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Report of Activity for 1992-93

POLARIZATION EXPERIMENTS WITH HADRONIC AND ELECTROMAGNETIC PROBES

Submitted by

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II. Introduction

This is a yearly report of Dr. Vina Punjabi (principal investigator) K. Wilson, Abraham Logan and Duane White's (undergraduate students at Norfolk State University) activity during the grant period of July 1, 1992 to June 30, 1993, and a request for funding for the second year of this three-year DOE grant.

The PI has been involved in the following research activities during the past one year grant period with three undergraduate students participating in some of these research activities:

a) Calibration of focal plane polarimeter POMME up to 2.4 GeV at Saturne National Laboratory (LNS) in Saclay.

b) Measurement of Tensor Analyzing Power T_{20} and Polarization Transfer κ_0 at Saturne up to 2.1 GeV in Elastic Backward dp Scattering $\vec{d}p \rightarrow \vec{p}d$.

c) Measurement of Tensor Analyzing Power T_{20} at Synchrophasotron in Dubna up to 4.4 Gev in Elastic Backward dp Scattering $\vec{d}p \rightarrow pd$.

d) Resubmission of conditionally Approved G_{Ep} Proposal 89-14 at CEBAF.

e) Start construction of focal plane polarimeter (FPP) for CEBAF hall A hadron spectrometer.

The above activities are described in detail in section III.

The planned work for the next grant period includes:

a) Construction of FPP for CEBAF hall A hadron spectrometer will continue.

b) Continuation of polarization transfer κ_0 and tensor analyzing power T_{20} in elastic backward dp scattering at Saturne.

c) More measurements of tensor analyzing power in $^{1}H(^{6}Li,d)X$, $^{1}H(^{6}Li,\alpha)X$, $^{1}H(^{6}Li,t)X$ and $^{1}H(^{6}Li,^{3}He)X$ reactions at Saturne.

d) Polarization transfer in $^{2}H(\vec{e},e'\vec{p})n$ reaction at Bates.

These planned activities are described in section IV.

III. Activities During 1992-93

a) Calibration of focal plane polarimeter POMME up to 2.4 GeV at Saturne National Laboratory in Saclay.

Results of the new calibration of POMME[1] at 1.05, 1.35, 2.0, 2.24 and 2.4 GeV, in the form of the inclusive analyzing power from a 31.2 cm graphite analyzer, are shown in fig. 1. These results were obtained after first measuring the beam polarization from elastic pp scattering at 16.12°, 13.9° and 11.6° into SPES 4 and simultaneously with a beam polarimeter located in a beam line fed from a second extraction, also using elastic pp scattering at 16.12°, 13.9° and 11.6°. POMME was then calibrated by sending the same beam straight through SPES 4, without hydrogen target, still monitoring the beam polarization from the polarimeter on the second extraction.

The analyzing powers in fig. 1 are the result of a Fourier analysis of the azimuthal angle (angle ϕ) distribution of the secondary scattering from the polarimeter graphite, in steps of 1° in the polar angle θ between 3° and 25°. The data were taken with a fast rejection cut of 2° on the scattering angle in the polarimeter, to avoid recording events in the Coulomb dominated forward peak. The fraction of incident protons usable for this analysis was about 1 in 6; when corrected for the overall efficiency of POMME, these data indicate that 1 in 2 protons is scattered in the graphite at an angle $\theta>2°$. The corresponding "coefficient of merit" are close enough from the Monte Carlo prediction made in the G_{Ep} (89-14)[2] proposal at CEBAF, to justify the expectation that a polarimeter of design similar to POMME will work up to 2.4 GeV with acceptable performance.

The curves in fig. 1 were obtained using the new parametrization valid from 0.8 to 2.4 GeV, including our points at 1.6 and 1.8 GeV obtained in 1990, and complementing the original 1988 which extended up to 1.2 GeV. Duane White, a physics senior, has worked using Minuet to obtain this parametrization. Our calibration of POMME is thus concluded with this run.

Kevin Wilson who graduated in December 1992, worked on the POMME data obtained in 1990. He analyzed data with high multiplicity in chambers situated behind the carbon analyzer. The conclusion of this analysis was that events with multiple tracks were because of neutral particles. When there was no charged particle went through the chamber, some how many amplifiers gave signal, so these events had high multiplicity but very little charge.

b) Measurement of Tensor Analyzing Power and Polarization Transfer at Saturne up to 2.1 GeV in Elastic Backward dp Scattering $\vec{d}p \rightarrow \vec{p}d$.

A proposal to investigate the backward elastic dp reaction was submitted with this PI as a co-principal investigator. It was a joint proposal to study the spin structure of the reaction from 0.2 to 2.3 GeV at SATURNE in Saclay, and from 2.0 to 7.2 GeV at the Synchrophasotron in Dubna.

Although the kinematical region accessible at Saturne is limited to k=0.57 GeV/c, the interest to do a careful study of the polarization transfer, from the lowest practical internal momentum, k of about 0.15 GeV/c to the highest possible value (potentially k=1.05 GeV/c in Dubna), is the prospect that such data will map the passage to an asymptotic regime, going from the nucleon dominated mode to the quark dominated mode in the dp interaction. Obtaining all polarization observable data over the whole range of q or k-values accessible at Saturne and Dubna is the ultimate goal of this collaboration. Such data will give a rare opportunity to characterize the deuteron in a distance region down to 0.2 fermi, with a simple, clean and homogeneous ensemble of data including cross section, T_{20} and polarization transfer.

Experiment no. 249 was to be the measurement of tensor analyzing power T_{20} and of the polarization transfer ratio κ_0, defined as the ratio of the proton polarization to that of the incident deuteron, in the backward elastic scattering reaction dp $\rightarrow$ pd, at energies between 0.2 and 2.3 GeV. This experiment was to receive 9 days of beam, between May 25 and June 3, 1992. Unfortunately, a thunderstorm of catastrophic proportion stopped the experiment on the 31 of May. At this point the experiment was in its routine data taking phase, and 5 of the 10 energies proposed had been done. These are 1.0, 1.2, 1.5, 1.8 and 2.1 GeV. Results at these 5 energies for T_{20} are systematically less negative than those obtained by Arvieux et al[3] as shown in fig. 2. At 2.1 GeV our value is about half as large as in ref. 3. We also see the outline of a structure near 1.4 GeV deuteron energy, as had been discovered in ref. 3. Our data have very small statistical uncertainty, and small systematics too. The 1982 data of ref. 3 were obtained with a hodoscope rather than drift chambers, and a 20 cm rather than 40 cm collimator. Never-the-less, the new results are puzzling; they ought to be placed in the framework of an earlier experiment by Igo et al[4] who's results at 0.8, 1.6 and 2.0 GeV were essentially zero. We feel that this situation is unacceptable and necessitates checking the results of last summer, as well as a detailed mapping of a presumed structure near T_d=1.4 GeV, with small beam energy steps.

The data analysis of the polarization transfer κ_0 data is in progress at William and Mary.

c) Measurement of Tensor Analyzing Power at Synchrophasotron in Dubna up to 4.4 Gev in Elastic Backward dp Scattering $\vec{d}$p -> pd.

Measurement of tensor analyzing power T_{20} at Synchrophasotron in Dubna took place in February-March 1993. Tensor analyzing power was measured at six deuteron energies for internal momenta of 0.540 GeV/c to 0.800 GeV/c. The lowest energy investigated at Dubna is the same as the highest energy at Saclay so that we can compare our results. We found that the two results are in excellent agreement within error bars.

d) Resubmission of conditionally Approved G_{Ep} Proposal 89-14 at CEBAF.

The understanding of the structure of the nucleon is of fundamental importance; ultimately such an understanding is necessary for the first principle description of the nuclear force. The distribution of charge and currents inside the nucleon is best revealed by the electromagnetic probe, through the interaction of the virtual photon with the quark constituents of the nucleon.

The standard method of analysis of the differential cross section for elastic scattering of an electron by the nucleon is based on

the Rosenbluth formula:

$$\frac{d\sigma}{d\Omega_e} = \frac{d\sigma}{d\Omega_{Mott}} [\![G_E^2(Q^2) + \tau G_M^2 [1+2(1+\tau)\tan^2(\frac{\theta_e}{2})]]\!] = \frac{d\sigma}{d\Omega_{Mott}} \cdot I_0 \qquad (1)$$

where G_E and G_M are the Sachs electric and magnetic form factors of the nucleon, $Q^2=-q_\mu{}^2$ is the four-momentum transfer squared, $\tau=Q^2/4M$, with M the nucleon mass, and θ_e is the lab. scattering angle of the electron. In eqn. 1 $d\sigma/d\Omega_{Mott}$ is the Mott cross section for a point charge:

$$\frac{d\sigma}{d\Omega_{Mott}} = (\frac{\alpha}{2E_e})^2 \frac{\cos^2(\frac{\theta_e}{2})}{[1+2\frac{E_e}{M}\sin^2(\frac{\theta_e}{2})]\sin^4(\frac{\theta_e}{2})} \qquad (2)$$

where E_e is the incident electron energy.

The Sachs form factors are related to the Dirac and Pauli form factors F_1 and F_2 by:

$$G_E = F_1 - \tau F_2 \text{ and } G_M = F_1 + F_2.$$

A complete description of the electromagnetic structure of the nucleon requires measurement of the form factors G_E and G_M for both the proton and the neutron, for all values of Q^2 from 0 to ∞.

A recent determination of the magnetic form factor G_{Mp} for the proton by Bosted et al[5] has total uncertainties ≤ ±0.01 for the ratio G_{Mp}/G_{MD}, where G_{MD} is the dipole form factor, up to Q^2=6 GeV^2.

The electric and magnetic dipole form factors have no fundamental meaning, but have been found convenient to fit older data; for the proton they are defined as follows:

$$G_{ED}=\frac{1}{(1+\frac{0.71}{Q^2})^2},\ G_{MD}=\frac{\mu_p}{(1+\frac{0.71}{Q^2})^2} \quad (3)$$

For the <u>electric form factor</u> of the proton the experimental situation is much less satisfactory. Fig. 3 shows all data up to $Q^2=8.8\ GeV^2$; the results of ref. 5 are shown as full circles. All data points in fig. 3 have been obtained by the Rosenbluth separation method. The results of various experiments are not consistent within the error bars. Also shown as full squares in the same figure are the expected results of proposed experiment 89-14[2] at CEBAF, which will use the recoil polarization method discussed below; this method has been discussed in detail by Arnold, Carlson and Gross[6]. As shown in ref. 6, the elastic scattering of longitudinally polarized electrons on the proton will result in a polarization of the recoil proton, with mainly two components P_t and P_l, transverse and longitudinal in the reaction plane, respectively. A component P_n normal to the scattering plane does not arise in the one-photon exchange process which dominates elastic ep scattering. P_t and P_l are given by:

$$P_t=\frac{-2\sqrt{\tau(1+\tau)}\,G_{Ep}G_{Mp}\tan(\frac{\theta_e}{2})}{I_0} \quad (4)$$

$$P_l=\frac{\frac{E_e+E_e'}{M}\sqrt{\tau(1+\tau)}\,G_{Mp}^2\tan^2(\frac{\theta_e}{2})}{I_0} \quad (5)$$

where I_0 is defined in eqn. 1. It follows from equations 4 and 5 that measuring P_t/P_l gives the ratio G_{Ep}/G_{Mp}. The advantage of the polarization method is that it gives G_{Ep} as an interference term, and as a second advantage P_t and P_l are measured simultaneously. The Rosenbluth separation requires measuring cross sections at several energies and angles for a given Q^2, with corresponding difficulties in keeping the systematic uncertainties small.

The proton polarization is measured in a focal plane polarimeter, like the one planned for the hadron arm in hall A. In the polarimeter the protons are scattered in a thick graphite bloc; the azimuthal distribution of the rescattered protons is:

$$N(\theta,\phi)=N(\theta)[\![1\pm hA_C(\theta)\,[P_t'\sin\theta+P_n'\cos\theta]]\!] \quad (6)$$

where P_n' and P_t' are the normal- and transverse components of the polarization at the graphite scatterer, related to the polarization at the target by:

$$P_t'=P_t,\, P_n'=P_l\sin\chi+P_n\cos\chi \quad (7)$$

and θ and ϕ are the polar- and azimuthal scattering angles in the graphite, respectively; h is the helicity of the beam, χ is the precession angle of the spin in the spectrometer B-field and $A_C(\theta)$ the analyzing power of graphite. As P_n is ≈ zero, Fourier analysis of the ϕ-distribution in eqn. 6 gives the two quantities:

$$a=hA_CP_s,\, b=hA_CP_l\sin\chi \quad (8)$$

if averaging over the polar angle θ is assumed. The quantities a and b then determine two physically interesting and independent quantities:

$$\frac{G_{Ep}}{G_{Mp}}=-\frac{a}{2b}\frac{(E_e+E_e')}{M}\sin\chi\tan\left(\frac{\theta_e}{2}\right) \quad (9)$$

and

The proposal submitted anticipates measurements of the G_{Ep}/G_{Mp} ratio, and therefore determination of G_{Ep} with the help of the G_{Mp} data base, up to Q_2=4.5 GeV^2; an extension to Q^2=6 GeV^2 would become possible with a 6 GeV beam. The anticipated performance at the Q^2 values proposed are found in table 1. The original numbers in ref.

$$A_c = \frac{\left(\frac{a^2}{2b}\right)\left(\frac{E_e+E_e'}{M}\right)^2 \sin^2\chi + b\tau\left[\frac{1}{\tan^2\left(\frac{\theta_e}{2}\right)} + 2(1+\tau)\right]}{h\left(\frac{E_e+E_e'}{M}\right)\sqrt{\tau(1+\tau)}\sin\chi} \tag{10}$$

2 have been verified by a series of polarimeter calibrations at SATURNE[1] up to a proton energy of 2.4 GeV, which corresponds to the point at Q^2=4.5 GeV^2 in table 1. Eqn. 10 shows that this experiment will also calibrate the polarimeter analyzing power A_c; the last column in table 1 shows the expected total relative uncertainties expected for A_c.

e) Start construction of focal plane polarimeter (FPP) for CEBAF hall A hadron spectrometer.

Polarization measurements in the focal planes of a magnetic spectrometers is a well established experimental technique. A polarimeter in nuclear physics is a secondary scattering device using a thick block of carbon (graphite) as the analyzer because of its large analyzing power.

The FPP group is in process of building a polarimeter to be used in the hall A hadron arm spectrometer at CEBAF. The design of the polarimeter is similar to POMME at Saturne[7] and LAMPF HRS polarimeter[8], i.e. graphite analyzer sandwiched between the particle tracking detectors. Fig. 4 taken from this report shows the detector arrangement for the polarimeter. It shows two front and two rear particle tracking detectors. The polarimeter will contain segmented carbon analyzer up to 60 cm in thickness. This will allow the polarimeter to be useful over a wide range of proton energies (200 - 2400 MeV).

Two different technologies were considered and researched to build the particle tracking detectors, (1) detectors with scintillating fibers and position sensitive photomultipliers, and (2) drift straw detectors.

The detector technology chosen for the tracking detectors of the FPP for the hadron arm in hall A is drift straws. The straws will be 11 mm in diameter, and the drift time digitized to reach a position resolution of a few 100 μm.

Straw chambers differ from conventional MWPC's in that each anode wire is placed in an individual cylindrical tube (the straw), rather than having a anode and cathode wires and ground planes in a common chamber. In comparison with standard chambers, straw tubes have the advantages of an angle-independent response in the measured coordinate and a lower hardware cost. Another advantage of this type of detector, is that each straw forms an independent chamber, and almost any physical problem with a given straw, such as electrostatic, broken wire, contamination does not affect the remainder of the detector.

The FPP group received funding from NSF to build the polarimeter.

So far the clean room has been constructed at William and Mary for manufacturing straws. A physics junior Abraham Logan from NSU has been actively involved in this construction.

IV Planned Work for 1993-94

a) Construction of FPP for CEBAF hall A hadron spectrometer will continue.

In fig. 5 the straw and gap sizes are shown for a 3 layer configuration. The straws will be oriented in U and V directions; these U and V planes are then transverse to the beam, and rotated 45° relative to the usual dispersion and transverse directions X and Y. The choice of UV over XY is intended to equalize the rates and wire lengths in the two readout coordinates, and to shorten the maximum wire length. To facilitate analysis of events with multiple tracks out of the analyzer, an additional 3X planes will be located next to chamber 3 for the stereo information.

The following activities will take place next year.

a) build and test prototype.

b) Manufacture straw tubes by undergraduate students from William and Mary and NSU.

i) tests of frame rigidity.

b) Polarization Transfer and tensor analyzing power in Elastic Backward dp Scattering at Saturne $\vec{d}p \rightarrow \vec{p}d$

As described in previous section in part b) the measurement of tensor analyzing power T_{20} and of the polarization transfer ratio κ_0 in the backward elastic scattering reaction dp $\rightarrow$ pd, at energies between 0.2 and 2.3 GeV at Saturne, Saclay was interrupted due to a thunderstorm on the 31 of May, 1992.

In December, 1992 we have received an additional 10 days to finish this experiment in May-June 1993.

c) <u>In-flight breakup of polarized ^{6}Li on hydrogen at SATURNE</u>

Experiment no. 233, the measurement of T_{20} in the breakup of 4.5 GeV 6Li, has received 15 shifts in July, 1991. Despite a number of difficulties due to the quality of the beam, about 72 hours could be used for data taking. These data have been fully analyzed, and a paper published in Physical Review C[9]. Also an invited talk was presented by the PI at the Seminar for High Energy Problems in Dubna[10], this last September; the latter includes a more comprehensive discussion of the significance of the results of expt. 233 than found in the Phys. Rev. paper.

The results are interesting first because we have observed a signature of the D-state in T_{20}, which was not a priori evident because the D-state component in the αd vertex is certainly very small, with a total probability of order 10^{-4} to 10^{-3}.

Second, T_{20} starts at low q with the same sign as in the deuteron, and clearly changes sign near 150 MeV/c. This change of sign of T_{20}, at least within the limitations of the impulse approximation, indicates a change of the relative sign between the S and D-state momentum space wave functions. It occurs just were predicted from the existence of a node in the S-state position wave function, near 0.7 fm. Both Lehman[11] and Kukulin[12], and probably others have discussed the likelihood of such a node. Its existence is due to the Pauli principle making the αN potential repulsive because the S-state is saturated with 4 nucleons. To my knowledge the node has never been seen directly before; it most definitely cannot be seen in cross sections data. Finally we observed a significantly larger analyzing power in the α channel than in the deuteron channel; a simple minded explanation for this striking effect is presented in the Dubna preprint.

We have received 21 shifts to finish this experiment. The time will be used to do the following:

i) extend the measurement in the d-channel to negative q-values, i.e. deuteron momentum less than p(beam)/3; the prediction is for the exact same behavior for T_{20} versus q; these data would directly show the effects of distortion from final state interaction.

ii) get data in the α channel for small q values, to ascertain the existence of a node in this channel; the 1991 data just suggest that there may be a similar node.

iii) get data in the A=3 channel (^3H and ^3He), as proposed in the approved part of the proposal. The few points we have suggest that T_{20} is not zero, and that it might have a node at much larger q than the d and α channels. Very little is known on the D-state in the ^3H-^3He decomposition of ^6Li, and this experiment has proven that breakup data do indeed, at the very least qualitatively, give a unique signature of the D-state over a region of q.

d) The approved experiment 88-21 at Bates was to measure a total of 5 kinematics for the $^2H(\vec{e},e'\vec{p})n$ reaction. Additional beam time was requested to measure 4 additional kinematics. These kinematics include four values of three momentum transfer ($\vec{q}$ = 524, 659, 779 and 900 MeV/c) to examine the Q^2 dependence of the reaction at p_R = 0 MeV/c. For these kinematics the free form factors will also be measured in $^1H(\vec{e},e'\vec{p})$. Another four kinematics with p_R = 63 and 127 MeV/c have been chosen to study the angular distribution at $\vec{q}$ = 779 MeV/c. Kinematics with $\vec{q}$ = 524 MeV/c is chosen for comparison with the similar experiment designed to measure the neutron electric form factor with the $^2H(\vec{e},e'\vec{n})p$ reaction.

The FPP is being installed at present in the focal plane of OHIPS. This experiment will probably happen in July or August of this year (1993). The PI will participate in the experiment.

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Figure Captions

Fig. 1 The analyzing power of the polarimeter POMME with 31.2 cm of graphite, as a function of the scattering angle in the graphite for 1.05, 1.2, 1.35, 1.6, 1.8, 2.0, 2.24 and 2.4 GeV protons.

Fig. 2 Tensor analyzing power in backward elastic dp as a function of deuteron beam energy.

Fig. 3 The ratio of G_{Ep}/G_D for data from different experiments. Symbols as in ref. 5. Squares for planned experiment 89-14.

Fig. 4. Conceptual design for the detector package for the focal plane of hadron spectrometer in hall A at CEBAF.

Fig. 5 Straw configuration in a two layer arrangement, illustrating the left-right uncertainty problem.

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High energy experiments with deuteron beams
C.F. Perdrisat and V. Punjabi
presented at the XIth Intern. Seminar on High Energy Physics Problems. Dubna (Russia), Sept. 7-12, 1992

Investigation of a Position Sensitive Photomultiplier
R. Pourang, A. Day, D. Koechner, B. Kross, S. Majewski, C.F. Perdrisat, V. Punjabi, D.Raine, A. Weisenberger, R. Wojcik, K. Zorn , IEEE Nucl. Sc. Symposium, Orlando Fl. Oct. 25-31, 1992

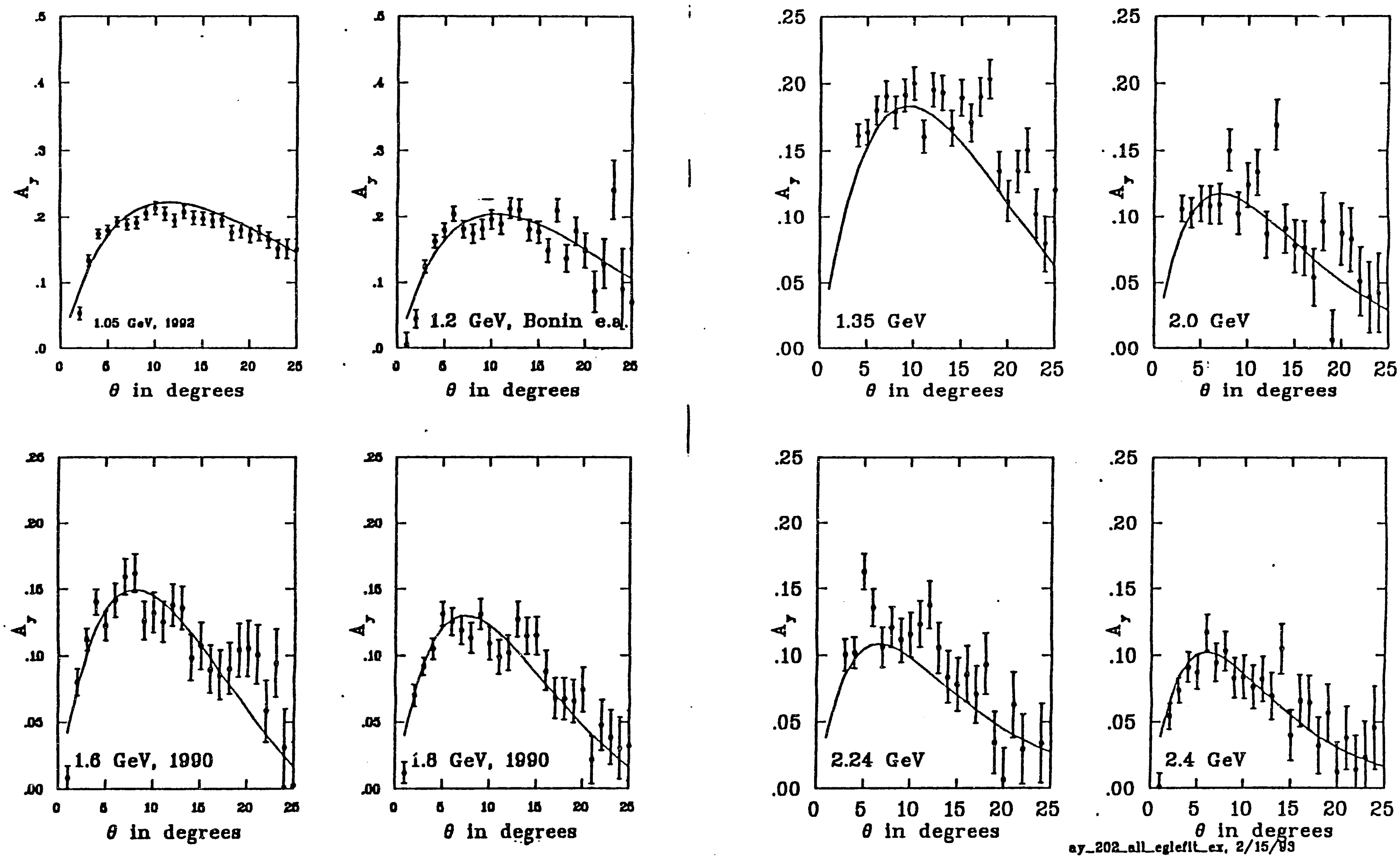

1.05 GeV, 1992
1.2 GeV, Bonin e.a.
1.35 GeV
2.0 GeV
1.6 GeV, 1990
1.8 GeV, 1990
2.24 GeV
2.4 GeV
A_y
θ in degrees
ay_202_all_eglefit_ex, 2/15/93

Fig. 1

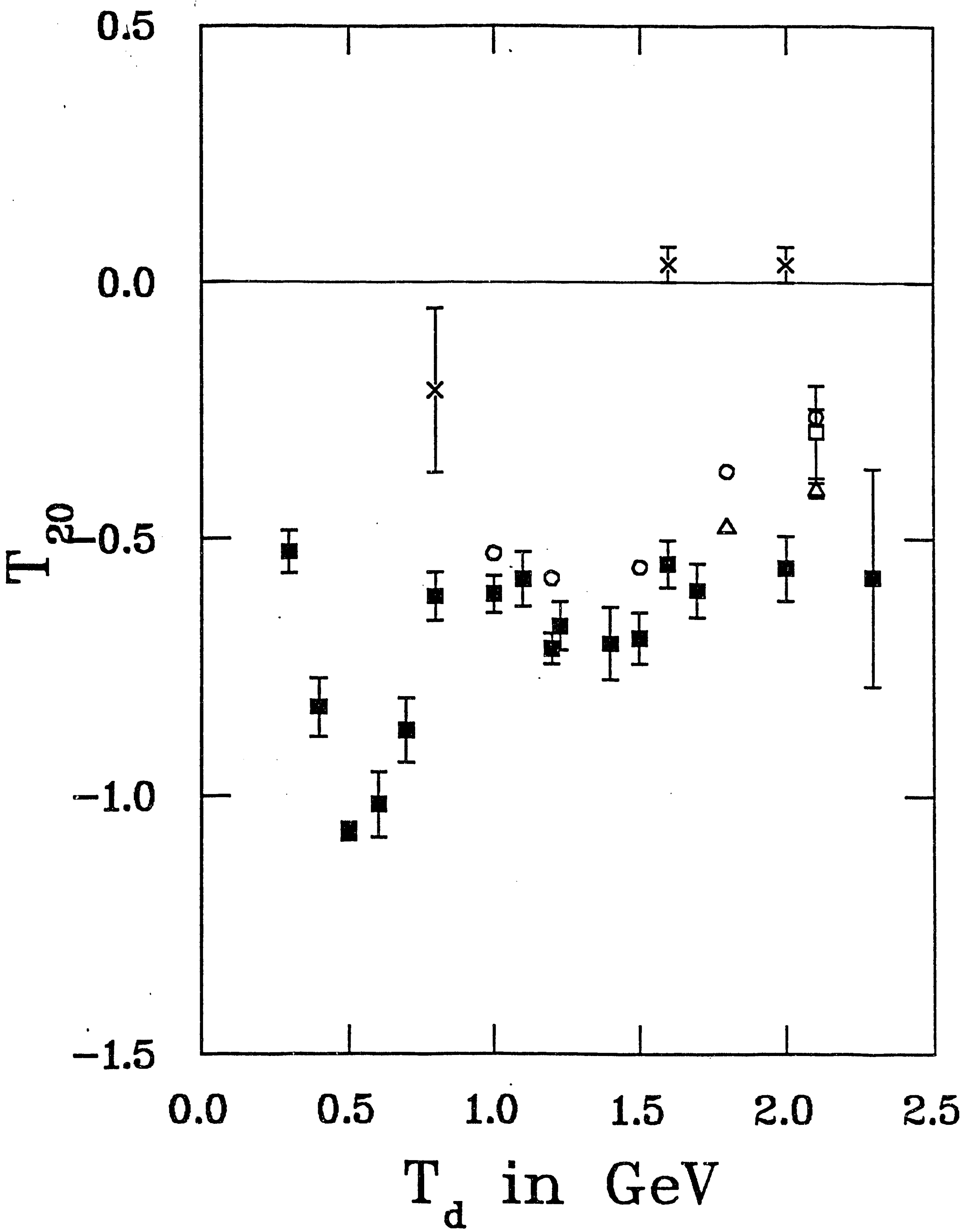


Fig. 2

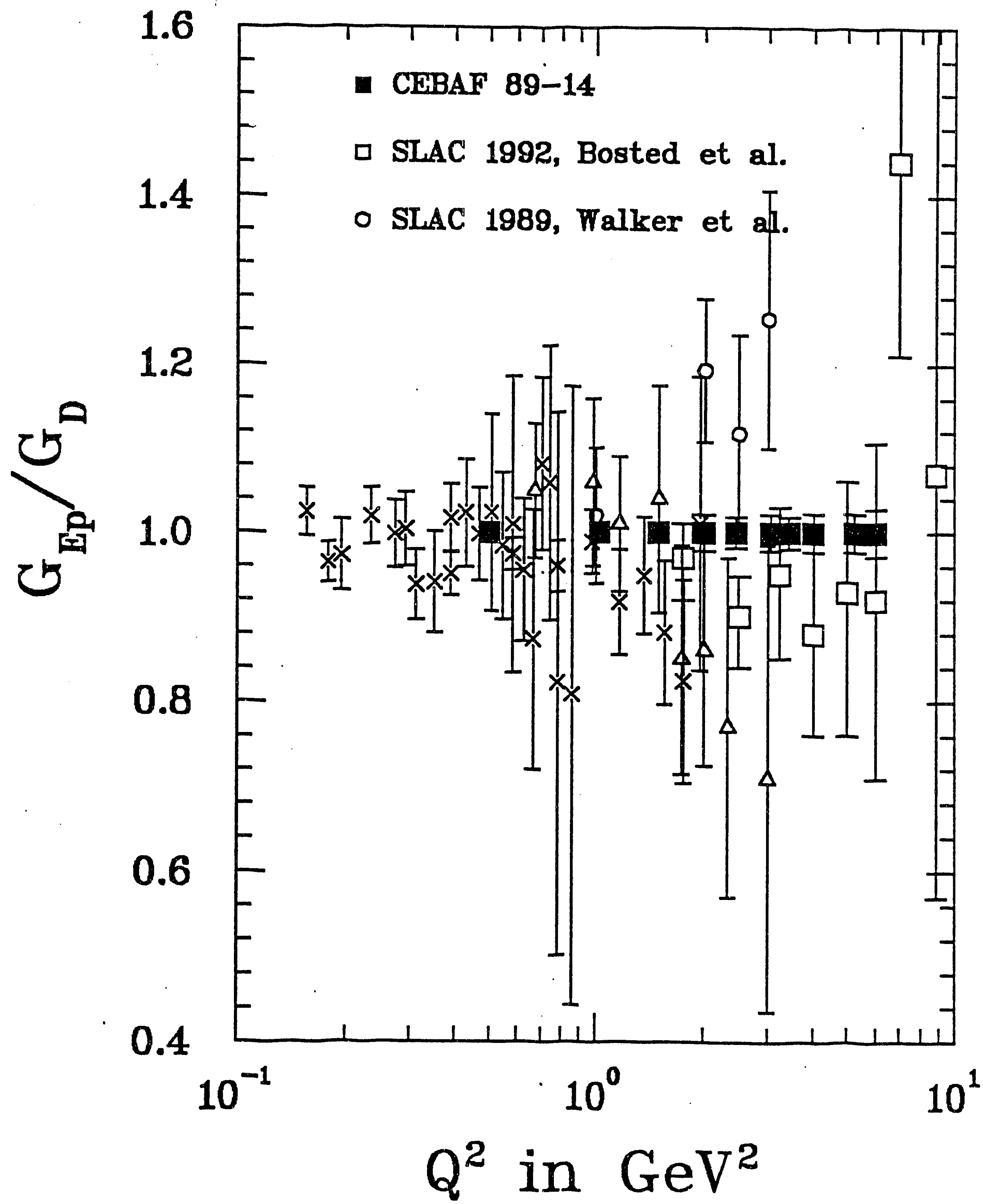

CEBAF 89-14
SLAC 1992, Bosted et al.
SLAC 1989, Walker et al.
1.6
1.4
1.2
1.0
0.8
0.6
0.4
G_{Ep}/G_D
10^{-1}
10^0
10^1
Q^2 in GeV^2

Fig. 3

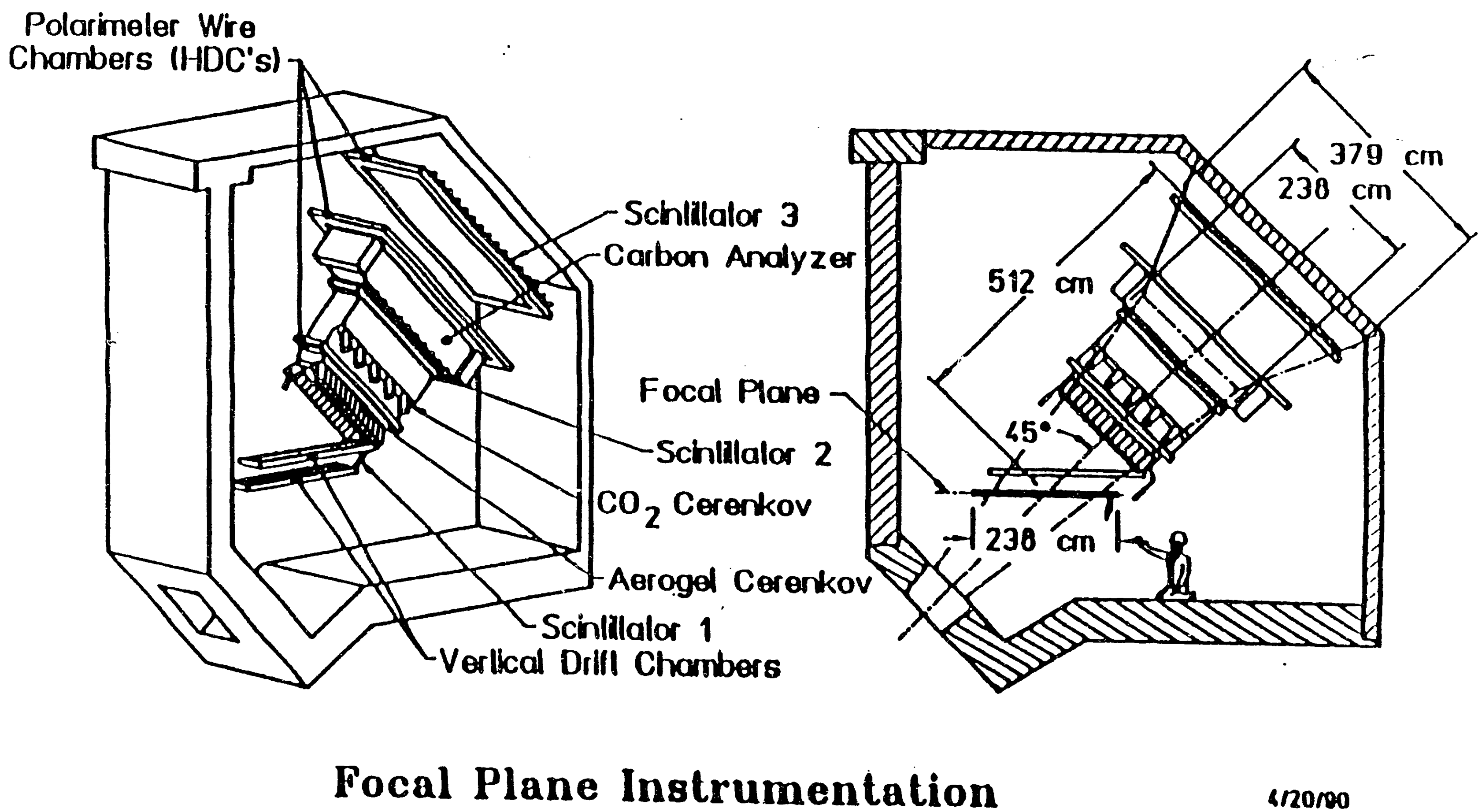
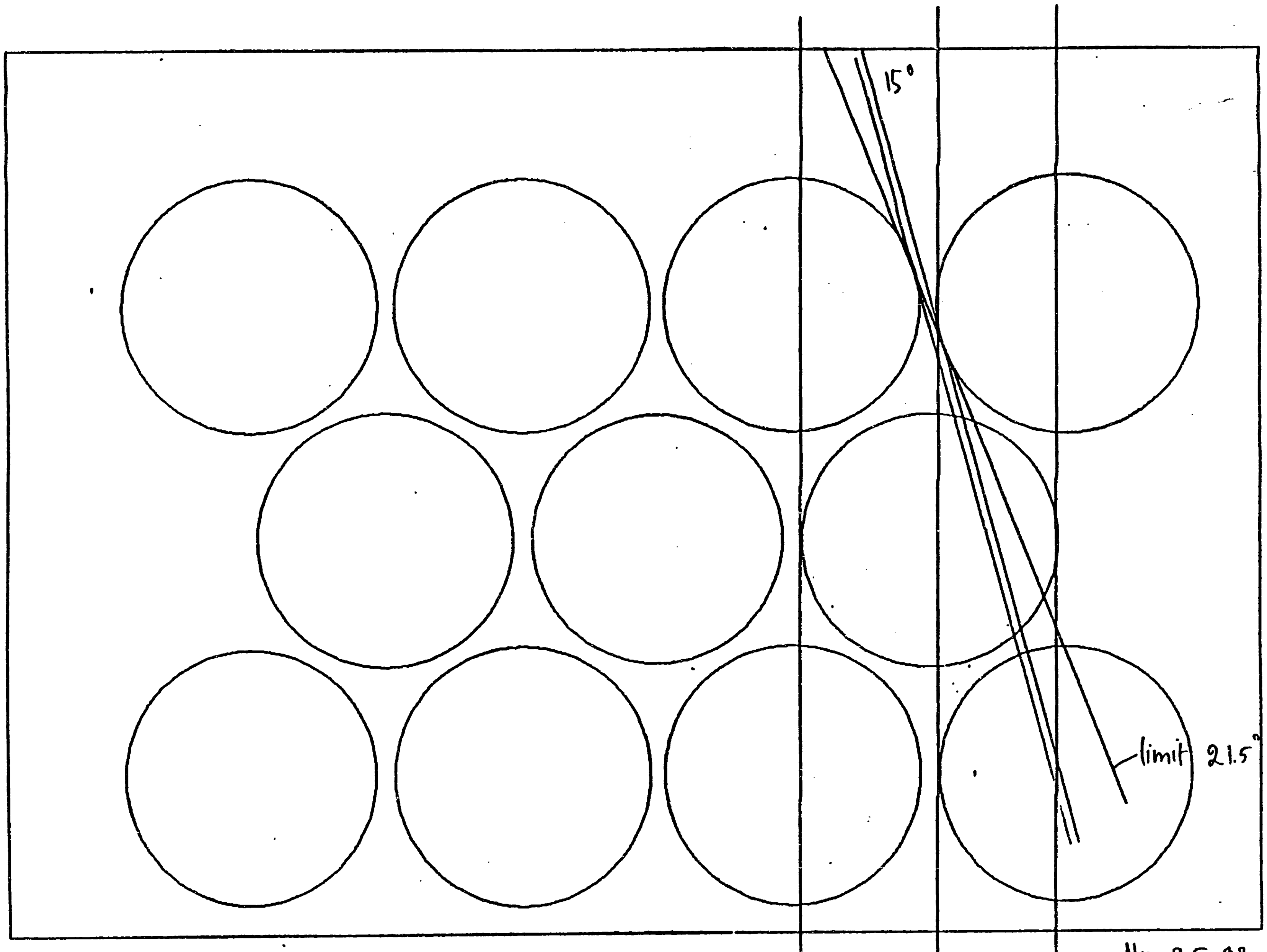


Figure 4 The Detector Assembly for the High Resolution Hadron Spectrometer.



Nov. 25-92

Fig. 5

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