EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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PHYSICS I

ELECTRONICS EXPERIMENTS COMMITTEE

PROPOSAL

MEASUREMENT OF THE HELICITY AMPLITUDES FOR ASSOCIATED PRODUCTION $\pi^- p \to K^o \Lambda$

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In a previous memorandum to the E.E.C.[1] we stated our intention to measure the helicity amplitudes for the associated production $\pi^- p \rightarrow K^o \Lambda$. We now present a proposal to perform this experiment using the CERN-Helsinki frozen spin polarized target which is scheduled for operation in the CERN-ETH magnet early in 1974.

Measurement of Helicity Amplitudes:

The reaction $\pi^- p \rightarrow K^o \Lambda$ is described completely by two complex amplitudes, helicity flip F_{+-} and non-flip F_{++}. These amplitudes can be determined up to an overall phase from $d\sigma/dt$ and the spin rotation parameters P, A and R (see Appendix I). The latter are extracted from analysis of the Λ decay angular distribution following its production from a polarised proton target.

Information is needed on the amplitude structure of two-body processes (in the proposed reaction, $K^*(890)$ and $K^*(1420)$ trajectories are expected to be dominant). Relations can be derived among these amplitudes for many such processes, not only the line reversed processes $K^- p \rightarrow \pi^o \Lambda$ and the pair $\pi^+ p \rightarrow K^+ \Sigma^+$; $K^- p \rightarrow \pi^- \Sigma^+$ but also, via SU(3), for the non-hypercharge exchange (ρ and A_2) processes: e.g. $\pi^- p \rightarrow \pi^o n$, $\pi^- p \rightarrow \eta n$, $K^- p \rightarrow \bar{K}^o n$ etc. [2, 3].

In order to avoid possible s-channel complications [2] we propose to perform the measurement at or above 5 GeV/c.

Experimental Method:

This experiment follows naturally from a series of three experiments (S102) performed during 1971/72 using a butanol polarized target in the CERN-ETH magnet spark chamber system. Two of these experiments, viz $\bar{p}p\uparrow \rightarrow \bar{n}n$ (submitted to Phys. Letters) and $K^- p \rightarrow \bar{K}^o n$, were designed to measure the polarization parameter P, extracted from the spin-up, spin-down asymmetry. The third experiment measured the helicity amplitudes for the 'backward' peak in $\pi^- p \rightarrow \Lambda K^o$, in which the fast forward going Λ decay was observed in the magnet spark chambers.

The polarized target used in these experiments required a 2.5 T field and hence large supplementary pole pieces in the target region. These pole pieces would have restricted too severely the detection of Λ decays in this present experiment where the Λ is a slow wide angle recoil. In order to provide the required wide acceptance in the target region, a frozen spin target is necessary as this will operate without pole pieces in the 1 T field of the CERN-ETH magnet (see Appendix II). The detector will be required to observe both Λ decay and the forward going K^o decay (allowing a 4-C fit and separation of production off free protons from production off bound protons in complex nuclei in the target). Furthermore the detection of the slow Λ should be relatively unbiased. The detection system proposed is shown in fig. 1. The small pole pieces shown produce a 2.5 T field for target polarization. After polarization in this field the target is moved into the '4π-acceptance' region. The spark chamber modules 4, 5 and 6 will be the existing modules (1 gap per 2 cm), while modules 1, 2 and 3 will have double this spark gap density in order to improve the detection and measurement of the slow Λ. The film camera will be replaced by television cameras (see Appendix III) so as to allow higher data rates and higher statistics.

We will use a neutral final states trigger, provided by a scintillator Tungsten sandwich anticoincidence counter $\bar{R}$ completely surrounding the target which will veto charged particles and γ-rays. The downstream counter E will demand the charged K^o_s decay.

Detection Efficiency and Rates:

We investigated the detection efficiency using Monte Carlo simulation of $\pi^- p \rightarrow K^o\Lambda$ with the known production angular distribution. We found that the trigger system selects 13% of the 13 μb cross section in which the $K^o \rightarrow \pi^+\pi^-$. Almost all the loss of events occurs because the Λ's decay before emerging from the veto counter $\bar{R}$. This loss is greatest at low t, which is an advantage as it enhances the statistics at high t relative to low t.

We require that both the decay products of the Λ are measurable. We have taken a minimum of 8 sparks in one track and 20 sparks in the other as our criterion for measurability of the Λ; 60% of charged Λ decays satisfy this criterion. The effective cross section for producing measurable Λ's (4C fits) is thus 0.7 μb.

We intend to use a 15 cm long 2 cm diameter propanediol target giving an interaction rate from free protons of 0.47×10^{-6} events/μb/incident particle. If we use an effective beam intensity of 2×10^{5} incident pions/burst, we obtain the following events (4C fits) from free protons:

$$0.7 \times 0.47 \times 10^{-6} \times 2 \times 10^{5} = 0.066 \text{ events from free protons/burst,}$$

this rate is equivalent to 2×10^{4} events (4C fits)/10 day period.

From our previous experiments we know that the trigger rate for a similar counter arrangement was ~ 40×10^{-6} per incident pion at 5 GeV/c.

Analysis:

We estimate that ~1% of the triggers recorded will satisfy 4-constraint kinematic fits to $\pi^- p \to K^o \Lambda$ from free protons. These are initially selected by identification of the V^o decays which will leave ~ 5% of the triggers for the 4C production fit. The 'background' is contributed by the following processes which will be accepted by the trigger.

1) $\pi^- p \to K^o \Lambda$ on bound protons in the target.
2) $\pi^- p \to K^o \Sigma^o$
3) $\pi^- p \to \Lambda K^o$ (backward peak)
4) $\pi^- p \to K^o Y^*$; $Y^* \to \bar{K}^o n$
5) $\pi^- p \to K^o \bar{K}^o n$.

We do not expect serious contamination from process (2) which can in any case be monitored using the γ veto counter R. We have already collected data on processes (3), (4) and (5) using a polarised target; however the present experiment should increase by a factor ~ 10 the available statistics for reactions (4) and (5) and by a factor ~4 for reaction (3).

The precision which we can obtain for the parameters P, A and R is estimated in Appendix I. A total of 60,000 events $\pi^- p \to K^o \Lambda$ from free protons within the momentum transfer interval $0 < -t < 1.5$ $(GeV/c)^2$ will allow a determination of A and R to better than ± 0.1 in 15 't bins'. The precision on the polarization parameter P will be better (limited only by systematic errors).

We therefore request 3 periods of 18 days for production in a suitable negative beam (10^6 pions/burst at 5 GeV/c).

We are requesting approval of this proposal from the RHEL selection panel meeting in April. We intend to analyse the data on the RHEL IBM 360/195 and ask only facilities for sample analysis on the CERN computers.

References

1) PH 1/COM-71/41
2) A. Martin, C. Michael and R. Phillips, Nucl. Phys. B43 (1972) 13.
3) G. Fox, Proceedings of the second conference on polarized targets, LBL Berkeley (1971).

APPENDIX I

If the helicity-flip and non-flip amplitudes are F_{+-} and F_{++} respectively, then we define the parameters P, A and R by:

$$P = \frac{2\, I_m\, (F_{++}\, F^*_{+-})}{|F_{++}|^2 + |F_{+-}|^2}$$

$$A = \frac{|F_{++}|^2 - |F_{+-}|^2}{|F_{++}|^2 + |F_{+-}|^2}$$

$$R = \frac{2\, R_e\, (F_{++}\, F^*_{+-})}{|F_{++}|^2 + |F_{+-}|^2}$$

and $$\frac{d\sigma}{dt} \propto |F_{++}|^2 + |F_{+-}|^2$$

These parameters are constrained as follows:

$$P^2 + A^2 + R^2 = 1$$

Defining the angles ϕ, θ, ψ as in fig. 2, the probability distribution function $W(\cos\theta, \phi, \psi)$ describing the Λ decay is given by:

$$W(\cos\theta, \phi, \psi) = \frac{1}{8\pi^2} \Big[1 + P \sin\theta \sin\psi + P_T \{P \sin\phi + \alpha(\sin\phi \sin\theta \sin\psi + R \cos\phi \cos\theta + A \cos\phi \sin\theta \cos\psi)\}\Big]$$

where P_T is the target polarization and α is the asymmetry parameter of the Λ decay (0.645 ± 0.016).

Extracting A and R by a moment analysis leads to statistical errors

$\sigma_A = \sigma_R = \pm \frac{1}{\alpha P_T'} \sqrt{\frac{6}{N}}$, here N is the number of events in the 't bin' and

P'_T is the effective polarization of the target. For example in the interval $0.6 < -t < 0.7$ $(GeV/c)^2$, where we expect to obtain 2400 events, we get $\sigma_A = \sigma_R = \pm 0.11$ for an effective target polarization $P'_T = 0.7$.

The statistical errors on P will be about a factor of three smaller than those on A and R. Use of the maximum likelihood technique together with the constraint $P^2 + A^2 + R^2 = 1$ will further reduce the statistical uncertainty on A and R.

We will be able to correct for any bias in the Λ decay angular distribution by comparing the measured distributions from an unpolarized target (obtained by combining the normalised target spin-up with the spin-down data) with the expected distribution function

$$W(\theta,\psi) = \frac{1}{8\pi^2}\,(1 + \alpha P \sin\theta \sin\psi),$$

here the parameter P can be obtained in an unbiased way from the usual spin-up , spin-down asymmetry. Events from bound protons may also be included for the purpose of estimating a correction function.

APPENDIX II

The CERN polarized target group is at present preparing a frozen spin target to be installed next winter in the CERN-ETH magnet.

The frozen spin technique involves polarizing the protons in a magnetic field with the required strength and homogeneity and afterwards transferring the polarized target into a holding field which is adapted to the requirements of the scattering experiment. The polarization then decreases as $P(t) = P_o e^{-t/T_o}$; T_o is the relaxation time which is strongly dependent on the holding field and the temperature. Fig. 3 shows the characteristics for 1, 2 propanediol ($C_3H_8O_2$) which will be used as target material. For propanediol the ratio of free protons to bound protons is 1/4 but with high initial polarization (> 80%).

For a holding field of 1.0 T (CERN-ETH field) one sees that for temperatures < 0.1 K one can have T_o > 100 hrs. This time is well matched to the need for polarization reversal every day or so, the polarization falling by ~ 20% in that time. The NMR technique will be used to measure P(t) to ± 2% during data taking.

Temperatures of ≲ 0.1 K for polarized target samples have been achieved in a prototype He_3-He_4 dilution cryostat that has been developed by the Helsinki Technical University group.

APPENDIX III

A system of 7 TV cameras is used to read out the optical spark chambers. A diagram of the proposed layout is shown in Fig. 4. Six of the cameras are mounted above the magnet and arranged in 3 stereo pairs (A_1, A_2; B_1, B_2; C_1, C_2 ; the letter denotes the pair and the numeral the view) with each pair viewing a different set of chambers in the magnet. The virtual camera positions are 270 cm above the median plane and the separation of cameras in a pair is 58 cm, giving a stereo angle of 11^o. The separation of virtual camera positions of the 3 cameras of a given view is kept to a minimum in order to reduce software pattern recognition problems. The 7th camera (D in figure 4) is mounted at beam height upstream of the magnet and is used to give a 90^o stereo view of tracks near the target region. Perspex prisms are mounted just in front of the chamber optical windows in order to allow the cameras to "see" into the chamber gaps. The prisms for the top views are the same as were used successfully in previous experiments while the prisms for camera D will have to be manufactured and tested for optical distortions.

As can be seen in Figure 4 the areas viewed by the different camera pairs are unequal, with pairs A and B each viewing an area only half as large as that viewed by pair C. Two criteria were considered in choosing this layout.

1) Since the Λ energy is low the trajectories of its decay products are at wide angles and many have relatively short track lengths within the chamber volume. In order to make a good measurement of the Λ direction and energy it is therefore desirable to minimize the measuring errors on sparks appearing in the upstream half of the magnet where most of the Λ decay products appear. With the proposed layout the demagnification in the upstream half of the magnet is a factor $\sqrt{2}$ less and hence the measuring errors a factor $\sqrt{2}$ better than in the downstream half of the magnet.

2) Because the cameras are read out in parallel, the overall cycle time of the system is dictated by the cameras with the most scan lines. Thus in order to minimize readout cycle time it is necessary for all cameras to view approximately the same number of spark gaps. With the proposed layout each camera scans 36 spark gaps and 4 fiducial "gaps" for a total of 40 scan lines per camera. Camera D scans 60 gaps but with shorter scan lines and will be operated in a mode of twice the line scan frequency.

The TV cameras and the associated readout system are identical to those used in the Omega system. The cameras are driven in parallel and operated in a mode in which the scanning rasters of the cameras are adjusted to give one scan line per chamber gap. The readout cycle of the cameras consists of 3 separate scans of the line raster. The first scan after an event trigger is a "pre-read" scan which reduces the magnitude of charge images produced by bright sparks. This is necessary in order to reduce the dynamic range of signals during the read cycle to a level which can be handled by the digitizing system. The second cycle is the read cycle in which the positions of spark images are digitized by scaling a 90 MHz clock with scalers which are started at the beginning of each scan line and stopped sequentially as spark images are encountered during the line scan. When the end of line is reached, the scaler contents are dumped into buffers which are read into the computer while the cameras are scanning the following line. The third cycle is a "heavy wipe" one in which residual charge images are removed. At the end of the heavy wipe cycle the cameras are ready for another trigger and are operated in a light wipe mode until the arrival of the next trigger.

The line scan speed is 110 μs/line/cycle which yields a total dead time for a 40 line raster of 3 cycles x 40 $\frac{\text{line}}{\text{cycle}} \times \frac{110\ \mu\text{s}}{\text{line}} = 13.2$ ms.

The digitizing system consists of specially built Camac modules made up of a master driver and any number of scaler units which each contain 5 scalers. We propose to use 2 scaler units per camera making the system capable of handling up to 10 sparks (or fiducials) per gap.

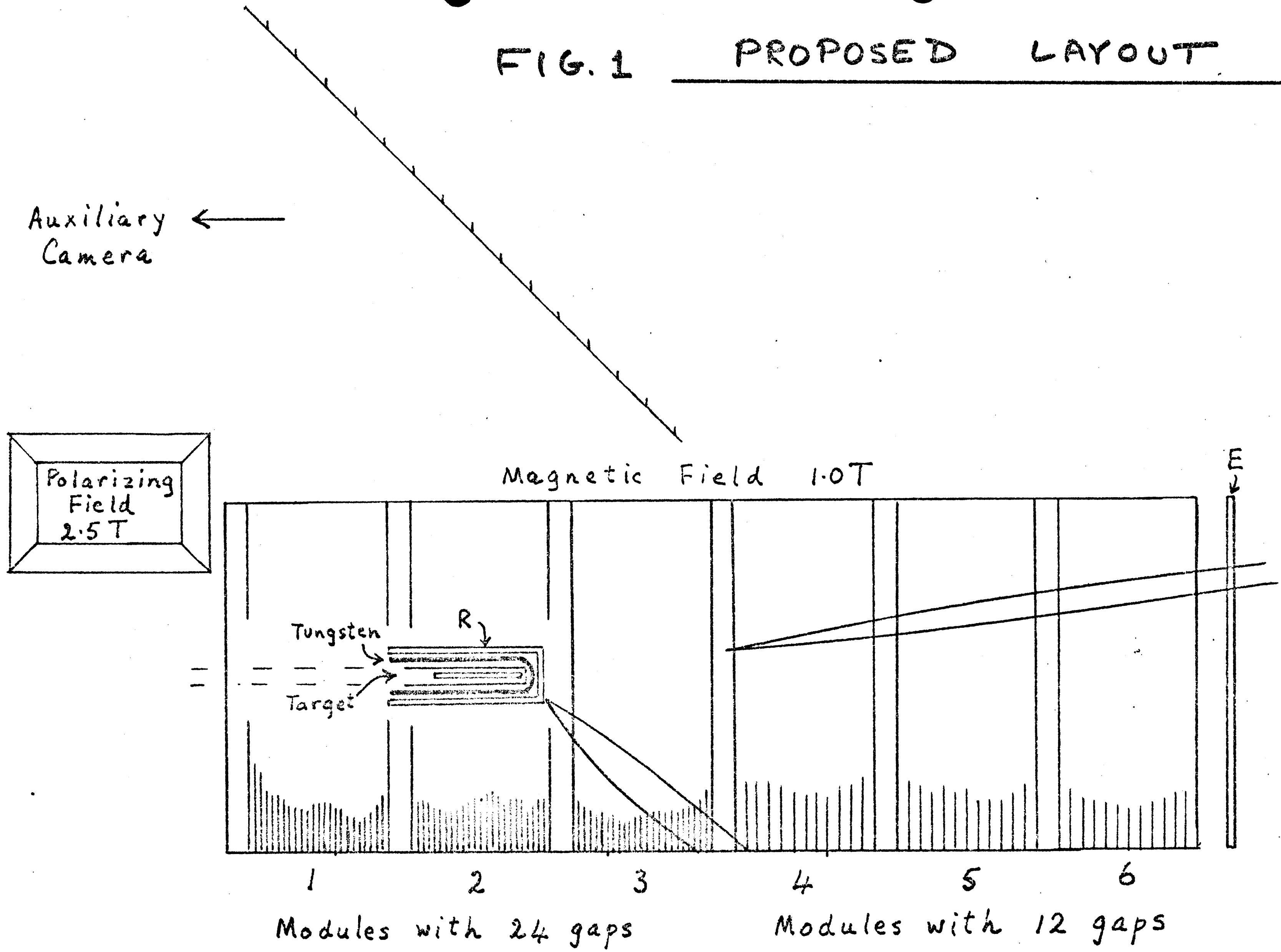
We propose to read out the system using the Honeywell 516 computer presently used by Imperial College at the Rutherford Laboratory. We would require the addition of 8 k of memory, a larger disk and a second tape unit. Assuming an average of 1,000 data words per event, the system would be able to operate at up to 20 events/burst.

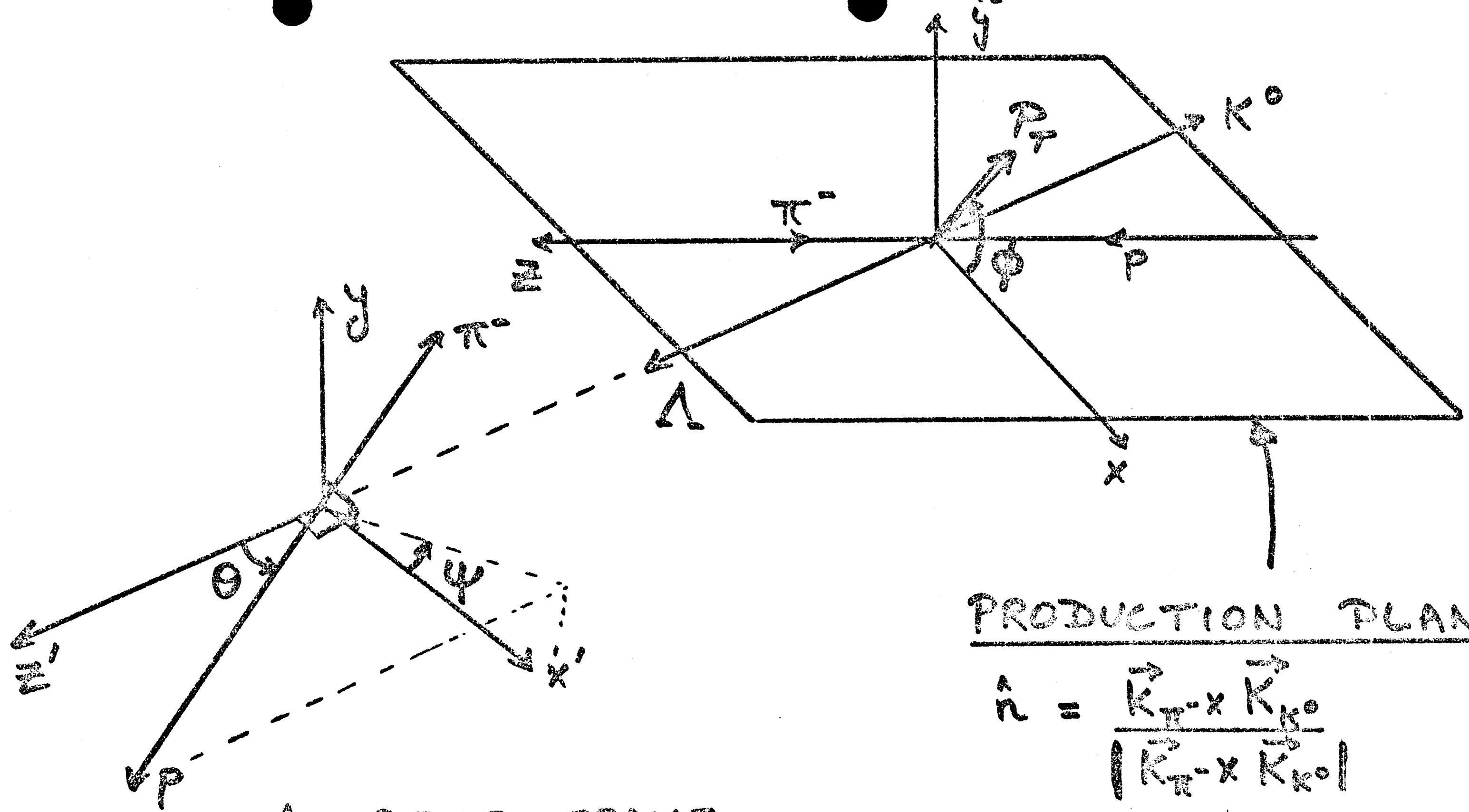
Accuracy

We calculate the spark digitizing precision of our proposed system assuming the same digitizing accuracy as measured in the Omega system. With only the 3 pairs of cameras the following accuracies are obtained - in the upstream chambers the spark measurement accuracy will be ± 0.18 mm in the horizontal direction and ± 1.7 mm vertically. The precision in the downstream half of the magnet will be ± 0.27 mm horizontally and ± 2.5 mm vertically. Camera D improves the vertical accuracy in the target region to ± 0.2 mm.

The measuring accuracy of the system may be improved with the addition of pulse height measurement of spark signals and software correction for signal amplitude. Such a system is presently being tested in Omega and results should be available at the end of April.

FIG. 1 PROPOSED LAYOUT





PRODUCTION PLANE

$$\hat{n} = \frac{\vec{K}_{\pi^-} \times \vec{K}_{K^0}}{|\vec{K}_{\pi^-} \times \vec{K}_{K^0}|}$$

P_T is target Polarization

Λ REST FRAME

FIG. 2 Our Convention for ϕ, θ and ψ

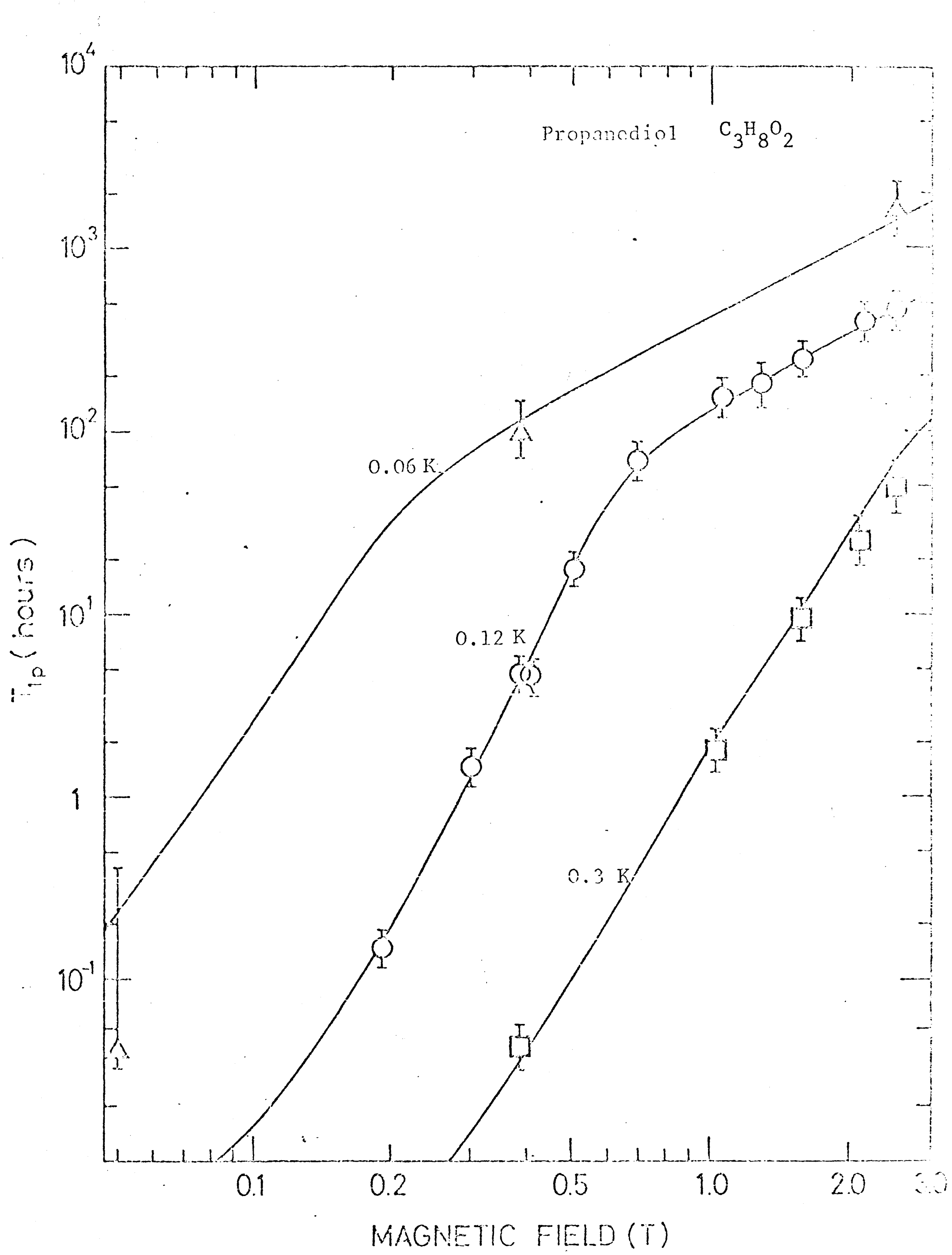

Propanediol $C_3H_8O_2$
0.06 K
0.12 K
0.3 K
T_{1p} (hours)
10^4
10^3
10^2
10^1
1
10^{-1}
0.1
0.2
0.5
1.0
2.0
3.0
MAGNETIC FIELD (T)

Fig. 3

FIG. 4

PROPOSED LAYOUT OF TV CAMERAS