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PHYSICS WITH POLARIZED BEAMS ABOVE GeV REGION

by

Akihiko Yokosawa

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Physics With Polarized Beams Above GeV Region*

A. Yokosawa
High Energy Physics Division
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439 USA

Abstract

During the past several years we have observed many exciting and unexpected results in experiments with polarized beams. We review those results briefly. A new polarized beam line up to 600 GeV/c is also discussed.

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During the past several years, experiments with polarized beams produced various unexpected results which affect current theoretical models. We review polarized-electron experiments at SLAC, polarized-proton experiments up to the Argonne ZGS energy, and future experiments at Fermilab energies.

I) SLAC Experiments

An attempt has been made to obtain information about the spin distribution of quark-partons by using a longitudinally polarized electron beam and a longitudinally polarized proton target in the kinematic range $2 < \omega < 10, 1 < Q^2 < 4$ $(\mathrm{GeV}/c)^2$, and $2 < W < 4$ GeV.[1] The results of the asymmetry measurements in the deep inelastic scattering strongly imply that parent spin is communicated to the constituent quarks; spin of the nucleon is carried by a single quark.

The other significant experimental results were from measurements of parity-violating asymmetries in the inelastic scattering of longitudinally polarized electrons from deuterium and hydrogen at 19.4 and 22.2 GeV. An asymmetry $A = (\sigma_R - \sigma_L)/(\sigma_R + \sigma_L) = (-9.5 \pm 1.6) \times 10^{-5}\, Q^2$, Q^2 in $(\mathrm{GeV}/c)^2$, for values of Q^2 near 1.4 was found.[2] This result is consistent with predictions from the standard Weinberg-Salam SU(2) x U(1) model. Using the simple quark-parton model of the nucleon, one obtans $\sin^2\theta_W = 0.20 \pm 0.03$.

II) Polarized-Proton-Beam Experiments Up to the Argonne ZGS Energy[3]

Just as measurements using a new facility usually bring many surprises, we have observed exciting and unexpected results in nucleon-nucleon scattering using polarized beams at the Argonne ZGS.

Experimental groups using the ZGS polarized beam have been taking data for some years on a variety of topics:

i. Total and elastic cross sections for pp and pn scattering from 1 to 12 GeV/c with spins oriented along, sideways, and normal to the direction of motion.

ii. Asymmetries in inclusive production $pp \rightarrow \pi$ + anything, etc., with polarized beams.

iii. A search for parity violation in the pp total cross section with a longitudinally polarized beam.

iv. Inelastic reactions such as $pp \rightarrow \Delta^{++}n$ and $pp \rightarrow p\pi^{+}\pi^{-}p$.

The data on the inelastic reactions come almost completely from the Argonne Effective-Mass Spectrometer (EMS) facility and will take some time to be analyzed. In this report inelastic reactions are not discussed.

Polarized Beams at the Argonne ZGS

The successful acceleration of polarized beams was achieved at the Argonne ZGS in the middle 1970's. Experiments with polarized beams were almost exclusively performed in External Proton Beam I(EPBI) as shown in Fig. 1, where Beams 1, 5, 21 (21S, superconducting beam line), 22, and 23 are shown. The first experiment was carried out in Beam 1 by a University of Michigan group and their collaborators.

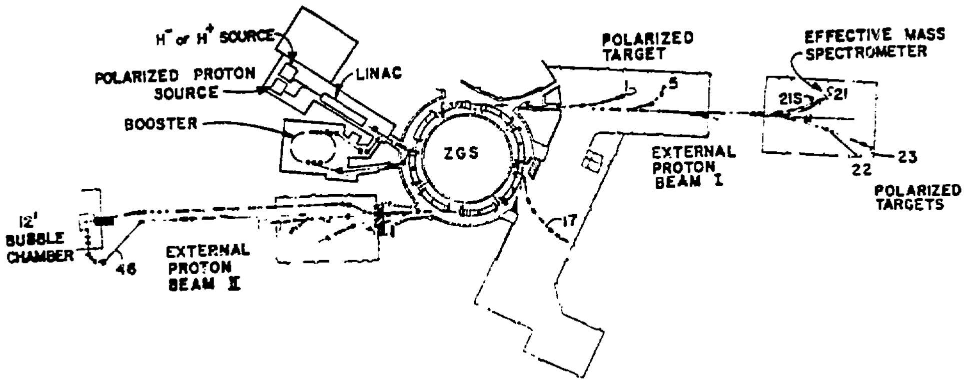

Fig. 1 Beam lines and experimental area at ZGS.

Before we describe the main feature of each beam line, we define the spin directions N, L, and S of the polarized beam, the polarized target, and the recoil particles in the lab system as shown in Fig. 2. Polarized targets were provided in Beams 1, 22, and 23, and various experiments performed using polarized beams both with and without polarized targets were as follows:

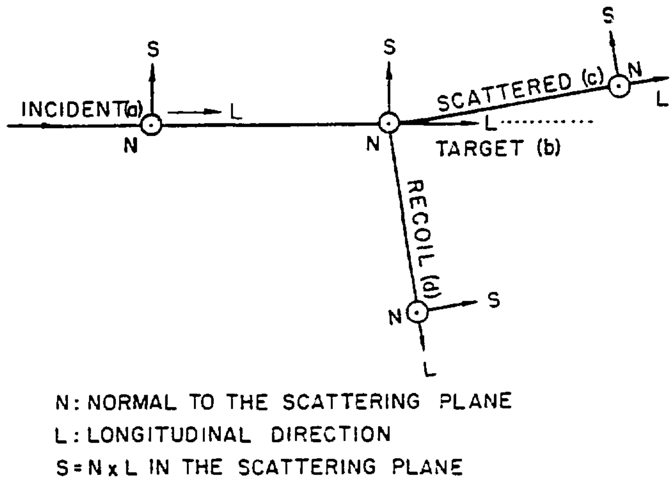

Figure 2 Description of spin directions.

$$\vec{N} = \frac{\vec{p}_a \times \vec{p}_c}{|\vec{p}_a \times \vec{p}_c|}$$

N: Normal to the scattering plane,
L: Longitudinal direction,
S = N x L in the scattering plane.

Beam 1 Polarized beam ($\vec{N}$) + polarized target ($\vec{N}$) by a Michigan-Argonne collaboration.

Beam 2 Polarized beam ($\vec{L}$) + water target, by a Chicago-Illinois-Los Alamos collaboration (later a Los Alamos-Ohio State-Argonne-Elmhurst collaboration).

Beam 5 Polarized beam ($\vec{N}$) + hydrogen target by a Minnesota-Rice-Argonne collaboration.

Beam 21 Polarized beam ($\vec{N}$) + hydrogen or deuteron target by the Argonne EMS group.

Beam 22 Polarized beam ($\vec{N}$) + polarized proton or deuteron targets ($\vec{N}$)
($\vec{S}$) ($\vec{S}$)
($\vec{L}$) ($\vec{L}$)

with some analysis of the spin of recoil protons ($\vec{N}$) and ($\vec{S}$), by the Argonne PPT Group.

Beam 23 Polarized beam ($\vec{N}$) + polarized proton or deuteron targets ($\vec{N}$) by a Rice University group and their collaborators.

We describe details of polarized-beam facilities concentrating on Beam 22, which accommodates various spin directions of beams and targets. The spin of polarized protons emerging from the ZGS is in the N direction. Superconducting solenoids with a field of 24.0 T·m at 12 GeV/c, for example, are used to rotate the spin of the incident beam from the N to the S direction. The longitudinally polarized beam is produced by a bending magnet with a vertical field to precess the proton spins in the S direction until their polarization is parallel to the beam momentum. This scheme of operation avoiding the use of a horizontal field does not require vertical adjustment of polarized targets. The sign of beam polarization is flipped on alternate pulses, and this is essential to reduce systematic errors.

The polarized proton target in Beam 22 is 2 x 2 x 8-cm ethylene glycol doped with $K_2Cr_2O_7$ and maintained at 0.4 K. For free protons in the target, the polarization is 0.8-0.9. Two kinds of superconducting magnets are used to provide three directions (N, S, and L) of target spins.

The spin analyses of recoil protons in the N and S directions are done by a carbon polarimeter together with proportional wire-chamber detectors.

Experimental Programs and Beam Lines

Nucleon-nucleon physics studies at the Argonne ZGS were in the following areas:

- Structures in nucleon-nucleon system and dinucleon resonances-Beams 22 (PPT Group) and 23 (Rice Group).
- pp scattering-amplitude measurements--Beams 1 (Michigan-Argonne), 5 (Minnesota-Rice), and 22 (PPT Group).
- Nucleon-nucleon elastic scattering at high $p_\perp$--Beams 1 (Michigan-Argonne), 5 (Indiana), and 22 (PPT Group).
- pp inclusive--Beams 1 (Michigan-Argonne), 5 (Minnesota-Rice) and 22 (PPT Group).
- Search for parity violation--Beam 2 (Argonne-Elmhurst-Los Alamos-Ohio).
- pn polarization and pp inelastic--Beam 21 (EMS Group).

The intensity of the polarized beams was ~10^{10}/pulse in Beam 1, where a relatively simple detection system was used, and below 10^7/pulse in the rest of the beam lines.

Brief Summary of Experiments

Measurements of differences between total cross sections for antiparallel and parallel spin states (longitudinal and transverse) in both pp and pn scattering show remarkable structure in the 1- to 3-GeV/c momentum range. Together with other data such as polarization and spin-spin correlation parameters at all angles, the above results have been interpreted as evidence of the existence of dinucleon resonances in both I = 0 and I = 1.

Large-angle pp scattering was studied by measuring the spin-spin correlation parameter C_{NN} covering the range up to $\theta_{c.m.} = 90°$ and energy up to 12.75 GeV/c. The results show unexpectedly large values and interesting structure. A similar study was also made by measuring the correlation parameters C_{LL}, C_{LS}, and C_{SS} at 11.75 GeV/c covering also the region of $\theta_{c.m.} = 90°$.

A complete set of measurements with low values of t has been done at 6 GeV/c in order to determine the pp amplitudes; 14 parameters were measured. This is the first determination of these amplitudes at high energy. The results show, in addition to the expected Pomeron dominance and π-exchange contributions, a large A_1 exchange component.

III) Polarized Beams at Fermilab

The construction of the polarized-beam facilty is underway in the meson laboratory at Fermilab. This project was originated by a collaboration of Argonne, Kyoto, LAPP (Annecy), LBL, Rice and Trieste.[4,5]

Some of the most topical and interesting subjects in strong-interaction physics include phenomena on large $p_\perp$, direct-photon production, and lepton-pair production, With polarized beams we can study these phenomena in different ways from common cross-section measurements; namely, we would measure the asymmetry effect of these reaction processes. We have already seen high polarization in Λ production at high $p_\perp$ at Fermilab and ISR, and also in π° production at CERN. The various spin effects seem to continue to exist at high energies.

The experiments proposed so far are directed toward studying constituent interactions. Using a polarized beam with unpolarized and polarized targets, we will measure hadron production (eventually jet production and also di-muon production) at large $p_\perp$ and also measure pion production at large x and small $p_\perp$. To investigate the rising total cross section, we will measure the total cross section in pure spin states.

The polarized beam should be useful with a nuclear target to study the space-time structure of interactions, and be useful with a parity-violation search for tests of Weinberg-Salam theories.

Desirable features of the Fermilab polarized-beam facility are as follows:

i) Polarized beams are polarized protons and polarized antiprotons decaying from Λ and $\bar{\Lambda}$, respectively; acceleration of polarized protons is not necessary and accordingly the use of the polarized beam does not interfere with experiments by other users.

ii) For a given primary-proton energy, polarized beams are available in a wide region of energy, unlike accelerated polarized beams, which are at the accelerator energy.

iii) Spin of the polarized beam will be reversed after each pulse in order to minimize the systematic error.

Predicted intensities (beam polarization = 45%) with 400- and 1000-GeV/c primary beams are shown in Fig. 3. There is a large increase in the flux of polarized $\overline{p}$'s and high-momentum protons from 100-GeV/c operation. Spin directions can be $\vec{N}$, $\vec{L}$, or $\vec{S} = \vec{N} \times \vec{L}$.

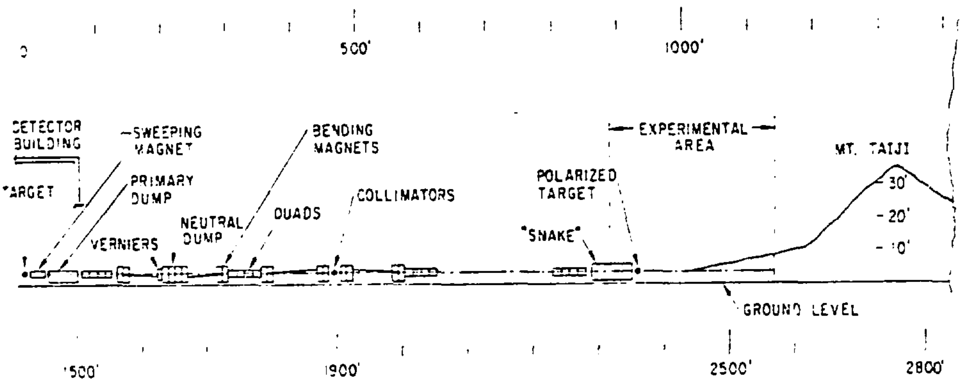

Fig. 3 The polarized beam line.

The overall view of the polarized beam line is shown in Fig. 4. Conventional bending magnets and superconducting quadrupoles are used.

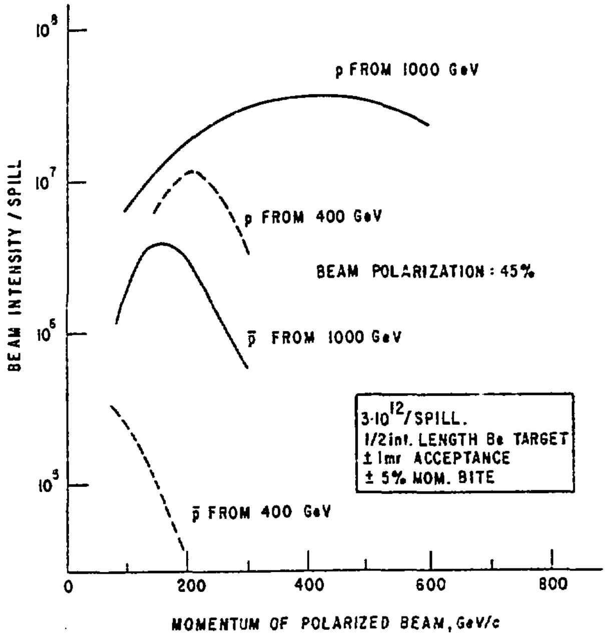

Fig. 4 Predicted intensities of the polarized beam.

Maximum $p_\perp$ attainable, with statistical accuracy of ±0.01 in the spin parameter, depends on the type of reaction, one-spin or two-spin measurements, the type of the polarized target, etc. We give one example in a jet-production experiment.

	Maximum $p_\perp$
$p^{\uparrow} p \rightarrow (\text{jet}) + x$	~7 GeV/c
$p^{\uparrow} p^{\uparrow} \rightarrow (\text{jet}) + X$	~6 GeV/c

We note that there are many theoretical predictions on large $p_\perp$ phenomena. Polarized quarks could be used to test fundamental theories in the future.

References

1. M. J. Alguard et al., Phys. Rev. Lett. 37, 1261 (1976).

2. C. Y. Prescott, AIP Conference Proceedings No. 51, p. 202 (1978).

3. For details, see "Review of Experimental Results from the Polarized-Beam Program at Argonne ZGS", A. Yokosawa, to be published in Physics Reports.

4. Details are in the Fermilab E-581 proposal.

5. A polarized beam at Fermilab, D. Underwood et al., ANL-HEP-PR-78-05.