Talk Presented at the LAMPF II Workshop, Los Alamos National Laboratory Study Center, Los Alamos, N.M., July, 1982

COO-3244-99
Conf-820745--2

SEARCHES FOR A POSSIBLE STRANGENESS S = -2 DIBARYON

P. D. Barnes

Carnegie-Mellon University

DOE/ER/03244--99

DE83 001040

INTRODUCTION

Since the advent of QCD there has been a strong interest in manifestations of quark degrees of freedom in medium energy nuclear and particle physics. Within the framework of multiquark states the emphasis has centered on states with more than three quarks bound by "colour" forces rather than by the conventional "mesonic" forces. Dibaryon systems have played an important role within that framework.

One of the most spectacular and exciting predictions is the possible existence, according to the MIT bag model, of a stable, flavor-singlet, strangeness = -2,$J^P = 0^+$ dihyperon, called by R. Jaffe the "H" particle [1]. It is a six-quark object (2u, 2d, 2s quarks) with a predicted mass around 2150 MeV, i.e., below the $\Lambda\Lambda$ mass with a binding energy around 80 MeV! Its decay channels would be restricted to ΣN and ΛN, via the weak interaction. Figure 1 shows the relevant two body states. A similar prediction was obtained on the basis of the same model by Mulders et al. [2], with a mass of 2164 MeV for this state. For completeness it should be mentioned that in a recent estimate [3] of the center-of-mass correction to the static MIT bag model, the authors suggest that the dilambda mass moves up to just above the $\Lambda\Lambda$ threshold. These calculations are undergoing further tests [4]. Although all these results come from a specific model, Lipkin has argued that the general features of QCD and the known baryon mass splittings imply that the six-quark state with charge zero, spin zero, and strangeness = -2 would have the greatest binding potential [5].

DISCLAIMER

PREVIOUS EXPERIMENTS

The experimental situation is quickly summarized. There has been one experiment at BNL searching the missing-mass spectrum of the reaction $pp \rightarrow K^+K^+X$ for a narrow six-quark resonance in the mass range 2.0-2.5 GeV [6]. The incident beam momentum was 5-6 GeV/c resulting in a rather large momentum transfer. No narrow structure was observed, with upper limits for the production cross section in the range of 30 to 130 nb. The conclusion drawn from the measurement was that in the absence of more reliable estimates of the production cross section, the possibility of the existence of the H cannot be excluded. This experiment is being repeated with a factor of 100 higher sensitivity [7]. At CERN the Rome-Saclay-Vanderbilt collaboration (experiment PS 159) searched, in the charge Q = -1 channel, for strangeness = -2 dibaryonic states [8]. The reaction studied was $K^-+d \rightarrow K^++X$ at 1.4 GeV/c. No evidence for the presence of structures was found in the mass range ~2.1-2.5 GeV.

CMU PROPOSAL:

VERSION A

Within the CMU group we have focused on low momentum transfer reactions in order to enhance the probability for the two Λ's to stick together and perhaps to form the H. Our basic scheme involves tagged production of a slow Ξ^- followed by $\Xi^-+p \rightarrow$ H using the following two reactions

$$K^- + p \rightarrow K^+ + \Xi^- \qquad (1)$$

$$\Xi^- + d \rightarrow H + n \qquad (2)$$

In the second reaction the neutron in the deuteron acts as a spectator and carries away momentum that contains information on the H mass. Notice that both steps are two-body reactions and that two different targets would be used. This arrangement we all version A (see Fig. 2). In order to increase the yield of reaction (2) we are considering ranging out the Ξ^-'s which recoil into the deuterium target. The Ξ's would then be absorbed at rest from an atomic orbit:

$$\Xi^- + d \rightarrow (\Xi^- d)_{Atom} + \text{X-rays}$$
$$\quad\quad\quad\quad\quad\quad \hookrightarrow H + n$$

The neutron from reaction (2) and the K^+ from reaction (1) would be detected in coincidence. Formation of the H will be reflected in a sharp peak in the coincident neutron energy spectrum at an energy of

$$T_n = B_H + Q - T_H = \frac{B_H + 26}{1 + \frac{M_n}{M_H}} \quad (\text{MeV})$$

where B_H = binding energy of the H, T_H = kinetic recoil energy of the H, and Q = Q values of the reaction = 26 MeV. For $B_H \sim 80$ (59) MeV we get $T_n \sim 74$ (53) MeV.

Some advantages of the stopped Ξ^- approach are that a) every stopped Ξ^- will ultimately interact with the nucleons and b) the $\Xi^- d$ elastic scattering out-going channel is closed (E = - atomic binding energy). Thus there are two open channels, the formation of the H as discussed above and $(\Xi^- d)_{Atom} \rightarrow \Lambda + \Lambda + n + 26$ MeV, i.e., quasifree formation of two Λ's, as the only possible reactions. The latter reaction results in a relatively low energy neutron and, ultimately, the decay products of the Λ's. For identification of events of this type one might look for the π^- from the Λ decay.

Instead of deuterium as second target, ^{3}He could be used: $(\Xi^{-3}He)_{Atom} \rightarrow H + d^+$. This set-up would have the obvious advantages of deuteron detection over neutron detection: higher efficiency, better resolution and large solid angle with less detector material. More detailed calculations of the branching ratios for H formation are necessary in order to judge the merit of the different target choices. In another variation of this approach which we have discussed, one leaves out the neutron spectator and uses hydrogen instead of deuterium as the second target. Then one looks for high energy photon emission from radiative capture into the H state (see Fig. 1):

$$(\Xi^- p)_{Atom} \rightarrow H + \gamma$$

For $M_H \sim 2150$ MeV this reaction would have a Q value of ~ 110 MeV. In this case there would of course be strong competition from quasifree production of two Λ's, i.e.,

$$(\Xi^- p)_{Atom} \rightarrow \Lambda + \Lambda + 29 \text{ MeV}$$

and from:

$$(\Xi^- p)_{Atom} \rightarrow \Xi^0 + n$$

However monoenergetic, high energy γ rays would represent a rather clean signature for H formation.

VERSION B

We also consider a second scheme for the experiment, called Version B, which corresponds to combining the proton and deuterium targets into one to give a ^3He target. Independently from us, C. B. Dover and A. Aerts at BNL have brought up this scheme recently and are working on a theoretical calculation of the rate for the reaction [9]: $K^- + {}^3He \rightarrow K^+ + n + H$. Here an intermediate Ξ^- is produced on one proton and interacts within the same nuclear volume. Neutron and K^+ detection would remain about the same. The competing quasifree reactions in this case are

$$K^- + {}^3He \rightarrow K^+ + (\Xi^- p\ n)$$

and

$$K^- + {}^3He \rightarrow K^+ + (\Xi^- d)\,.$$

The ^3He approach a) eliminates the slowing-down-time issue (see rate estimates below), b) has the advantage of larger high momentum components in the ^3He wave function than available in deuterium, c) has the disadvantage that the Ξ^- might elastically scatter and leave the ^3He nuclear volume i.e., the breakup channel is open, not closed as in the $(\Xi^- d)$ atom case.

Ultilization of heavier target nuclei in this scheme is not feasible. For a clean signature of H formation what is desired is a proton rich nucleus with few remaining spectator nucleons.

We are working on further analysis and optimization of these choice-of-target questions (version A vs. version B).

Decay of the H

Apart from studying the formation reaction of the H it is important to look into the possible decay modes. Depending on the mass of the H its weak decays will result in Λn , $\Sigma^- p$, $\Sigma^o n$ (see figure 1). Jaffe's original estimate for M_H would have the H only ~15 MeV above the ΣN thresholds so that Λn looks like the most probable decay channel. It should be noted that this decay mode will produce neutrons in the same energy region as the formation reaction (2) leading to two peaks in the neutron energy spectrum. While B_H is currently unknown, the sum energy of these two peaks can be calculated from known masses and gives an internal check on the interpretation of the results.

Hardware Requirements

The main hardware requirements are listed below.

a. Beam line.

The available Ξ^- production data is summarized in Figure 4 (compiled by C. B. Dover). Thus we need a K^- beam of 1.3-2.0 GeV/c with the highest possible flux. The two existing beam lines that we have looked at are the AGS beam B4 [10] and the KEK beam K2 [11]. The AGS beam B4 is extremely long (81 m!) and delivers 1.2×10^5 K^-/sec per 10^{12} protons on the production target at 4 GeV/c. For the same production cross section, the flux at 2 GeV/c would be reduced by a factor of 15 due to kaon decay, i.e., only ~8×10^3 $K^-/sec/10^{12}$ protons. It is obvious that this beam line would have to be shortened dramatically to increase the flux. For instance, for 25 m length one could expect ~3.4×10^5 $K^-/sec/10^{12}$ protons, again at P_{K-} = 2 GeV/c. The KEK beam K2 is designed as a kaon beam in the 1-2 GeV/c momentum region with a factor of 6 larger acceptance than B4 at the AGS and a length of 28 m. The measured beam intensity at 2.1 GeV/c is $1 \times 10^5 K^-$ per 10^{12} primary protons [11] at this 12 GeV facility.

b. K^+ Spectrometer

The kaon spectrometer has to detect K^+ at forward angles. For version A, i.e., two targets with a hydrogen target for the Ξ^- production, this could in principle be fairly simple. We need to identify positive kaons at small angles (see Figure 5) in a beam of negative kaons and to pions and to pick out the large hydrogen reaction peak. A simple magnetic dipole magnet plus time-of-flight and Cerenkov detectors should give sufficient resolution and ensure large solid angle. A better quality spectrometer would give a cleaner trigger which may turn out to be very desirable. Version B, i.e., one target consisting of ^3He, would seem to require a higher resolution K^+ spectrometer thus cutting down on the solid angle. It could be structured similar to the existing Moby Dick spectrometer at Brookhaven's LESBI.

c. Targets

Both versions of the experiment require cryogenic targets (hydrogen, deuterium, ^3He). Corresponding targets have been built at various labs and those designs could be copied. The hydrogen and deuterium targets need to be thin due to Ξ^- range and lifetime considerations.

d. Neutron Detection

The neutrons have to be detected in large area time-of-flight counters. Achievement of high efficiency and large solid angle is, to a large extent, a question of money since very large volumes of plastic scintillators are required. Efficiency for E_n = 10-100 MeV can be around 20%. The energy resolution depends on the quality of the counters (intrinsic time resolution) and on the neutron flight path. For example: to get a solid angle of $\sim 1\pi$ sr at a distance of 2 m and 20% efficiency one needs a volume of $\sim 12.5\ m^2 \times 0.15\ m = 1.9\ m^3$ of plastic scintillator. The modular construction could be similar to the neutron detectors that are being introduced into the CMU hypernuclear lifetime experiment at BNL.

RATES (Rough Estimates):

VERSION A (^1H+d targets)

a. Tagged Ξ^- production rate:

Assume K^- flux = $4 \times 10^5\ K^-$/sec (Modified B4?)

$$\frac{d\sigma}{d\Omega} = 50\ \mu b/sr \quad \text{(see figure 5)}$$

$\Delta\Omega$ = 50 msr (set-up similar to CERN experiment PS 159 [12])

LH_2 target: 1.2 cm = 0.07 g/cm^2

This gives a rate of $\sim 150\ \Xi^-$/hour.

b. $(\Xi^- d)_{atom}$ formation rate:

Assume 0.5 cm tungsten degrader and 0.7 cm LD_2 stopping target. Losses due to Ξ^- decay, absorption and out-scattering in degrader and range straggling. Stopped rate of Ξ^- $\sim$20/hour ($\sim$13% of all Ξ^- produced).

c. Coincident neutron rate:

Assume 10% branching ratio from $\Xi^- p$ to H particle formation (see figure 1), 20% neutron detection efficiency and 1π solid angle for the neutron detectors.

Overall event rate in H particle peak in coincident neutron spectrum $\sim$0.1 event/hour. To obtain 100 events would thus require $\sim$40 days.

Not taken into account are losses in the tagged Ξ^- rate due to decay losses of the outgoing K^+. Obviously some of the above numbers carry large uncertainties, in particular the assumption of 10% branching ratio for $(\Xi^- d)_{atom} \rightarrow H + n$ may be on the optimistic side.

VERSION B (^{3}He target, reaction: $^3He(K^-,K^+n)H$)

$$K^- \text{ flux} = 4 \times 10^5/\text{sec}$$

$(d^2\sigma/d\Omega_K d\Omega_n)_{\theta_K=0}$ $\sim 0.022\ \mu b/sr^2$ (preliminary result from ref. 9 at $P_{K-} = 1.9$ GeV/c)

$\Delta\Omega_{K+} = 20$ msr (K^+ spectrometer similar to Moby Dick)

$\Delta\Omega_n = 1\pi$ sr, $\Sigma_n = 0.2$

Liquid ^{3}He target: 10 cm ~ 0.9 g/cm^2

This gives a K^+-neutron coincidence rate of $\sim 2 \times 10^{-5}$ sec^{-1} = 7.2×10^{-2}/hour. To obtain 100 events would thus require $\sim$60 days of running.

In conclusion, it is obvious from these rough rate estimates that the expected counting rates, even under optimistic assumptions, are quite low. The much higher kaon fluxes anticipated at LAMPF II would certainly be crucial for these exciting experiments.

The material presented in this report has developed from extensive discussions with B. Bassalleck, D. Marlow, J. Szymanski, and other members of the C-MU medium energy physics group.

REFERENCES

1. R. L. Jaffe, Phys. Rev. Lett. 38 (1977) 195 and 617.
2. P. J. G. Mulders et al., Phys. Rev. D21 (1980) 2653.
3. K. F. Liu and C. W. Wong, Phys. Lett. 113B (1982) 1.
4. C. B. Dover, private communication.
5. H. J. Lipkin, in Prospects for Strong Interactions at Isabelle, edited by D. P. Sidhu and T. L. Trueman (BNL, Upton, N.Y., 1977).
6. A. S. Carroll et al., Phys. Rev. Lett. 41 (1978) 777.
7. A. S. Carroll et al., Brookhaven Experiment #722, in progress.
8. G. d'Agostini et al., CERN-EP/82-68 preprint, June 1982.
9. A. Aerts and C. B. Dover, work in progress and private communication. For some results see C. B. Dover's contribution to this workshop.
10. BNL High Energy Physics Users Handbook, 1978.
11. KEK Preprint 81-24, February 1982.
12. G. d'Agostini et al., Nucl. Instr. and Methods 188 (1981) 29.

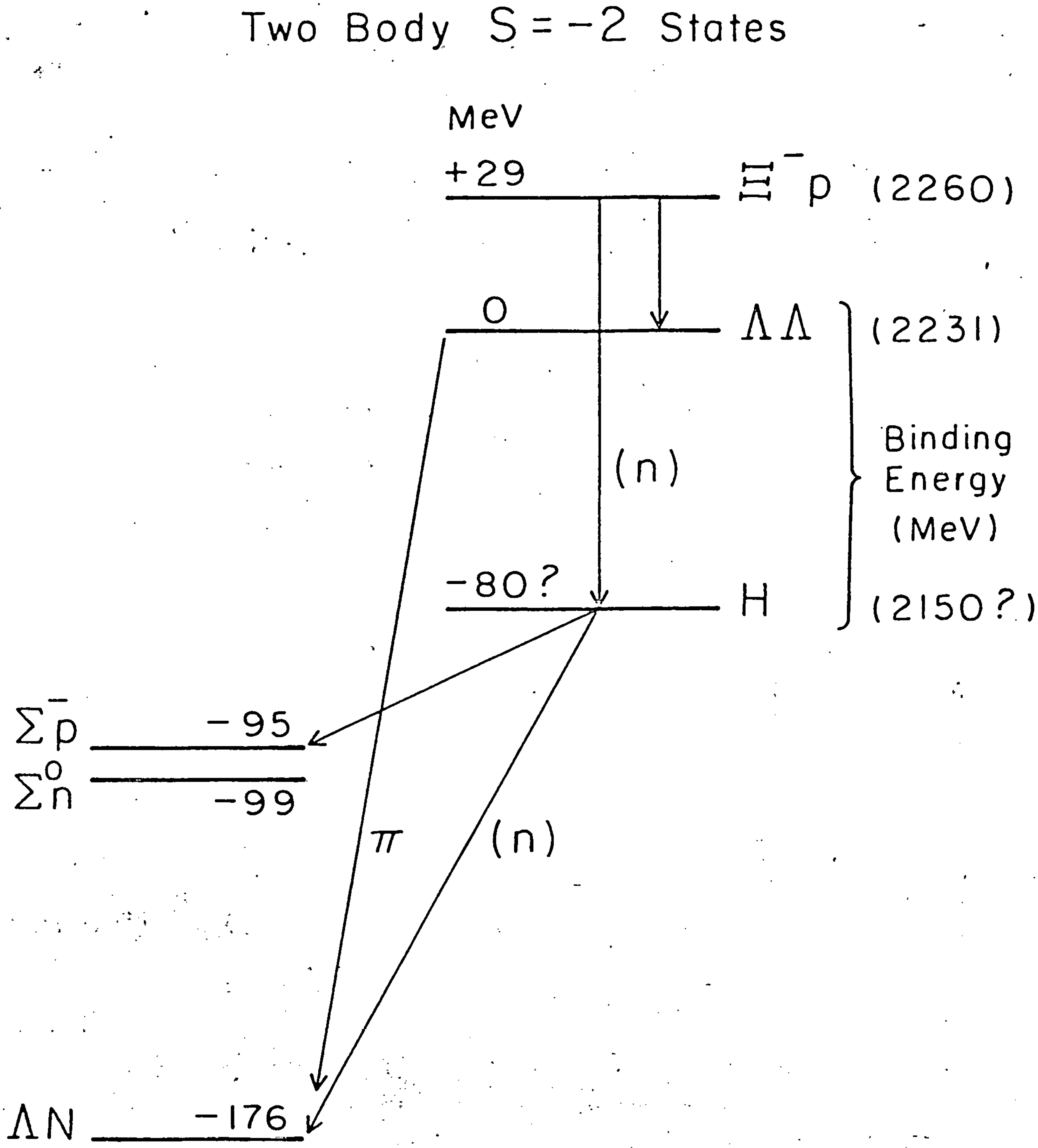

Two Body S = −2 States
MeV
+29
Ξ⁻p (2260)
0
ΛΛ
(2231)
Binding Energy (MeV)
(n)
−80?
H
(2150?)
Σ⁻p
−95
Σ⁰n
−99
π
(n)
ΛN
−176

Fig. 1

Target Set-up (Version A)

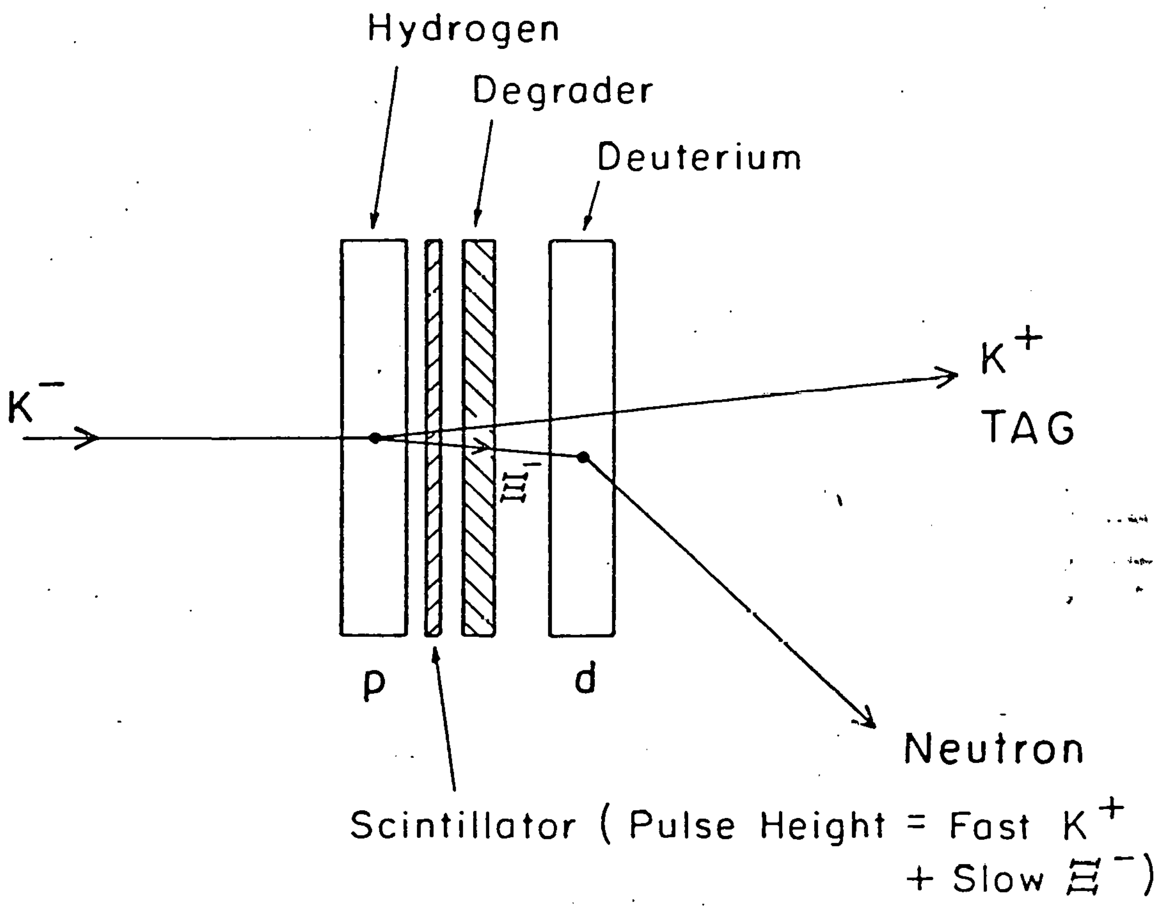


Fig. 2

Reaction Mechanism for Version B

$$K^- + {}^3He \longrightarrow K^+ + n + H$$

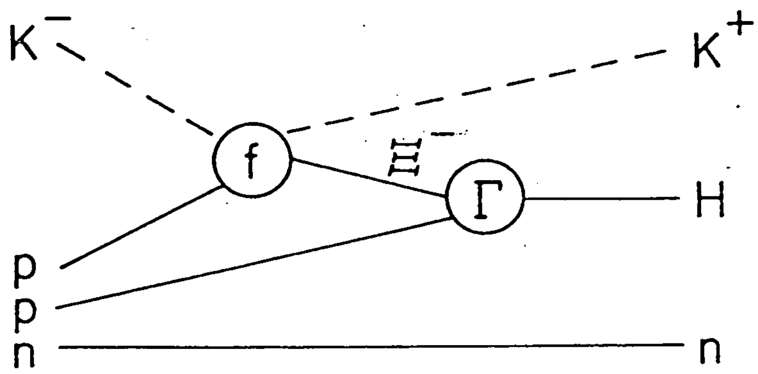
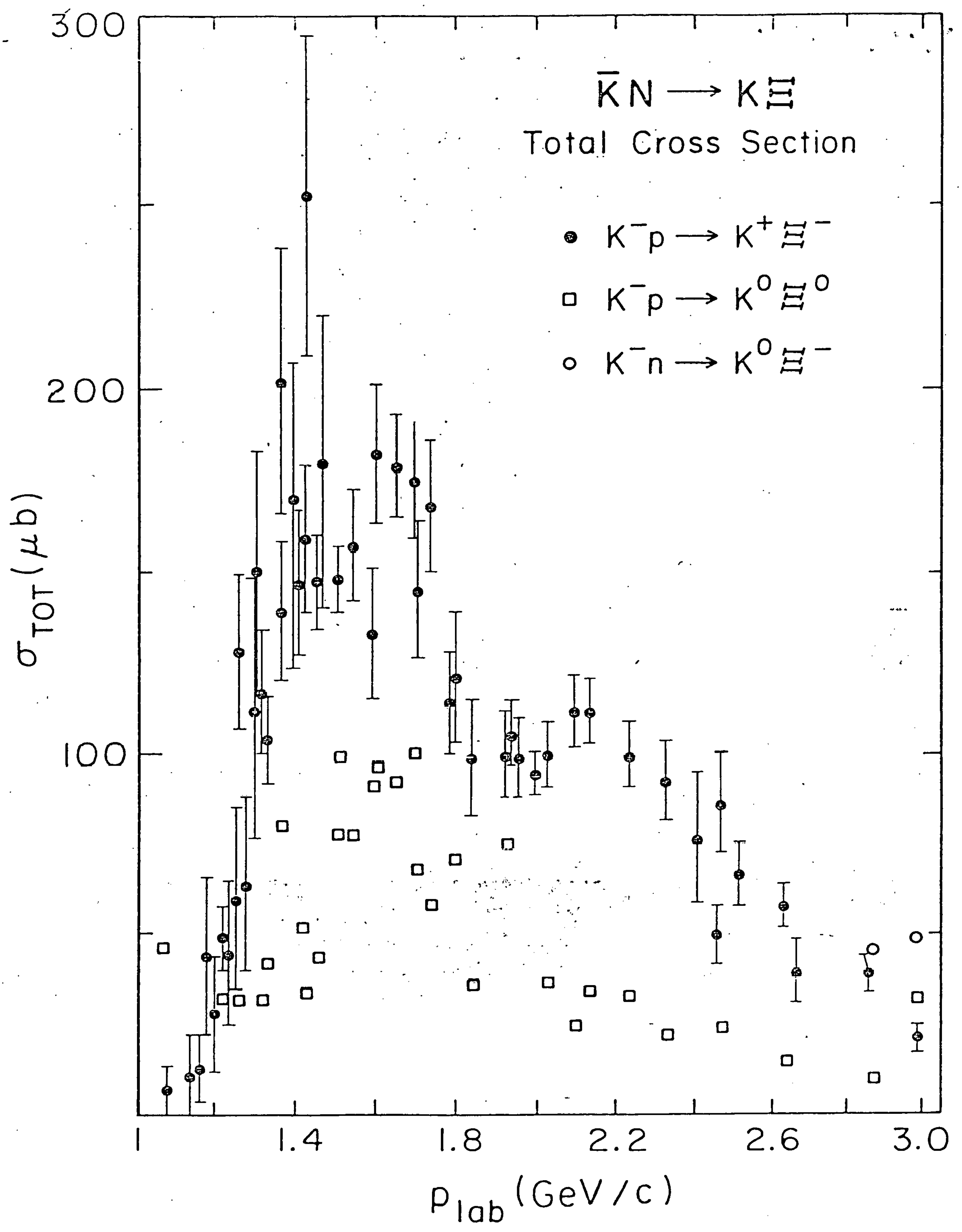
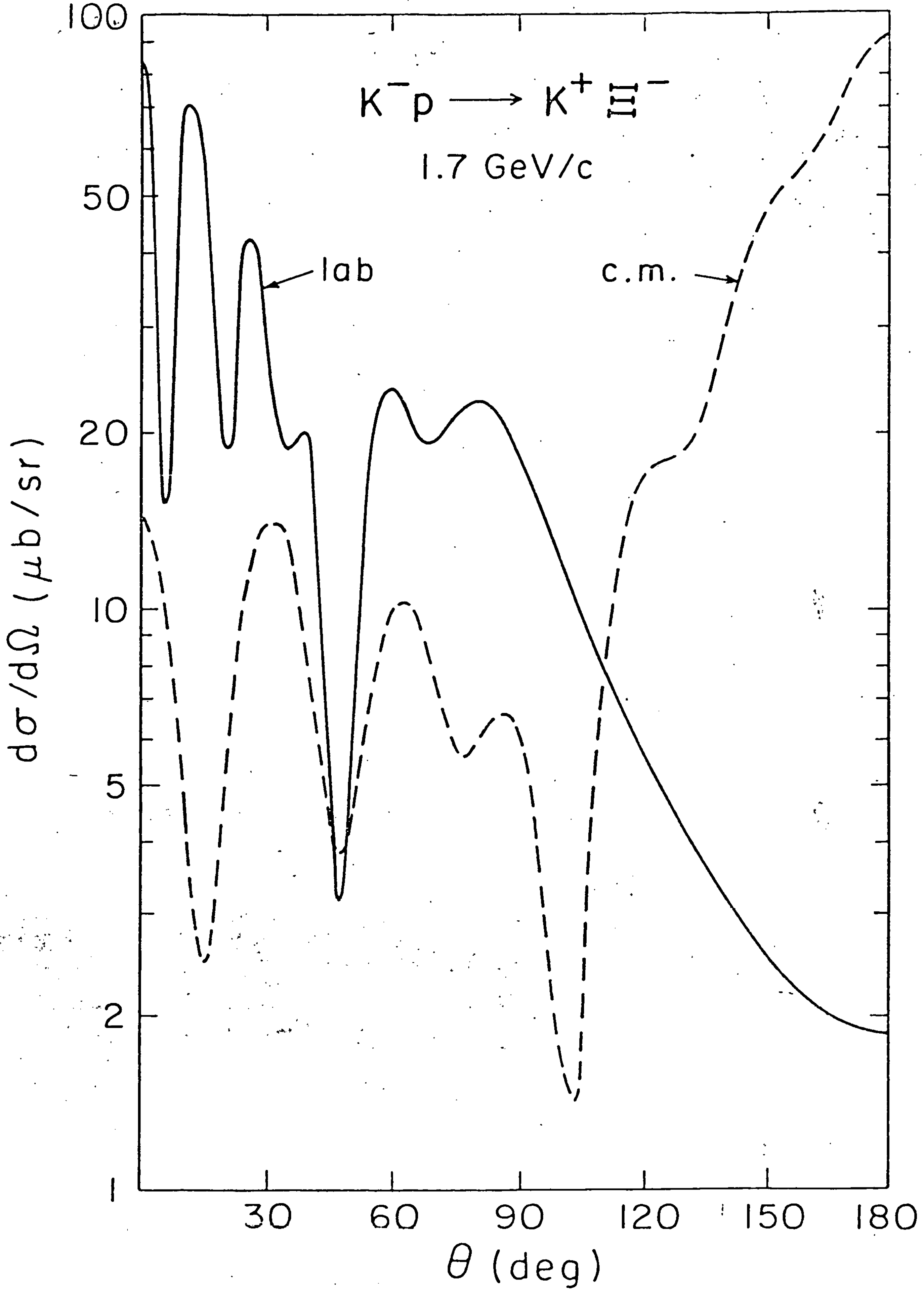


Fig. 3



$\bar{K}N \longrightarrow K\Xi$
Total Cross Section
$K^-p \longrightarrow K^+\Xi^-$
$K^-p \longrightarrow K^0\Xi^0$
$K^-n \longrightarrow K^0\Xi^-$
300
200
100
$\sigma_{TOT}(\mu b)$
1
1.4
1.8
2.2
2.6
3.0
p_{lab}(GeV/c)

Fig. 4



K⁻p ⟶ K⁺ Ξ⁻
1.7 GeV/c
lab
c.m.
dσ/dΩ (μb/sr)
100
50
20
10
5
2
1
30
60
90
120
150
180
θ (deg)

Fig. 5