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FUTURE IMPACT OF THE EXPERIMENTAL RESULTS FROM THE ARGONNE ZGS

by

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FUTURE IMPACT OF THE EXPERIMENTAL RESULTS FROM THE ARGONNE ZGS*

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Abstract

Experimental programs at Argonne ZGS are reviewed with emphasis on experiments using polarized beams.

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On the morning of October 1, 1979, a button was pushed to shut down the 12.5-billion-electron-volt Argonne's Zero Gradient Synchrotron for the last time. Experiments running at that time were all using polarized proton beams. It was the end of a nearly 16-year career that has made Argonne an active laboratory in the field of high-energy physics. Experiments performed at ZGS will continue to have an impact on the field for years to come.

Experimental results from the ZGS have recently been reviewed during the symposium on the history of the ZGS held on September 13-14, 1979. To start with, I will brief you on the physics results reviewed in the symposium during which the following talks were given:

The 30-in. bubble chamber and the 7^{o} beam line (by W. D. Walker)

The early strong-interaction counter experiments (by K. M. Terwilliger)

The external proton beam and the p-p experiments (by L. G. Ratner)

The streamer chamber and K physics (by A. Abashian)

Experiments with polarized target and/or polarized beam (by A. Yokosawa)

The effective mass spectrometer (by D. S. Ayres)

The polarized beam program (by J. B. Roberts)

The neutrino program and the superconducting bubble chamber (by M. Derrick)

Figure 1 shows the location of 30-in. bubble chamber in the 7^{o} beam line; beam lines 1, 5, 21, 22A, 22B, and 23 in EPB-I; and the 12-ft. bubble chamber in EPB-II.

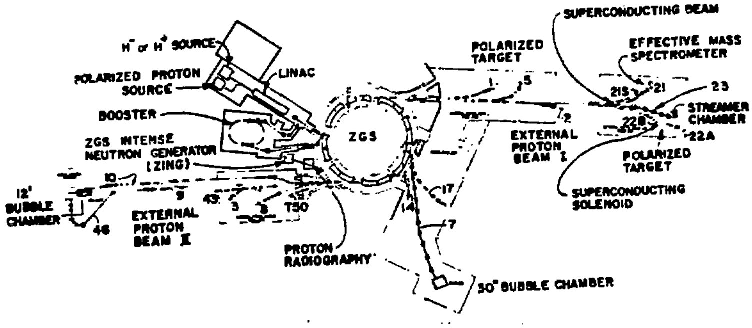

Fig. 1 Beam lines and experimental area at ZGS.

At the end of the reviews, as a summary talk, highlights and future speculations were presented by T. H. Fields.* He had chosen the following areas of high-energy physics where the ZGS had played a pioneering role and ripened for further work:

- The 0^+ meson
- Hadron interaction at low $p_\perp$
- Dibaryon resonances
- Spin effects at large $p_\perp$

I will follow his views but will place more emphasis on the physics with polarized beams and/or targets.

1. The 0^+ Meson

In the 30-in. bubble chamber, an ANL-Northwestern collaboration (1968) observed a boson resonance of mass 980 MeV decaying into $\pi^-\eta$, $\delta(970)$, and

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* His talk is published in the Proceedings of the Symposium on the History of the ZGS, September 1979.

a Wisconsin-Toronto collaboration (1970) observed $\varepsilon(1200) \to \pi\pi$. The first one was the result of a search for a charged meson produced in k^-p interactions at 5.5 GeV/c and decaying via the $\pi\eta$ mode. An enhancement was observed in the $\pi^-\eta$ system at mass 980 ± 10 MeV. Later an Ohio State-Michigan State-Canada collaboration performed a high-statistics measurement of δ in $\pi^-p \to \eta\pi^+\pi^-n$. The second observation is the result of a study for $\pi\pi$ scattering up to 1.4 GeV of dipion mass by looking at reactions as $\pi^-p \to \pi^-\pi^+n$ (4191 events) and $\pi^-p \to \pi^-\pi^\circ p$ (7555 events) at 7 GeV/c. Later the study for $\pi\pi$ scattering was tremendously improved by the Argonne EMS (Effective Mass Spectrometer) counter group, which obtained 500,000 $\pi\pi$ events.

In an experiment studying the reaction $\pi^-p \to nK^\circ_S K^\circ_S$ at 6 and 7 GeV/c utilizing the 1.5-m streamer-chamber facility, a Notre Dame-ANL collaboration observed the production of a new scalar meson of mass around 1255 MeV. The EMS group has studied reaction $\pi^-p \to k^-k^+n$ (110,000 events) and $\pi^+n \to k^-k^+p$ (50,000 events) at 6 GeV/c in which they isolated isospin-0 and isospin-1 k^-k^+ states covering k^-k^+ masses below 1750 MeV.

Present issues are i) is there a 0^+ nonet, ii) are the 0^+ mesons "really" $qq\bar{q}\bar{q}$ as predicted by the MIT bag model, and iii) where are the glue balls, $0^+ = gg$?

2. Hadron Interaction at Low $p_\perp$

This subject is a well-studied area of strong interactions with theoretical models having predictive power which included Regge exchange phenomena, duality, etc. Intensive studies both theoretically and experimentally have been made on two-body exchange processes ($AB \to CD$), amplitude analyses of two-body reactions, and multiparticle inclusive phenomenology. I regret that I can not go through the various interesting experimental results, but would like to point out the following experiments, which provided a definitive test of theoretical models:

i) Results of a high-statistics experiment using the EMS to pursue the crossover effect in $\pi^{\pm}p$, $k^{\pm}p$, and $p(\bar{p})p$ elastic scattering are shown in Fig. 2.

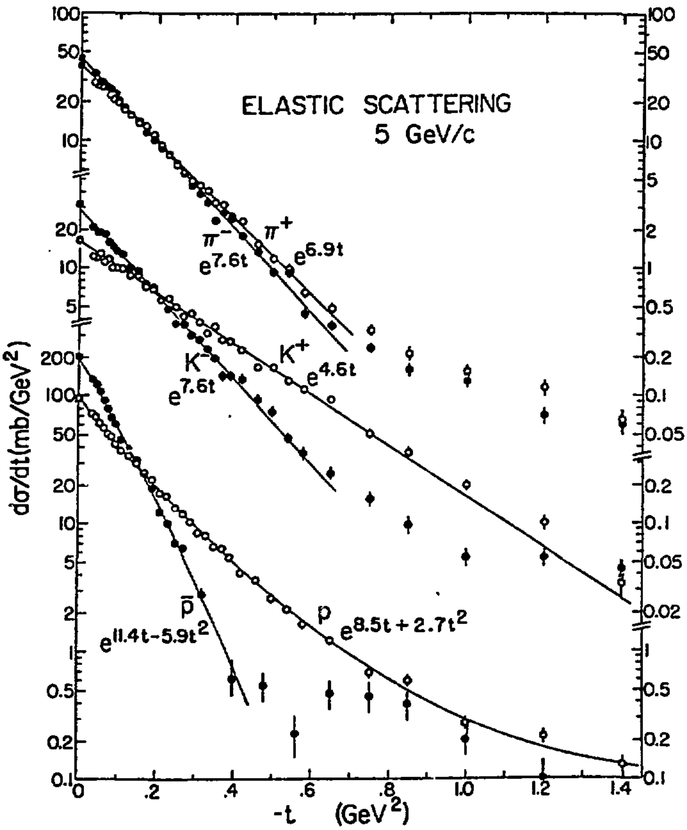


Fig. 2 Differential cross section for the elastic scattering of six different particles from protons at 5 GeV/c.

ii) Definitive investigations of hypercharge exchange processes were carried out by an Argonne-Michigan group with wire spark-chamber techniques pioneered at ANL, and a typical result is shown in Fig. 3.

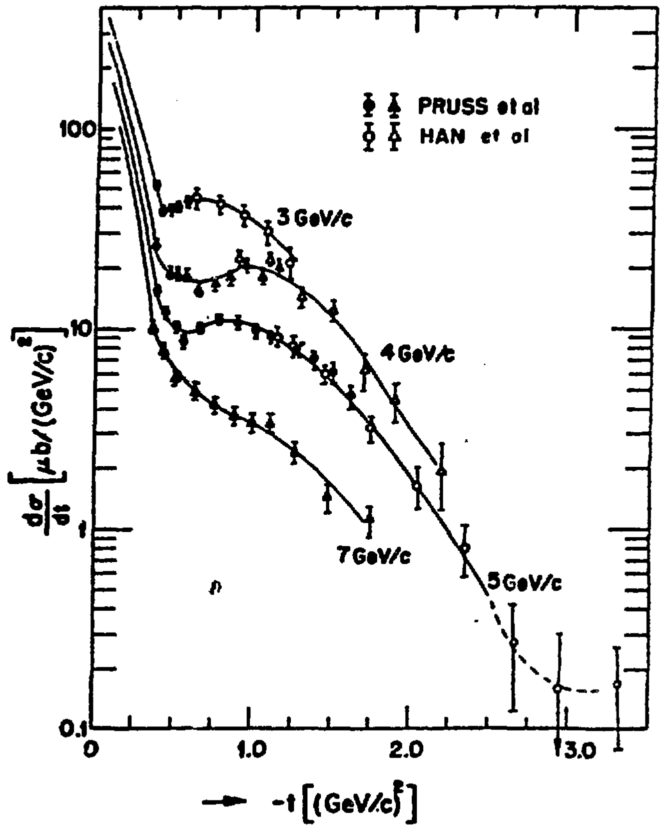


Fig. 3 Differential cross sections for $\pi^+ p \to K^+ \Sigma^+$.

iii) Polarization phenomena are extensively investigated, and the results are discussed in Sections 4 and 5.

3. Neutrino Physics

The 12-ft. chamber project was the worldwide pioneering effort in the construction of giant bubble chamber. The 107-ton magnet will be used for a PEP experiment.

The study of neutrino interactions on nucleons was the principal reason for building the 12-ft. bubble chamber. Some results of particular note are:

i) The measurement of the weak axial-vector form factor of the nucleon.

ii) The first measurement of the isospin properties of high-energy weak interactions through charged-current single pion production.

iii) One of the earliest observations of the weak neutral-current interaction.

4. Experiments with Polarized Targets (See also Section 5)

At the beginning of the ZGS, an experimental group was formed with the specific goal of studying polarization phenomena. The group continued this program throughout the history of the ANL high-energy physics program.

Pion-nucleon resonances: The N*(2190) resonance was discovered in polarization data and assigned the quantum number $G_{7/2}$ (S. Suwa et al.).

Mirror symmetry: Polarization in $\pi^{\pm}p$ elastic scattering are equal in magnitude but opposite in sign as shown in Fig. 4 (N. Booth et al.). These data remain one of the touchstones of exchange-model phenomenology.

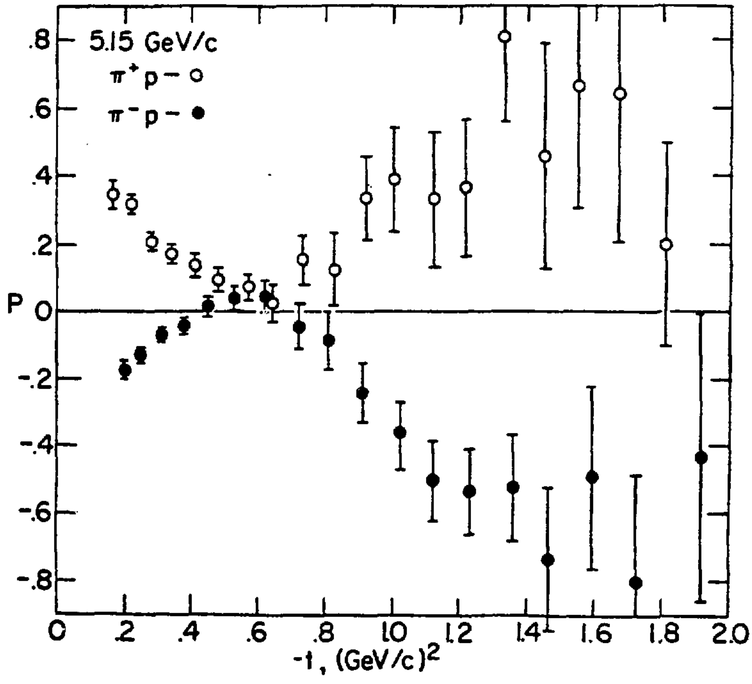


Fig. 4 Forward polarization in π^+p and π^-p elastic scattering.

Pion-nucleon charge exchange: $\pi^-p \rightarrow \pi^\circ n$, one of the simplest from the point of view of exchange models; an expectation of the theory that there should be no polarization was proved to be wrong.

Exotic resonance: The analysis of polarization data in K^+p elastic scattering suggested the presence of an exotic Z*(1900) resonance (S. Kato et al.).

Backward scattering: Polarization in $\pi^\pm p$ backward scattering, for $\theta_{c.m.}$ = 90° to 180°, revealed striking energy dependence. Similar results were found in an experiment at KEK (National Laboratory for High Energy Physics).

5. <u>Physics with Polarized Beams with or without Polarized Targets</u>

Since polarized beams are unique to the Argonne ZGS and the results are relatively new, I would like to go over various experiments performed with polarized beams with or without polarized targets.

Experiments were performed in the following five beam lines:

Beam 1 Polarized beam ($\vec{N}$) + polarized target ($\vec{N}$) by University of Michigan et al.

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

Polarized beam ($\vec{L}$) + hydrogen by a Chicago-Los Alamos collaboratio
(later a Los Alamos-Ohio State collaboration)

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

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

with sometimes analyzing the spin of recoil protons ($\vec{N}$) and ($\vec{S}$) by the Argonne PPT group.

Beam 23 Polarized beam ($\vec{N}$) + polarized proton and deuteron targets ($\vec{N}$) by Rice University et al.

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

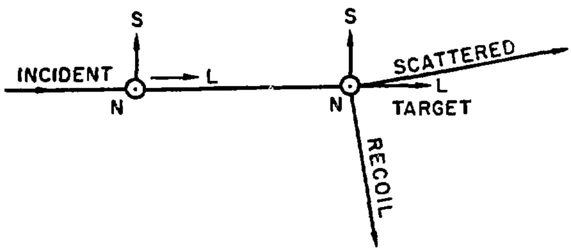
- o Structures in nucleon-nucleon system and dibaryon resonances - Beam 22 (PPT group) and 23 (Rice group)
- o Proton-proton scattering-amplitudes measurements - Beam 22 (PPT group)

- o Proton-neutron polarization - Beam 21 (EMS group)
- o Proton-proton elastic scattering at high $p_\perp$ - Beams 1 (Michigan et al.) and 22 (PPT group).
- o pp inclusive (Minnesota-Rice collaboration, Michigan et al.)
- o Search for parity violation (Chicago-Los Alamos-Ohio collaboration)
- o pp inelastic - Beam 21 (EMS group)

i) <u>ZGS Facilities Providing Spin Directions</u>

I will mainly describe the ZGS facilities concentrating on Beam 22 which accommodates various spin directions of beams and targets.

The spin directions N, L, and S of the polarized ebam, the polarized target, and the recoil particles are defined below.



N: NORMAL TO THE SCATTERING PLANE
L: LONGITUDINAL DIRECTION
S=N x L IN THE SCATTERING PLANE

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 the vertical adjustment of polarized targets. The sign of beam polarization is flipped on alternate pulses, and this is essential to reduce systematic errors.

ii) Proton-Proton Scattering-Amplitude Measurements

We define s-channel helicity scattering amplitudes as follows:

$$\left.\begin{array}{l} \langle ++|++\rangle = \phi_1 \\ \langle --|++\rangle = \phi_2 \\ \langle +-|+-\rangle = \phi_3 \end{array}\right\} \quad \text{net helicity nonflip amplitude}$$

$$\langle +-|-+\rangle = \phi_4 \qquad \text{double flip}$$

$$\langle ++|+-\rangle = \phi_5 \qquad \text{single flip}$$

We adopt the notation (Beam, Target; Scattered, Recoil) to express observables; * indicates that spin directions is known; 0 means that spin direction is not known. We assume that the spin direction of scattered particles cannot be measured.

Observables	Description	Symbol
(0,0;0,0)	Cross section	σ
(*,0;0,0) or (0,*;0,0)	Polarization	P

$(*,*;0,0)$	Correlation tensor	C_{jk}
$(*,0;0,*)$	Polarization transfer tensor	K_{jk}
$(0,*;0,*)$	Depolarization tensor	D_{jk}
$(*,*;0,*)$	High-rank spin tensor	H_{ijk}

These observables are described elsewhere (see Proceedings of the Meeting on Two-Nucleon Systems and Dibaryon Resonances, Hiroshima, November 1979). In three-spin measurements, we can determine three to four parameters simultaneously from one measurement.

Measured observables toward the amplitude determination are as follows:

P, $C_{NN}(N,N;0,0)$, $C_{SS}(S,S;0,0)$, $C_{LL}(L,L;0,0)$,

$C_{SL}(S,L;0,0)$, $K_{NN}(N,0;0,N)$, $K_{SS}(S,0;0,S)$, $D_{NN}(0,N;0,N)$,

$D_{SS}(0,S;0,S)$, $D_{LS}(0,L;0,S)$, $H_{SNS}(S,N;0,S)$,

$H_{NSS}(N,S;0,S)$, and $H_{LSN}(L,S;0,N)$

iii) <u>Structures in Nucleon-Nucleon System and Dibaryon Resonances</u>

(See an article by A. Yokosawa in these Proceedings.)

iv) <u>Measurement of Asymmetries in Inclusive Proton-Proton Scattering</u>

(ANL-Minnesota-Rice collaboration)

They have used the polarized proton beam at the Argonne ZGS to measure left-right asymmetries in the process $p^{\uparrow}p \rightarrow (\pi^{\pm}, p, k^{\pm}, d) + x$ at $p_0 = 6$ and

11.8 GeV/c, and $x = P_{\ell}^{*}/P_{max}^{*} = 0.1$ to 0.9. The asymmetries are almost always negative for π^{+} and positive for π^{-}, and increase with both increasing $p_{\perp}$ and increasing x. The asymmetries for inelastic proton scattering are about an order of magnitude smaller than those for pion production but definitely nonzero. The Kaon asymmetries show indications of being sizable but structureless.

The asymmetries in $pp \rightarrow p$ + anything are small, but definitely nonzero. The K^{+} asymmetries are everywhere positive, and the K^{-} asymmetries hint at being sizable ($\sim$ 30%) at large x.

V) Search for Parity Violation in Polarized Proton Scattering at 6 GeV/c

Experiments were carried out on a beryllium target by a Chicago-Los Alamos collaborat n. The experiment performed in April 1975 showed a large parity-violating effect, namely $(-15 \pm 2.4) \times 10^{-6}$. A plausible explanation for this effect is that the apparatus detected a small fraction of parity-violating weak decays of polarized hyperons; e.g. $\Lambda \rightarrow p^{+}\pi^{-}$. To eliminate such effects, the apparatus was augmented by a spectrometer which rejected any hyperon decay products.

Experimental results of 6-GeV/c polarized protons striking on hydrogen are:

$Ay = \Delta\sigma/P2\sigma = (3.1 \pm 3.8) \times 10^{-6}$ (without systematic errors) using ion-chamber detectors, and

$Ay = (-1.9 \pm 2.6) \times 10^{-6}$ (without systematics) using scintillator detectors.

Data with one order improved will be available soon by a Ohio State-Los Alamos collaboration.

vi) Polarization in pn Elastic Scattering and pp Inelastic Scattering

The Argonne EMS group measured pn polarization together with pp polarization. There seems to be a bigger energy dependence in pn than pp system.

Concerning the pp inelastic scattering, the group measured many inelastic channels with good accuracy. However, I have no time to cover all of them and will show you a typical one, $p^{\uparrow}p \to \Delta^{++}n$, as shown in Fig. 5.

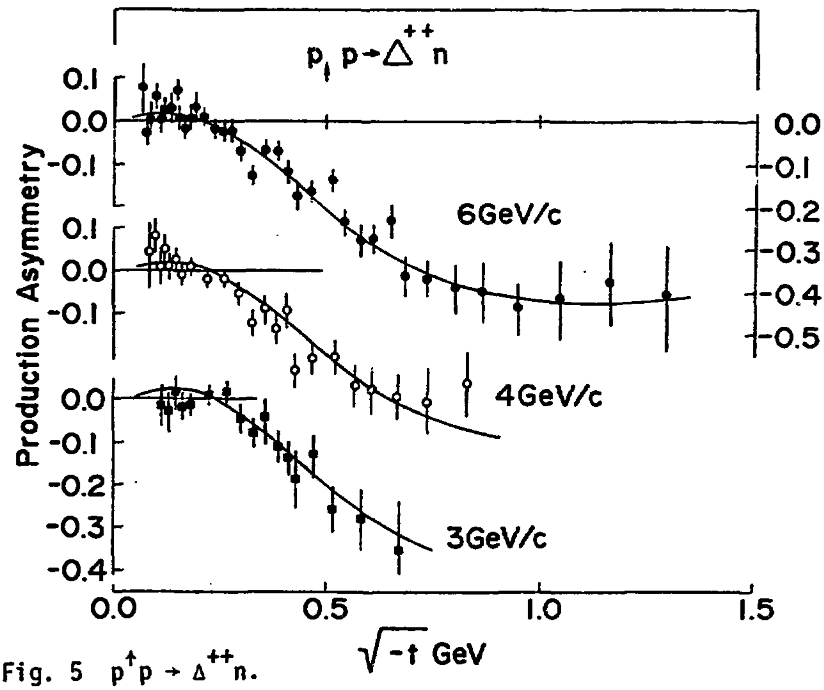
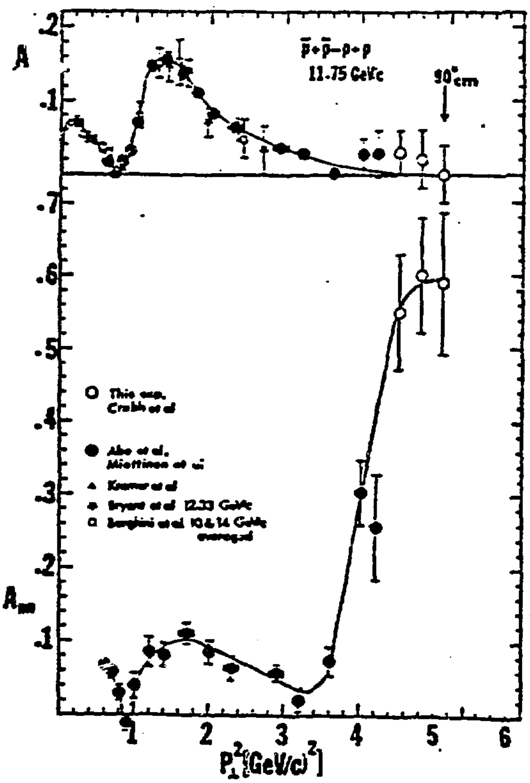


Fig. 5 $p^{\uparrow}p \to \Delta^{++}n$.

vii) pp Elastic Scattering at High $p_\perp$

Measurements of spin-spin correlation parameters have been extended to high $p_\perp$, revealing the importance of the spin-dependent interaction. These measurements may shed light on the nature of the constituents and their interactions.

The values of the C_{NN} (or A_{NN}) = (N,N;0,0) parameter have been measured up to 12 GeV/c covering $\theta_{c.m.}$ = 90° and show unexpectedly large values and interesting structure. The measurements were performed in Beam 1 (see page 9). Figure 6 shows the C_{NN} data at 11.75 GeV/c together with the polarization data, and also C_{NN} data at $\theta_{c.m.}$ = 90° as a function of $p_\perp^2$ and p_{lab}.



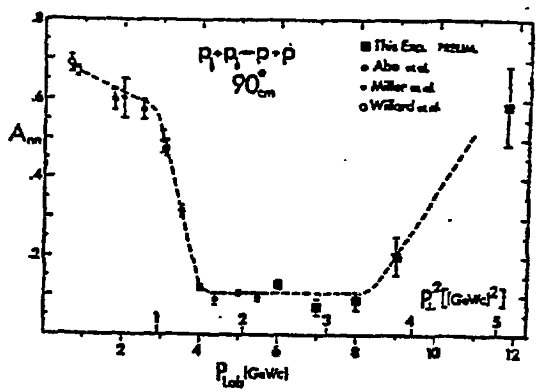


Fig. 6 C_{NN} at 12 GeV/c, and C_{NN} at $\theta_{c.m.}$ = 90° as a function of p_{lab}.

Preliminary data on C_{SL} = (S,L;0,0) and C_{LL} = (L,L;0,0) are shown in Figs. 7 and 8, respectively. The values of C_{SL} are essentially zero over the t range, while those of C_{LL} are negative at higher t and large in magnitude.

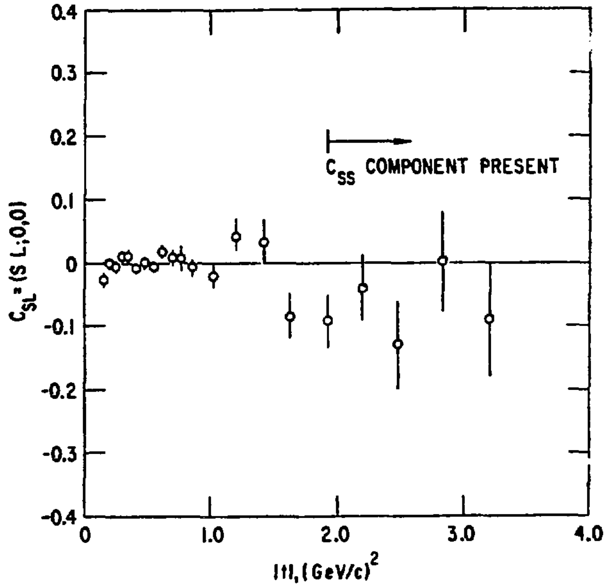


Fig. 7 C_{SL} = (S,L;0,0) at 6 GeV/c.

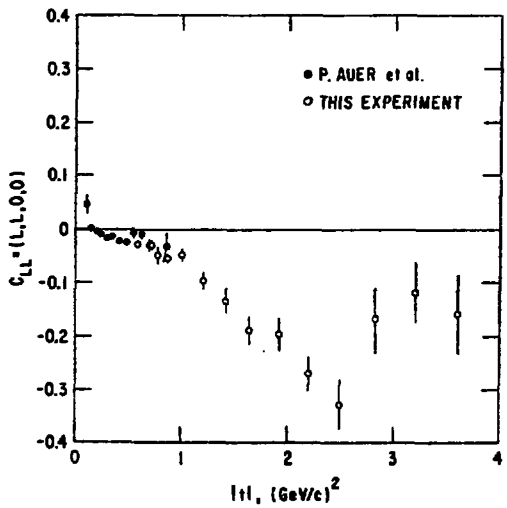


Fig. 8 C_{LL} = (L,L;0,0) at 6 GeV/c.

To understand high $p_\perp$ phenomena, we need to determine the scattering amplitudes in that region. As discussed in Section V, several parameters besides C_{NN} have been measured, and the data should be available soon.

There are several theoretical papers which predict values of observables at high $p_\perp$. These calculations are based on the quark-parton model.