A TEST OF PARITY VIOLATION IN THE INELASTIC SCATTERING OF POLARIZED ELECTRONS AT THE LEVEL OF THE WEAK INTERACTION

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BEAM: Solid State Polarized Electron Source, (under development) 10^{11} $\bar{e}$/pulse (10 ma peak 1.6 usec), 50% polarized, 180 pps.

TARGET: 30 cm LD_2.

EQUIPMENT: 8 GeV/c and 20 GeV/c spectrometers, modified for high counting rates; Counting House electronics and computers.

RUNNING TIME: 300 hours at 200 pps and 100 hours checkout at 30 pps
100 hours at 19.42 GeV
100 hours at 16.18 GeV
100 hours at 17.80 GeV

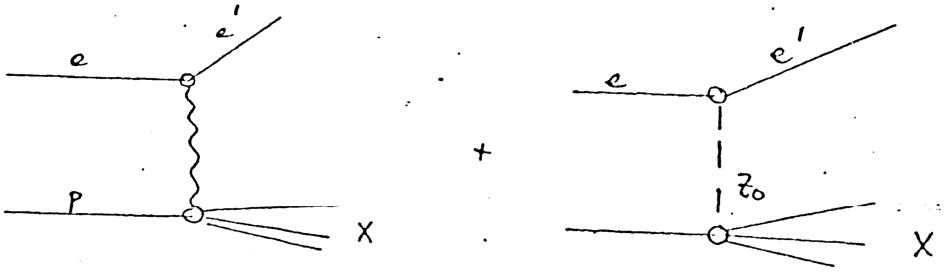
E-95 was proposed to look for parity violation in the scattering of polarized electrons (from PEGGY) from unpolarized protons. Present experiments do not set very tight limits on the existence of neutral axial vector currents which may give rise to such effects. We are anxious to perform E-95 (which will measure asymmetries with an error near one part in 10^4 at $Q^2 \approx 1$) as soon as practicable. Concurrently, we are developing experimental tools which allow us to extend to accuracy of experiments like E-95 to the level of the weak interactions (see letter of intent, Nov. 1, 1974).

Since E-95 was proposed and approved, experiments at FNAL, Argonne, and CERN have shown clear signals for events with neutrinos interacting with hadrons for which no charged lepton is seen emerging. As a result, it is now widely accepted that neutral currents in neutrino interactions with hadrons exist. Measurements of $\nu + N \to \nu + X$ and $\bar{\nu} + N \to \bar{\nu} + X$ are in fair agreement with the Weinberg model gauge theory of weak interactions and the parton model of nucleons. The same model predicts neutral current effects in deep inelastic electron scattering(1).

Parity violation arises in this reaction

$$e + p \to e' + X$$

through an interference between the usual virtual photon exchange and some other process which contributes axial-vector terms to the amplitude.



Following the development of Berman and Primack(1) calculating to lowest order in the weak and electromagnetic currents, the asymmetry can be expressed as follows:

$$A = \frac{Q^2}{Q^2 + M_Z^2} \; \frac{g_A\left[2 R_1 Q^2 + R_2(4EE' - Q^2)\right] - g_v R_3 Q^2 (E + E')/M}{2W_1 Q^2 + W_2 (4EE' - Q^2)}$$

where g_v and g_A are the vector and axial vector couplings at the lepton $-Z^o$ vertex, $Q^2 = 4EE' \sin^2\theta/2$ is the 4-momentum transfer-squared, and R_1, R_2 and R_3 are defined analogously to the W_1, W_2 and W_3 structure functions for the interference tensor of the electromagnetic and weak neutral hadron currents (see Ref. 2). Using the coupling as given in the Weinberg model and assuming the hadron to be composed of 4 quarks, 3 usual ones and a fourth charmed quark, Berman and Primack obtain the result

$$A = - \frac{G\,Q^2}{2\;\;2}\;\frac{9}{10}\left[\left(1 - \frac{20}{9}\sin^2\theta_W\right) - \left(1 - 2\cos^2\theta_w\right)\frac{y(2-y)}{2-2y+y^2}\right]$$

Here, $y = (E_o - E')/E_o$ is the usual scaling variable, and θ_w is the Weinberg angle, which enters here through the parameterization of the coupling constants.

The value of $\sin^2\theta_w$ presently favored by experiment is in the range of ¼ to ½. For values of $\sin^2\theta_w$ near .3, the asymmetry becomes very small and can even vanish in certain kinematical regions due to a cancellation of terms. The dependence of A on y and $\sin^2\theta_w$ is shown in Fig. 2.

It has been clear for some time that E-95 will not be able to observe this interference if $\sin^2\theta_w = .3$. We (along with E. Garwin and R. Miller) recently began the development of a new polarized electron source, which we hope will provide more intense beams of polarized electrons.

We propose to use this new beam and to develop some novel counting techniques, to achieve asymmetry measurements at the level of $\sim 10^{-5}$. If the Weinberg angle is sufficiently different from $\sin^2\theta_w = .3$ we will observe the effects of neutral currents. (See Fig. 2). In any case, we will gain the experience needed to develop equipment which will push the limits on measurable asymmetries even lower.

EXPERIMENTAL DETAILS:

Briefly, the solid state source consists of a GaAs crystal surface coated with several layers of cesium and oxygen. Light ($\lambda \approx 7300$ Å) falling on the crystal surface will photoexcite valence band electrons into the conduction band. The cesium-oxygen layers produce a surface of negative electron affinity. Photoexcited electrons which reach the surface are free to escape into the vacuum. Polarization of the electrons require that circularly polarized light be used for the photoexcitation.

The band structure of GaAs is well known.(3). The electron wave function is a J = 3/2 state for the bound electrons in the valance band, while the conduction band wave functions are J = ½ states. For a circularly polarized photon with angular momentum along the incoming direction, 3 electrons with spin opposite the photons direction are excited for every electron with spin parallel, corresponding to a 50% polarization of the electron beam.(4) In practice, spin dependent effects (such as spin relaxation) or other effects not fully understood can generate somewhat different values of polarization.

The feasibility of such a source has been demonstrated.(5) Practical quantum yields of 10% to 50% can be achieved with good cesium-oxygen coatings in clean vacuums, and polarizations as high as 60% have been measured. With a GaAs source operating at SLAC as an injector to the accelerator, it seems reasonable to expect 10^{11} $\bar{e}$/pulse with a polarization of 50%, and perhaps the full SLAC intensity of 5×10^{11}/pulse can be achieved.

Reversal of the electron spin is accomplished by reversal of the circular polarization of the incident light. This can be achieved by rotation of a λ/4-wave plate in the optical path. Using high quality optical components and a well-aligned system, we believe we can achieve reversal of the electron spin direction with a beam of electrons essentially unchanged in intensity or phase space. It is this feature of the solid state source, the systematic free reversal of spin by optical means, that makes it possible to search for very small asymmetries.

In order to measure such small asymmetries, we also need to adopt new schemes for the detection of the scattered electrons.

Increases in the solid angle for the spectrometers are desireable in order to achieve the higher counting rates needed to reach small asymmetries. One means to achieve this is the insertion of counters in the spectrometer optics closer to the target. Increases in the solid angle come primarily from increases in the momentum acceptance $\Delta p/p$. Figure 1 shows the elements of the 20-GeV spectrometer and 8-GeV spectrometer.

In the 20-GeV spectrometer, the vacuum pipe will be modified to become a Cerenkov counter. The magnetic elements of the 20-GeV transport are sketched on Figure 1. The straight section between B201 and B202 is 4.0 meters long containing the sextupole S201 and the quadrupole Q201. The vacuum pipe, from the entrance to B202 will be filled with atmospheric H_2 gas. An opaque thin window will be placed in front of S201, and a thin mirror will be placed in front of B202. Cerenkov light reflected from the mirror is collected onto a 5" photomultiplier placed to one side and adequately shielded. This device is a directional gas Cerenkov counter that responds to electrons but not to π-mesons with less than 8.4 GeV/c momentum. The acceptance of the counter, $\Delta\theta\Delta\phi\Delta p/p$, is about a factor of 25 increase over that of the 20-GeV/c counters in the hut. The counting rate will be high, perhaps 50 $\bar{e}$ /pulse, so that single counting techniques will not suffice. Instead, the total charge/pulse from the photomultiplier will be integrated, digitized and accumulated. Pion contamination to this signal is estimated to be small. Calibration of this device will be carried out at low counting rates using the counters in the 20-GeV hut. We hope that some calibration measurements can be done during regular E-95 measurements.

In the 8-GeV spectrometer, the beam pipe through Q83 will be modified to form a H_2 gas Cerenkov counter followed by a lead-glass shower counter. Counting rates up to 4/pulse will be encountered here, and conventional coincidence counting techniques should suffice here. Fig. 1 shows the location of the Cerenkov and lead-glass shower counters in the 8-GeV spectrometer.

We propose to use a 30cm LD_2 circulating target. Deuterium is preferable over an LH_2 target of the same length because of the increased counting rates generated without an increased radiation length. Bremsstrahlung followed by photoproduction of background particles may give higher backgrounds from higher Z targets. If not,a solid target could be used to give even higher counting rates.

Shown in Table I are the counting rates for scattered electrons in both the 20 and 8-GeV spectrometers. Both are considered useful, because the 8-GeV spectrometer has larger acceptance while the 20-GeV/c can operate at smaller angles. The rates are calculated using radiatively corrected values for W_1 and W_2 obtained from data available at SLAC. Comparison of the statistical errors on A with the Weinberg model is shown in Figure 2.

The statistical accuracy on the measurement of an asymmetry A is given by

$$\Delta A = \sqrt{(1-A^2)/N_o} \quad \text{where } N_o = N_\rho + N_\alpha = (1+A)/2 \ N_o + (1-A)/2 \ N_o$$

$$\simeq 1/\sqrt{N_o} \quad \text{for small A's}$$

The statistical accuracy is a fundamental limit for measuring small asymmetries. For example, the measurement of an asymmetry of 10^{-5} requires accumulating in excess of 10^{10} counts. Clearly such larger numbers will not be obtained at the rate of 1 count/pulse or even 10 counts/pulse. Going to high counting rates requires techniques different from digital counting, such as the Cerenkov "flux" counter. The statistical limitations for the proposed 8 and 20-GeV flux counters, based on the number of electrons seen in the acceptances, are given in Table I and compared with the Weinberg model on Figure 2. The ability to reach the statistical limits must be proven, since such a device may be susceptible to larger systematic problems which could limit its sensitivity.

The study and control of unwanted systematic effects is an essential ingredient in an experiment designed to reach to small effects. The important techniques to be used here are:

a) to provide a rapidly reversible, systematic free beam of polarized electrons. The objective in design is to provide beams of opposite polarization, which in all other respects are indistinguishable. The intensity and phase space must be identical. Reversal of polarization is accomplished optically by rotation of a ¼-wave plate. Careful alignment and high quality optics should provide a light beam which can be reversed with undisturbed intensity and undeflected direction.

b) To provide rapid reversal of the spins permitting experimental averaging over harmonic variations in the beam structure and over random variations in the beam and detection efficiencies. It may be possible to reverse polarizations as rapidly as once per beam pulse, with a pattern which is random (for example, using a computer random number generator) or predetermined to some set pattern.

c) To provide control of dead time uncertainties by guaranteeing that the average beam intensities are independent of the sign of the polarization. The objective is to obtain a balance between spin + intensity to spin - intensity to 1 part in 10^3. Dead time corrections should be less than 10% and, if made carefully, should give systematic dead time problems below the 10^{-5} level. For the Cerenkov flux counter, linearity of the charge integrating circuitry to the 10% level should suffice to eliminate rate dependent systematic effects. In the offline analysis, runs can be balanced by discarding, selectively, beam pulses which contribute too much or too little charge; also

d) to take advantage of the precession of the electron spin through the A-beam bending magnets. Runs with the electron spins transverse and opposite to the beam direction provide a clean separation for false asymmetries from the real asymmetries looked for. The spin precesses in bending magnets according to

$$\theta_{prec} = \gamma \left(\frac{g-2}{2}\right) \theta_{bend}$$

where θ precession is the angle <u>relative</u> to the beam directions. For the A-bend system of magnets, the value of θ_{prec} grows linearly in E_o and increases by π for every 3.23 GeV. For this proposal, E_o = 19.42 and 16.18 GeV for 6 π and 5 π precession, respectively, and, if time is available, E_o = 17.80 GeV gives transversely polarized electrons, corresponding to 5½π precession; and

e) to monitor the beam current using two toroid charge monitors. At high currents the toroids are accurate to about .3% but should be much better for measuring the ratio charge (spin +) /charge (spin -) during a run.

f) to provide a magnetized thin iron target (a Möller target) which can be inserted in the beam line, so that accurate polarization measurements can be made in a few minutes of running time. The polarization would be measured several times per day.

In summary, we request 400 hours of beam time including 100 hours of test time and 300 hours of beam time using the new solid state polarized electron source. We will develop a detection scheme which will detect many particles in an individual pulse.

In these 300 hours, we expect to reach asymmetries at the 10^{-5} level. Although predicted asymmetries may fall below this level for some values of the Weinberg angle in the simple Weinberg model, modified versions predict larger asymmetries. The timetable of the new source is somewhat uncertain, but it could be ready as early as April or May of 1976. Naturally, we are anxious to try out these new techniques as soon as possible. This experiment will test out the concepts required for the detailed design of large solid angle devices, such as we described in our earlier letter of intent.

REFERENCES

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TABLE I - 300 hr. Run Plan

SETTING I E_o = 19.42 GeV (100 hours) ; Spin precession 6π

Spect.	$\langle E' \rangle$	θ	$\langle Q^2 \rangle$	W	ω	y	Counts/pulse	Counts/hr.	A^*	ΔA(100 hrs.)
20	16.0	4°	1.51	2.41	4.2	.18	160	1.17×10^8	$.75 \times 10^{-4}$	$.92 \times 10^{-5}$
8	6.0	12°	5.09	4.58	4.9	.69	2.6	1.7×10^6	2.5×10^{-4}	$.8 \times 10^{-4}$

SETTING II E_o = 16.18 GeV (100 hours) ; Spin precession 5π

Spect.	E'	θ	Q^2	W	ω	y	Counts/pulse	Counts/hr.	A^*	ΔA(100 hrs.)
20	13.00	4°	1.0	2.41	5.8	.20	224.	1.45×10^8	$.5 \times 10^{-4}$	$.83 \times 10^{-5}$
8	6.0	12°	4.24	4.0	4.5	.63	4.3	2.8×10^6	2.1×10^{-4}	$.6 \times 10^{-4}$

SETTING III E_o = 17.80 GeV (100 hours) ; Spin precession $5\frac{1}{2}\pi$

Spect.	E'	θ	Q^2	W	ω	y	Counts/pulse	Counts/hr.	A^*	ΔA (100 hrs.
20	15.0	4°	1.3	2.2	4.0	.16	198.	1.3×10^8	0	$.88 \times 10^{-5}$
8	6.0	12°	4.67	4.28	4.7	.66	3.3	2.1×10^6	0	$.69 \times 10^{-4}$

* The value for A here is $PQ^2 * 10^{-4}$ for P = .5. The counting rates assume 10^{11} e^-/pulse into a 30 cm LD_2 target, 180 pps.

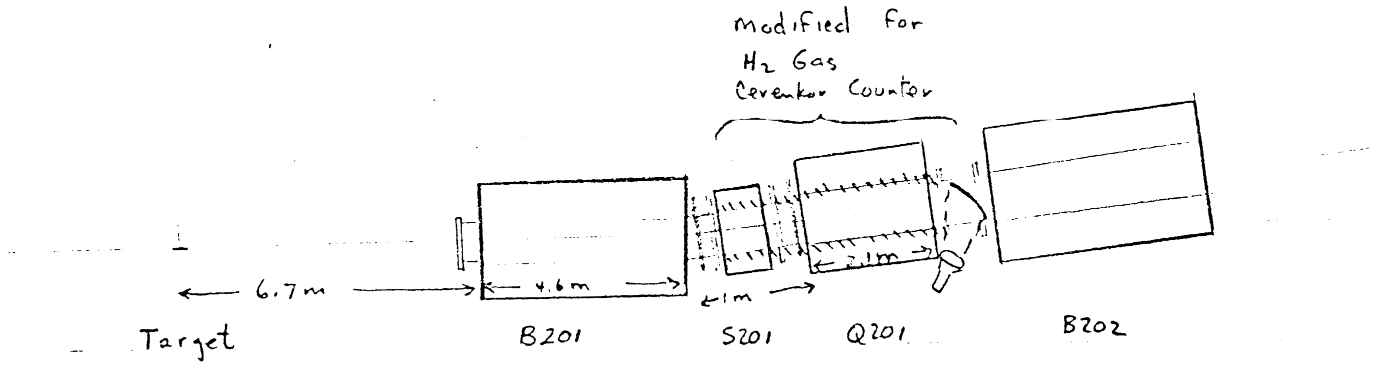


FIGURE 1a SKETCH OF 20 GeV Front End

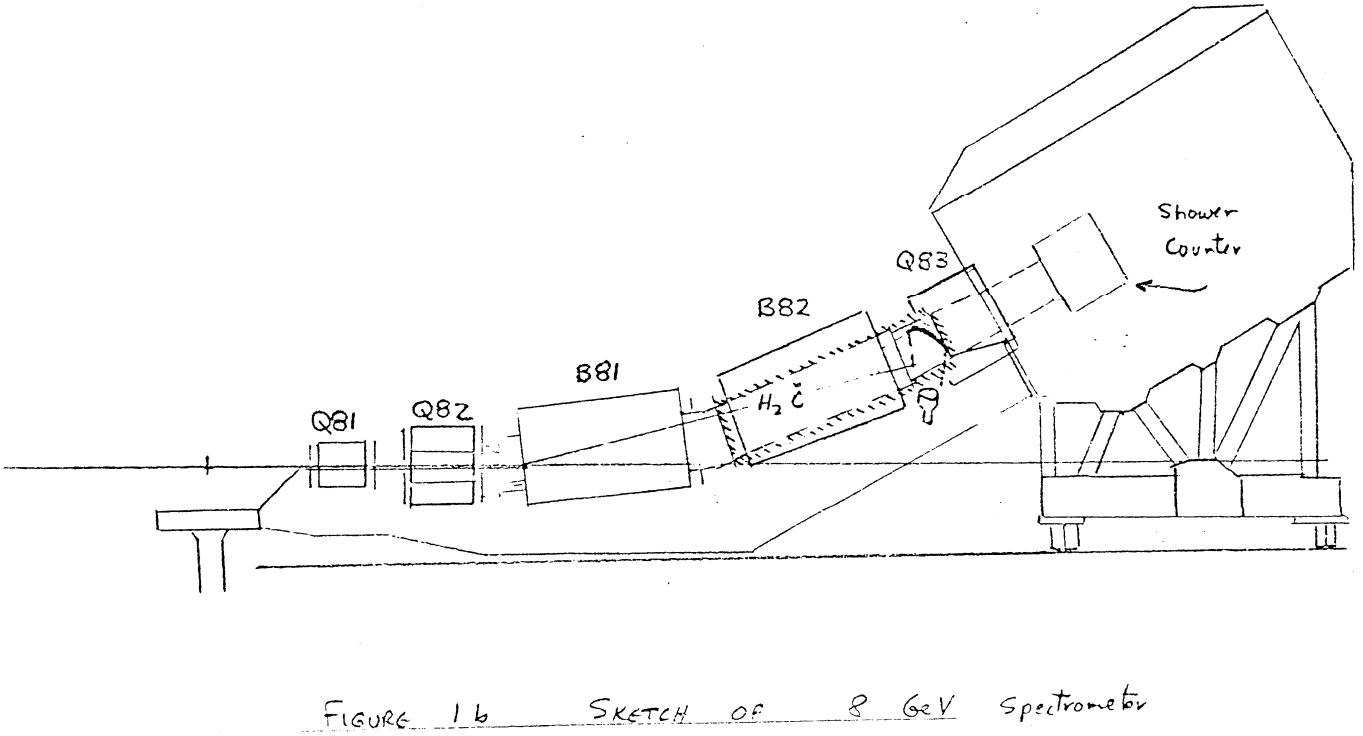
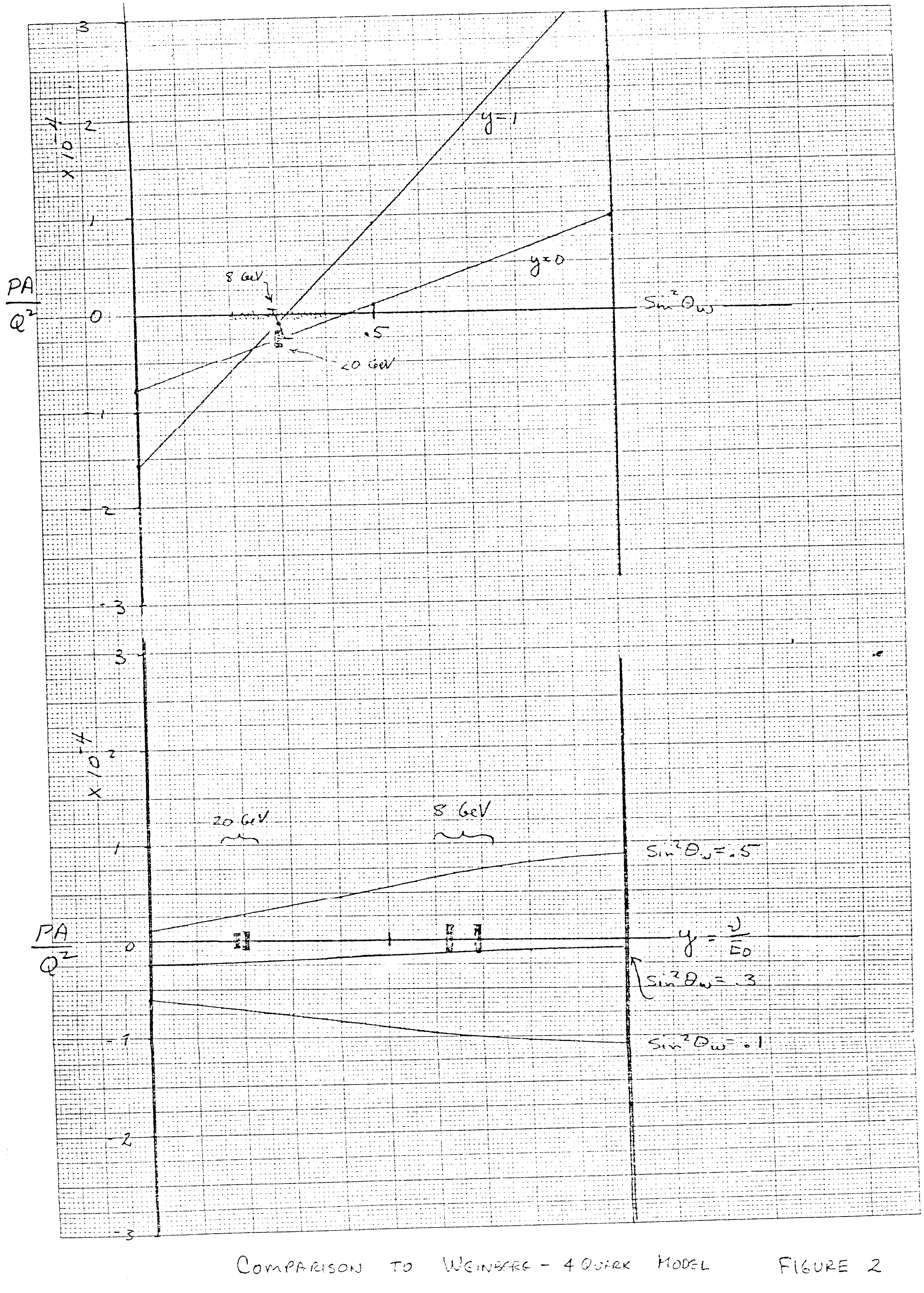


FIGURE 1b SKETCH OF 8 GeV Spectrometer



COMPARISON TO WEINBERG - 4 QUARK MODEL FIGURE 2