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Experiments with Polarized Beams and Targets

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A polarized ion source is being installed in the 13 GeV Argonne ZGS. Because of the zero field gradient it should be possible to accelerate and extract high energy polarized protons for the first time. This lecture will cover possible experiments at this facility and a little discussion of the spin dependence of strong interactions. Parts of this lecture have appeared during the past two years as parts of various internal reports,¹ proposals,² and preprints.³

The most interesting experiments will probably be studies of the differences between the various initial spin states in p-p scattering. The $\uparrow\uparrow$ and $\downarrow\downarrow$ states are pure triplet while $\uparrow\downarrow$ and $\downarrow\uparrow$ are a mixture of singlet and triplet. It is certain that there will be differences because a recent CERN elastic scattering experiment⁴ showed a significant asymmetry ($\sim 20\%$) up to 14 GeV, as shown in Fig. 1

Acceleration

The first step in the acceleration of polarized protons at the ZGS involves the installation of the polarized proton source, a second Cockcroft-Walton preaccelerator, and the new dome now being constructed next to the existing dome as shown in Fig. 2. A switching magnet just before the linac will allow rapid switching between the polarized and normal source. Just after the linac will be a low energy polarimeter, as shown in Fig. 2. This consists of a carbon target and short counter telescopes to measure the left-right asymmetry (A) in P-carbon elastic scattering. The asymmetry parameter A_{PC} has been measured at 38 MeV.⁵ By de-

grading the 50 MeV protons from the linac down to 38 MeV we can measure the polarization of the linac beam.

The 50 MeV protons (of now known polarization) will be injected into the ZGS, and accelerated. We expect depolarizing resonances to exist at about every 1 GeV.⁶ An extensive tuning period will be required to get the polarized beam to pass quickly through these resonances, so it is not depolarized very much. This tuning will use pulsed quadrupoles to change the ZGS tune, about a millisecond before reaching the γ of the resonance, thus changing ν and rapidly sweeping through the resonance, before the beam is depolarized significantly.⁶ Let me stress that passing through these resonances is the most critical part of the project.

Since protons are not lost in these resonances but only depolarized, we need a high energy polarimeter for ZGS diagnostics. This second polarimeter will be in EPB I where the protons go after extraction using the Piccioni-energy loss target extraction system. This extraction does not significantly effect the polarization. Since the depolarizing resonances should occur approximately every 1 GeV it will be necessary to progressively tune through them, one after another.

We will measure the polarization of the protons with a "polarimeter" which is a pair of double arm spectrometers each measuring proton proton elastic scattering from a liquid hydrogen target as shown in Fig. 3. We will measure the left right asymmetry (A_{HE}) between these two spectrometers, and then use the p-p asymmetry parameter (A_{pp}) measured in other experiments to give the polarization of the EPB (P_B).

$$A_{HE} = P_B A_{pp} \quad (1)$$

At each energy we will choose a scattering angle where A_{pp} is measured and large. The existing data ^{4,7} on A_{pp} is shown in Fig. 4.

We hope to be able to extract a few 10^9 polarized protons, at energies up to 12 GeV with a polarization of about 60%.

σ_{TOT} Measurement

Our first measurement will be a quick determination of the equality of the total cross sections in the different spin states. It seems likely that they will be roughly equal; for if they were very unequal that would mean that the p-p interaction has a spatial size which depends on the spin state. This would be so surprising that it must be regarded as unlikely; but there is no data to contradict this and it must be studied. A few percent difference would be less surprising, but rather interesting. However, we do not plan to probe below 5% at first.

With a polarized beam and a polarized target we can measure the total cross section with the normal transmission method as shown in Fig. 5. The only problem will be to stop the intensity down to about 10^6 or less. This will be done by defocusing the beam and using a collimator. We then can study the two possible spin states by merely flipping the spin in the target or the beam.

Elastic Cross Sections with Initial Spin Defined

With a polarized beam and polarized target we can measure the elastic cross section for the different initial spin states. There are eight obvious cross sections

↓↓ and ↑↑ in scattering plane

↑↑ and ↓↓ in scattering plane

↓↓ and ↑↑ perpendicular to scattering plane

↑↑ and ↓↓ perpendicular to scattering plane

Since the polarization of the ZGS beam must be in the vertical plane (the ZGS B field is vertical) it will be necessary to do the scattering experiment in both the horizontal and vertical plane to measure all eight amplitudes.

Our main experiment will be a study of elastic scattering in the ↑↑, ↓↓, ↑↓ and ↓↑ states with the polarization perpendicular to the scattering plane. The asymmetry results of Borghini et al⁴ imply that there must be big differences between the different spin states. In fact the differences may be even more pronounced in our experiment where pure initial spin states are studied. In a normal asymmetry experiment with a polarized target, but an unpolarized beam you average over some states and thus differences between singlet and triplet cross sections cannot be seen.

$$A \equiv \frac{\frac{d\sigma}{d\Omega}(\theta) - \frac{d\sigma}{d\Omega}(-\theta)}{\frac{d\sigma}{d\Omega}(\theta) + \frac{d\sigma}{d\Omega}(-\theta)} = \frac{\uparrow\uparrow + \uparrow\downarrow - \downarrow\downarrow - \downarrow\uparrow}{\uparrow\uparrow + \uparrow\downarrow + \downarrow\downarrow + \downarrow\uparrow} \quad (2)$$

With a polarized beam and polarized target we can study all four states one by one.

From Fig. 1 we see that the asymmetry starts becoming quite large at around $p_1^2 \approx 1(\text{GeV}/c)^2$. This is the position of the first break in the p-p elastic scattering cross section shown in Fig. 6.

It is possible that the three regions seen in the elastic cross section could be associated with different spin states. In fact this was first suggested⁸ by Fig. 6. which required an assumption about the spin dependence to handle particle identity effects at 90° ($f_s = \sqrt{3}f_t$). At the same time the diffraction peak should have $f_s = f_t$ if it is really diffraction scattering through unitarity. Thus we have some reason to believe that the breaks in the p-p elastic cross section may be caused by the different spin states. If true this would be a very important result.

Our experimental apparatus is shown in Fig. 3 along with the polarimeter which is used now to measure the polarization of the incident beam for each data run, rather than to tune the ZGS. The cross section is measured in a way similar to earlier elastic scattering experiments in extracted beams. There are magnets for momentum analysis and steering and scintillation counters to count events in coincidence and to define the solid angle. The only difference is that the target is now polarized and the beam is now polarized.

Assymetry in Elastic Scattering

One can redo with a polarized beam and a normal liquid hydrogen target all experiments that have been done with unpolarized beams and polarized targets. However, since the polarized targets contain at most 13% hydrogen atoms with perhaps 80% polarization, we get only $.13 \times .80 \approx 10\%$ of the nucleons contributing to the assymetry. If we assume a 60% beam polarization then 60% of the nucleons will contribute to the assymetry. Since we are looking

for an assymetry, going from 10% to 60% gives a real gain in sensitivity.

Now I will discuss some experiments which can be done with polarized beams, which I hope and expect will be done by other groups working at Argonne.

Elastic Cross Section with Initial and Final Spins Defined

If we define both the initial and final state then the amplitude is completely defined. Jacob and Wick first described this in terms of the 5 independent helicity amplitudes. However, since the spin will be general be perpendicular to the momentum for these experiments it is more convenient to describe things in terms of spin-up and spin-down states. The five independent states are

$$\begin{array}{ll} \uparrow\uparrow \rightarrow \uparrow\uparrow & \\ \uparrow\downarrow \rightarrow \uparrow\downarrow & \text{no flip} \\ \uparrow\uparrow \rightarrow \uparrow\downarrow & \text{flip} \\ \uparrow\uparrow \rightarrow \downarrow\downarrow & \\ \uparrow\downarrow \rightarrow \downarrow\uparrow & \text{double-flip} \end{array} \quad (3)$$

To define both the initial and final states we would set up the experiment as for the above initial spin only elastic experiment and then also have a spin measuring apparatus at the end of each of the two spectrometers. This could be a hydrogen target in which we checked the left-right assymetry of the emerging particles. Assume we use a hydrogen target that is 10% of an interaction length and look at 4% of the elastically scattered events which

occur. Then note that the elastic events comprise 25% of the total events so that in each arm we get the polarization with an efficiency of

$$10\% \times 4\% \times 25\% = 10^{-3} \quad (4)$$

Then if we set a counting limit of 5 events/hour we can get the cross sections from the equation

$$\text{Events/hour} = 2 \cdot 10^{33} \left(\frac{d\sigma}{d\Omega} \right) (Eff)_L (Eff)_R \quad (5)$$

For measuring one of the final spins we can measure down to

$$\left(\frac{d\sigma}{d\Omega} \right)_{\min} = 2.5 \cdot 10^{-30} \quad (6)$$

For measuring both final spins we can go down to

$$\left(\frac{d\sigma}{d\Omega} \right)_{\min} = 2.5 \cdot 10^{-27} \quad (7)$$

Since the forward cross section is about $100 \cdot 10^{-27}$ this means that we can get reasonable accuracy over about 2 decades of the diffraction peak. Obviously this full spin state determination experiment requires much more detailed design, but it can clearly be done in this way and it can NEVER be done if you don't have both a polarized beam and a polarized target. There are no proposals yet for this experiment.

Inelastic Proton Proton Scattering

One can observe the cross section for pion, kaon and anti-proton production with the initial spin states defined both in the plane of production and perpendicular to the plane of pro-

duction

$$p+p \rightarrow \pi + \text{anything}$$

$$p+p \rightarrow K + \text{anything} \quad (8)$$

$$p+p \rightarrow \bar{p} + \text{anything}$$

The rates for these inclusive reactions are similar to the rates for a similar experiment which has been done at Argonne without a polarized target or beam and easily measured over the entire available range with excellent statistics.

It would be extremely interesting if the inclusive cross sections depended on the spin states and even more interesting if the dependence for K-production was different than that for π -production.

One can also observe the inelastic proton proton scattering cross section

$$p + p \rightarrow p + \text{anything}$$

while holding fixed the spin of one or both of the initial protons. In addition one could determine the spin of the outgoing forward proton in $p+p \rightarrow p + \text{anything}$ and thus completely determine the spin structure for this type of cross section. The different spin states are:

$$\uparrow\uparrow \rightarrow \uparrow$$

$$\uparrow\downarrow \rightarrow \uparrow$$

$$\uparrow\uparrow \rightarrow \downarrow$$

$$\uparrow\downarrow \rightarrow \downarrow$$

(9)

With $\Delta\Omega\Delta p \approx 10^{-5}$ sr GeV/c and an efficiency of 10^{-3} in the final spin measurement one should be able to measure this cross section to about 10^{-4} below its maximum value. There are now three proposals to measure inclusive polarized cross sections at the ZGS^{10,11,12}. I believe one of these also hopes to use the polarized Λ 's that should be produced to redo their $\Lambda - p$ decay experiment.

P and T Violations in Strong Interactions

One can also look for P and T violations in experiments with polarized beams and polarized targets. No such violations have ever been observed in strong interactions; however, most experiments have averaged over the spin states. Thus violations in individual spin states could be canceled by equal and opposite violations in other spin state. However, if one studied pure spin states such violations might be seen.

One can look for P and T violations in proton proton elastic scattering or $\pi - p$ elastic scattering. In p-p scattering there can be a T violation even if P is conserved while in $\pi - p$ scattering P must first be violated before a T violation can be seen. The disadvantage of the p-p test is that it requires the determination of all 4 spins; thus the $\pi - p$ test which requires the measurement of only 2 spins may be a more appropriate first test.

I last year proposed³ measuring the spin flip cross section for $\pi - p$ elastic scattering at around $-t = 1.5$ (GeV/c)², with the spins measured perpendicular to the scattering plane. P - conservation states that this spin flip amplitude must be zero and T - conservation states that any non zero flip amplitude for scattering to the left must be equal for the flip amplitude

for scattering to the right. A possible apparatus for doing this experiment is shown in Slide 7. The main problem of the experiment is rate; for an event rate of 20/hour a pion flux of about $2 \cdot 10^7$ /pulse will probably be needed. This is difficult but not impossible.

I suggested making the measurement at around $t \approx 1.5 \text{ (GeV/c)}^2$ because that is where the Assymetry was found⁴ to be large even at high energies as shown in Slide 8. My intuition suggests that if there is a P or T violation it will occur here where the spin effects appear to be most important. This experiment clearly has a low probability of success. However, I believe there is no data to contradict such a violation at large t and I think the experiment should be tried.

Summary

I have listed several types of experiments which can be done with a polarized beam and polarized target. There are certainly many others which can be done.

It seems that these measurements are clearly interesting for there are two possible results:

1. All different spin states have exactly the same cross sections at all angles and all energies.
2. Some have some differences.

If the first case is true it shows an important simplicity in strong interactions. If the second case is true it opens a whole new area of strong interactions.

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FOOTNOTES

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1. The Use of Polarized Proton Beams, A.D. Krisch, University of Michigan Preprint 71-7, (Dec. 1970).
2. Proposal No. 324 for Argonne ZGS, S.W. Gray et al. (Feb. 1972).
3. A test of P and T Violations in Strong Interactions, A.D. Krisch, University of Michigan Preprint 72-7 (Jan. 1972).
4. M. Borghini et al., Phys. Letters 36B 493; 497; 501 (1971).
5. C.F. Hwang et al., Phys. Rev. 131, 2602 (1963).
6. T.K. Khoe, ZGS Technical Report TKK-10 (May 1972);
D. Cohen, Rev. Sci. Instruments 33, 161 (1962);
M. Froissart and R. Stora, Nucl. Instr. and Meth. 7, 297 (1960).
7. P. Grannis et al., Phys. Rev. 148, 1297 (1966);
M. Borghini et al., Phys. Letters 24B, 77 (1967); Phys. Letters 31B, 405 (1970); M.J. Longo et al., Phys. Rev. Letters 16, 536 (1966)
G. Cozzika et al., Phys. Rev. 164, 1672 (1967).
8. A.D. Krisch, Phys. Rev. Letters 19, 1149 (1967). In this plot we assume that $f_s = f_t$ in the second region; while $f_s = \sqrt{3} f_t$ otherwise as in the original paper.
9. C.W. Akerlof et al., Phys. Rev. 3, 645 (1971).
10. ZGS Proposal P-336 R. Winston et al., (May 1972).
11. ZGS Proposal P-339 A.B. Wicklund et al., (May 1972).
12. ZGS Proposal P-338 E.W. Beier et al., (May 1972).

FIGURE CAPTIONS

- Slide 1. Assymetry Parameter in p-p elastic scattering at high energy. Data is from Ref. 4.
- Slide 2. Layout of ZGS preaccelerator area with polarized ion source shown in new preaccelerator.
- Slide 3. Layout of high energy polarimeter along with spectrometer for our elastic scattering experiment.
- Slide 4. Tabulation of all assymetry parameter data for p-p elastic scattering above 1 GeV. Date is from Ref. 4 and Ref. 7.
- Slide 5. Layout of equipment for measuring σ_{TOT} .
- Slide 6. Plot of p-p elastic data from Ref. 8.
- Slide 7. Layout for measurement of spin flip amplitude in $\pi - p$ elastic scattering.
- Slide 8. Plot of assymetry parameter for $\pi - p$ elastic scattering at 10 GeV. Data is from Ref. 4.

POLARIZATION IN p-p SCATTERING

FIG 1

PP POLARIZATION

PROTON-PROTON ELASTIC SCATTERING