Hadron Physics at the Japanese 50 GeV Proton Accelerator

Hadronic beam experiments encompass a very broad range of particle physics topics. This talk will concentrate on measurements that complement experiments at RHIC, CERN, FNAL, JLAB for possible inclusion in the JHF program.

It is assumed that there will be work on hypernuclei, continuing the fine AGS experiments, and also on rare K decays, so these will not be discussed.

- Partonic content of nuclei ($\bar{q}(x)$).
- Transition region between nucleon+meson and quark+gluon pictures of the strong interaction.
- Spin physics in forward scattering and total cross sections.
- Baryon and meson spectroscopy.

H. Spinka - ANL

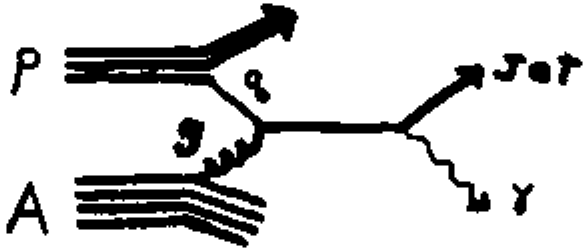
10 Dec. 2001

Partonic Content of Nuclei

- Nuclear physics has studied the makeup of nuclei in terms of protons, neutrons, and pions in the past. More recently, measurements are focussing on the structure of nuclei in terms of quarks and gluons.

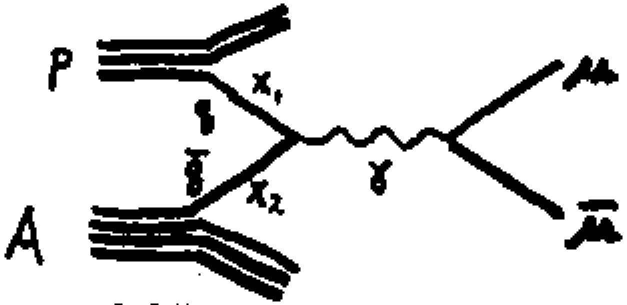
$q(x) + \bar{q}(x)$ from Deep Inelastic Scattering

$\ell A \rightarrow \ell' X$



$G(x)$ planned at RHIC

$p A \rightarrow \gamma + \text{Jet} + X$



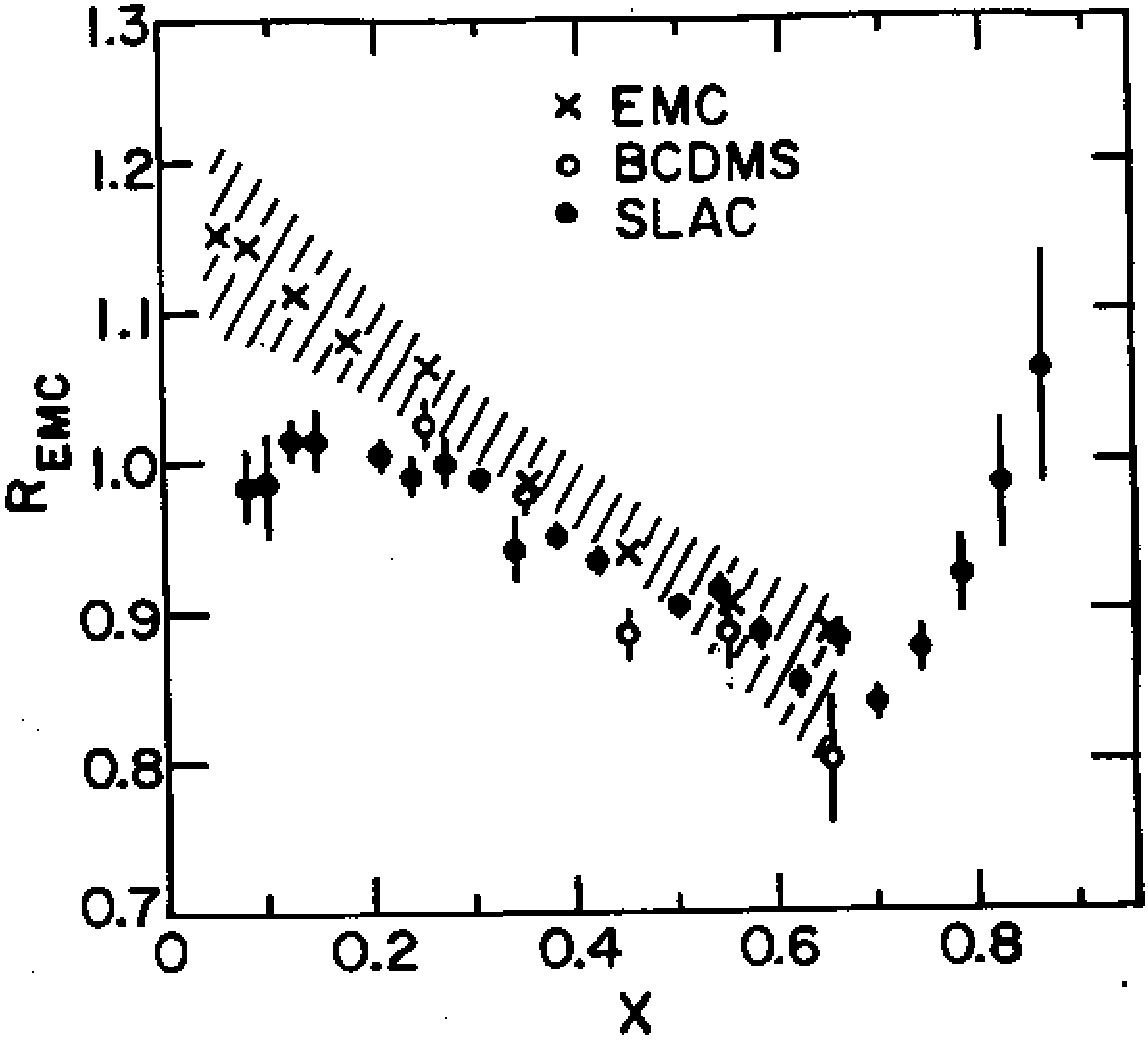
$\bar{q}(x)$ Drell-Yan at RHIC, FNAL, JHF

$p A \rightarrow \mu^+ + \mu^- + X$

$x_2 = M_{\mu\mu}^2 / x_1 s$

RHIC - small x_2, FNAL - medium x_2, JHF - large $x_2 \geq 0.25$

(Also $\Delta\bar{q}(x)$ in polarized pp, pd collisions - complementary to RHIC)



$R_{EMC} = F_2(Fe)/F_2(d)$

$F_2 \sim \sum e^2 (q + \bar{q})$

E.L. Berger and F. Coester
PR C32 1071 (1985)
Ann Rev Nucl Part Sci.
37 463 (1987)

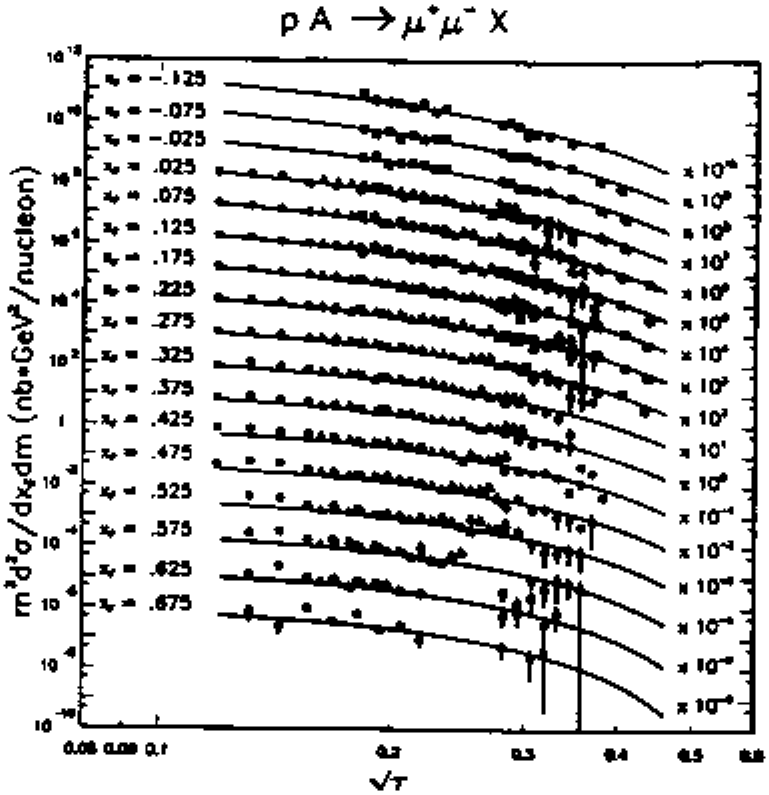
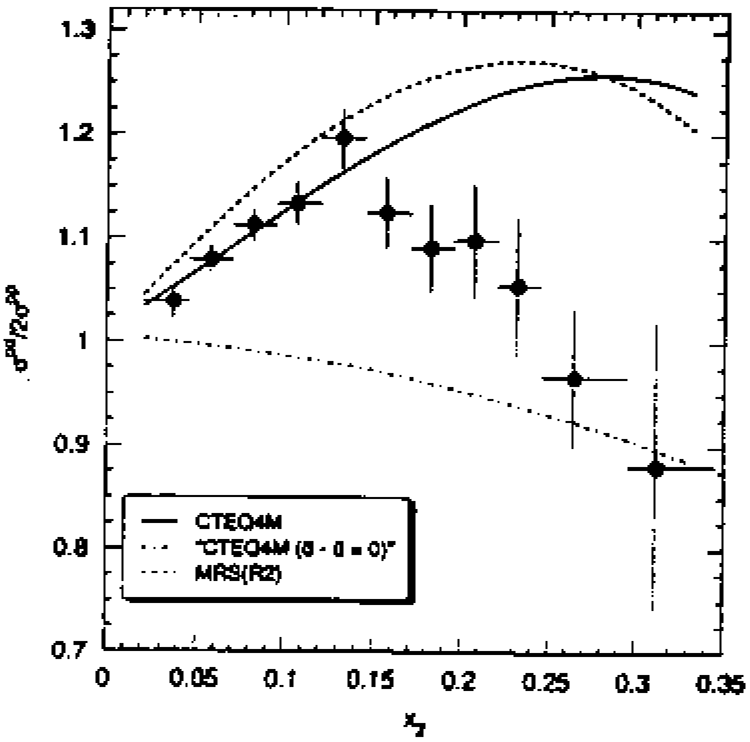


Figure 3 Proton-induced Drell-Yan production from experiments NA3 (8) (triangles) at 400 GeV/c, E605 (9) (squares) at 800 GeV/c, and E772 (10; PL McGaughey et al, unpublished data) (circles) at 800 GeV/c. The lines are absolute (no arbitrary normalization factor) next-to-leading order calculations for p + d collisions at 800 GeV/c using the CTEQ4M structure functions (11).

FNAL E866



P.L. McGaughey, J.L. Moss, and J.C. Peng, Ann Rev Nucl Part Sci 49, 217 (1999)

Figure 7 The ratio $\sigma^{pd}/2\sigma^{pp}$ of Drell-Yan cross sections vs x_2 from Fermilab E866 (2). The curves are next-to-leading order calculations, weighted by acceptance, of the Drell-Yan cross section ratio using the CTEQ4M (11) and MRS(R2) (30) parton distributions. In the lower CTEQ4M curve, $\bar{d} - \bar{u}$ was set to 0 to simulate a symmetric sea.

Transition Region Physics

- The Constituent Quark Model has been very successful in explaining many features of hadronic "structure" at relatively low Q^2.
  The constituent quark effective degrees of freedom interact in this model via flux tubes or potentials or are confined in a "bag". The successes of this approach suggest the effective masses, sizes, and interactions of these objects should be derivable from QCD.

  Recent measurements at JLAB of the cross section for $\gamma d \rightarrow p n$ show agreement with constituent counting rules for the energy dependence of exclusive processes

  $$d\sigma / dt\,(ab \rightarrow cd) \sim s^{2-N} f(t/s) \qquad N = n_a + n_b + n_c + n_d$$

  n_i = # leptons, γ's or quarks in particle i.

  The same is true of pp elastic scattering. However, in that case, some spin observable data at the same kinematic conditions do not agree with the predictions of the model. S.J. Brodsky and G.R. Farrar PRL 31, 1153 (1973)

  It is suggested to investigate other exclusive reactions with a simpler amplitude structure ($\pi p \rightarrow \pi p$, $Kp \rightarrow Kp$) to test $d\sigma/dt$ and P against constituent quark model predictions. This will assist in the search for the correct effective interaction.

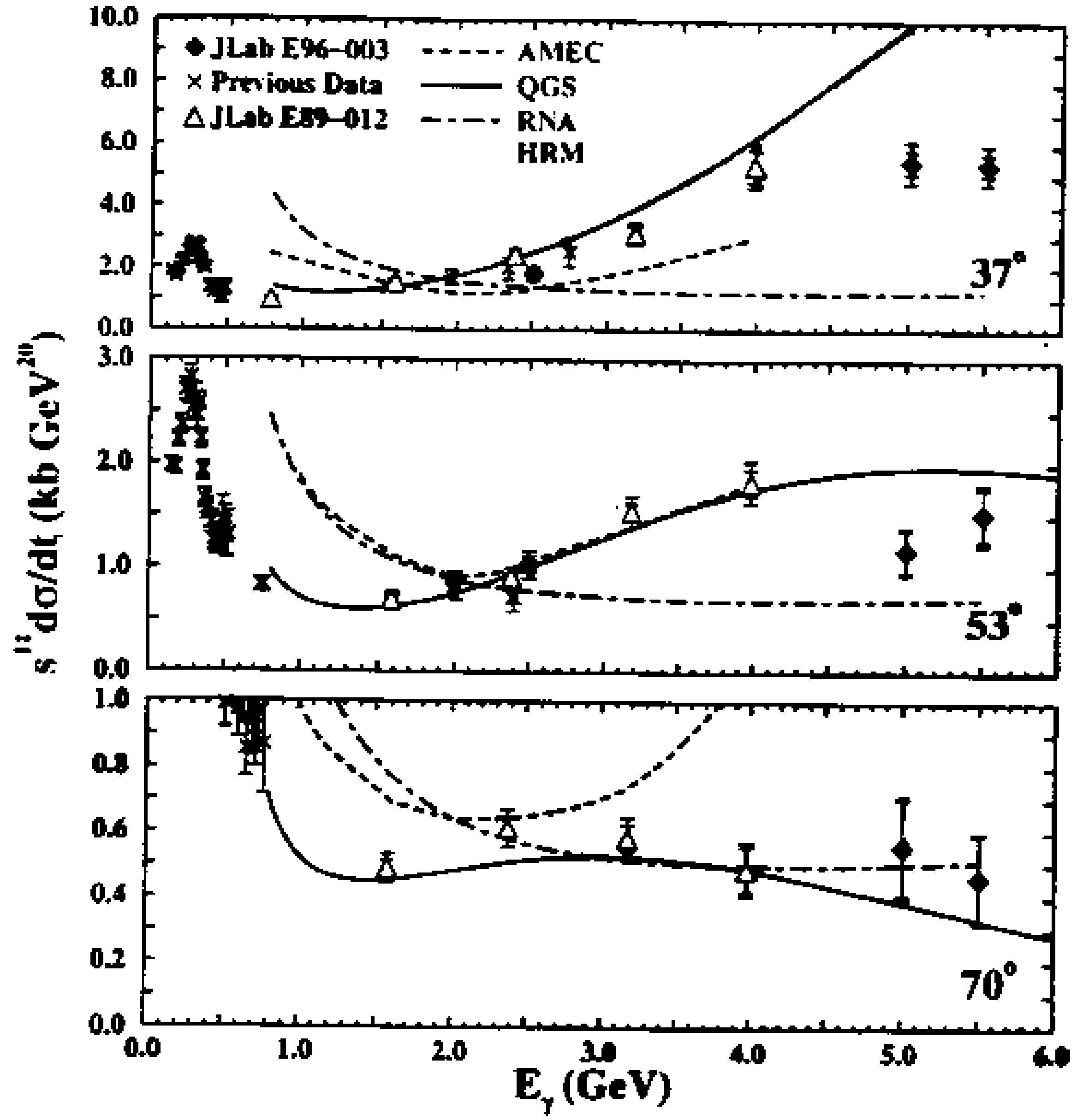


FIG. 2. $s^{11}\frac{d\sigma}{dt}$ vs E_γ for $d(\gamma, p)n$. The present data are shown as solid diamonds. Errors for JLab data are statistical and total errors. All others are statistical only. E89-012 data are shown as open triangles. All other data are shown as crosses and are as presented in Refs. [2,3,22]. The solid line is the QGS calculation [10]. The long-short dashed line is the RNA calculation [11]. The short dashed line is the AMEC [15]. The grey area is the HRM [9].

E. C. Schulte et al.
PRL 87 102302 (2001)

The striking similarity of data for

$$p\,A \rightarrow \overrightarrow{hyperon} + X$$

over a wide range of hyperons, A, and energy suggests a common mechanism.

Sizeable polarizations are observed at large x_F and $p_T \sim 1$ GeV/c.

A variety of models attempt to explain the observed results.

There are suggestions that

$$\vec{p}\,A \rightarrow meson + X$$

reactions also follow a simple pattern, perhaps related to the hyperon results above.

Sizeable polarizations have been seen for π^+, π^-, π^0, and η^0 at large x_F and $p_T \sim 1$ GeV/c for fixed target energies up to 200 GeV. (Some RHIC spin experimenters hope these polarizations persist to much higher energies.)

Such measurements need to be extended to other mesons, nuclei, and energies.

Models with an effective interaction among constituent quarks are probably appropriate to try to explain these observations.

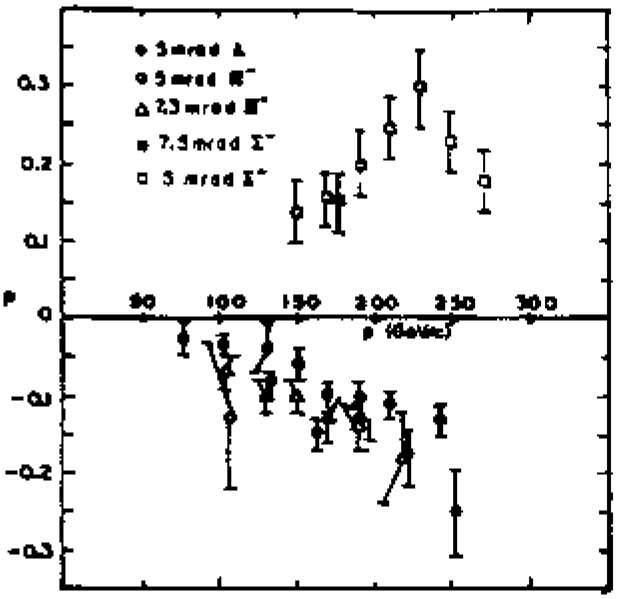


Fig. 100. Polarizations of charged and neutral hyperons plotted on the same graph. The Σ^+ and Σ^- polarizations have the opposite sign from the others.

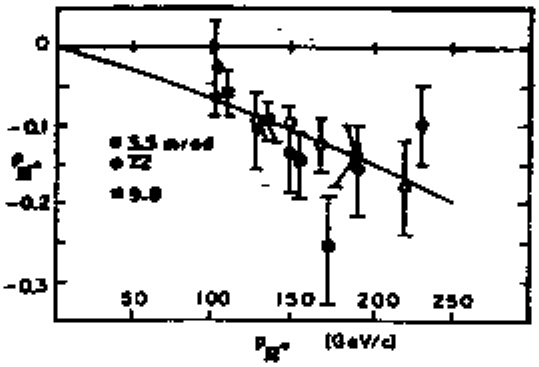


Fig. 98. Polarization of Ξ^0 produced by 400 GeV protons on Be. The solid curve is the $p_\perp$ independent fit $P = -0.29x - 0.017x^2$ given in table 16.

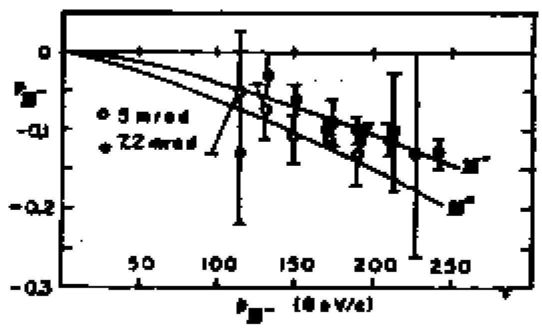


Fig. 99. Polarization of Ξ^- produced by 400 GeV protons on Be. The solid curves are the Ξ^- and Ξ^0 fits from table 16. The data indicate that the Ξ^- polarization is about 0.7 times the Ξ^0 polarization.

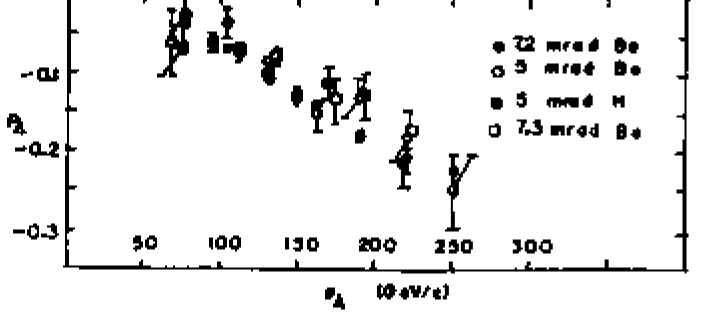


Fig. 97. Comparison of various experiments which measured Λ polarization from hydrogen and Be. The data are from refs. [78, 97]; the solid squares are from ref. [47]; and the open squares are from ref. [72]. The results, all from Λ production by 400 GeV protons, are internally consistent.

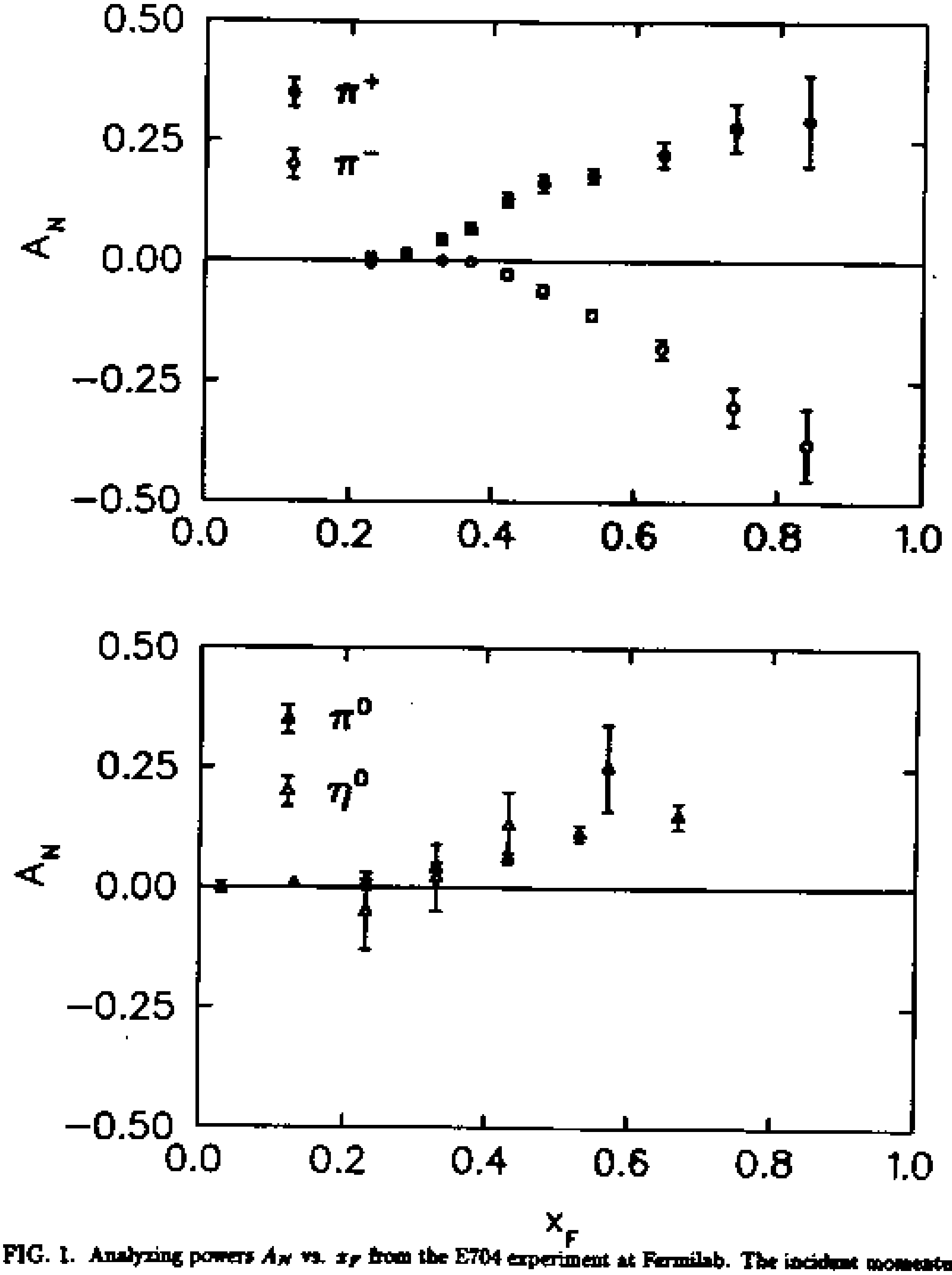


FIG. 1. Analyzing powers A_N vs. x_F from the E704 experiment at Fermilab. The incident momentum of the polarized proton beam for E704 was 200 GeV/c. The p_T− acceptance ranges for $\pi^\pm$, π^0, and η^0 were 0.2 to 2.0, 0.5 to 2.0, and 0.7 to 2.0 GeV/c, respectively. a) π^+ and π^- data. b) π^0 and η^0 results.

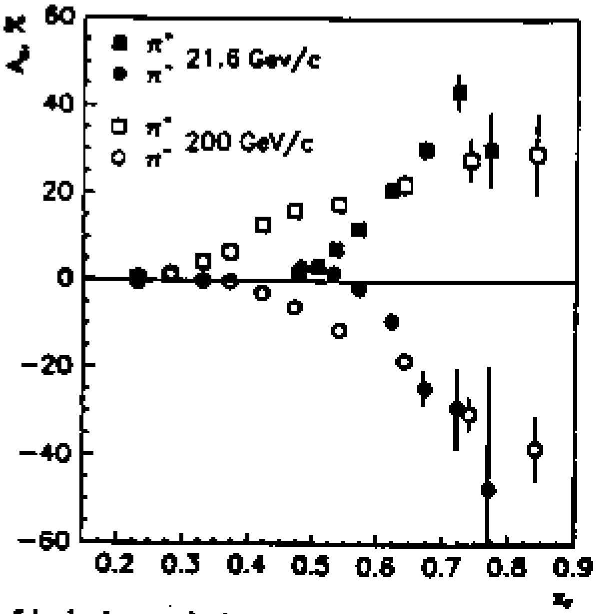


FIG. 22. Comparison of inclusive analyzing powers A_N from carbon at 21.6 GeV/c and hydrogen at 200 GeV/c [2].

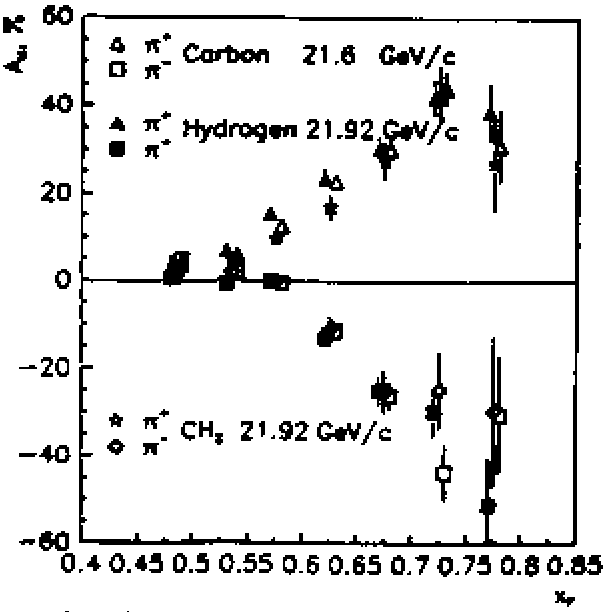


FIG. 19. Analyzing power for π^+ and π^- as a function of x_F on carbon, CH_2, and hydrogen. Note some points are slightly offset from the true value of x_F to make it easier to distinguish the points.

- Regge theory suggests Pomeron exchange (multi-gluon exchange) should become increasingly dominant with increasing energy.

$$|\mathrm{Ampl}_i| / |\mathrm{Ampl}_1| \underset{E\to\infty}{\longrightarrow} 0 \qquad i = 2 - 5.$$

This is observed in the total cross sections $\Delta\sigma_T$ and $\Delta\sigma_L$.

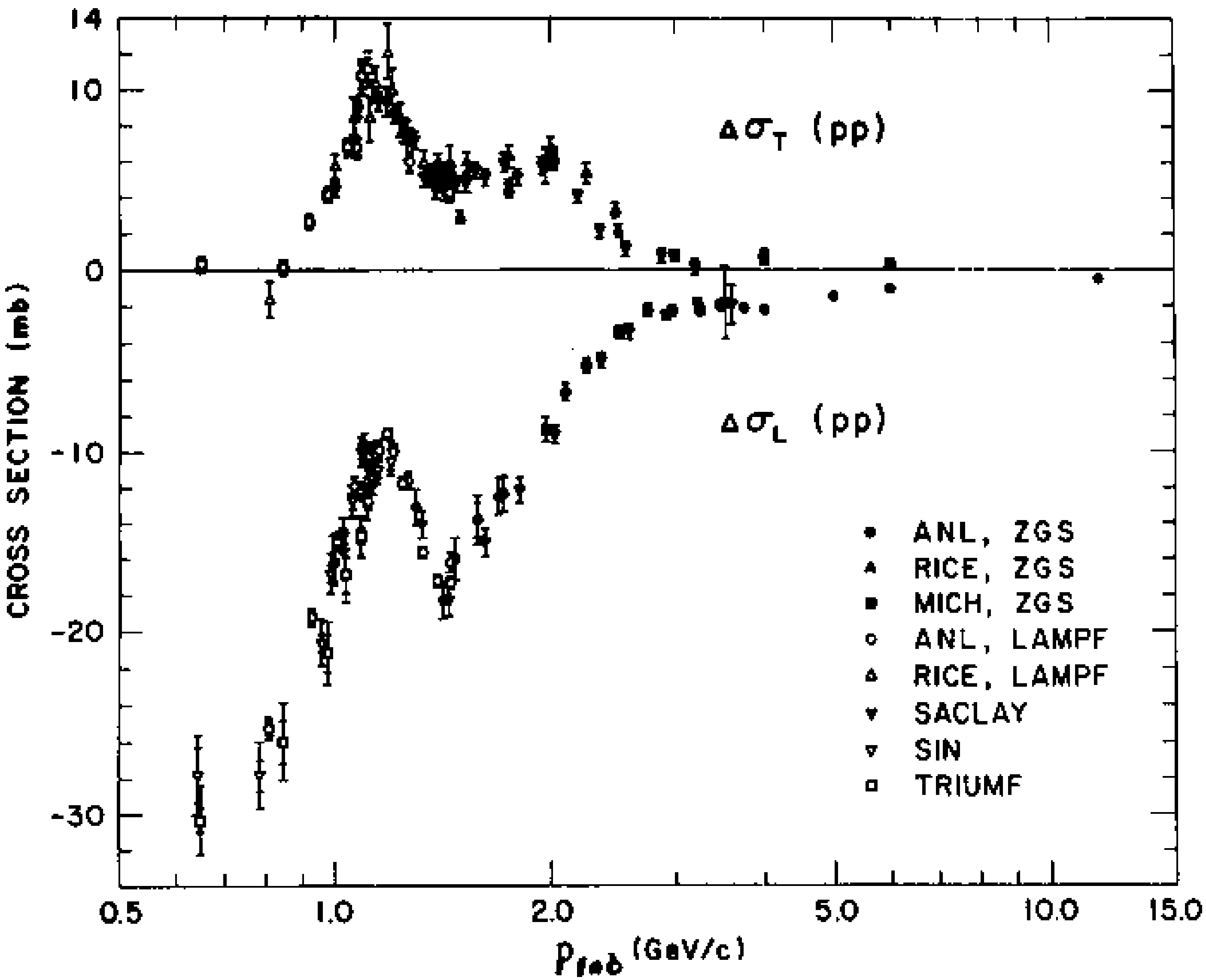
At very small angles, there is interference between Coulomb and strong interactions. Then, with the assumption above,

$$P\, d\sigma/dt \sim \mathrm{Im}\,[\mathrm{Ampl}_1\,(0)] \bullet \mathrm{Re}\,[\text{Spin Flip Ampl}_{EM}]$$

This is only roughly checked for pp scattering at high energies (FNAL E704).
N. Akchurin et al., PR D48, 3026 (1993)

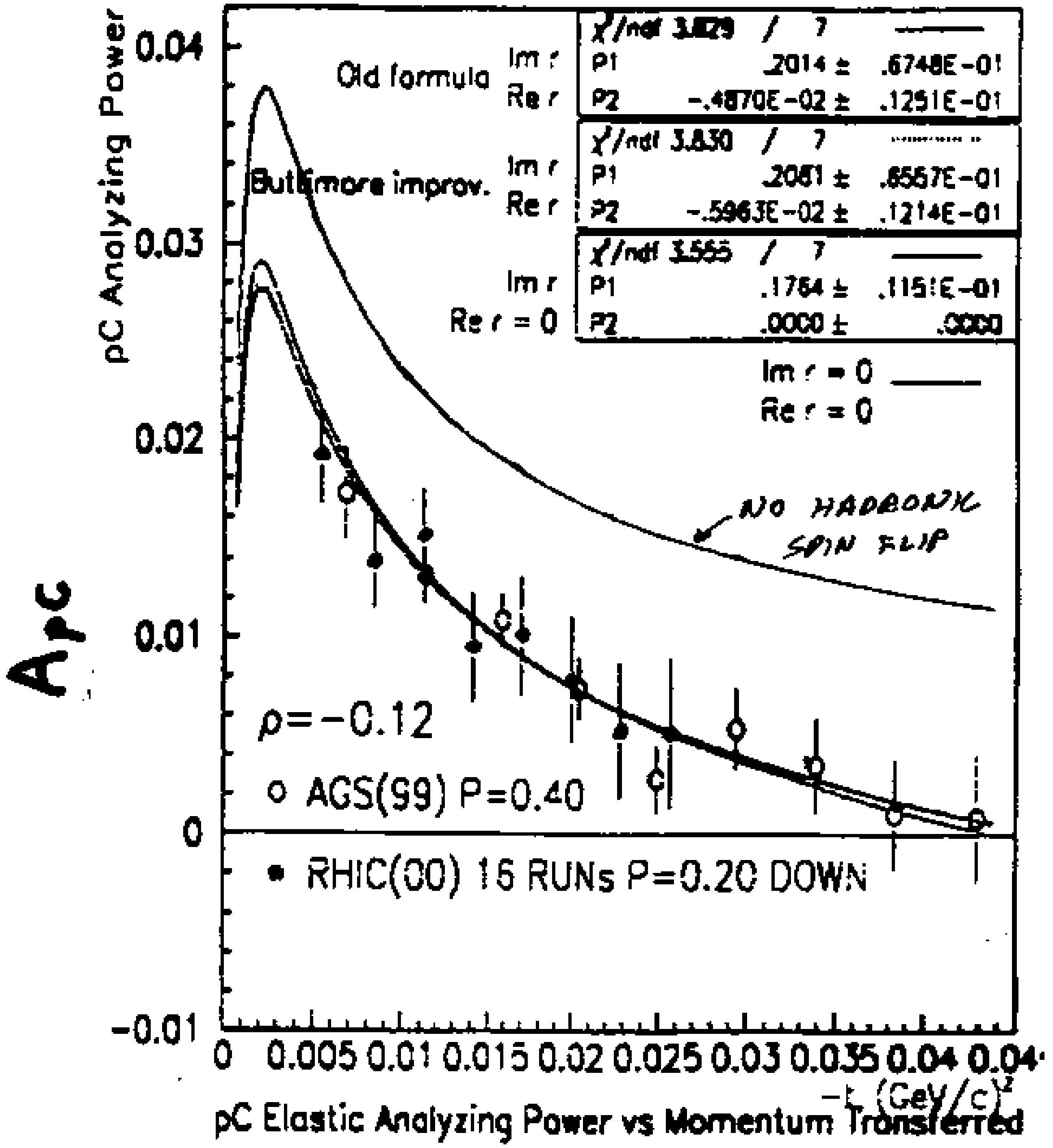
A similar result was expected to hold for p + C elastic scattering. Recent AGS measurements suggest a disagreement at 22 GeV/c.

The polarization in the Coulomb-nuclear interference region should be measured vs. energy and A. This is important for JHF and high energy proton polarimetry.



$\Delta\sigma_L$, $\Delta\sigma_T$
$\rightarrow 0$
WITH $E \rightarrow \infty$

$\vec{p} C \to p C$



$-t \ (GeV/c)^2 \longrightarrow$

A hadronic spin-flip term would be sensitive to the static constituent quark structure of the proton (nucleus).

Hadron Spectroscopy

- Quark inspired models have been quite successful at explaining many observed hadron states and classifying them into multiplets. But there are some challenges remaining:

  - Where do the gluonic degrees of freedom appear in the spectrum?

    $\bar{q}qg$, ggg, $qqqg$

  - Where are the missing $\Lambda^*, \Sigma^*, \Xi^*, \Omega^*$ states?

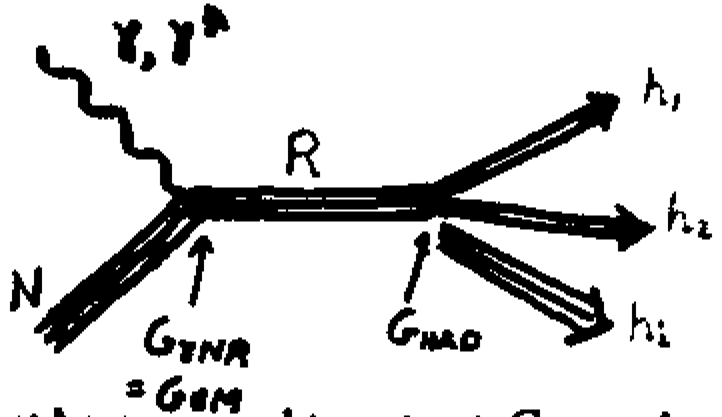
    Using known N^* and Δ^* states and multiplets to which they are assigned, the number of hyperon states can be determined. The number of observed states is much less.

  - Are there additional symmetries in the data that could point to new effective degrees of freedom?

    Parity doubling and restoration of axial U(1) symmetry?

    Quark-diquark or qqq picture more appropriate?

- CLAS at JLAB will do studies of electro- and photoproduction of baryon and meson states. The mass, width, and branching ratios can be obtained from the data.



The electromagnetic coupling, $G_{\gamma NR}$, would be very helpful to assist in assigning states to multiplets, especially at higher energies. The hadronic coupling must be measured to extract $G_{\gamma NR}$. A baryon resonance program at JHF with separated π and K beams would be complementary to the CLAS measurements.

Higher beam intensities than at past accelerators plus nearly hermetic detectors should allow vastly improved data compared to that collected decades ago with bubble chambers.

Some reactions also allow isospin selectivity:

$$K^- p \rightarrow \pi^0 \Lambda^0,\ \pi^0 \pi^0 \Sigma^0,\ \eta^0 \Sigma^0,\ \ldots \quad I = 1 \qquad \Sigma^*$$

$$\rightarrow \pi^0 \Sigma^0,\ \pi^0 \pi^0 \Lambda^0,\ \eta^0 \Lambda^0,\ \ldots \quad I = 0 \qquad \Lambda^*$$

- Glueballs and hybrids are predicted by QCD, and some candidates have been seen/identified.

  These are from high statistics studies in nearly hermetic detectors.

  $\bar{p}\,p$ interactions are considered an excellent way to form and study the properties of glueballs.

  JHF would have an opportunity to use a <u>unique tool</u> in such studies - a polarized antiproton beam from a secondary (separated) antiproton beam - if such measurements would be helpful. The properties would be:

  * polarization ~ 20 %
  * intensity ~ 2×10^{-4} of the secondary beam intensity
  * momenta ~ 0.5 - 2.5 GeV/c
  * the unscattered antiprotons in the secondary beam could be used in a beam line for a different experiment

E.W. Vaandering et al., NIM A351, 266 (1994)

- OTHER METHODS TO MAKE A POLARIZED ANTIPROTON BEAM HAVE BEEN SUGGESTED

FORMATION OF $\bar{H}$ ATOMS

K. IMAI OSAKA CONF. (1985)

H. POTH INTERSECTIONS CONF IN LAKE LOUISE (1986)

STERN - GERLACH SEPARATION OF SPIN STATES

T.O. NIINIKOSKI AND R. ROSSMANITH NIM A255, 460 (1987)

Y. ONEL, A. PENZO, R. ROSSMANITH INTERSECTIONS CONF. IN LAKE LOUISE (1986)

POLARIZED P GAS TARGET - RELY ON DIFFERENCE OF $\sigma(\rightrightarrows)$ AND $\sigma(\rightleftarrows)$ FOR $\bar{p}p$

P.L. CSONKA NIM 63, 247 (1968)

G. GRAW INDIANA CONF. ON POLARIZED BEAMS AND TARGETS (1989)

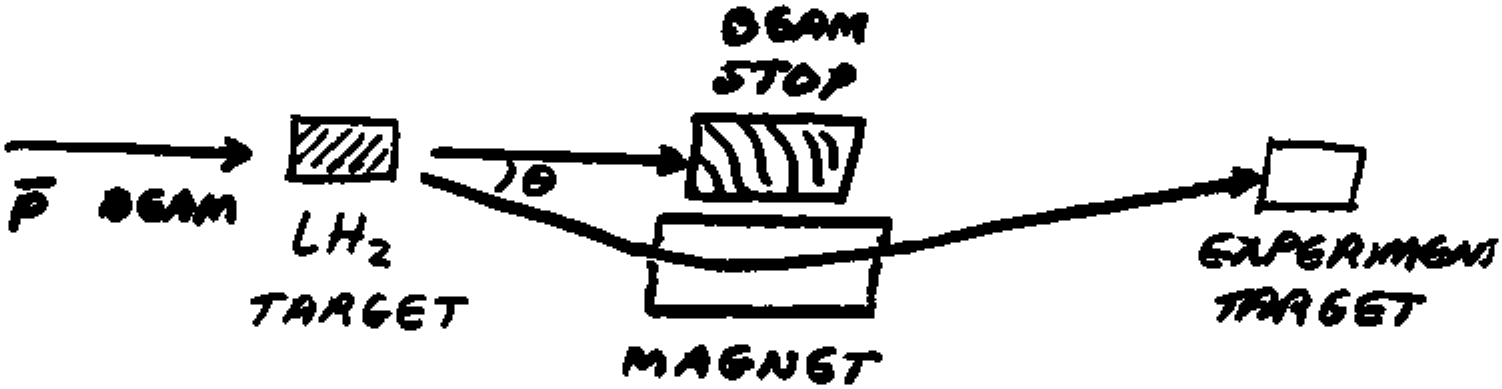
(TESTED WITH PROTON BEAMS)

F. RATHMANN et al. PRL 71, 1379 (1993) AND THIS CONF.

THESE METHODS ALL REQUIRE DEDICATED RUNNING OF THE ACCELERATOR AND INVOLVE LONG (HOURS) POLARIZING TIMES.

PRELIMINARY DESIGN, RATES, ETC.

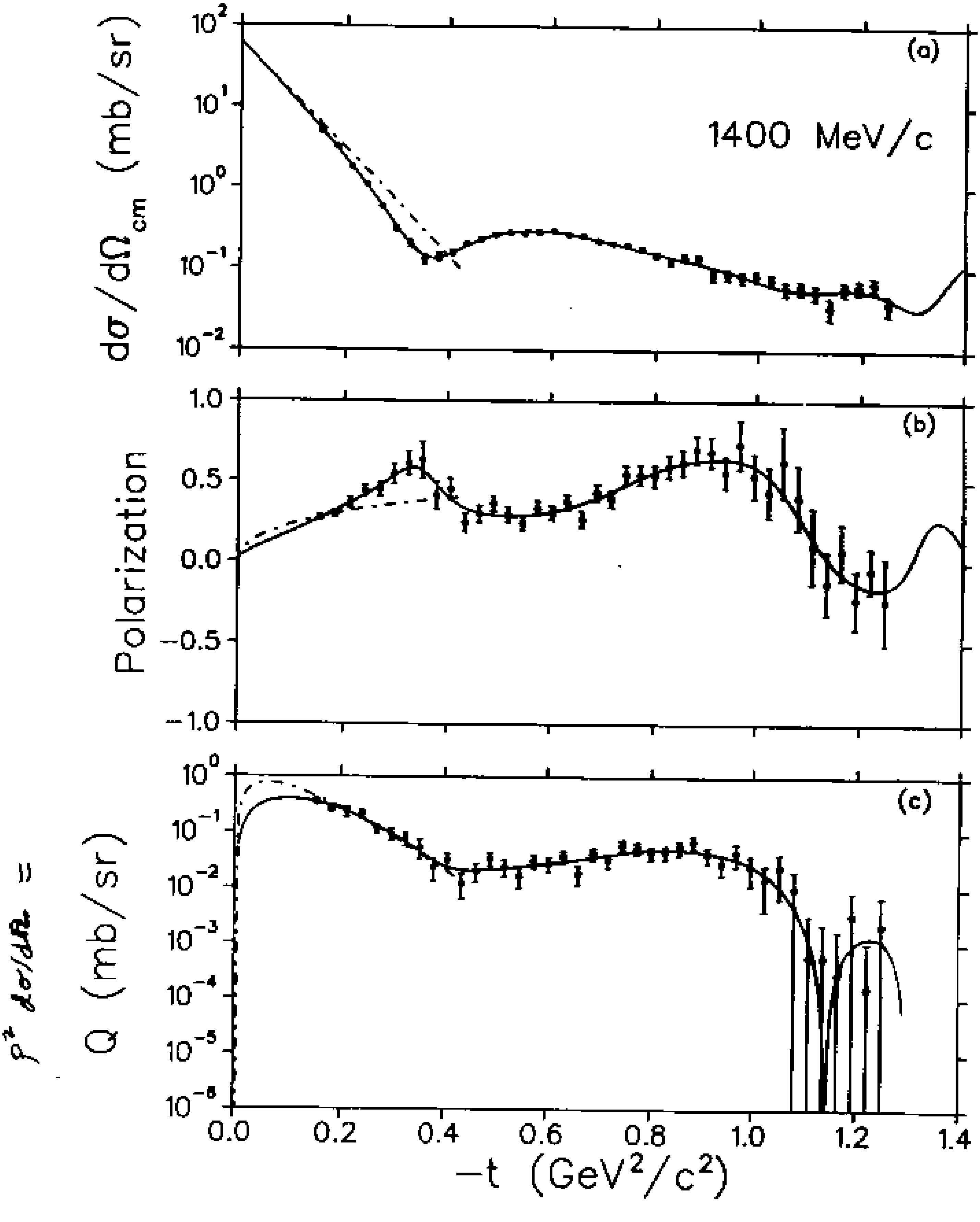
- THE $\bar{p}p$ POLARIZATION PARAMETER IS <u>NONZERO</u>. SO, USE A $\bar{p}$ BEAM INCIDENT ON A LH_2 TARGET, AND SCATTER AT $\theta \neq 0$. THE $\bar{p}$ SPIN WILL BE $\perp$ TO THE SCATTERING PLANE.

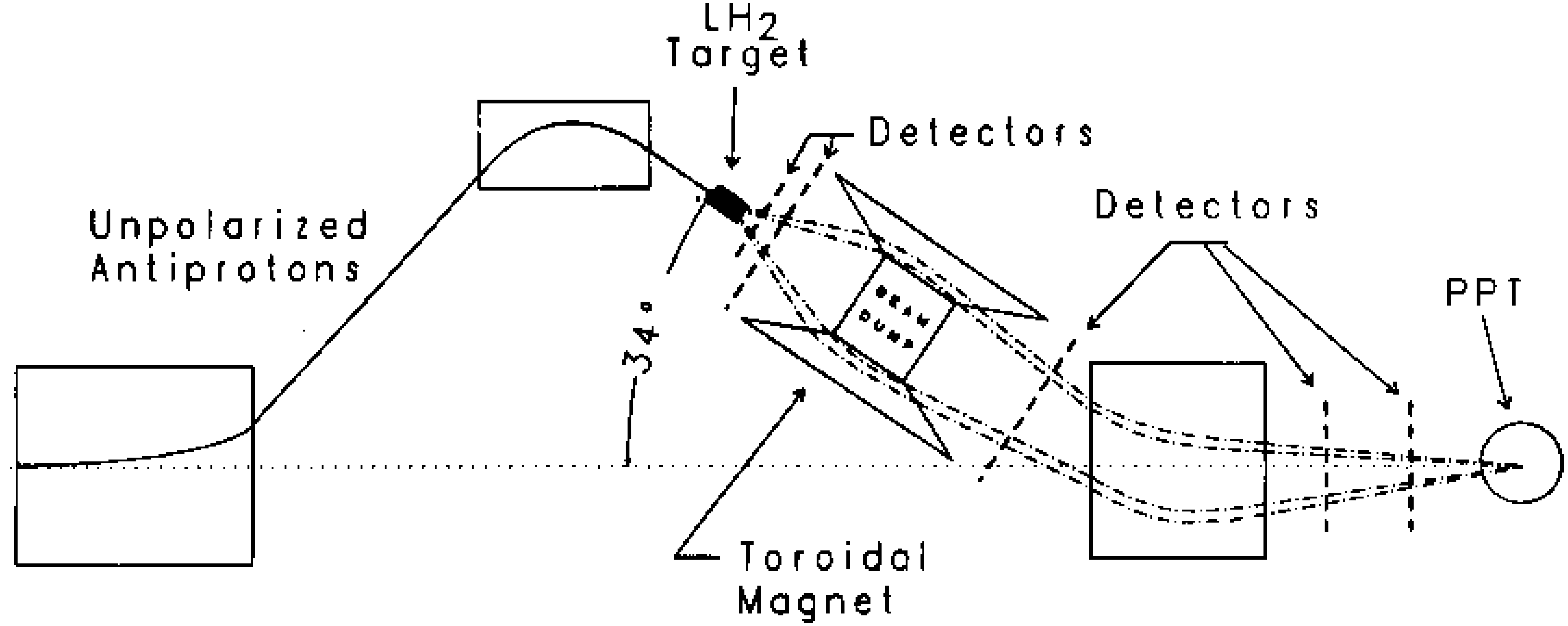


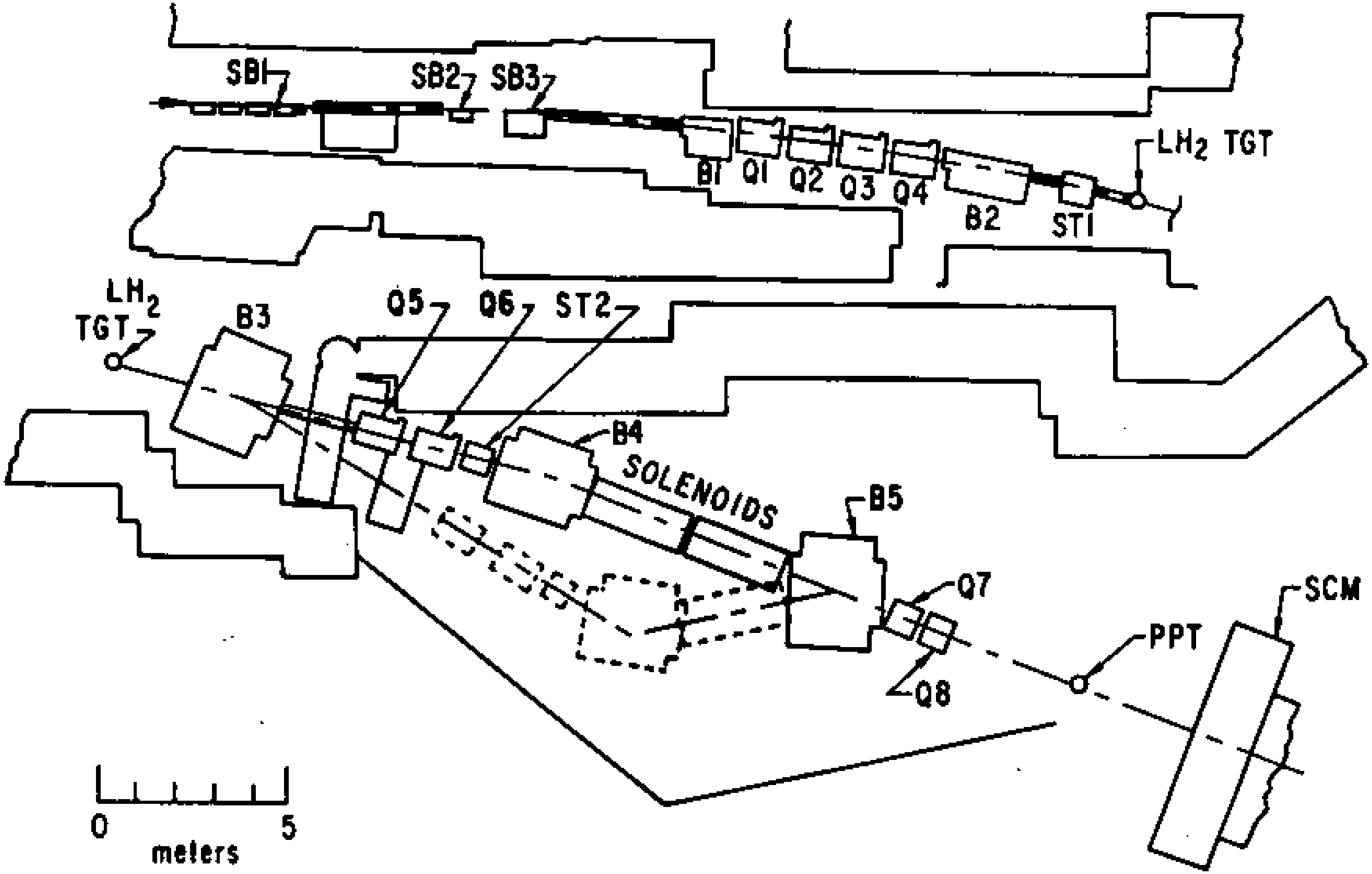
NOTE, THE MAGNET DOES NOT PRECESS THE $\bar{p}$ SPIN IN THIS CASE. HOPEFULLY THE ELASTIC SCATTERING EVENTS WILL NOT NEED TO BE "TAGGED".

- IT IS DESIRED TO MAXIMIZE THE POLARIZED $\bar{p}$ INTENSITY, WITH HIGH $\bar{p}$ POLARIZATION.

R.A Kunne et al.
NP B323, 1 (1989)




LH2
Target
Detectors
Unpolarized
Antiprotons
Detectors
PPT
34°
BEAM
DUMP
Toroidal
Magnet



ZGS BEAMLINE → E. COLTON et al, NIM 151, 85 (1978)
I.P. AUER et al., PR D34, 1 (1986)

Summary

There is a broad range of important hadron physics experiments that can be performed at JHF. In addition to hypernuclear and rare K decay physics, there are measurements that are important to complement heavy ion studies at RHIC and baryon spectroscopy at JLAB.

Probably there will continue to arise numerous experiments in the transition region between descriptions of reactions in terms of mesons + nucleons and gluons + quarks. The search for, and understanding of, effective interactions and degrees of freedom in the nonperturbative QCD region will also require complementary work at JHF and JLAB.

If of sufficient physics interest, a polarized antiproton beam may be built soon. On a longer time scale, the possibility of accelerated, polarized proton beams will offer many possible new measurements for JHF.

Forward Scattering

- The **Optical Theorem** connects **total** cross sections to forward elastic scattering amplitudes. For pp scattering there are 5 (6 with parity violation) amplitudes, 2 of which are zero in the forward direction.

$$(1/k)\ \mathrm{Im}\,[\mathrm{Ampl}_1\,(0)] \propto \sigma_{TOT} = (\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow})/2$$

$$(1/k)\ \mathrm{Im}\,[\mathrm{Ampl}_2\,(0)] \propto \Delta\sigma_T = \sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}$$

$$(1/k)\ \mathrm{Im}\,[\mathrm{Ampl}_3\,(0)] \propto \Delta\sigma_L = \sigma^{\rightarrow\leftarrow} - \sigma^{\rightarrow\rightarrow}$$

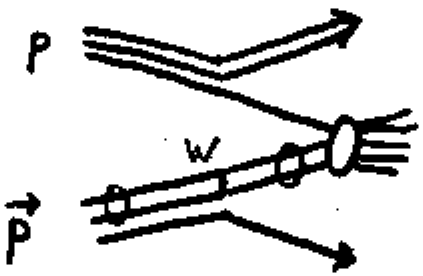
$$(1/k)\ \mathrm{Im}\,[\mathrm{Ampl}_{PV}\,(0)] \propto \Delta\sigma_{PV} = \sigma^{\rightarrow} - \sigma^{\leftarrow}$$

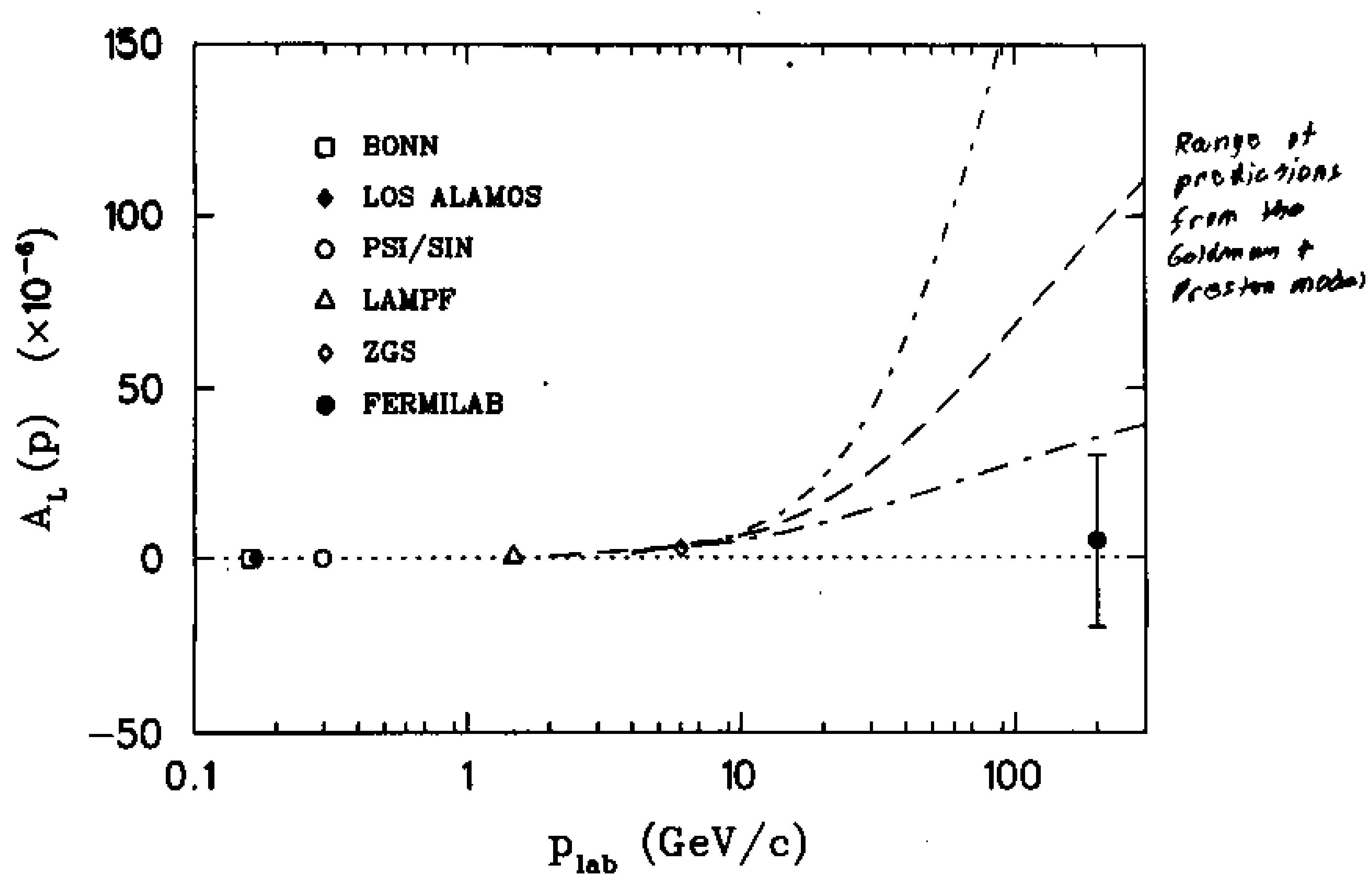
$$\text{or} \quad A_L = \Delta\sigma_{PV} / 2\,\sigma_{TOT} \qquad (\approx 10^{-6} - 10^{-7})$$

At low energies, A_L or $\Delta\sigma_{PV}$ are described in terms of a meson exchange model. At momenta above ~ 1 GeV/c, a quark model calculation normalized at the old ZGS point has been performed. It agrees with the LAMPF datum.

T. Goldman and D. Preston, NP B217, 61 (1983) and PL 168B, 415 (1986)

New measurements need to be made.





D. Grosnick et al. PR D55, 1159 (1997)