suggested.

A relativistic particle (or a nucleus) at cp=(8–10) GeV/n penetrating at small impact parameters into a nucleus, even into a light one like $^{12}C$, may produce a rather high compression of nuclear matter in a time interval about an order of magnitude shorter than the mean lifetime of a $\Gamma \sim 10$ MeV/$c^2$ wide multibaryon resonance. The compressed nuclear matter may become a source of secondary particles/9/. If the relativistic nuclear fluid dynamics/10/ were applicable to our case, then the maximal compression would achieve $n/n_0$=14–18, where $n_0$ is the normal nuclear matter density. This would be far enough for a partial hyperonization of the compressed nuclear matter providing thus a small number of dilambda states. Moreover, this possible mechanism could ensure di- and multibaryon, especially multihyperon, resonance formation. If multibaryon resonances could be formed via only two possible mechanisms: nuclear matter compression and final sate hyperon-nucleon resonant interaction, then the possible tribaryon $\Lambda\Lambda p$ resonance would be formed only via the first one, predominantly in central collisions, whereas the $\Lambda p$ and $\Lambda\Lambda$ resonances could be formed via both mechanisms.

The occurrence of a definite mechanism for dibaryon resonance production should depend on the magnitude of the impact parameter occurred in the collision act.

The above remarkable proximity of the di- and tribaryon resonance production effective cross sections proves an important role of the compression mechanism. Most probably, multibaryon resonances ($B > 2$) can be created practically only via this mechanism.

The detection of enhancements at almost all the predicted $\Lambda\Lambda$ and $\Lambda\Lambda p$ resonance mass values/3/, the forms of the $\Lambda\Lambda$ and $\Lambda\Lambda p$ effective mass spectra themselves shown in figs 1 and 2 suggest that the compression mechanism at certain conditions can excite practically only pure resonant multibaryon states with negligibly small contributins of nonresonant background states. The background due to the adjacent resonances attain about 30% of both $\Lambda\Lambda$ 2365.3 MeV/$c^2$ and $\Lambda\Lambda p$ 3568.3 MeV/$c^2$ peaks. The significance of the $\Lambda\Lambda p$ peak is defined then by 4.5 s.d. with C.L.= $6.10^{-5}$, whereas the significance of the $\Lambda\Lambda$ peak is defined by 6.0 s.d. and with C.L. = $1.8 \cdot 10^{-8}$ /4/.

Multibaryon resonances formed via the compression mechanism in light nuclei survive the ultra-high density short lifetime environment and decay if fast enough in free or if slow in a rather rarefied nuclear matter without substantial rescattering of resonance decay products. Thus, multibaryon resonances produced in light nuclei are detectable. In the extreme case of very light nuclei such as deutron or helium, this mechanism should be very improbable. Perhaps, this reason could explain the absence of the 2256 MeV/$c^2$ peak in the $\Lambda p$ spectra from the $K^{-}d$ experiments /11 - 15/ . In the controversial extreme case of heavy nuclei such as Br or Pt the ultra-high density states could exist during the time intervals comparable to multibaryon mean lifetimes. On the other hand, in this case the dimensions or the compressed nuclear matter volume should be larger than in light ($^{12}C$) nuclei. These reasons result in heavy rescattering of resonance decay products smearing out the peaks in the $\Lambda p$ and $\Lambda\Lambda$ spectra from the heavy liquid bubble chamber experiment/5,6,7/ and the $\Lambda\Lambda$ peak from the $K^{-}Pt$ experiment/8/.

The compression mechanism must not seem to be extremely fantastic because if the quark confinement and infrared slavery principles are valid, both a multiquark and a three-quark systems should be confined to a bag of the same volume. This means that a multibaryon resonance should be an ultra-high density and a strange or superstrange ( $|S| > 1$) entity at the same time. And the multibaryon resonance formation via the compression mechanism reduces to the phase transition of the normal density nuclear matter into the ultra-high density superstrange multibaryon hadronic matter revealing itself as a multibaryon resonance.

Thus, we state the following:

1. The formation of all hadronic resonances, including the multibaryon ones, is governed by the hypercharge selection rule /1f-1/: "The hypercharge of hadronic resonances cannot exceed one ($Y \leqslant 1$)".This rule governs the above phase transiton also.

2. The narrowness of the discovered $\Lambda p$, $\Lambda\Lambda$ and $\Lambda\Lambda p$ resonances is a direct experimental demonstration that they are single multibaryon hadron states. But hadron states require the geometrical volume of all hadrons, including the multibaryon resonances ($B > 1$), to be universal constant. The quark confinement, asymptotic freedom and infrared slavery concepts are the manifestations of this fact.

Thus, at the same time multibaryon resonances are ultra-high density, superstrange objects or states of hadronic matter.

The formation of ultra-high density states needs huge external pressures. Ultra-High density states can be formed in Nature in the central regions of galaxies and quasi-stellar objects. Enormous gravitational forces ensure high external pressures which are enough to initiate and maintain phase transitions of the nuclear matter into multibaryon resonant states. Thus, it is very probable that the central regions of these celestial objects are formed of huge multibaryon or even multihyperon resonances, the quasi-stationary states of which are possible up to certain values of the matter density.

The conclusion suggests itself that the hypothetical ultra-high density states of the protostellar matter, brought up by V.A.Ambartsumian/16/ in connection with his cosmogonic concepts, are identical with the huge multibaryon, even multihyperon, resonances which must be strange or even superstrange and of ultra-high density due to the hypercharge selection rule ($Y \leqslant 1$).

In terrestrial conditions, high pressures and compressions of the nuclear matter can be attained bombarding nuclei with relativistic particles and nuclei. The droplets of ultra-high density hadron matter, multibaryon or multihyperon resonances thus obtained, can live at most $10^{-21}$- $10^{-20}$ sec in the absence of corresponding external pressures. Thus, the most direct way to detect ultra-high density states in laboratory conditions is the detection of multibaryon resonances. Other ways seem to be hopeless.

Thus, in our experiment, apart from the discovery of multibaryon resonances, we have succeeded in the observation of ultra-high density superstrange states of hadronic matter.

In conclusion we note that the exciting program of study of multibaryon resonances and ultra-high density superatrange states requires machines, accelerating heavy ions up to tens of GeV/n or even higher energies, because both the hyperon production effective cross sections and the hyperonization via the compression of the nuclear matter increase with the energy of bombarding projectiles.

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## References

1. B.A.Shahbazian et.al., a) Proc. of the 13-th Int.Conf.on High Energy Physics, Berkley, 1966; b) Letters to JETP, 1967, 5, p.307; JINR, P1-3169, Dubna, 1967; c) Proc. of the 14-th Int. Conf.on High Energy Physics, 173, Vienna, 1968; JINR, E1-4022, 1968; d) High Energy Physics and Nuclear Structure, 524,Plennum Press, N.-Y.-L., Sept.8-12, 1968; JINR,E1-4584,Dubna,1969; JINR, Annual Report, 1969; e) Proc. of the 15-th Int.Conf.on High Energy Physics, 187, Kiev, 1970; JINR, Annual Report, 1970; f) Proc. of the Int. Conf. on Elementary Particles, Amsterdam, 1971 (N.H.Amsterdam, 1972); JINR, E1-5935, 1971,Proc. of the 4th Int.Conf. on High Energy Physics and Nuclear Structure, Dubna, 57, 1971; Comm. JINR, P1-6439, Dubna, 1972; g) Proc. of the 16th Int.Conf., 855, Batavia, 1972; JINR, E1-6704, Dubna, 1972; h) Nucl.Phys., 1973, B53, 19; i) Lett. Nuovo Cim., 1973, v.2, p.63; j) FECHAYA, 1973, v.4, vyp.3, p.811; k) JINR, E1-7669, Dubna, 1974; l) Proc. of the 18th Int.Conf. on High Energy Physics, C-35, July, 1976; JINR, E1-10037, 1976.

2. R.L.Jaffe, Phys.Rev.Lett., v.38, No 5, 195; Phys.Rev.Lett., v.38, 617, 1977.
3. A.Th.Aerts, P.J.G.Mulders and J.J. de Swart, Phys.Rev., D17, 260, 1978.
4. B.V.Vinogradov et.al., Preprint JINR, P1-7155, 1973.
5. P.Beilliere et.al., IIHE-76.9.
6. P.Beilliere et.al., Phys.Lett., 39B, 1972, 671.
7. C.Wilquet, Phys.Lett., 57B, 1975, 97.
8. J.G.Guy, J.Kadyk, RL-77-054/A.
9. G.F.Chapline et.al., Phys.Rev., 8D, 4302, 1973; B.A.Shahbazian, P.P.Temnikov,A.A.Timonina, Nuclotron and Relativistic Nuclear Physics, 85, Dubna, 8309, 1974; JINR, P1-8153, Dubna, 1974.
10. A.A.Amsden et.al., LA-UR-31, 1977. Phys.Rev. 17C, 2080, 1978.
11. Tai Ho Tan, Phys.Rev.Lett., 1969, v.23, 395.
12. D.T.Cline et.al., Phys.Rev.Lett., 1968, v.20, 1452.
13. W.Sims et.al., Phys.Rev., 1971, v.3D, 1162.
14. D.Eastwood et.al., Phys.Rev., 1971, v.3, 2603
15. O.Braun et.al., Nucl.Phys., B 124, 1977, No 1, 45.
16. V.A.Ambartsumian, Observatory, v.75, 72, 1955.

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