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OBSERVATION OF CANDIDATES FOR HEAVY POSITIVELY CHARGED $S=-2$ H^{+} DIBARYON WITH A WEAK DECAY CHANNEL $H^{+} \to \Lambda + p + \pi^{0}$

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1 Introduction

At present the existence of S=-2 dibaryons which are stable against strong decays predicted by a number of theoretical models [1-14] is identified in the experiments[15-32]. After Jaffe's MIT bag model prediction, many other studies have been performed by using relativistic quark bag models, Skyrme models, quark cluster models , and lattice QCD. The estimated binding energy of the H particle is model dependent, which is ranging from positive (unbound) to negative strong bound states(-650MeV). The heavy isotriplet stable dibaryon H (I=1, J=0+, Y=0,B=2, S=-2) of a 2370 MeV/c^2 mass is predicted by the soliton Skirme-like model[11,13,14].

The total cross section of H-particle production formulated by the coalescence model is about 2.6μb in Ne+Ne collisions and 0.2μb in p+Ne collisions at a momentum of 5 GeV/nucleon [3]. The calculated Ξ^- hyperon production cross section σ in N+N collisions at p_{lab}=10 GeV/c is equal to 7μb. The experimental cross section of H production is about 5-10 mb in central Si+Au-interactions at a momentum of ≈11 GeV/nucleon(AGS)[17], which is approximately by 10^7 times larger than in pp collisions for this energy:$\sigma(pp \to HK^+K^+)$ ≈1 nb [8].

A reliable identification of the above events needs a multivertex kinematic analysis which is in its turn feasible only by using 4π-detectors and high precision measurements of the sought objects. The 2 m propane bubble chamber is the most suitable instrument for this purpose. The identification of particles was performed by using the well - known methods[32-41].

A few events, detected on the photographs of the JINR 2m propane bubble chamber exposed to a 10 GeV/c proton beam, were interpreted as follows:- one of them as heavy neutral H^0[29](Fig.1) and three - as heavy positively charged H^+ [29-31] stable dibaryons(Table 2)(Figs.2,3).

2 Method

The moderate density (0.41g*$\cdot$ cm^{-3}) and the average charge of propane (Z<10) ensure measurement accuracies sufficient for the reliable inclusive and exclusive multivertex kinematic analysis and identification of exotic events, as well as for successful rejection of background events able to imitate the genuine ones. The fit GRIND -based program GEOFIT[39] is used to measure the kinematic track parameter 1/p,α, β(Fig.5b). This program goes with PBC technique. The magnetic field (B=15.2 kG) measurement error is ΔB/B=1%. The actual measurement in the photographs gives the curvature $\frac{0.3B}{pcos\alpha}$, dip tanα and azimuthal angle β.

Fig.5a shows the length of stopping particles R versus the momentum for π, K, p secondary charged particles in propane, where R is determined versus kinetic energy T as [36,41]:

$$R \approx constT^{1.8} \tag{1}$$

The errors of the run length δR for stopping particles in propane have been estimated as $\sim$ 1%[36].

Experimental ionization is measured by an enlarger (the value of magnification is 30 times). The ionization is determined by the average length of gaps by using the number of gaps($\overline{n}$) larger than D/2(the diameter of blobs) [36, 37, 38]. The average length of gaps is determined by the formula:

$$\overline{n} = 1/\overline{\lambda}\ \exp^{-l/\overline{\lambda}}, \quad at\ \ l \geq l_{min} \geq D\ \ , \tag{2}$$

$$\lambda = \overline{\lambda}\ sec\alpha + D(sec\alpha - 1), \tag{3}$$

$$I\ =\ 1/\lambda,\ \gamma_i = ID_1,\quad D_1 = D + l_{min}, \tag{4}$$

where the statistical errors of ionization from merged bubbles [36, 38] are equal to:

$$(\Delta I/I) = \sqrt{D_1/L}(\sqrt{\frac{e^{\gamma_i}}{\gamma_i}}-2) \mid 1-\gamma_i \mid^{-1} . \tag{5}$$

This method allows one to measure the experimental ionization of the charged tracks with $\sim$ 20% errors that is the sum of statistical and measurement errors.

The conventional BETHE-BLOCH equation gives the rate of energy losses for charged particles[36]:

$$-dE/dX = 4\pi N_0 r_e^2 m_e c^2 (Z/A)\rho(1/\beta^2)z^2[ln(2m_e c^2\beta^2\gamma^2/I_p)-\beta^2-\delta/2], \tag{6}$$

Fig.6 presents a relative experimental ionization behavior determined over a range $\beta\gamma$ <100 by the formula [36]:

$$I = A/\beta^2[B + ln(\beta^2\gamma^2) - \beta^2], \tag{7}$$

$$I/I_0 = [(-dE/dx)_s\ cos(\alpha)]/(-dE/dx)_{beam}, \tag{8}$$

where $\overline{\lambda}$ is the average length of gaps, I- the ionization of secondary charged tracks, I_0- the ionization of beam tracks, L -the track length, l_{min}- a minimal length of gaps, $\overline{n}$- the number of gaps larger than l_{min}, α - the corner of track immersion, N_0 - the Avogadro number, r_e-the classical electron radius, I_p= 50 eV - the ionization potential of the propane medium, ρ - the medium density, Z - the medium charge, A - the atomic number, z the charge of the particle traversing the medium, B $= \ln(2.m_e c^2/I_p) = 9.9$ for propane, and δ - the "density effect" describing the energy losses of high relativistic velocities. The ionization of protons (all particles) at $\beta\gamma \approx$ 2-3 goes through a broad minimum. The ionization is by 1.14 time greater for the beam protons at the momentum of 10 GeV/c at its $\beta\gamma$ =8.4 relative to its minimum value (7). Therefore, the relative ionization of particles is 1.14 times lower in our case, Fig.6a.

The estimate of ionization, the peculiarities of the end track points of stopping particles permitted one to identify them over the following momentum ranges : protons of $0.150 \leq p \leq 0.900$ GeV/c, $\pi^{\pm} of p \leq$ 0.3GeV/c,$K^{\pm} of p \leq$0.6, Ξ^- of p$\leq$ 1.5 GeV/c and deuterons of p$\leq$ 2.0 GeV/c.

The smallest value of the momentum error was 2%, where the permissible limit was about 30%. The average value of measurement errors for the momentum was equal to 10%. The mean values of measurement errors for the dip and azimuthal angles were relatively equal to $< \Delta tg\alpha >= 0.0099 \pm 0.0002$ and $< \Delta\beta >= 0.0052 \pm 0.0001$ (rad.).

3 Identification of V^0

V^0 events were identified using the following criteria: 1)two-prong stars from the photographs were selected according to $\Lambda \to \pi^- + p$ and neutral $K_s \to \pi^- + \pi^+$;

2)two-prong stars should have the effective mass of K_s^0 and Λ;

3) these V^0 events are directed to some vertices(complanarity);

4) they should have one-one vertex, three - constraint fit the hypotheses with M_K, M_Λ $\chi^2 < 15$[34-39] and a momentum limit of K_s^0 and Λ greater than 0.2 GeV/c.

The method of Lagrangian multipliers α is used by the GEOFIT-GRIND program to calculate χ^2:

$$\chi^2 = (m-m^0)^T\, G_m(m-m^0) \,+\, 2\alpha^T f(m,y) = minimum. \qquad (9)$$

To visualize what it means, we rewrite χ^2 in the indexed notation neglecting the correlations for the moment, i.e. preserving the diagonal elements of G_m:

$$\chi^2 = \sum_{i=1}^{4} \frac{(m_i - m_i^0)^2}{\sigma_i^2} + \sum_{k=1}^{3} \alpha_k f_k(a, y) = minimum. \quad (10)$$

To identify the decays from V^0 particles, the following f_k vector of constraints is used, where the momentum p_0 of V^0 is unmeasured (1 vertex 3C fit):

$$f_1 = p_0 cos\beta_0 cos\alpha_0 - \sum_{i=1}^{2} p_i cos\beta_i \cos\alpha_i = 0,)$$

$$f_2 = p_0 sin\beta_0 cos\alpha_0 - \sum_{i=1}^{2} p_i sin\beta_i \cos\alpha_i = 0,$$

$$f_3 = p_0 tg\alpha_0 cos\alpha_0 - \sum_{i=1}^{2} p_i tg\alpha_i \cos\alpha_i = 0, \quad (11)$$

$$cos\alpha_{0,i} = 1/\sqrt{1 + tg^2\alpha_{0,i}},$$

$$f_4 = \sqrt{m_0^2 + p_0^2} - \sqrt{m_1^2 + p_1^2} - \sqrt{m_2^2 + p_2^2} = 0.$$

Here m^0 and m are the vectors of the measured and corrected parameters after fitting, y-s are the unmeasured parameters, G_m is the error matrix for m,m_0 is the mass of V^0 particle decaying into 2 other particles whose masses and momenta are m_1, p_1 and m_2, p_2, respectively; α_0, α_i and β_0, β_i are the dip and azimuthal angles for V^0 particles(α_0, β_0) and particles after decays (α_i, β_i), respectively.

The lifetimes of Λ and K^0 are estimated by the maximum likelihood method using the Bartlett S-function[34,40]. The lifetimes obtained by this method are in good agreement with the tabular data[34].

As a 4π detector, the weight w of V^0 events is determined by the formula:

$$W = 1/w, \quad w(p, \phi) = \frac{1}{2\pi} \int_0^{2\pi} \int_{l_{min}(\Psi,\phi)}^{l(\Psi,\phi)} \frac{1}{v\tau} e^{-l/v\tau} dl d\Psi \sim e^{-l_{min}/v\tau} - e^{-l/v\tau}, \quad (12)$$

where w is the decay of the V^0 registration probability, Ψ- the azimuthal angle V^0, ϕ- the emission angle of V^0, l_{min} a minimum necessary length for the V^0 registration, l- the observed run length in the chamber, $v = \beta c$-velocity, $\tau = \gamma\tau_0$ the lifetime data of V^0,τ_0 - the lifetime from the particle data book[15]. The average geometrical weight w for Λ registration from beam proton interactions is equal to $\approx$ 1.8.

The experimental events with V^0 strange particles of more than 700000(two parts of the chamber) photographs (or 336*2 tapes) are still being collected. The total number of events in two parts of the chamber from the primary beam protons ($\sim$5.2) , secondary neutral and charged particles ($\sim$ 5.4) is equal to $\sim$ 10.6. Table 1 presents (67% of all experimental events) the number of V^0 events produced in different types of interactions without weights for: a) primary beam protons, b)secondary charged particles and c)secondary neutral particles.

Figs.7a,b and 7c,d show the mass distribution of Λ,K^0 particles and their χ^2 kinematic fits, respectively, produced from the beam protons interacting with propane targets. The measured masses of these events have the following Gaussian distribution parameters $< M(K_s) >=$ 497.7, s.d.= 23.9 MeV/c^2 and $< M(\Lambda) >$ =1117.0, s.d.=10.0 MeV/c^2.

The cross section for the reaction p$^{12}C \rightarrow \Lambda X$ measured with the same method gives $\sigma_\Lambda = (1.3 \pm 0.5)$ mb[33] at a beam momentum of 4.75 GeV/c. The preliminary estimate of the experimental total cross sections for Λ production in the p^{12}C collisions at 10 GeV/c is σ_Λ= 6.0$\pm$1.5 mb.

Several Ξ^- hyperons in Table 3(29% of all experimental events) were identified by the same method in these collisions. The preliminary average minimal geometrical weight for Ξ^- production from the beam proton p+C_3H_8 interactions is equal to w_{min} $\approx$2.2. Therefore, the preliminary cross section including the above weights is equal to $\approx$ 19.6 $\pm$ 11.4μb. Fig.4 shows two events identified as a Ξ^- hyperon. Similarly, the formally estimated effective cross section for H^+ dibaryon production in the pC_3H_8 interactions at a momentum of 10 GeV/c is $>$ 0.6 μb.

4 Identification of $\Xi^- \rightarrow \pi^-\Lambda$

The candidates for Ξ^- dibaryons were observed in the sample of the so called one-negative-prong secondary events imitating a weak decay $\Xi^- \rightarrow \Lambda + \pi^-$. In these events, Λ - hyperons are directed to the vertices of one-negative-prong stars, produced by negative charged particles. 18 events were selected by the above samples from 29% of the experimental material. Five from these events were identified by using the kinematic (1V-2C)fits on the decay channel hypothesis $\Xi^- \rightarrow \Lambda + \pi^-$ (Table 3). The data of invariant masses are presented by the decay channel $\pi^-\Lambda$ on the same Table 3, too.

The first detected event (Fig.4a) is formed by the beam proton producing a twelve prong star. The appearance of first part of track, 4.64 cm long, with relative ionization $I/I_0 \approx 2$, suggests that it is due to a stopping, heavily ionizing, positively charged and more massive particle than the π^- .

After break of the second part of the track is identified as π^- 24.4 in length and a momentum of (217.0±21.4)MeV/c.

A V^0-particle 2.15 cm long is clearly seen near the star. Note that no interactions are seen in this photograph which could serve as potential V^0 emission vertices. The proton of $P_p = 642.7 \pm 15.2 MeV/c$ and the negative pion $P_{\pi^-} = 92.2 \pm 33.0 MeV/c$, which stops in propane, are particle decay tracks. Indeed, the invariant mass of the (p, π^-) pair is $1112.4 \pm 8.5 MeV/c^2$. Thus, the V^0 can be interpreted only as a weak decay of a Λ^0 hyperon. The hypothesis of emission of this hyperon from primary interactions fails because the fit of the hypothesis gives C.L.=0. The hypothesis of Λ-hyperon emission from the vertex kink fits well the event with χ^2(1V-3C) = 1.9, C.L.=64%, P_Λ =734.2±33.1 MeV/c, $\Delta p^\perp = 20 \pm 23 MeV/c, \eta$=0.054 rad.. There is complanarity with vector p_Ξ and the plane from vectors p_{π^-}, p_Λ, where $\Delta p^\perp$ = (-6.9 ± 12.5) MeV/c, η=0.010 rad..

The hypothesis of the inclusive two-body weak decay $\Xi^- \to \pi^- + \Lambda^0$, $\Lambda \to p + \pi^-$ fits the event with χ^2 (2V-5C)=0.46, CL=99.8 %, M_{Ξ^-}=1313±7.7 MeV/c^2, p_{Ξ^-}= (903.5±36.6) MeV/c.

There was no successful one or two-vertex fits for other reaction sequences given in Table 4.

5 Identification of H^+

5.1 The search for H^+

The candidates for H^+ dibaryons were observed in the sample of the so-called one-positive-prong secondary events imitating a weak decay $H^+ \to p + \Lambda^0 + \pi^0$. The dibaryons as V^0 were identified via a multivertex kinematic by analysis using the CERN program GRIND. The result for neutral and positively charged events has been published [28-32]. The first success event was interpreted as a heavy neutral stable S=-2 dibaryon H^0 produced from a two-prong star from the parent interactions of primary 10 GeV/c beam protons $p+^{12}C_3H_8 \to H^0 + K_1^+ + K^+ + M^0$, $H^0 \to p\Sigma^-, K_1^+ \to \mu^+\nu$(Fig.1). Only the sequnces of process $H^0 \to p\Sigma^-, \Sigma^- \to n\pi^-$fits the event with $\chi^2(2V - 3C)$ =3.05, C.L.= 38.4%, M_H = (2385±31.0) MeV/c^2. It should be stressed that the mass of heavy positive H^+ dibaryon was found to be $\approx$ $2370 MeV/c^2$ according to the predictions of the Skyrme-likes model and from identification of the neutral heavy H^0. The search for H^+ dibaryon candidates was continued in the above sample, and two events were registered.

There are approximately 2450 positive-prong stars from secondary positive charged particles with Λ, $\Lambda(K_s^0)$ selected from all the experimental events in 700000 pictures or 3.5 10^6 stars. Fig.8a shows the effective mass distribution for Λ combination with all positive charged particles from the secondary positive prong stars. To select the events from the above samples, the following criteria were used:
1) approximately 380 one-positive-prong secondary events with Λ, $\Lambda(K_s^0)$ particles ;
2)115 events identified by the hypothesis as protons or relativistic particles after the track break (Fig.8b);
3) 20 events with unsuccessful fits for the background hypothesis (1-8) possibly miming these weak decays are presented in the Table 9;
4) 8 events of heavily ionizing, positively charged and more massive (than the proton) secondary particles before break;
5)3 events with successful fits for the dibaryon hypothesis possibly miming weak decays.

5.2 The background from accidental coincidence events selected in the above samples

We have estimated the probability of accidental coincidences by the $H^+ \to p + \Lambda^0$ samples at average loading from the beam protons in the chamber. There were $\approx$ 2% (negligible quantity) of pictures from the chamber with overload from beam protons. The probability of accidental coincidences means that neutral two- prong stars per one stereo picture have the effective mass of Λ which is directed to a kink of the positively charged track, identified by the hypothesis as a relativistic particle or a proton. This probability w= $w_1w_2w_3w_4w_5w_6 < 10^{-7}$. What kind of probability per one picture is included in the expression of the value for

w? They are the following:
w_1 are the neutral two-prong stars as V^0;
w_2 - positively charged tracks before the kink identified by the hypothesis as a relativistic particle or a proton or a particle heavier than proton;
w_3 - V^0 point to some stars(complanarity) accidental;
w_4- the stars; w_5 - V^0 with the Λ mass accidental;
w_6 - positively charged tracks after the kink identified by the hypothesis as a proton or a relativistic particle.

5.3 The second event registrated as H^+

The second detected event (Fig.2,[30]) was produced from an eight-prong star in beam proton collisions with propane. The appearance of its first part, 21.85 cm long, with $P_{H^+} = (1.63 \pm 0.27)$GeV/c and average relative ionization I/I_0=2.06±0.44 (Table 5) suggests that it is due to a relativistic, heavily ionizing, positively charged and more massive (than the proton) particle. Table 6 shows that this ionization allows one to select only two H^+ or deuteron hypotheses of five possibilities which can imitate this track.

The second part is certainly due to a slow thick track identified as a proton 5.cm long, with a momentum of (297.7±17.6)MeV/c which stops in propane. It may be also interpreted as a decay $\Sigma^+ \to p + \pi^0$ with a probability of 12 % because there is a kink at the end of the track.

A V^0-particle is clearly seen near the star 0.53 cm long. Note that no interactions are seen in this photograph which could serve as potential V^0 emission vertices. The proton of $P_p = 768.7 \pm 11.6\ MeV/c$ (with ionization ≈ 2) and the negative pion of $P_{\pi^-} = 196.1 \pm 25.0 MeV/c$ are particle decay tracks. Thus, the V^0 can be only due to a weak Λ^0 hyperon decay. Indeed, the invariant mass of the (p, π^-) pair is 1108.9±6.3MeV/c^2. The hypothesis of emission of this hyperon from primary interactions fails because the fit of the hypothesis gives $\chi^2 = 967$. This negative result is due to a large noncomplanarity angle η=0.473 rad. or $\Delta p^\perp$ =-249± 50 MeV/c. Contrary to this, the hypothesis of Λ-hyperon emission from the kink vertex fits well the event with χ^2(1V-3C) = 1.2, C.L.=71%,P_{Λ^0} =928±93 MeV/c, η=0.016rad. and $\Delta p^\perp$ =37±34 MeV/c.

The hypothesis of the two-body weak decay $H^+ \to p + \Lambda$ did not fit. The first success hypothesis of the inclusive three-body weak decay $H^+ \to p + \pi^0 + \Lambda^0$, $\Lambda \to p + \pi^-$ fits the event with $\chi^2(2V - 3C) = 1.95, CL = 86\%, M_{H^+} = 2580 \pm 108 MeV/c^2$.

The second hypothesis of $H^+n \to \Sigma^+\Lambda^0 n$, $\Lambda \to p\pi^-$ is also probable with the best fits $\chi^2(2V-3C)=0.11, C.L.=99\%, and M_{H^+}=2410\pm90$ MeV/c^2. There is a track after the Λ (Fig.2) identified as a stopping proton 17.3 cm long and a momentum of (455.4±9.4)MeV/c. The one-positive-prong star is formed from a neutral particle. Thus, the kinematic parameter of the reaction $np \to pn$ was determined with fits χ^2 =0.09 and C.L. = 99%. Then, the hypothesis of $H^+n \to \Sigma^+\Lambda^0$ n with a kinematic parameter of this neutron is probable with χ^2(1V-3C)=0.15,C.L.= 98%, and M_{H^+}=(2425±29MeV/c^2. Taking into account the probability for Σ^+ hypothesis by length and by decay mode to $p\pi^0$, we have obtained the sum C.L. $\approx$ 6% for the reaction $H^+n \to \Sigma^+\Lambda^0$ n. The other kinematic fit including the above stopping proton does not allow to use d^2 imitating a one-prong-positive star with the $p(d^2)n \to \; pn\pi^0, \; nn \to \pi^-pn, np \to pn$ hypothesis.

The kinematic fit of reaction with the Σ^+ hypothesis is allowed to imitating the events with maximal probability $3.5*10^{-4}$. The probability of relative ionization with this hypothesis is equal to $\approx\; 1.8*10^{-2}$. The Σ^+ has an average run of 3.1 cm for the 1.53 GeV/c momentum and, so, the probability is equal to $8.3*10^{-4}$ for 21.8 cm long. So, the reaction with Σ is forbidden with the total of the above applied probabilities that is smaller than 10^{-9} (Table 9).

The results of fitting with the program GRIND for reaction sequences which are able to imitate weak H^+ dibaryon decays are presented in Table 9. So, the deuteron is a basic particle which can imitate this reaction. Therefore, this hypothesis was studied in detail. The kinematic threshold does not allow one to imitate the reaction with deuteron d_2^+ at a momentum of 0.780 GeV/c per nucleon without fermi motion(Table 9).

Now, let us examine a possibility of imitating the reaction with the d_2^+ hypothesis including fermi motion in deuteron. Fig.8c shows the fermi momentum distribution for nucleons in the deuteron with the Gartenhaus - Moravcik potential. The limit for fermi momentum is taken over a range of 3 standard deviations (250 MeV/c). Fig 8d gives the total momentum distribution of nucleons in the laboratory system obtained from the sum of their momentum with errors (Gaussian distribution) and fermi nucleon momentum in the deuteron. The maximum nucleon momentum is 1.2 GeV/c per nucleon (with prob.$< 10^{-3}$) and its average momentum (887.5±83.2)MeV/c(Fig.8).

A simple calculation of conservation energy laws does not allow the reaction with $p(d_2^+)n \rightarrow\ pnand\ nn \rightarrow \pi^- pn$, to be imitated at the momentum primary protons of 1.2 GeV/c. For the quasi elastic reaction p(d_2)n $\rightarrow$ pn, the 1V-3C fit gives χ^2 =3.6, prob.=16% at the emitted neutron momentum of p_n=(0.53±0.03) GeV/c. The minimum necessary momentum of the primary neutron for the second vertex nn$\rightarrow \pi^-$ pn is equal to 1.1 GeV/c. Therefore, the fit 2V-4C is not for reaction sequences $p(d_2^+)n \rightarrow\ pn\ and\ nn \rightarrow \pi^- pn$.

The $p(d^2)n \rightarrow\ pn\pi^0,\ nn \rightarrow \pi^- pn$ hypothesis is impossible because a primary proton having a maximum momentum of 1.2 GeV/c does not give the kinematic fit by momentum to: a 0.3 GeV/c proton, a 1.1 GeV/c or greater than this momentum of neutron (1.1 GeV/c - minimum momentum threshold of the 2nd vertex) and a π^0-meson of any momentum.

The simulation reaction: p(d^2) + ^{12}C $\rightarrow$ neutron+x at a maximum momentum of 1.2 GeV/c using the model FRITIOF includes fermi motion in carbon (Fig.9a). The probability of primary protons at a momentum of 1.2 GeV/c per nucleon is $< 10^{-3}$(Fig.8b). Then one the cut of the momentum of event after the kink of track was used. The momentum distribution of the neutron in Fig.9b shows, the probability of neutrons of this reaction yield is greater than the threshold of momentum only for the 2 vertices (p$^{thresh} > 1.100 MeV/c$) and is equal to $< 10^{-4}$. Thus, the total probability of imitation is smaller than 10^{-7}.

The process with a stripping proton from d^2 cannot be imitated because: there is noncomplanarity with vectors $p_{H^+}$and $p_p p_\Lambda$ (it is $sin\mu$=0.2); a 84^0 angle between $p_p^\wedge p\Lambda$; and the difference of transverse momentum $\Delta P^\perp$ between the vector p_{H^+} and the sum $p_p p_\Lambda$ is equal to (222.1± 21.7)MeV/c.

5.4 The third event registrated as H^+

The third event detected in the same sample (Fig.3) is produced from the beam range. The appearance of its first part, 52.8 cm long, with a momentum of $P_{H^+} = (1.56 \pm 0.12)$GeV/c and average relative ionization $I/I_0 \approx 2.23 \pm 0.51$(Table 7)suggests that it is due to a relativistic, heavily ionizing, positively charged and more massive (than the proton) particle. Table 8 shows that this ionization allows one to select only two H^+ or deuteron hypotheses of five possibilities which can imitate this track.

The second part is due to the proton 33.95 c.m. long, with P_p =

(942.8 ± 75.6)MeV/c and relative ionization $I/I_0 \approx 1.56 \pm 0.32$.

A V^0-particle is clearly seen near the star 2.6 cm long. Note that no interactions are seen in this photograph which could serve as potential V^0 emission vertices. The stoping proton of $P_p = 446.0 \pm 9.0\ MeV/c$ and the negative pion $P_{\pi^-} = 166.1 \pm 33.0\ MeV/c$ are decay particle tracks. Thus, the V^0 can be only due to a weak a Λ^0 decay. Indeed, the invariant mass of the (p, π^-) pair is $1120.9 \pm 12.9 MeV/c^2$. The hypothesis of Λ-hyperon emission from the kink vertex fits well the event with χ^2(1V-3C) = 1.9, C.L.=60%, P_{Λ^0} =$542.3 \pm 9.0 MeV/c, \Delta p^{\perp} = 6 \pm 20 MeV/c, and \eta = 0.017 rad$.

The hypothesis of the exclusive two-body weak decay $H^+ \to p + \Lambda$ does not fit. The hypothesis of the inclusive three-body weak decay $H^+ \to p + \gamma + \Lambda^0$, $\Lambda \to p + \pi^-$ fits the event with $\chi^2(2V - 3C) = 2.85, C.L. = 73\%, and M_{H^+} = 2448 \pm 47 MeV/c^2$. The $H^+ \to p\pi^0\Lambda^0, \Lambda^0 \to p\pi^-$ hypothesis fits the same event with $\chi^2(2V - 3C) = 2.86, C.L. = 72\%, and M_{H^+} = 2488 \pm 48 MeV/c^2$.

The kinematic fit of the reaction with the Σ hypothesis is allowed to imitate the registrated event with the maximum C.L. 67%. But the reaction with Σ is forbidden because the Σ^+ average run is 3.0 cm for a 1.46 GeV/c momentum and, so, the probability P< $1.15 * 10^{-8}$ for the length of 52.8 cm. The possibility of imitating the reactions with the Σ^+ hypothesis for the observed event by the reactions is presented in Table 9.

The kinematic threshold does not permit imitating the reaction with d_2^+ deuteron including fermi motion. We have the same momentum distribution for nucleons with fermi motion in the deuteron as in the previous event. A simple calculation by conservation energy laws does not permit the reaction with $p(d_2^+)n \to\ pn,\ nn \to \pi^- pn$ to be imitated. The 1V-3C kinematic does not allow the fit for quasi-elastic scattering hypothesis for the first vertex $p(d_2^+)n \to\ pn$, because the angle between $p^\wedge n$ is much smaller than 90^0 and equal to 53^0.

The $p(d^2)n \to\ pn\pi^0,\ nn \to \pi^- pn$ hypothesis is impossible, too. The $nn \to \pi^-$ pn hypothesis for the second vertex gives 1V-1C fits with χ^2=1.7, C.L.=25% and the emitted neutron momentum of p_n=0.367 GeV/c . Thus minimum necessary momentum of the projectile neutron for the second vertex $nn \to \pi^-$ pn is equal to 0.900 GeV/c. Primary proton having a maximum momentum of 1.2 GeV/c does not give the kinematic fit for the first vertex by the momentum to: a 0.943 GeV/c proton, $\geq$ a 0.900 GeV/c neutron (minimum momentum threshold of the 2-nd vertex) and a π^0-meson of any momentum.

Then the simulation reaction p(d^2) + $^{12}C \rightarrow$ neutron x at the maximum momentum 1.2 GeV/c using the model FRITIOF with including fermi motion in carbons, too (Fig.9a). The probability of primary protons at a momentum of 1.2 GeV/c for first vertex is $< 10^{-3}$(Fig.8b). Then one the cut of the momentum of event after the kink of track was used. Fig.9c shows, that the momentum distribution of emitted neutrons of this reaction yield is greater than the threshold momentum of reaction for the second vertex ($p^{thresh} > 900 MeV/c$) which is equal to $< 10^{-4}$. Thus, the sum probability of imitation is less than 10^{-7}.

The process with a stripping proton from d^2 cannot be imitated because: there is noncomplanarity with vectors $p_{H^+}$and $p_p p_\Lambda$(it is $sin\mu$=0.2), a 53^0 angle between $p_p^\wedge p\Lambda$ and the difference of transverse momentum $\Delta P^\perp$ between the vector p_{H^+} and the sum $p_p p_\Lambda$ is equal to (247.1$\pm$ 37.3)MeV/c.

6 Conclusion

The observed two events are interpreted as a S=-2 positively charged heavy **H⁺-dibaryon**, in the photographs of the JINR 2m propane bubble chamber exposed to a 10 GeV/c proton beam(Table 2). The background from accidental coincidence events selected by the $H^+ \rightarrow p + \Lambda^0 + \pi^0$ samples at average loading from beam protons in the chamber is less than w$< 10^{-7}$. There were no successful fits for other reaction sequences in Table 9. The preliminary total cross section of Λ production in p^{12}C collisions at 10 GeV/c is $\sigma_\Lambda \approx$ 6.0$\pm$1.5 mb. The same method has identified Ξ^- hyperons with the preliminary cross section of $\approx$ 19.6 $\pm$ 11.4μb in p+C_3H_8 interactions. The formal estimated effective cross section for H^+ dibaryon production in p + C_3H_8 interactions at a momentum of 10 GeV/c is greater than 0.6 μb. The average life time $\tau_{H^+} \approx 10^{-9}$ s. We have been convinced once again that the identification of H particles needs a much more information about tracks and a multivertex kinematic analysis because it makes possible to cut off a lot of background processes.

Table 1:The amount (67%) of V^0 events from interactions of different types which were registrated on photographs with propane bubble chambers method.

Chanel	The amount events from interactions.: primary beam protons	sec. charged particles	sec. neutral particles	Total events
$\to \Lambda(only)x$	4304	2174	913	7391
$\to K_s^0(only)x$	3473	1378	453	5304
$\to (\Lambda$ and $K_s^0)$ x	975	282	120	1377

Table 2: Mass and weak decay channels for the registration of dibaryons (* - new result).

Channel of decay	Mass H (MeV/c^2) Dibaryon	C.L. of fit %	references
$H^0 \to \Sigma^- p, \Sigma^- \to n\pi^-$	2385 ± 31	34	[29]
$H^+ \to p\pi^0\Lambda^0, \Lambda^0 \to p\pi^-$	2376 ± 10	87	[29]
$H^+ \to p\pi^0\Lambda^0, \Lambda^0 \to p\pi^-$	2580 ± 108	86	[30,31]
$H^+ n \to \Sigma^+\Lambda^0\ n, \Lambda^0 \to p\pi^-$	2410 ± 90	6	-.-
$H^+ \to p\gamma\Lambda^0, \Lambda^0 \to p\pi^-$	2448 ± 47	73	*
$H^+ \to p\pi^0\Lambda^0, \Lambda^0 \to p\pi^-$	2488 ± 48	72	-.-

Table 3:Mass and a momentum Ξ hyperon is determined by weak decay channels of $\to \pi^-\Lambda$.

N	Momentum of Ξ^- GeV/c	$M_{\pi^- p}$ invariant mass of Ξ^- (GeV/c^2)	Mass of Ξ^- with fits (GeV/c^2)	C.L. One vertex fit%
1	0.902±0.037	1.312±0.009	1.313±0.008	89.2(1V-2C)
2	0.973±0.038	1.316±0.008	1.315±0.007	96.0(1V-2C)
3	1.320±0.055	1.315±0.006	1.321±0.009	75.3(1V-2C)
4	1.298±0.038	1.313±0.007	1.323±0.008	29.8(1V-2C)
5	2.777±0.335	1.315±0.006	1.398±0.023	6.9(1V-2C)

Table 4: Sequences of strong reactions and weak decays presumed to be able to imitate weak decays for the candidates S=-2 Ξ^- hyperon by channel $\Xi^- \to \pi^- + \Lambda$.

Process sequences	C.L. for the one- or two-vertex fits for events
$\pi^- + n \to \pi^- + \Lambda + K^0$	no fit(1V-1C)
$\pi^- + n \to \pi^- + n, n + n \to \pi^- + p + n$	no fit(2V-6C)
$K^- + n \to \pi^- + Y^0$	no fit(1V-1C)
$K^- + n \to \pi^- + \Lambda$	no fit(1V-2C)
$K^- + 2n \to \pi^- + \Lambda + n$	no fit(1V-1C)
$\overline{p} + n \to \pi^- + \pi^0, \pi^0 + n \to \pi^- + p$	no fit(2V-6C)
$K^- \to \pi^- + \pi^0, \pi^0 + n \to \pi^- + p$	no fit(2V-6C)
$\Sigma^- \to \pi^- + n, n + n \to \pi^- + p + n$	no fit(2V-6C)
$\Sigma^- + n \to \pi^- + \Lambda + n$	no fit(1V-1C)

Table 5: Measurements of experimental ionization with magnifying enlarger (the value of magnification is 30 times).

Type of track	Length of tracks L(mm)	Number of gaps	Minimal length of gaps(mm)	$1/\lambda$ exp. ion. (mm^{-1})	ΔI/I exp. error
Primary proton	445.0	62	1.00	0.50	0.06
Secondary track for the H^+ hyp.	551.0	45	1.30	1.03	0.14

Table 6: Estimate of imitation for different ionization hypothesis of secondary track before a break (H^+ hypothesis). Experimental estimate of ionization equal to I_{H+}/I_{beam}= 2.06±0.44.

No	Type of Hypoth.	Momentum (GeV/c)	I_{H+}/I_{beam} Bethe-Bloch	$\chi^2/1(d.f.)$
1	H^+	1.63±0.26	2.03	0.5
2	$D+$	1.56±0.20	1.61	1.2
4	Σ^+	1.53±0.20	1.14	5.0
5	$p+$	1.53±0.16	1.01	6.6
6	K^+	1.52± 0.14	0.90	8.0
7	π^+	1.52± 0.14	1.00	6.8

Table 7: Mesurements of experimental ionization with magnifying enlarger (the value of magnification is 30 times).

Type of track	Length of tracks L(mm)	Number of gaps	Minimal length of gaps(mm)	$1/\lambda)$ exp. ion. $(mm^{-1}$	$\Delta I/I$ exp. error
Primary beam proton	1424	171	1.3	0.86	0.12
Secondary track for the H^+ hypothesis	1273	58	1.9	1.92	0.18
Secondary track after break for the proton hypothesis	801	20	1.8	1.23	0.18

Table 8: Estimate of immitation for different ionization hypothesis secondary track before break(on H^+ hypothes). Estimate experimental measurement ionization equal to I_{H+}/I_{beam}= 2.23±0.51.

No	Type of Hypoth.	Momentum (GeV/c)	I_{track}/I_{beam} cal. with Bethe-Bloch	$\chi^2/1(d.f.)$
1	H^+	1.56± 0.12	2.22	0.0
2	d^+	1.52± 0.11	1.73	1.0
3	Σ^+	1.46± 0.09	1.17	4.3
4	p	1.46± 0.09	1.07	5.2
5	K^+	1.45± 0.14	0.90	6.8
6	π^+	1.45± 0.14	1.00	5.8

Table 9: Sequences of strong reactions and weak decays presumed to be able to imitate weak decays for the fourth and the fifth candidates for H^+ stable S=-2 dibaryon. The value of C.L. equal to 0 means that it is less than 10^{-7}. The threshold value of energy for these two events changed negligible.

N	Process sequences	S.M. Energy of reaction (GeV)	Thresh. energy for channel	C.L. for the 2-vertex fits 2, 3-th events
1	pn $\to pK^0\Lambda$	2.1	2.6	0. (2V-4C)
2	$\to nK^+\Lambda$	-.-	-.-	0. (2V-4C)
3	$\to pK^{*0}\Lambda$	-.-	≥ 2.6	0. (2V-3C)
4	$\to p\pi^0 n, nn \to np\pi^-$	-.-	2.0	0. (2V-2C)
5	$\to pn, nn \to np\pi^-$	-.-	1.9	0. (2V-4C)
6	$K^+n \to K^+\Lambda K^0$	2.0	2.1	0. (2V-4C)
7	$\to K^+n, nn \to np\pi^-$	-.-	1.4	0. (2V-4C)
8	$\to K^+n\pi^0, nn \to np\pi^-$	-.-	1.6	0. (2V-2C)
9	Σ^+n$\to p\Lambda$	2.4	2.1	0.(2V-7C)
10	$\to p\pi^0\Lambda$	-.-	2.2	0. (2V-4C)
11	$\to p\gamma\Lambda$	-.-	2.2	0. (2V-4C)
12	$\Sigma^+2n \to p\Lambda n$	3.5	3.0	0.(2V-4C)
13	$p(d^+)n \to pn, nn \to np\pi^-$	2.01	1.88	0.(2V-4C)
14	$\to pn\pi^0, nn \to np\pi^-$	2.01	2.01	0.(2V-2C)
	With Fermi motion			
15	$p(d^+)n \to pn, nn \to np\pi^-$	2.05	1.88	0.(2V-4C)
16	$\to pn\pi^0, nn \to np\pi^-$	2.05	2.01	0.(2V-2C)

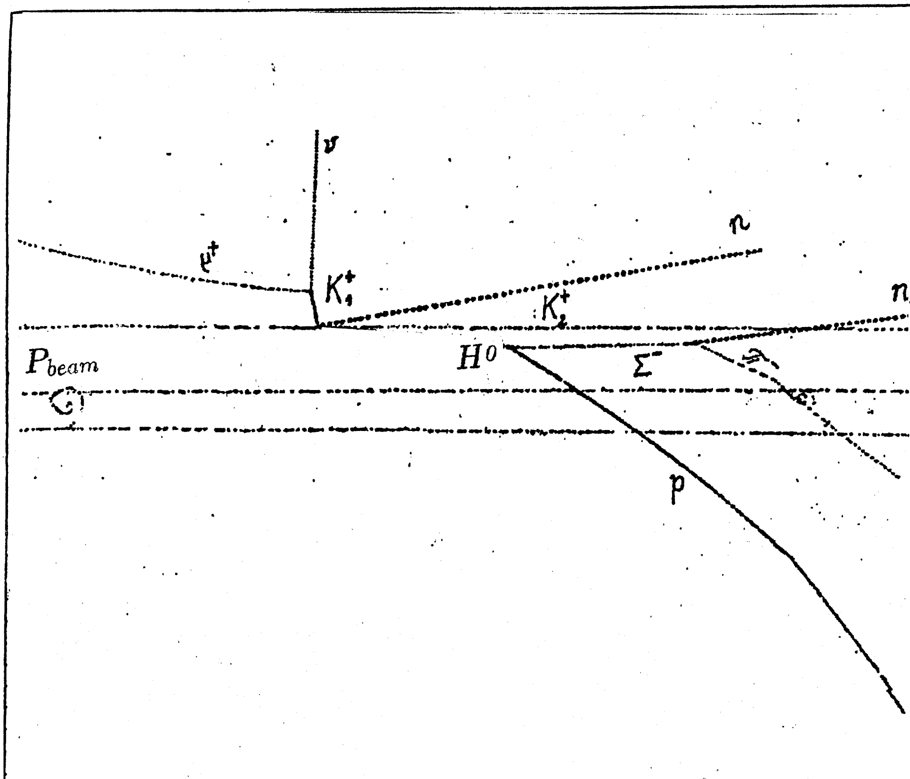

Figure 1. Two-body weak decay of heavy, stable, neutral dibaryon $H^0 \to p + \Sigma^0$, $\Sigma^0 \to \pi^- n$.

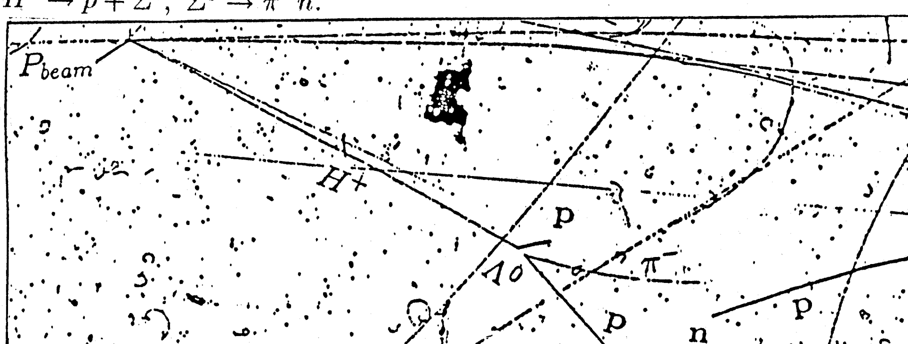

Figure 2. Three-body weak decay of heavy, stable, positively charged dibaryon $H^+ \to p + \pi^0 + \Lambda$, $\Lambda \to p\pi^-$ (the hypothesis $H^+n \to \Sigma^+\Lambda n$, $\Lambda \to p\pi^-$).

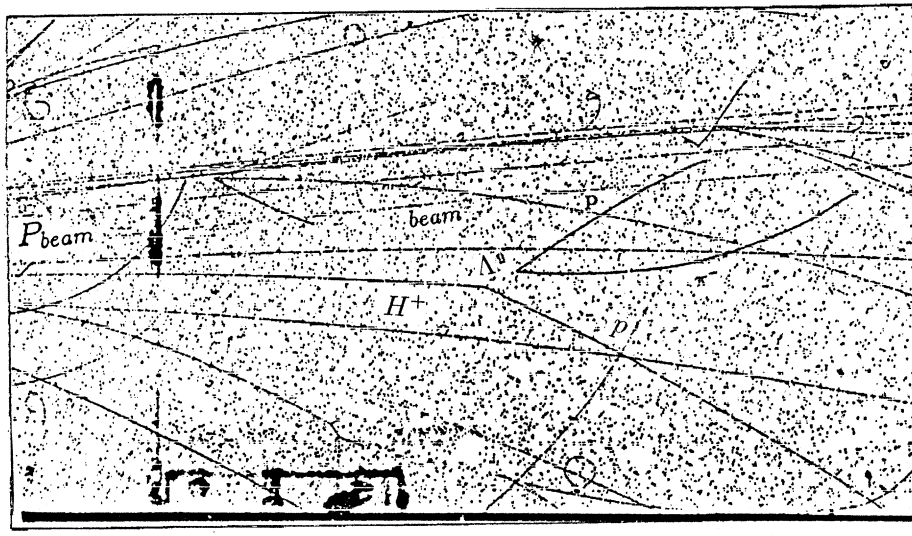

Figure 3: Three-body weak decay of heavy, stable, positively charged dibaryon $H^+ \rightarrow p + \pi^0 + \Lambda$, $\Lambda \rightarrow p\pi^-$ (the hypothesis $H^+ \rightarrow p + \pi^0 + \gamma$ is probable, too).

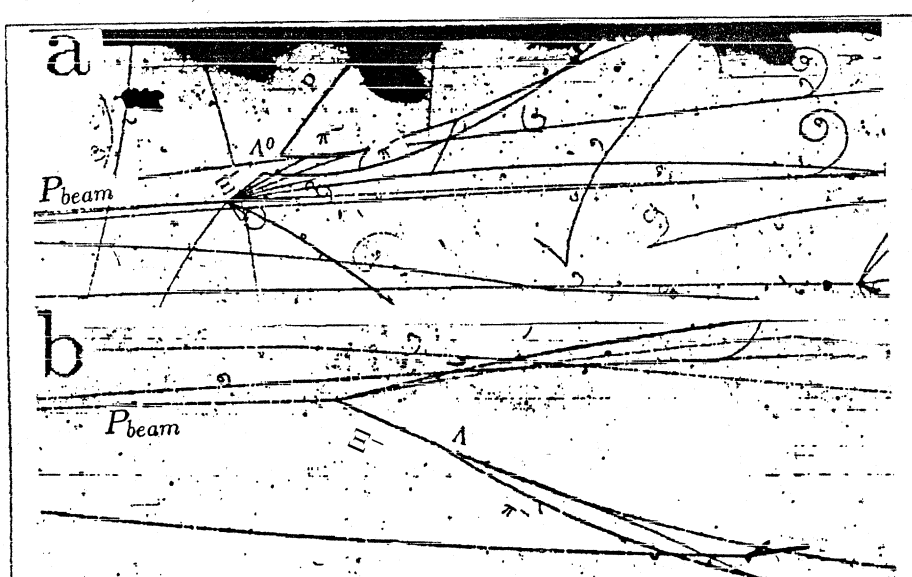

Figure 4: Two-body weak decay $\Xi^- \rightarrow \pi^- + \Lambda$, $\Lambda \rightarrow p\pi^-$: a)first event; b)second event.

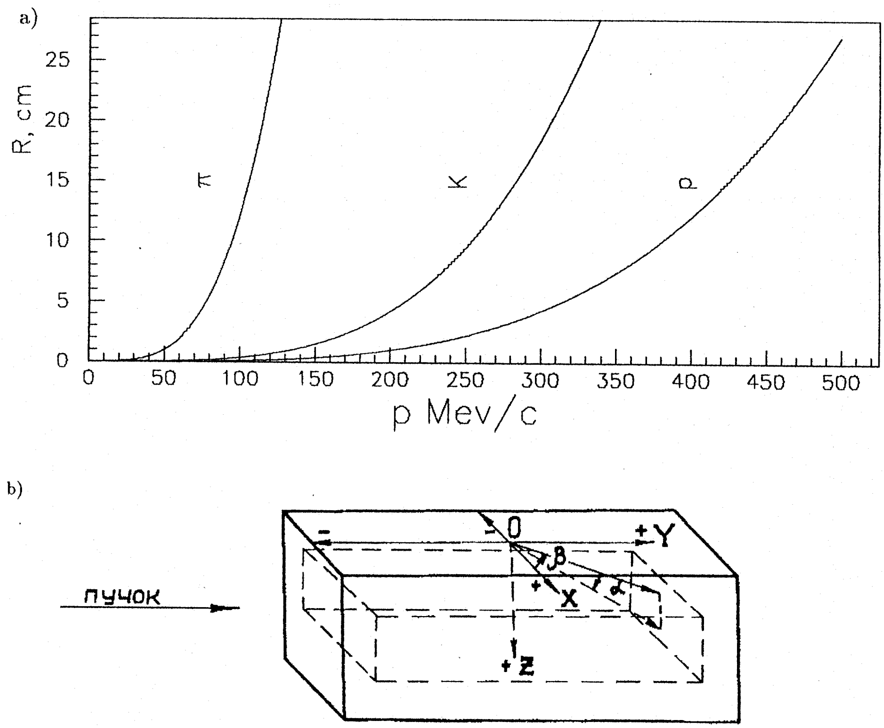

Figure 5.

a) Run length of stopping particles in propane (C_3H_8) versus of the momentum of $\pi^{\pm}, K^{\pm}$ and proton particles.
b) Scheme of the 2m propane bubble chamber with X:Y:Z=60:200:43 cm^3. The kinematic parameterss α (deep angle) and β(azimuthal angle) for track are shown.

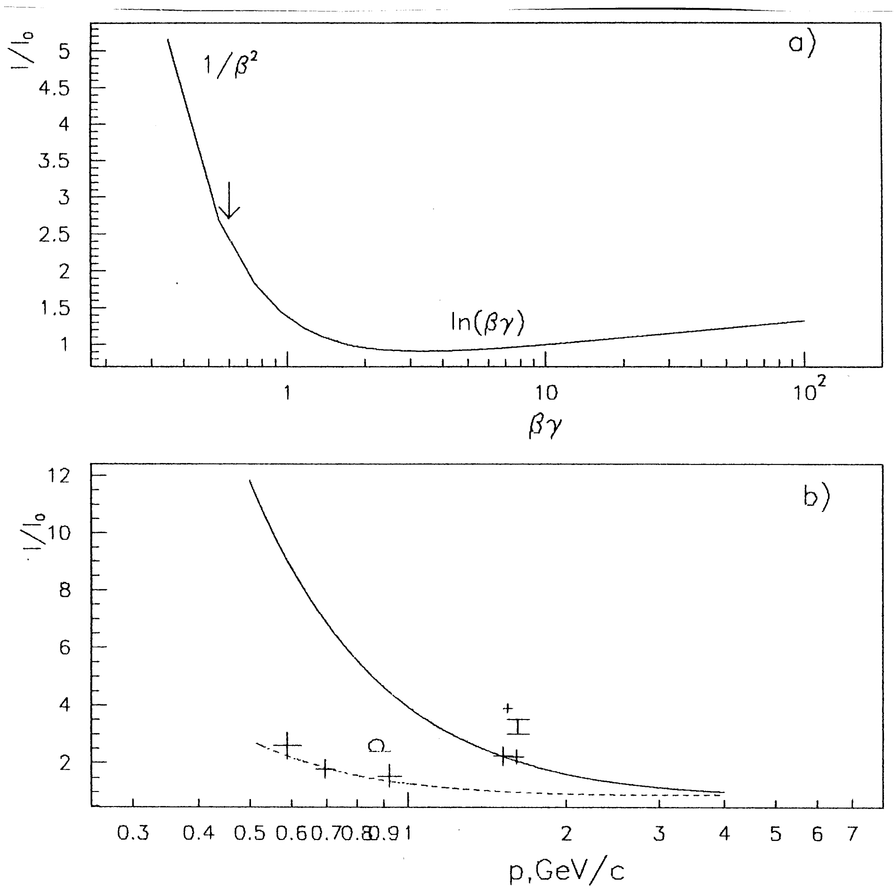

Figure 6. a)Rate of energy losses for charged particles versus $\beta\ \gamma$ as given by equation (7). b)Given by equation (7) th relative ionization versus a momentum: for proton (the dashed line) and H^{+}(the solid line)particles. + - measured by the method of average gap length (2) the experimental relative ionization.

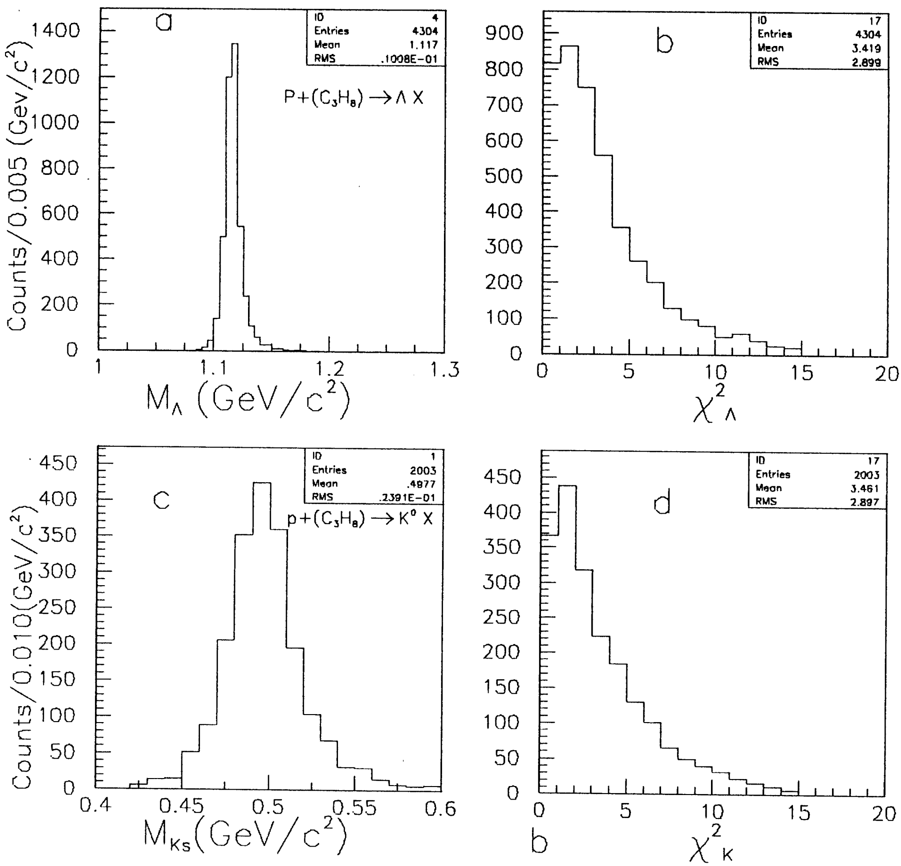

Figure 7. Distribution of experimental events produced from interactions of beam protons for: a) effective mass M_Λ; b) $\chi^2_\Lambda(1V-3C)$ of the fits via the decay mode $\Lambda \to \pi^- + p$; c) effective mass $M_{K^0_s}$; d) $\chi^2_{K^0_s}(1V-3C)$ of the fits via decay mode $K^0_s \to \pi^- + \pi^+$.

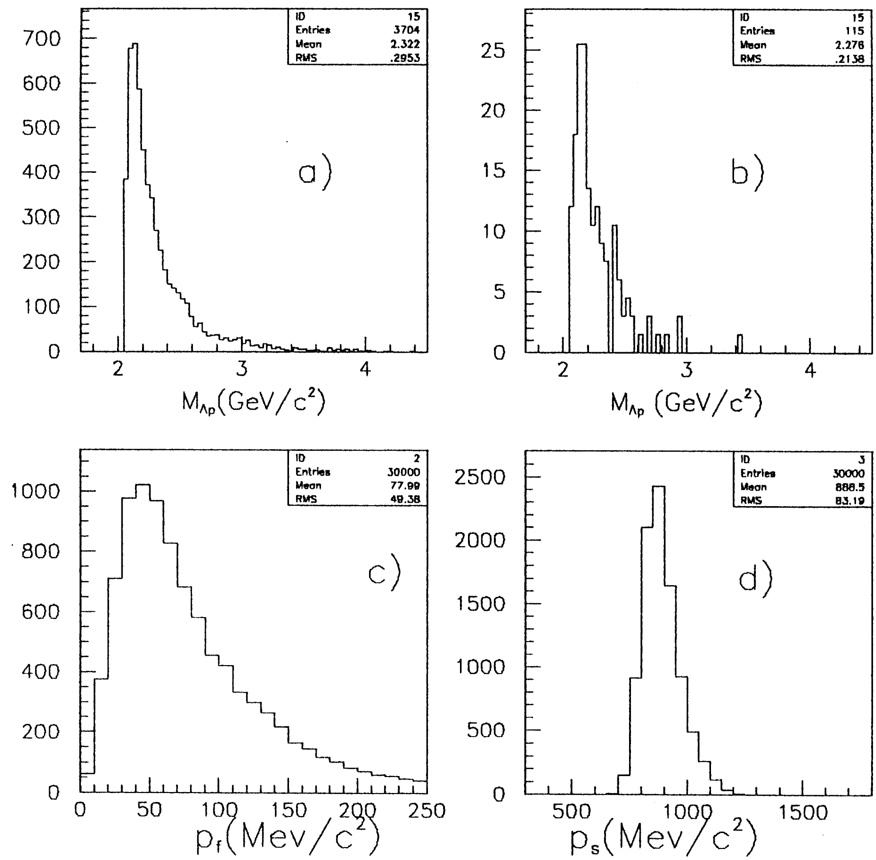

Figure 8. a)Distribution of the invariant mass for Λp combinations produced from all secondary positive tracks. b) Distribution of the invariant mass Λp combination produced from one-psitive-prong stars.
c)Fermi momentum p_f distribution of nucleons inside the deuteron using the Gartenhaus-Moravcik potential. d)Monte -Carlo distribution a momentum of nucleons in the deuteron for the laboratory system where there is a self-momentum with an error (Gaussian distribution) and a contribution from fermi momentum.

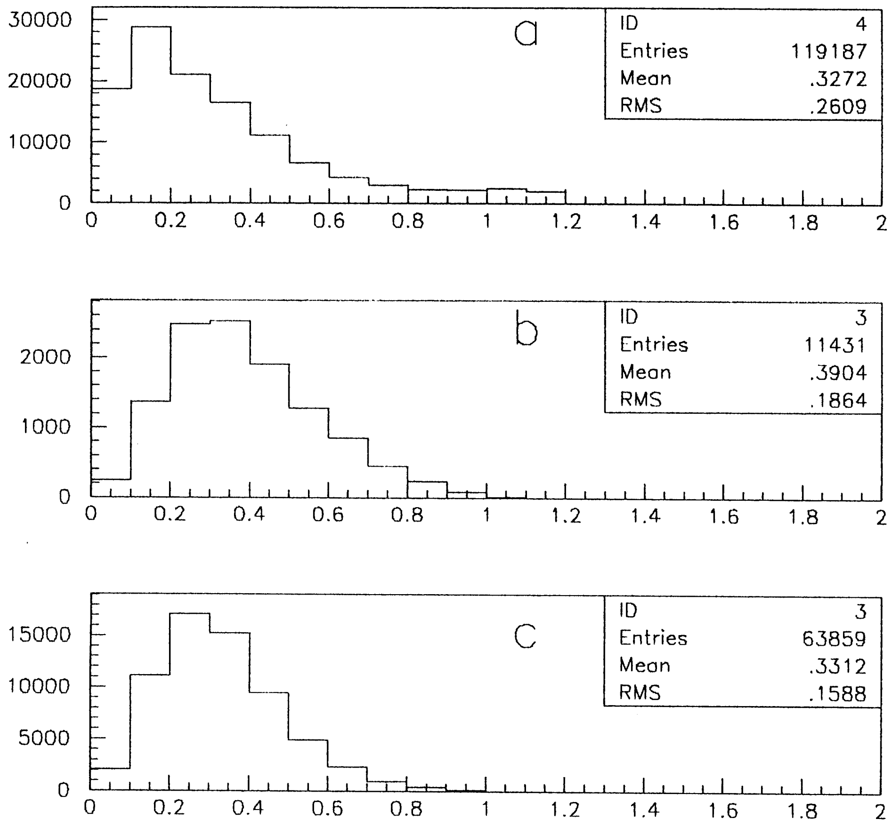

Figure 9. Momentum distribution of neutrons in the laboratory system with the model FRITIOF from the reaction $p^{12}C \to nX$ at a momentum 1.2 GeV/c(35000 events are simulated):a) all produced neutrons; b)with cuts of the second experimental event for a proton momentum $250 < p_p < 350$ MeV/c; c)with cuts of the third experimental event for a proton momentum of $717 < p_p < 1117$ MeV/c.

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Асланян П. Ж., Емельяненко В. Н., Рихвицкий В. С. E1-2001-265
Наблюдения событий — кандидатов в тяжелый $S=-2$
H^+-дибарион со слабым каналом распада $H^+ \to \Lambda + p + \pi^0$

На фотографиях, полученных с двухметровой камеры ОИЯИ, облученной протонами с импульсом 10 ГэВ/с, зарегистрированы два события, которые интерпретируются как распад по слабому каналу $H^+ \to \Lambda + p + \pi^0$ тяжелого, стабильного, $S=-2$ H^+-дибариона.

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Aslanian P. Z., Emelyanenko V. N., Rikhvitzkiy V. S. E1-2001-265
Observation of Candidates for Heavy Positively Charged $S=-2$
H^+ Dibaryon with a Weak Decay Channel $H^+ \to \Lambda + p + \pi^0$

Two events were detected on the photographs from the JINR 2m propane bubble chamber exposed to a 10 GeV/c proton beam, which can be interpreted as heavy $S=-2$ H^+ stable dibaryon with a weak decay $H^+ \to \Lambda + p + \pi^0$.

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

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