M E M O R A N D U M

Date: 27th August, 1962.

TO: The Electronic Experiments Committee.

FROM: L.W. Jones, D.O. Caldwell, B. Elsner, D. Harting and W.C. Middelkoop.

CONCERNING: The S_1 Experimental (π-p scattering at high energies)

The S_1 experiment was proposed in October 1961 by Jones, Harting and Middelkoop. The purpose of the experiment is the measurement of the differential cross-section for elastic π-p scattering at high energy, 12 GeV/c and 18 GeV/c were chosen for the incoming π momenta, up to the largest scattering angles and with the highest accuracy possible with present techniques.

With the proposed apparatus, a spark chamber arrangement with triggering counters, a limit of 1μb/sr for a 10% measurement was thought to be quite practicable. As no knowledge about the cross-section of the elastic π-p scattering at larger momentum transfers was available at that time for energies above 2.5 GeV/c an attempt was made to extrapolate existing data to the energy and angle region in which we were interested.

On the basis of this entrapolation the experiment was accordingly planned to cover all laboratory angles from 4° to 90° in the laboratory system, corresponding to an angular range from from 25° to 160° in the c.m.

At the meetings of the Rochester Conference of July 1962, we were able to appraise more recent data from experiments up to 5 GeV/$_c$ as well as results of pp scattering, and to discuss at greater length the present theoretical interests in the data. The information which has suggested a rearrangement of our experiment is primarily the observation that the differential elastic scattering cross-section is falling off rather rapidly beyond the diffraction peak at high pion energies and is expected to be well below 1μb/$_{sr}$ at our chosen energies already at much smaller angles than we considered necessary to cover in the original design. It seems, therefore, advisable to decrease the angular range covered in the first proposal which will result in a much better measurement of the cross-sections in the smaller angular range now considered. It is then possible to include an accurate measurement of momentum of all outgoing pions.

This is important for the following reasons. There is increasing interest in the diffraction inelastic process and in the details of the shrinking of the diffraction peak over a wide range of momentum transfers as a consequence of the theories related to the Regge pole concept. Also, by determining the momentum of the scattered pion in addition to an accurate measurement of the scattering angles, the lower limit to the cross-section that can be measured with e.g. 10% accuracy can be reduced by an appreciable factor and diffraction inelastic events can be measured much more quantitatively than in the original arrangement proposed for this experiment.

The apparatus layout as conceived for the improved experiment is indicated in the attached sketch.

The incoming and outgoing pion are momentum analyzed by 2 meter bending magnets to an accuracy of about 1.5% using pairs of spark chambers to define each track entering and leaving a magnet to about 7×10^{-4} radians. The same spark chambers determine the pion scattering angle to 10^{-3} radians. The recoil proton is not momentum analyzed, but its angle is measured to $<10^{-2}$ radians.

Three sets of trigger counters are used: each spanning a different (but overlapping) range of scattering angles from 15 to 130 milliradians. The lower limit is set by the range of the recoiling proton within the liquid hydrogen target; the upper limit is set by the good-field aperture of the 2 meter magnet.

From an optical model of diffraction scattering, the integrated cross-section for elastic scattering is one microbarn for $\theta \geq 4.5^{\circ}$ at 18 GeV/$_c$ and for $\theta \geq 6.5^{\circ}$ at 12 GeV/$_c$, not including the shrinking of the diffraction peak suggested by the recent theories growing out of the Regge pole concept. It is seen, then, that the range of θ included is compatible with the range over which we expect a cross-section detectable by this technique.

Using three sets of trigger counters, data would be collected at a high rate over the entire angular range covered, so that in 10^4 bursts of 10^4 pions per burst, 3×10^4 diffraction events would fall into the solid angle subtended by our trigger counters. This requires only two shifts of PS operation at 12 GeV/$_c$ and four shifts at 18 GeV/$_c$ pion momentum. We would devote the majority of our running time to operation where one and two of the coincidence channels were in anticoincidence to collect scattering data with good statistics at angles where the cross-section is small. Thus 20 shifts of PS running will provide 50 events of 1 microbarn cross-section.

Diffraction inelastic events are collected by removing the criterion of a proton coincidence, again running in the different modes indicated for the elastic triggering.

In summary, then, our programme is to improve our apparatus to select only those angles where we expect the cross-section to be measurable by our techniques, and at these angles then to take more precise data (e.g. momentum analyzed pions) than would have been possible with the previously described apparatus. The apparatus layout for this experiment is largely identical to that with which the S_2 (diboson) experiment has just been successfully completed. We will use the same beam, d12, which provides a very adequate intensity at both chosen momenta. The running time required is of course consistant with our previous request, as approved.

At the suggestion of the NPRC we have investigated what data were available from bubble chamber exposures to date. There seems to be only two sets of film related to this problem. One is the run at 16 GeV/$_c$ π^- made in the 30 cm chamber from which a meager sample of 300 elastic events has been obtained. The second is an exposure of the 81 cm chamber at 10 GeV/$_c$ π^- (below our lowest proposed energy) where a maximum of 3000 events may exist on the film, however a very small fraction of these have been analyzed. Of course, these all correspond to completely unselected events, and the majority lie at very small angles. We are very interested in even this sample and we would be willing to undertake analysis of this elastic data with the bubble chamber analysis facilities at the University of Michigan (the oldest and among the most advanced bubble chamber facilities in existence). However, as stated repeatedly, it is our objective in this experiment to get differential cross-sections to 10% statistics over a range of angles where bubble chamber exposures can be expected to have only one or two events total. In addition the π^+ data we will take cannot be collected by bubble chambers for some time to come.

The experiment as proposed and scheduled seems compatible with other counter experiments in period III. Specifically, the C_4 beam and experiments with it do not conflict. We do stress the advantages to all concerned in pressing this experiment forward with vigour to completion. In particular, the activities connected with the neutrino shielding may proceed with less conflict when our apparatus is removed, and the proposed m2 beam may be installed for a prolonged period after we are finished without interruption. From our indirect information concerning the status of experiments during period III we cannot escape the feeling that our elastic scattering experiment is of more immediate and vital interest than the proposed m2 experiments, and we feel it would be unfortunate for time to be lost to our experiment from this source.

As a final note, it is our conviction that the elastic scattering data must be collected with good statistics over the largest possible range of momentum transfers, and that only with results of high precision will definitive conclusions relative to the concepts of Regge trajectories be possible. Our feeling in this regard is strengthened by the recent paper of Hanajou, Phillips and Rarita pointing out just one facet of the potential complexities of the theory. We remain convinced that our experiment is the most suitable method of collecting this data, and that our results will substantially influence the interpretation of the recent theories of strong interactions.

Summary of Objectives of π - p Scattering Experiment

1. To measure the $\pi^{\pm}$ - p elastic scattering cross-section to as large a scattering angle as is possible with a reasonable amount of accelerator time. This objective is the same as in the previous proposal; we have simply revised our estimate of the size of that angle and of the effect of inelastic backgrounds.

2. To observe the narrowing of the diffraction peak with increasing energy. This is also as proposed previously, except that the measurements will now be extended to smaller angles. In particular it will be interesting to see whether the scattering can be fitted in the same manner as the p - p scattering case, predominantly by the vacuum Regge trajectory. Measurements at two energies over a range of momentum transfers determine this trajectory, and we will now be able to carry this closer to the poles. By including π^{+}p scattering, contributions from different trajectories may be studied.

3. To determine the momentum distribution of slightly inelastic pion scatterings ($\lesssim$ 2 GeV inelasticity) over a range of angles and at two incident energies to determine

   (1) If peaks appear in the momentum distribution, as in the p - p case.

   (2) If such peaks appear whether their energy and angle dependence fits a one-pion exchange model or the vacuum Regge trajectory.

4. To find whether the high energy slightly inelastic scattering really results in a two-body final state, the pion and a nucleon isobar. This can be checked more explicitly than

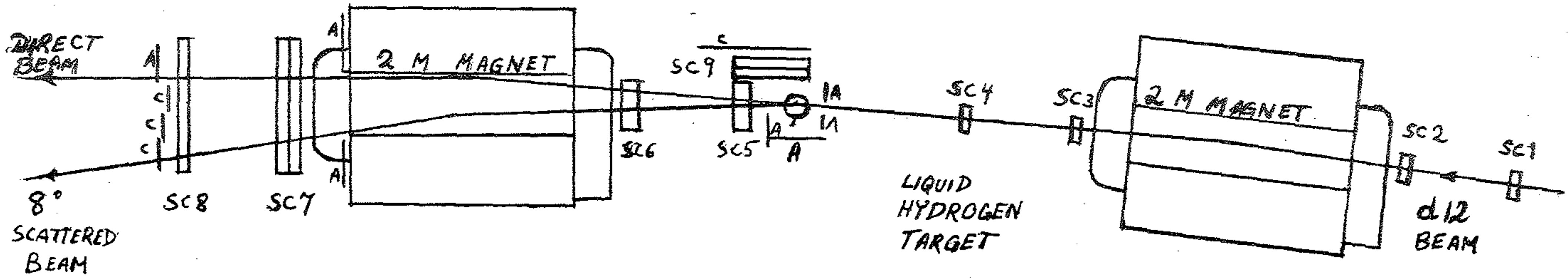
by the observation of peaks in the cross-section, since the kinematics are now determined by the pion angle and momentum and the proton angle.

The last two objectives were not possible in the previous experimental arrangement, and the first two can be achieved with more precision in the presently proposed configuration. Not only can a large range of four-momentum transfers be covered (0.1 to 5 $(\mathrm{GeV}/_c)^2$), but also these can be measured with excellent accuracy (12% to 3%, respectively).

Summary of Parameters

Target	: 20 cm Liquid Hydrogen (0.84×10^{24} $\frac{\text{protons}}{\text{cm}^2}$)
θ angle subtended	: 1° to 7.5° π angle (lab) [2.5° to 19° C.M.S. at 12 GeV/c; 3° – 22.5° C.M.S. at 18 GeV/c] 30° to 90° p angle (lab)
∅ angle subtended	: 16° from all points in target
Momentum resolution on scattered pion relative to incident pion.	: $\frac{\Delta p}{p} = 1.5\%$; $\Delta p \cong 200$ MeV/c at 12 GeV/c $\Delta p \cong 300$ MeV/c at 18 GeV/c
Resolution of pion scattering angle.	: $\Delta\theta = 10^{-3}$ radians
Resolution of proton angle.	: $\Delta\theta = 5 \times 10^{-3}$ radians
Negative pion beam flux.	: 12 GeV/c up to 2×10^{5} per burst; 18 GeV/c up to 4×10^{4} per burst } measured in d 12 beam
Positive pion flux	: not measured in d 12 beam yet, but expected to be about 10^{4} per burst at 12 GeV/c from experience in d 7 beam.

DESIGN OF S 1 EXPERIMENT AS AMENDED 25/8/62



SC 1 – SC 9 SPARK CHAMBERS
C COINCIDENCE COUNTERS
A ANTICOINCIDENCE COUNTERS

HYDROGEN HUT