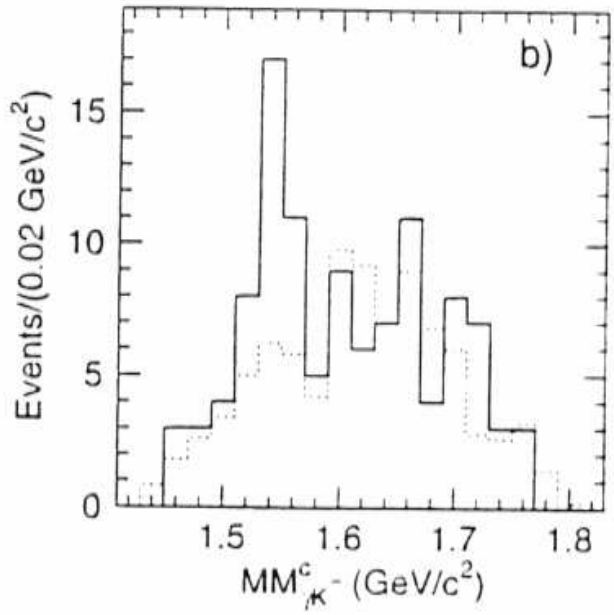
Pentaquark Experiments with Hadron Beams

J. R. Comfort

Arizona State University

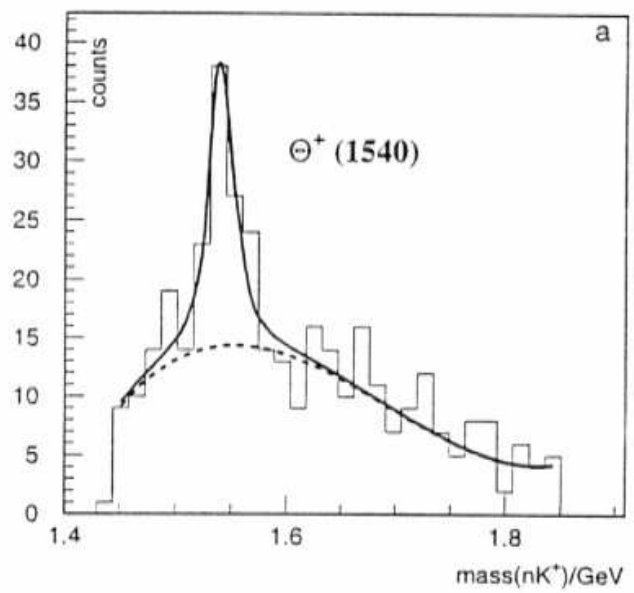
Spring8

$$\gamma\, n \;\rightarrow\; K^+\, K^-\, n$$
$$\rightarrow\; (n\, K^+)\, K^-$$



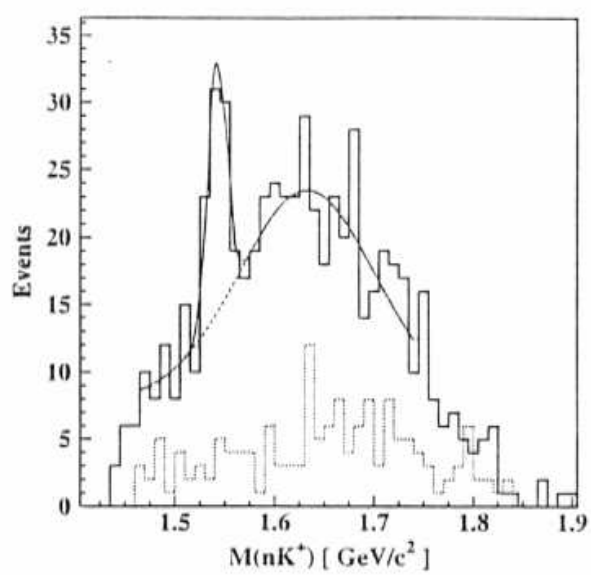
Bonn/ELSA

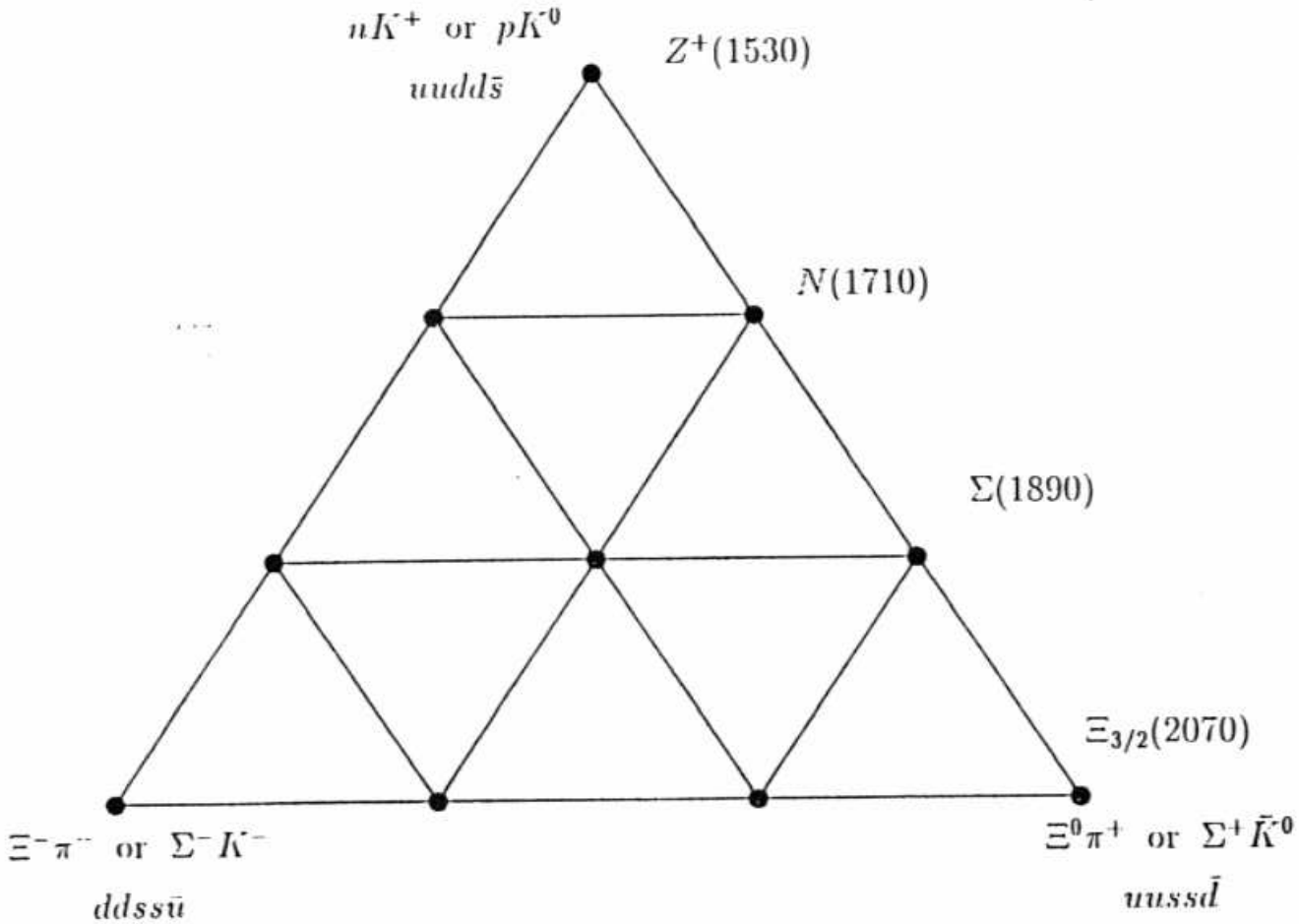
$$\gamma\, p \;\rightarrow\; K^+\, K^0_S\, n$$
$$\rightarrow\; (n\, K^+)\, K^0_s$$



JLab

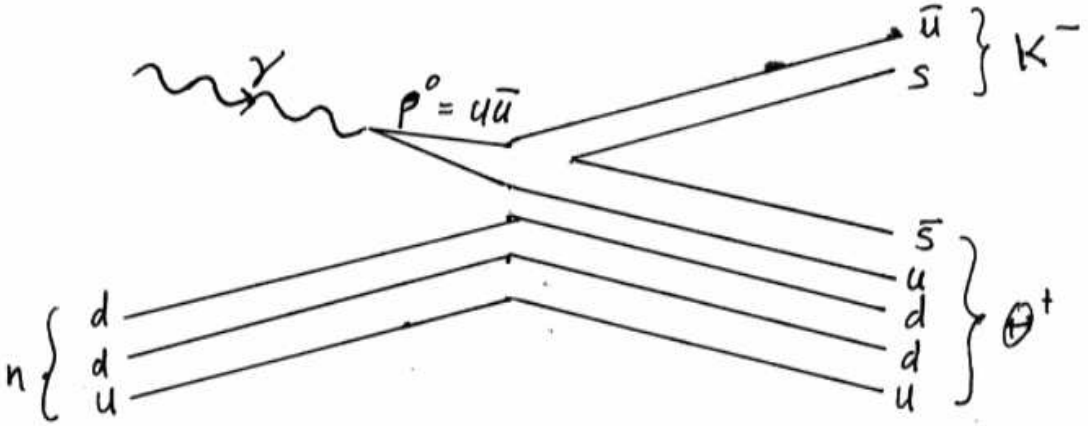
$$\gamma\, d \;\rightarrow\; K^+\, K^-\, n\, p$$
$$\rightarrow\; (n\, K^+)\, K^-\, p$$



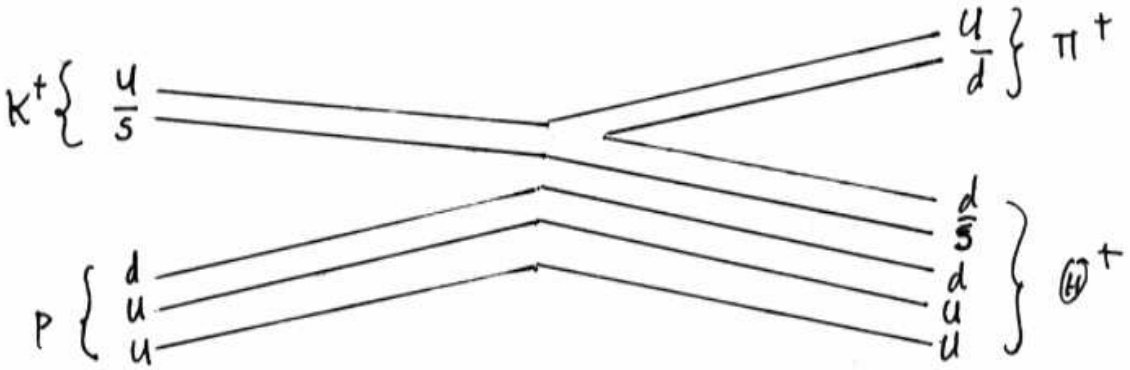

nK^+ or pK^0
$uudd\bar{s}$
$Z^+(1530)$
$N(1710)$
$\Sigma(1890)$
$\Xi_{3/2}(2070)$
$\Xi^-\pi^-$ or Σ^-K^-
$ddss\bar{u}$
$\Xi^0\pi^+$ or $\Sigma^+\bar{K}^0$
$uuss\bar{d}$

Θ^+ Production

$$\begin{array}{ccccc} \gamma & n & \rightarrow & \Theta^+ & K^+ \\ & udd & \rightarrow & uudd\bar{s} & \bar{u}s \end{array}$$



$$\begin{array}{ccccc} K^+ & p & \rightarrow & \Theta^+ & \pi^+ \\ u\bar{s} & uud & \rightarrow & uudd\bar{s} & u\bar{d} \end{array}$$



Constructing Θ^+ from Quarks

$$
\begin{aligned}
K^- + p &= \bar{u}s + uud \\
&= uu\bar{u}ds \\
&= uudd\bar{s} + \bar{u}\,\bar{d}\,s\,s \\
&= uudd\bar{s} + \bar{u}\,s + \bar{d}\,s \\
&= \Theta^+ + K^- + \overline{K^0}
\end{aligned}
$$

π & K Experiments for Pentaquarks

$K^+n \to \Theta^+$ Excitation Function

- Resonant $p_K = 442$ MeV/c, in nK CM.
- Look for $\Theta^+ \to K^+n \to \pi^+\pi^0 n$
  or $\to K^0 p \to \pi^+\pi^- p$.
- Sufficient flux at C2 port.
- Neutron target normally means a deuterium target.

$K^+p \to \Theta^+ + \pi^+$

- Threshold $p_K = 735$ MeV/c.
- Look for $K^+n\pi^+ \to \pi^+\pi^0 n\,\pi^+$
  or $K^0 p\pi^+ \to \pi^+\pi^- p\,\pi^+$.
- C2 Port probably OK.
- Matches better to D Line.

$M(\Theta^+) = 1540$ MeV

Mass of $p\,K^+\,\pi^0 = 1567$ MeV
[Threshold $p_{K^+} = 510$ MeV/c]

$K^- p \rightarrow \Xi^+ + K^0 + \pi^-$

- **Threshold $p_K = 1930$ MeV/c.**
- **Look for $\Xi^+ \rightarrow \Xi^0 \pi^+ \rightarrow \Lambda \pi^0 \rightarrow p\, \pi^- \pi^0 \pi^+$**
  or $\rightarrow \Sigma^+ \overline{K}^0 \rightarrow p\, \pi^0 \pi^+ \pi^-$
  with $K^0 \rightarrow \pi^+ \pi^-$
- **Near the limit of the D Line.**

$K^- n \rightarrow \Xi^{--} + K^+$

- **Threshold $p_K = 2860$ MeV/c.**
- **Look for $\Xi^{--} \rightarrow \Xi^- \pi^- \rightarrow \Lambda \pi^- \rightarrow p \pi^- \pi^-$**
  with $K^+ \rightarrow \pi^+ \pi^0$
- **Would need a beam-line upgrade.**

$M(\Xi^+) = M(\Xi^{--}) = 2070$ MeV.

Reactions and Threshold Beam Momenta

Reaction	Momentum (MeV/c)
$K^+ \; n \rightarrow \Theta^+$	442
$K^+ \; p \rightarrow \Theta^+ \; \pi^+$	735
$K^- \; n \rightarrow \Theta^+ \; 2K^-$	2570
$K^- \; p \rightarrow \Theta^+ \; K^- \; \overline{K}^0$	2570
$\pi^+ \; n \rightarrow \Theta^+ \; \overline{K}^0$	1700
$\pi^+ \; p \rightarrow \Theta^+ \; \overline{K}^0 \pi^+$	2010
$\pi^- \; n \rightarrow \Theta^+ \; K^- \; \pi^-$	2010
$\pi^- \; p \rightarrow \Theta^+ \; K^-$	1700
$K^- \; n \rightarrow \Xi^+ \; K^0 \; 2\pi^-$	3675
$K^- \; p \rightarrow \Xi^+ \; K^0 \; \pi^-$	1930
$K^+ \; n \rightarrow \Xi^+ \; 3K^0$	6110
$K^+ \; p \rightarrow \Xi^+ \; 2K^0 \; K^+$	6110
$\pi^+ \; n \rightarrow \Xi^+ \; 2K^0$	4500
$\pi^+ \; p \rightarrow \Xi^+ \; K^+ \; K^0$	4500
$\pi^- \; n \rightarrow \Xi^+ \; 2K^0 + \; 2\pi^-$	5460
$\pi^- \; p \rightarrow \Xi^+ \; 2K^0 \; \pi^-$	4960
$K^- \; n \rightarrow \Xi^{--} \; K^+$	2860
$K^- \; p \rightarrow \Xi^{--} \; K^+ \; \pi^+$	3300
$K^+ \; n \rightarrow \Xi^{--} \; 3K^+$	6110
$K^+ \; p \rightarrow \Xi^{--} \; 3K^+ \; \pi^+$	6660
$\pi^- \; n \rightarrow \Xi^{--} \; K^+ \; K^0$	4500
$\pi^- \; p \rightarrow \Xi^{--} \; 2K^+$	4500
$\pi^+ \; n \rightarrow \Xi^{--} \; 2K^+ \; \pi^+$	4500
$\pi^+ \; p \rightarrow \Xi^{--} \; 2K^+ \; 2\pi^+$	5465

Single-Arm Experiment for Θ^+

Suggested Experiments

- $K^+p \rightarrow \Theta^+\pi^+$ and $K^+d \rightarrow \Theta^+p$
- $p_K \sim 1$ GeV/c $\qquad \Delta p/p \sim 0.7\%$
- LH_2/LD_2 Targets
- Detect π^+ in Moby Dick spectrometer.
- A peak for Θ^+ must follow kinematics.
- $\Delta L = 0$ and 1, respectively.

Comments

- Kinematics gives $T_{\pi^+} = 0$ to 250 MeV.
- $\sigma_{\text{inelastic}} \sim 5$ mb.
- Many open channels with one or more π^+.

Strengths for $k^+p \to \Theta^+\pi^+$

Decays

$$\Theta^+ \to \begin{cases} K^+ + n & 50\% \\ K^0 + p & 50\% \end{cases}$$

$$K^+ \to \begin{cases} \pi^+ + \pi^0 & 21\% \\ \mu^+ + \nu_\mu & 63\% \end{cases}$$

$$K^0 \to 50\%\ K^0_S \qquad 50\%\ K^0_L$$

$$K^0_S \to \begin{cases} \pi^+ + \pi^- & 69\% \\ \pi^0 + \pi^0 & 31\% \end{cases}$$

Strengths

$$K^+p \to \begin{cases} \pi^+ + \pi^+\pi^0 + n & 10.5\% \\ \pi^+ + \mu^+\nu_\mu + n & 31.5\% \\ \pi^+ + \pi^+\pi^- + p & 17.2\% \\ \pi^+ + \pi^0\pi^0 + p & 7.8\% \\ \\ \pi^+ + (K^+\,n) & 8.0\% \\ \pi^+ + (K^0_L\,p) & 25.0\% \end{cases}$$

8.A.8 Nuclear Physics B20 (1970) 301-319. North-Holland Publishing Company

K^+p INTERACTIONS IN THE RANGE 0.9-1.5 GeV/c AND ELASTIC SCATTERING PHASE SHIFT ANALYSIS

G. GIACOMELLI, P. LUGARESI-SERRA, G. MANDRIOLI and A. M. ROSSI
University of Bologna, INFN - sezione di Bologna

F. GRIFFITHS, I. S. HUGHES, D. A. JACOBS, R. JENNINGS and B. C. WILSON
University of Glasgow

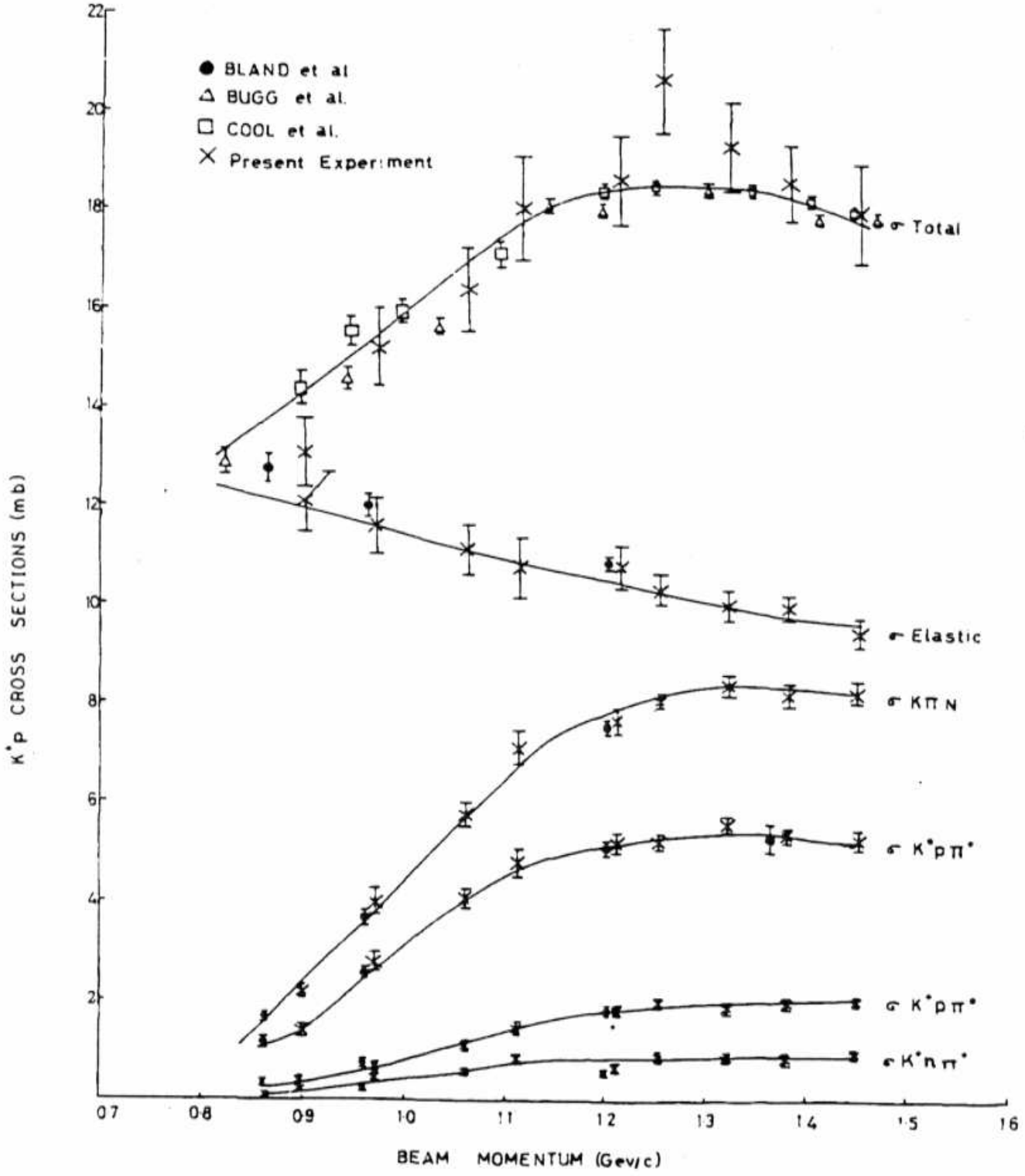
G. CIAPETTI, V. COSTANTINI, G. MARTELLOTTI and D. ZANELLO
University of Roma, INFN - sezione di Roma

E. CASTELLI and M. SESSA
University of Trieste, INFN - sottosezione di Trieste

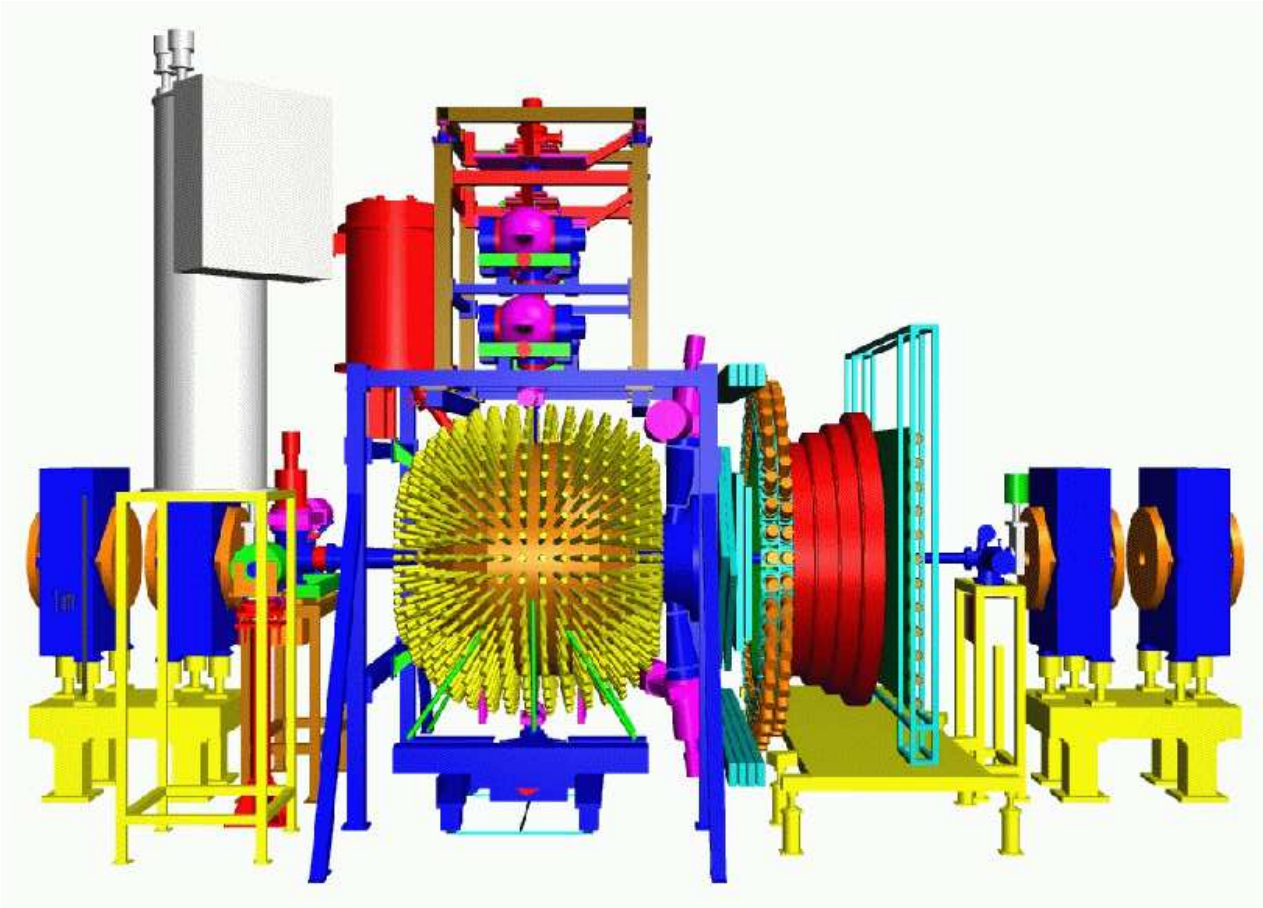
Received 3 February 1970
(Revised 20 March 1970)

1. INTRODUCTION

Interest in K^+ nucleon interactions in the momentum region 0.9-1.5 GeV/c was stimulated by the discovery of peaks in the total $I = 1$ and $I = 0$ cross sections in the K^+p and K^+d measurements of Cool et al. [1]. The results of Cool et al. were confirmed by measurements of Bugg et al. [2]. If these peaks are due to the formation of s-channel resonances, then the intermediate s-channel states have strangeness +1 and baryon number +1 (Z*s). The simplest SU(3) assignments of such states are an antidecuplet ($I = 0$) and 27-plet ($I = 1$). These multiplets cannot be formed in the simple three-quark model of baryons. In addition, there is no strong evidence for the existence of other particles which require such multiplets [3-5].


BLAND et al
BUGG et al.
COOL et al.
Present Experiment
σ Total
σ Elastic
σ KπN
σ K⁺pπ⁺
σ K⁺pπ⁰
σ K⁺nπ⁺
K⁺p CROSS SECTIONS (mb)
BEAM MOMENTUM (Gev/c)
22
20
18
16
14
12
10
8
6
4
2
0·7
0·8
0·9
1·0
1·1
1·2
1·3
1·4
1·5
1·6

WASA Facility



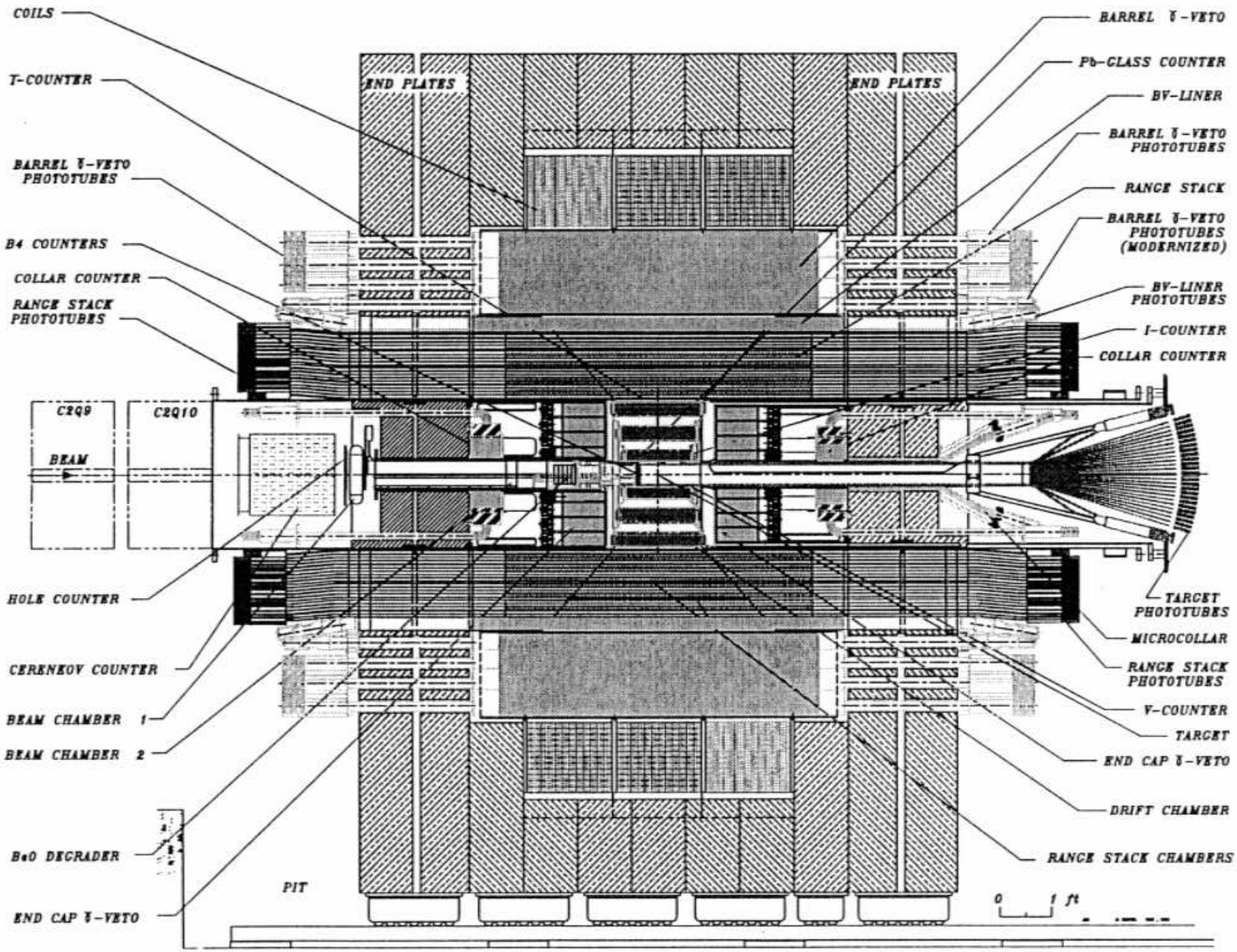


Figure 5: The E949 detector.

Director's Office

BROOKHAVEN
NATIONAL LABORATORY

Building 510F
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-5414
Fax 631 344-5820
tkirk@bnl.gov

managed by Brookhaven Science Associates
for the U.S. Department of Energy

www.bnl.gov

September 17, 2003

Dr. Curt Ekstrom
The Swedborg Laboratory
Uppsala University
Thunbergvagen 5A
S-75121 Uppsala
SWEDEN

Dear Dr. Ekstrom:

I have learned from Joe Comfort of the possibility that the WASA detector is likely to be available for use in experiments at other laboratories within the next 2-3 years.

• • •

In addition to the E927 experiment, I am aware of activities in the Nuclear Physics community to define a program in hadron spectroscopy using pions and kaons up to and beyond 2 GeV. BNL has, arguably, the best facilities worldwide for the goals of such a program in the near-term and the discussion has focused on establishing the program at the AGS. BNL would welcome proposals to carry out such a program. Again, the WASA detector has the right combination of features that to allow the experiments to succeed.

• • •

Sincerely,

Thomas B.W. Kirk
Associate Laboratory Director
High Energy and Nuclear Physics

Cc: J. Comfort

Summary and Conclusions

- **Pentaquarks are one of the most exciting developments in subatomic physics.**
- **This topic alone can justify an extended, systematic baryon spectroscopy program.**
- **Pentaquarks are being pursued vigorously at many laboratories, albeit with probes that are less than ideal.**
- **Pion and Kaon beams are best for future studies.**
- **BNL has the best π and K beams, now and for many more years.**
- **A suitable detector is a challenge, but the E787/E949 detector might be adaptable.**
- **Funding is a slow process. Expressions of community interest should begin now.**