EARLY STRONG INTERACTION COUNTER EXPERIMENTS

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ABSTRACT

The 17° beam and some π-p two body scattering experiments run in the beginning years of the ZGS are discussed.

INTRODUCTION

I would like in this talk to give you a bit of the flavor of the early counter experiments and their physics results. I will briefly describe the ZGS 17° beam line where the initial counter type scattering experiments took place, looking at the status of the line at machine turn-on, the equipment available, and the design of the beam for the counter program. This paper will then discuss a few of the early strong interaction counter experiments which turned out to be the start of major research areas at the ZGS. The experiments discussed will be limited to π-p two body scattering - most of the initial strong interaction experiments were of this type, and the kaon and proton work will be considered in other papers.

Two π-p elastic scattering experiments will be described. One, a systematic study of $\pi^{\pm}p$ angular distributions as a function of energy, and the second, π^-p backward scattering, right at 180°, with a very detailed energy dependence. The elastic scattering field has proven one of the strongest ZGS areas. An early large magnet spectrometer experiment presented here, on associated production, $\pi^+p \rightarrow K^+\Sigma^+$, was the start of a major spectrometer program, and was a predecessor of the highly successful Effective Mass Spectrometer. Finally, two experiments will be described that began ZGS polarization physics: measurements of the asymmetry parameter in π^-p elastic and charge exchange scattering using a polarized proton target.

17° BEAM

Experiments at the ZGS were first done using an internal target. Three main beams were planned for at turn-on: the 7° separated beam for the 30" MURA bubble chamber, the 17° beam for unseparated pion counter experiments, and the 30° beam for low momentum kaon physics. A layout for the initial stages of the three beams, which obviously coupled closely with the accelerator and shield wall, was worked out quite early, and gave the experimenters a well defined starting point for the detailed beam design required for their set ups. A schematic of the internal target region and planned initial stages of the three
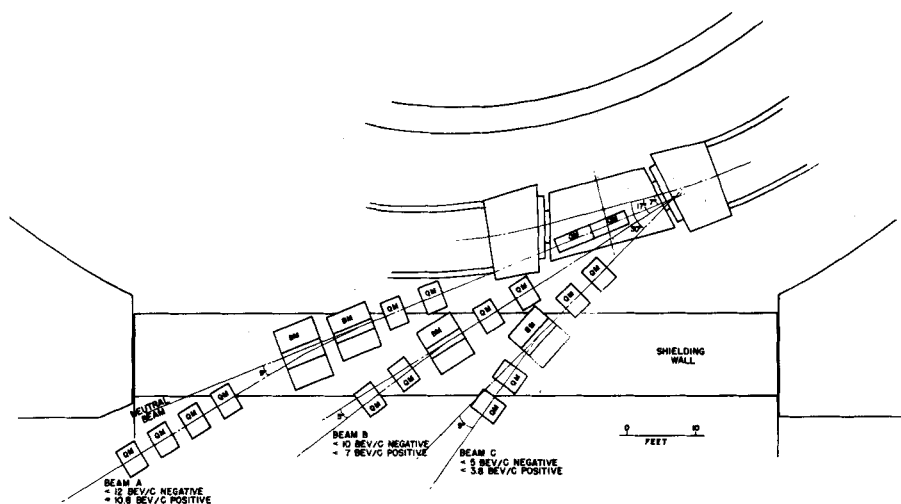
Fig. 1. Plans for internal target area and first stages
of beam lines.

beams is shown in Fig. 1. Looking back over the ZGS user
group meeting reports, I noted considerable discussion of
the expected flexibility of the shield wall and beams - in
fact some support posts originally in the design were
removed to keep the area open for beam line changes. Once
in position, however, the initial beam components became
rather permanent - the basic three charged beam line
arrangement remained for the life of the internal target,
and only the 30° shield wall section had a major reworking.
    The possible particle momenta for each beam, determined
by the machine field and target position, were calculated
by Larry Ratner and were readily available in the ZGS Users
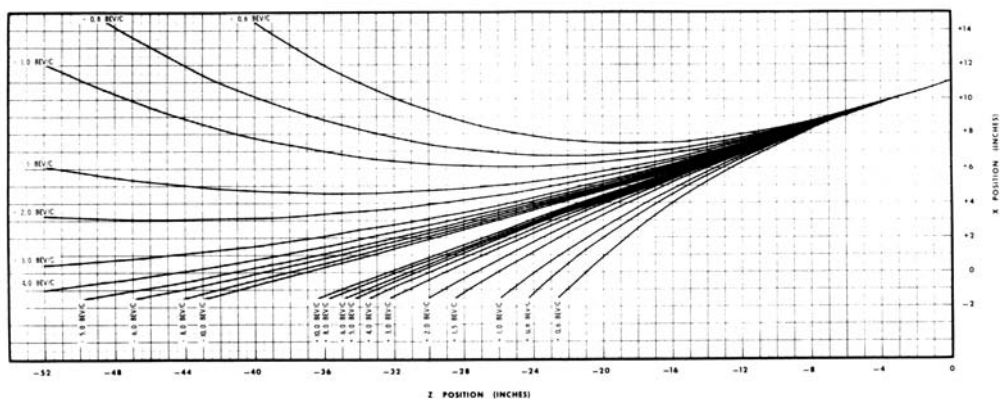Handbook. Fig. 2 is a page from the Handbook showing the

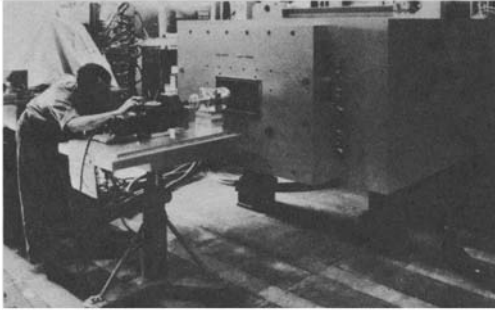Fig. 2. Allowed momenta for 17° beam.

Fig. 3. Bending magnet BM105.

17° beam range. Also available for initial experiments was an adequate supply of bending magnets and quadrupoles. Fig. 3 shows a standard ZGS bending magnet, BM105, being measured and Fig. 4 its properties. The magnets and quadruples were well measured and were standard enough that experimenters could generally take them as given units for a beam, and quite reliably design the beam and predict its properties. From the experimenters' sketches the ZGS staff would make layout
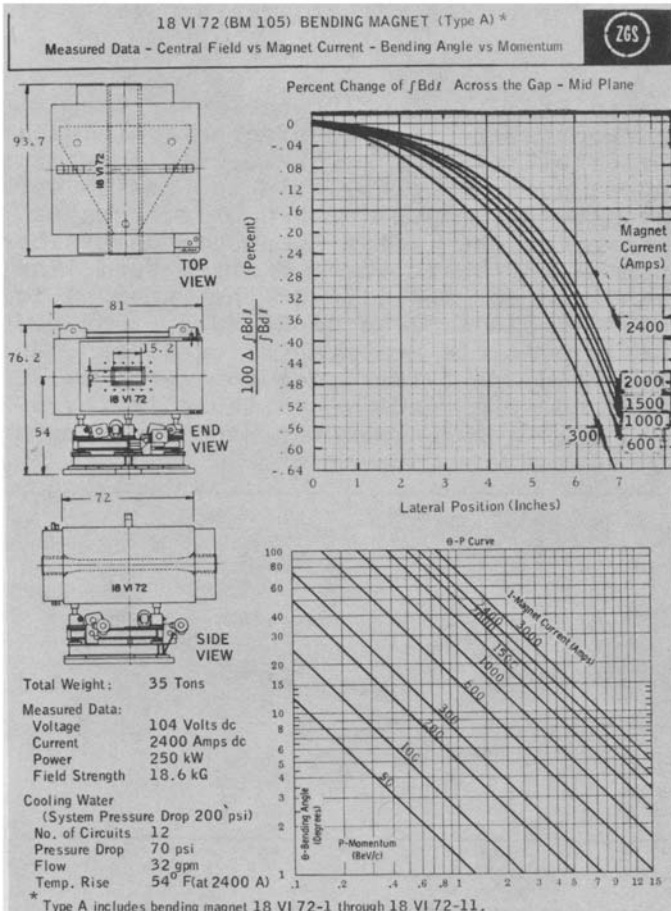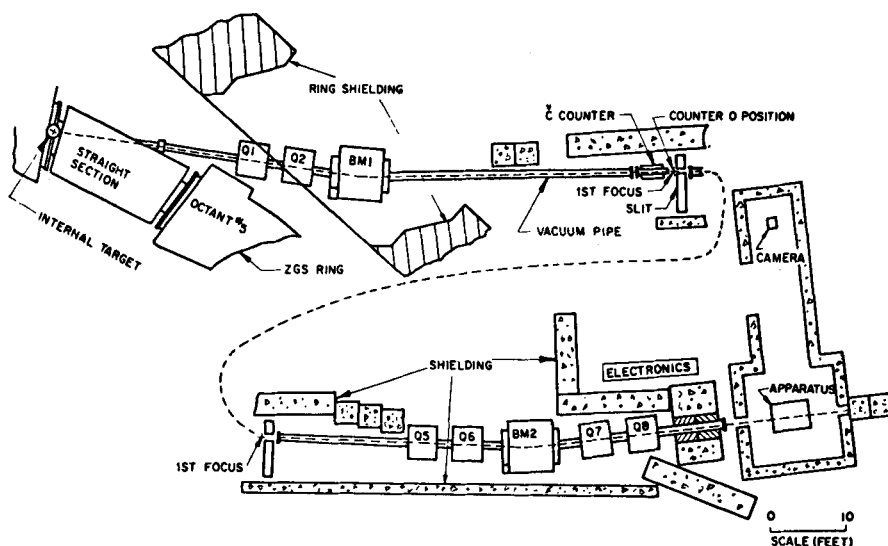

Fig. 4. BM105 properties.

Fig. 5. Layout of 17° beam and set up of optical spark chamber elastic scattering experiment.

drawings and position the magnets and shielding. An experimenter could rely on top quality professional help right at the start of the ZGS. For the 17° beam Wayne Nestander's layout drawings with small specified positioning errors materialized on the floor within specs. The 17° beam we worked up was quite simple - a two stage beam (Fig. 5) with $\sim$ 1% momentum resolution, about 2→6 GeV/c, delivering up to $\sim$ 3 x 10^5 π per 5 x 10^{11} accelerated protons; the π$^+$ intensity, with non-0° production, was much lower.

EXPERIMENTS

ELASTIC πp SCATTERING

π$^\pm$p Elastic Scattering 2.3→6 GeV/c (E-3)

This Michigan experiment[1] used optical spark chambers and was designed to be as simple as possible for the initial turn on - measuring elastic scattering in the horizontal plane. The general layout is shown in Fig. 5. A top view of the spark chamber and a photo of spark chamber tracks of an event are presented in Fig. 6. The experiment was just a bit too simple it turned out - four gap chambers are pretty minimal. We also had just two views of each chamber at 90° which made it hard to handle more than one track, limiting the data rate. Also some anticoincidence counters could have suppressed
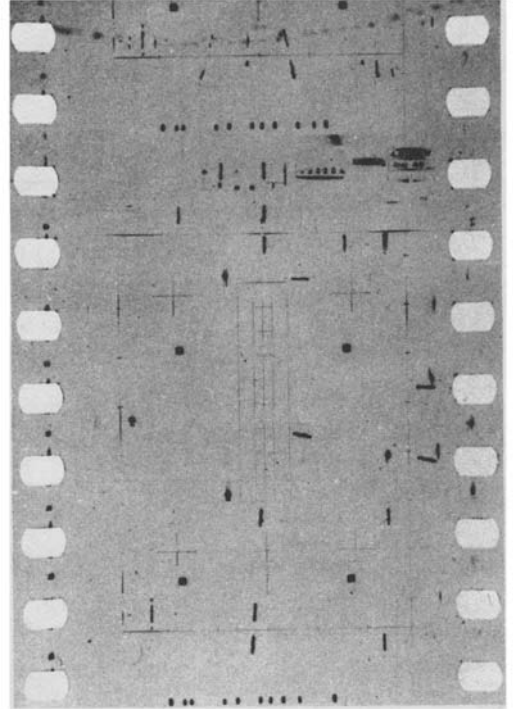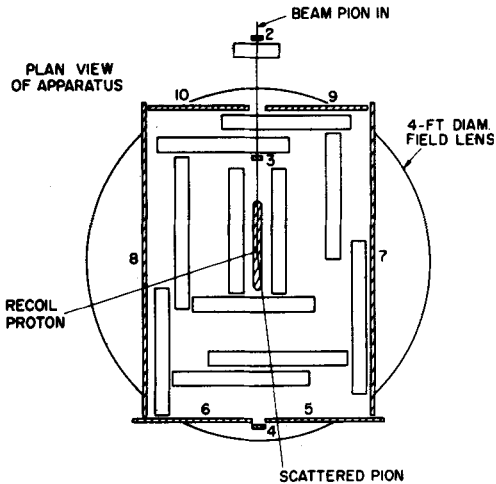
Fig. 6. Left, plan view of spark chambers, right, photo of an event, elastic $\pi^{\pm}$p scattering experiment.

many of the inelastics. So, we learned. But since the physics was simple, too, we got reasonable data which rather surprisingly had not yet been obtained elsewhere. Our results, in Fig. 7 and 8, show that the structure previously observed at lower energy in $\pi^- $p elastic scattering was in fact quite a systematic phenomenon, having similarities to the structure observed in charge exchange scattering.

π^-p 180° Elastic Scattering, 1.6 to 5.3 GeV/c. (E-30)

Another elastic scattering experiment, done the following year in the same 17° beam line by Alan Krisch and his group,[2] is probably one of the most often cited experiments from the ZGS - because the group made a set of precision measurements in a region where the theorists found their models could do a lot of predicting: exactly backwards π^-p elastic scattering. This experiment, like the subsequent experiments of Krisch and his group, is conceptually very simple - designed with what looks like more than enough constraints-
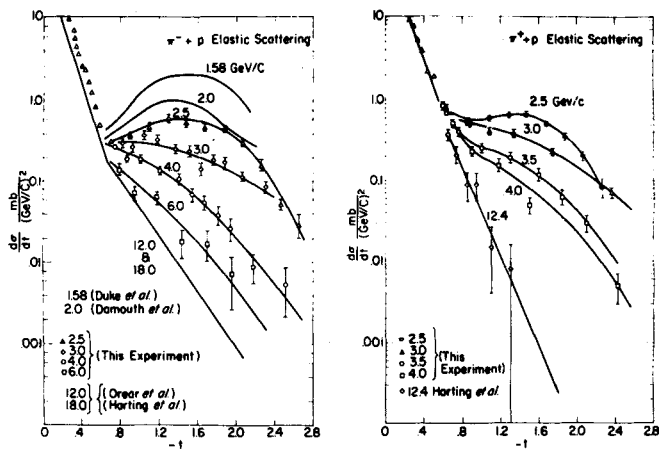
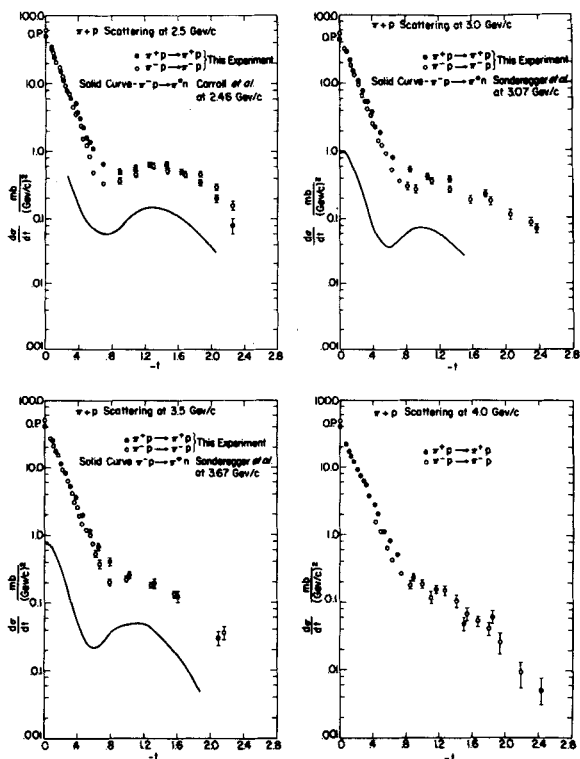Fig. 7. Energy dependence of angular distributions.

Fig. 8. Comparison with charge exchange scattering.

β_max

β_min

π Collimator

H Target

π₃ π₂

B₂

H

B₃

Last Quad in 17° Beam

τ Magnet

P Collimator

P Magnet

P_0 = 3.6 — 5.3 GeV/c

P_0 = 2.5 — 3.5 GeV/c

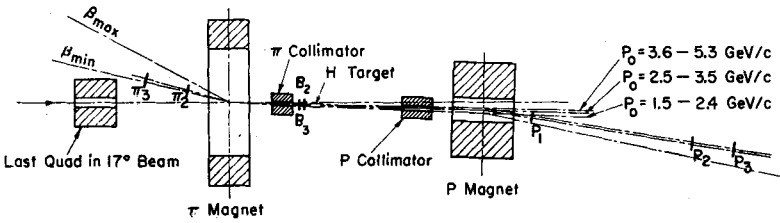P_0 = 1.5 — 2.4 GeV/c

P₁

P₂   P₃

Fig. 9.   Layout for backward elastic scattering experiment

an overdesign approach that generally pays off, since
there are usually problems one hasn't counted on. The
group's set up is shown in Fig. 9. With the magnets left
stationary they were able to do measurements over a wide
range of momenta by just changing fields and moving counters-
a style of operation the group has continued to use.   I
remember looking at the experiment for the first time -
I was somewhat startled by the number of lines on the floor-
there was one line for each point, and there were clearly
a lot of points being planned. They got their points
all right, as seen in Fig. 10.   The very rich structure
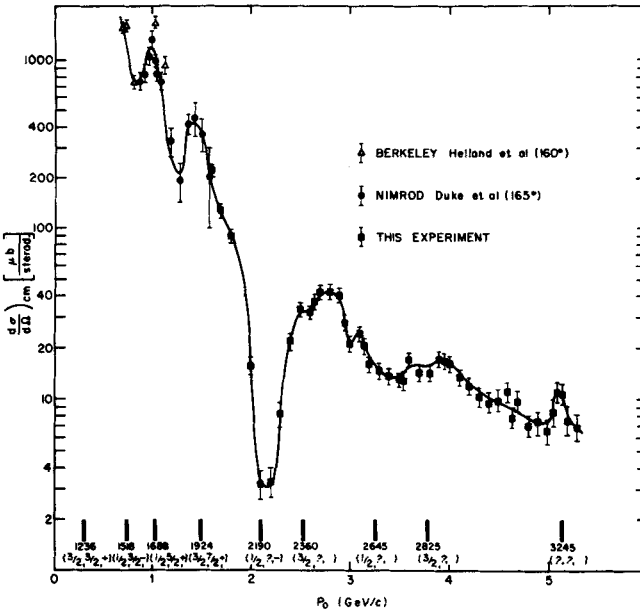showed strong resonance effects-particularly at the

$\frac{d\sigma}{d\Omega}$ cm $\left[\frac{\mu b}{sterad}\right]$

BERKELEY Holland et al (160°)

NIMROD Duke et al (165°)

THIS EXPERIMENT

1236   1518   1688   1924   2190   2360   2645   2825   3245

P_0 (GeV/c)

Fig. 10.   180° π⁻p elastic scattering cross section as a
function of π⁻ laboratory momentum.   Resonance positions
are indicated.

center of mass energy of 2190 MeV. The destructive or
constructive interferences with background enabled many
quite clear parity assignments. The couple of standard
deviation peak at 3245 MeV hasn't been seen by others -
though nobody else has looked at exactly 180° with better
statistics.

These two experiments were the first in a series of
very productive elastic scattering experiments involving
a variety of groups - it has been a strong program.

SPECTROMETER EXPERIMENT

Very early, well before ZGS turn on, Don Meyer was
pushing for the construction of a general purpose spectro-
meter magnet for spark chamber experiments.[3] The final
resulting magnet, SCM105, has turned out to be extremely
useful (as in the previous described experiment). A
schematic of the magnet, from the ZGS Users Handbook,
is shown in Fig. 11. This magnet was used by Meyer and
his collaborators for a very productive series of spark
chamber experiments. I consider that the Effective
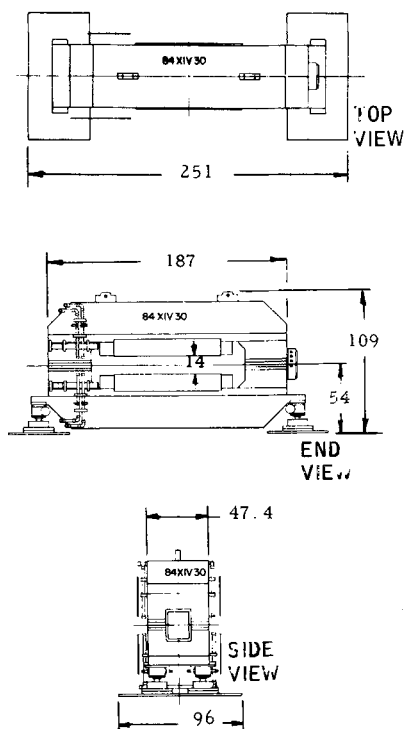Mass Spectrometer was at least in part an extension of

Fig. 11. Dimensions of the SCM105, a general purpose
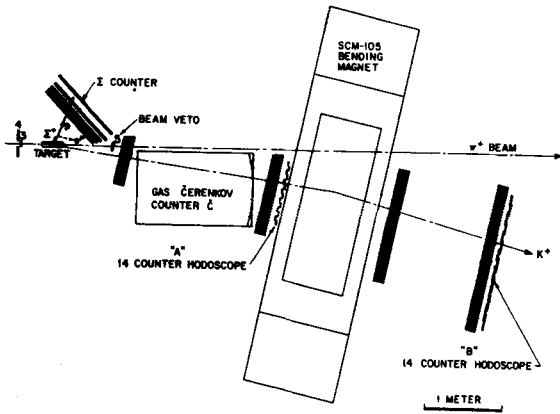spectrometer magnet.

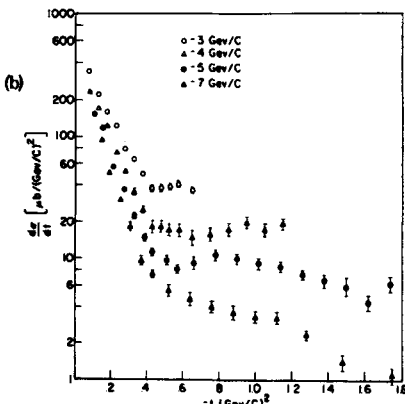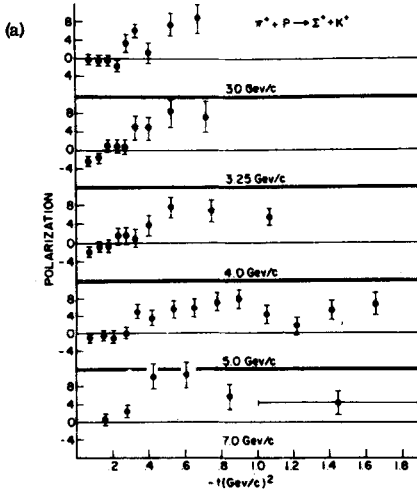Fig. 12. Plan view of the wire spark chamber experiment $\pi^+ p \to K^+ \Sigma^+$.

Fig. 13. $\pi^+ + p \to K^+ + \Sigma^+$ experiment.
(a) Polarization of the Σ^+.
(b) Differential cross section.

their experimental approach.

$\pi^+ + p \to K^+ + \Sigma^+$, 3 to 7 GeV/c (E147)

Their initial experiment[4] was in the External Proton Beam. Their layout is shown in Fig. 12. The forward K^+ momentum and angle determined the missing mass; the events in the Σ^+ peak were further selected by looking at the proton from the Σ^+ decay. The up-down asymmetry of the decay protons enabled the determination of the Σ^+ polarization. Their results are shown in Fig. 13. They saw a dramatic change in the slope of the differential cross section going from the diffraction region to $-t \geq .4$ $(GeV/c)^2$, and an apparently associated increase in Σ^+ polarization. This cross section and polarization behavior is not unlike that seen in pp scattering; a particularly interesting result for those looking at spin effects.

POLARIZED TARGET EXPERIMENTS

The study of polarization physics at the ZGS was started by Aki Yokosawa and his collaborators.

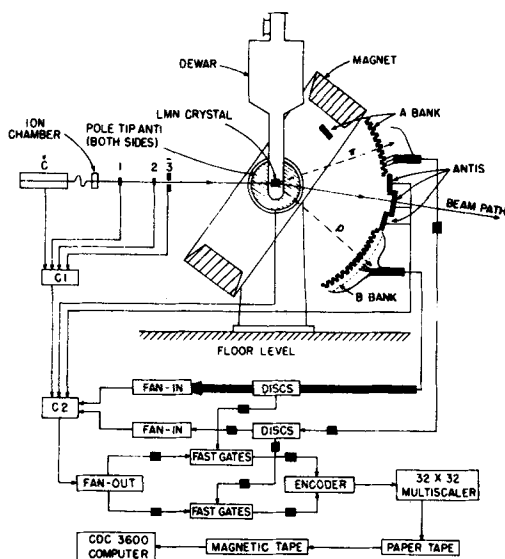DEWAR MAGNET

ION CHAMBER POLE TIP ANTI (BOTH SIDES) LMN CRYSTAL A BANK

ANTIS

BEAM PATH

B BANK

FLOOR LEVEL

FAN-IN DISCS

FAN-IN DISCS

FAST GATES

FAN-OUT ENCODER 32 X 32 MULTISCALER

FAST GATES

CDC 3600 COMPUTER MAGNETIC TAPE PAPER TAPE

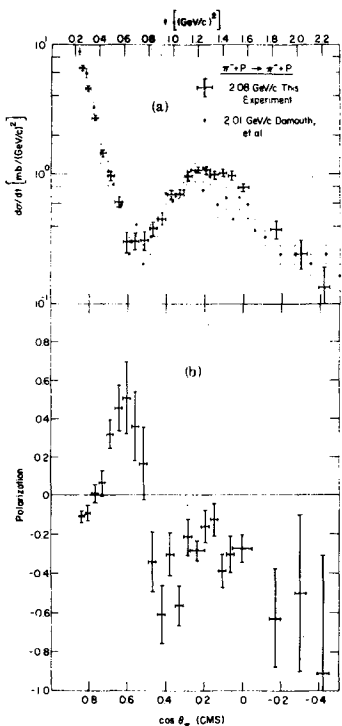Fig. 14. Schematic of apparatus for π⁻p elastic scattering polarization experiment.

Fig. 15. π⁻p elastic scattering 2.07 GeV/c. a) Differential cross section. b) Asymmetry parameter.

Their first two polarized target experiments, carried out in the 17° beam, are discussed here.

Polarization in π⁻p Elastic Scattering, 1.7 to 2.5 GeV/c (E17)

The setup for their π⁻p elastic experiment[5] is shown in Fig. 14. In these first experiments they had to cope with a large background from the LMN polarized target (97% non-hydrogen)- a 50% background subtraction was required in this experiment. Their target polarization was ∿ 50%. Even with these limitations they obtained quite good data, as seen in Fig. 15. Data of this type over a range of energies enabled the group to do a phase shift analysis, with results shown in Fig. 16. As indicated, they were able to establish the spin and parity of the resonance at 2.07 GeV/c (2190 MeV) to be 7/2⁺. Clearly polarization was a powerful tool.

Polarization in π⁻p→π°n, 2→5 GeV/c (E 111)

Their second polarized target experiment, polarization in charge exchange scattering,[6] required a considerable increase in complexity, as evident in their layout in Fig. 17. With neutron time of flight information
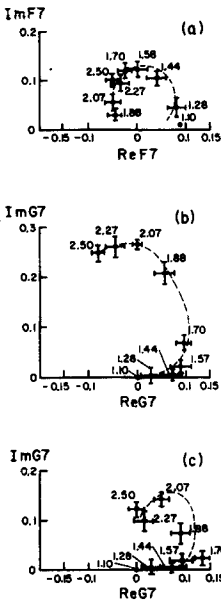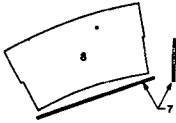
FIG. 16. The partial-wave amplitudes (a) A_{1+} and (b) A_{1-} obtained by starting from lower energy solutions and using a continuity condition. (c) The partial-wave amplitude A_{1-} obtained by starting from an optical mode.

they obtained a clear signal above background of π° from the polarized proton. Their polarization data and fits to $J=(\ell\pm1/2)$ predictions from an interference model are shown in Fig. 18. They were able to make a choice for many of the resonances.

Yokosawa and his group initiated the ZGS polarization physics work with these two experiments. They have continued this research line through the lifetime of the ZGS with very dramatic physics results.

In closing, I want to say that Roger Hildebrand's vision and determination to have the ZGS wide open to outside users obviously worked out well, as indicated by the experiments I've described: Michigan, one of the universities most heavily involved with MURA, has been able to be a major ZGS user.

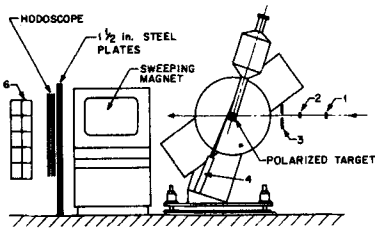This work has been supported by the U.S. Department of Energy.

FIG. 17. Side elevation of the experimental arrangement. (1)-(4) are plastic scintillation counters with respective dimensions of 1 in.×1 in., 1 in.×1 in., 10 in.×10 in. with a 1-in.×1-in. hole, and 3.5 in. ×8 in. The lead–Lucite Cherenkov counter (6) consists of ten modules, each 8 in.×16 in.×4 in. Anticoincidence counters (7) protect the 52 recoil-neutron counters (8).

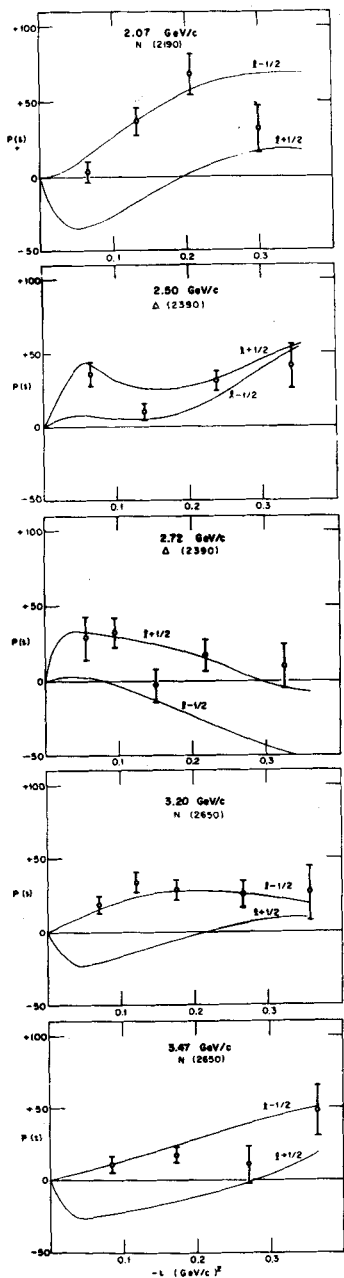Fig. 18. Polarization in $\pi^- p \rightarrow \pi^\circ n$ and fits to $J = (\ell \pm 1/2)$ predictions.

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