PEP-173

AN ALTERNATE WAY OF MEASURING BEAM POLARIZATION AT AN e^+e^- COLLIDING BEAM FACILITY

BY

D. Buchholz, G. Manning, and C. Prescott

ABSTRACT

The scattering of the electron (positron) beam from a low energy polarized electron beam is considered for monitoring beam polarization. The scattered and recoil electrons would be detected in coincidence. Significant asymmetries are predicted for both longitudinal on longitudinal and transverse on transverse polarizations. Use of the method is limited primarily by the absence of intense sources of polarized electrons. Possible future developments are discussed.

AN ALTERNATE WAY OF MEASURING BEAM POLARIZATION AT AN e^+e^- COLLIDING BEAM FACILITY

INTRODUCTION

Systems that have been seriously considered or used to date to measure beam polarization are the Touschek effect (internal scattering within one beam) and back scattering of a circularly polarized laser beam. Both of these methods have some experimental difficulties. This note describes an alternate method that has some useful features particularly for measuring longitudinal polarizations.

The basic idea is to scatter the electron or positron beam to be measured from a low energy polarized electron beam and to detect both scattered electrons. One is thus using QED in a region where it is well tested ($Q^2 \lesssim 0.015\ \text{GeV}^2$) to measure the polarization. An asymmetry is measured corresponding to a 180° rotation of the spin of the target (slow) electron.

$$\text{Asy} = \frac{N_+ - N_-}{N_+ + N_-}$$

where N_+ and N_- are the count rates for the two directions of target spin. The basic idea has been suggested before.[1]

KINEMATICS

Define the following quantities as:

E_o the beam energy ($\gamma_o = \frac{E_o}{m}$)

θ_L the scattering angle in the laboratory

θ the scattering angle in the center of mass.

For the scattered particles of interest

$$\gamma = \sqrt{\frac{\gamma_o+1}{2}} \approx \sqrt{\frac{\gamma_o}{2}}$$

$$\gamma_L \approx \frac{\gamma_o}{2}(1+\cos\theta)$$

$$\theta_L \approx \sqrt{\frac{2}{\gamma_o}}\ \frac{\sin\theta}{(1+\cos\theta)}$$

For 90° scattering in the center of mass system ($\theta = \pi/2$) each scattered particle has half of the beam energy and is at an angle in the laboratory of $\sqrt{\frac{2}{\gamma_o}} \approx 8.2$ mrad for $E_o = 15$ GeV.

ASYMMETRY AND AVERAGE CROSS SECTION

Define $\text{Asy} = \frac{N_p - N_A}{N_p + N_A}$

where N_p is the count rate for spins parallel and N_A is the count rate for spins anti-parallel. The average cross section

$$\overline{\left(\frac{d\sigma}{d\Omega}\right)} = \frac{1}{2}\left(\left(\frac{d\sigma}{d\Omega}\right)_P + \left(\frac{d\sigma}{d\Omega}\right)_A\right)$$

is the same as the unpolarized cross section.

Akheizer and Berestetski[2] give expressions for the cross sections for Moller and Bhabha scattering for arbitrary directions of polarization of both particles. McMaster[3] gives the cross sections for arbitrary electron or positron polarization on a stationary target electron with longitudinal spin.

We give below the Asy and $\overline{\left(\frac{d\sigma}{d\Omega}\right)}$ for longitudinal on longitudinal and transverse on transverse for both e^+e^- and e^-e^-. Only the relativistic limit is given.

LONGITUDINAL ON LONGITUDINAL

a) e^-e^- $\quad \text{Asy} = -\frac{\sin^2\theta\,(8-\sin^2\theta)}{(3+\cos^2\theta)^2}\,\rho_1\rho_2$

$$\overline{\left(\frac{d\sigma}{d\Omega}\right)} = \frac{r_o^2}{4\gamma^2}\,\frac{(3+\cos^2\theta)^2}{\sin^4\theta}$$

where $r_o = 2.82\text{x}10^{-13}$ cm

ρ_1 is the 15 GeV beam polarization

and ρ_2 is the low energy beam polarization.

Figure 1 gives plots of $\overline{\left(\frac{d\sigma}{d\Omega}\right)}$, Asy, and $\overline{\left(\frac{d\sigma}{d\Omega}\right)}$ x Asy^2 for $E_o = 15$ GeV. The later quantity is a measure of the count time required and is fairly independent of θ. It has its maximum value of 7.3 μ barns at $\theta = 90^{\circ}$.

b) e^+e^-

$$Asy = \frac{\sin^2\theta\,(8-\sin^2\theta)}{(3+\cos^2\theta)^2}\,P_1 P_2$$

$$\overline{\left(\frac{d\sigma}{d\Omega}\right)} = \frac{r_0^2}{16\gamma^2}\,\frac{(3+\cos\theta)^2}{(1-\cos\theta)^2}$$

Figure 2 gives $\overline{\left(\frac{d\sigma}{d\Omega}\right)}$, Asy, and $\overline{\left(\frac{d\sigma}{d\Omega}\right)}$ x Asy^2 for this case. Note that the asymmetry for e^+e^- is identical to e^-e^- except for the sign. At 90° $\overline{\left(\frac{d\sigma}{d\Omega}\right)}$ x Asy^2 is 1.8 μ barns but it has larger values for $\theta < 90^{\circ}$. For $\theta < 60^{\circ}$ it becomes more difficult to detect the scattered particles because the energy of the scattered electron is less than 4 GeV. An average value of $\overline{\left(\frac{d\sigma}{d\Omega}\right)}$ x Asy^2 is about 2.5 μ barns.

TRANSVERSE ON TRANSVERSE

a) e^-e^-

$$Asy = -\frac{\sin^4\theta}{(3+\cos^2\theta)^2}\,P_1 P_2$$

$$\overline{\left(\frac{d\sigma}{d\Omega}\right)} = \frac{r_0^2}{4\gamma^2}\,\frac{(3+\cos\theta)^2}{\sin^4\theta}$$

Figure 3 gives $\overline{\left(\frac{d\sigma}{d\Omega}\right)}$, Asy, and $\overline{\left(\frac{d\sigma}{d\Omega}\right)}$ x Asy^2. The scattering of electrons with transverse polarization is the same as the case of longitudinal polarization except that the asymmetry is multiplied by $\frac{\sin^2\theta}{8-\sin^2\theta}$. This means that transverse polarization is harder to measure because this multiplying factor is $\le 1/7$ depending on θ.

b) e^+e^-

$$Asy = \frac{\sin^4\theta}{(3+\cos^2\theta)^2}\,P_1 P_2$$

$$\overline{\left(\frac{d\sigma}{d\Omega}\right)} = \frac{r_0^2}{16\gamma^2}\,\frac{(3+\cos\theta)^2}{(1-\cos\theta)^2}$$

Figure 4 gives $\left(\frac{d\sigma}{d\Omega}\right)$, Asy, and $\left(\frac{d\sigma}{d\Omega}\right)$ x Asy^2 for this case.

DETECTION OF THE SCATTERED PARTICLES

a) Longitudinal on Longitudinal

Figure 5 shows the path through a possible magnet configuration designed to produce longitudinal polarization at the interaction point.[4] There is a mirror system on the other side of the interaction point. The 15 GeV beam leaves with zero displacement and zero deflection.

A 7.5 GeV particle with zero degrees vertical displacement and the same sign leaves the magnet system with about 50 cm displacement down. A 7.5 GeV particle of the opposite sign has a displacement of about 110 cm upwards. This assumes that the magnets have adequate vertical size. In practice they may not be as large but the dispersion is still large. The exit displacements are such that adequate shielding can be provided for the synchrotron radiation produced.

A production angle of 8.2 mrad (corresponding to 90° scattering in the center of mass) produces a displacement of 8.2 cm at the exit of the magnet and it should be possible to detect the full 2π range of azimuthal angles. The limitation on scattering angle will be determined by the energy of the particles. It should be possible to view $60^{\circ}<\theta<120^{\circ}$ corresponding to 3.8 to 11.2 GeV and have $\Delta\Omega = 2\pi$sr.

b) Transverse on Transverse

A possible measurement scheme would be to introduce the low energy electron beam midway between two ring dipoles as shown in Figure 6. With this arrangement the polarization for the e^+ and e^- could be measured simultaneously. A detector would consist of an elliptical counter that had at least two segments and possibly more. For the e^-e^- case a coincidence would be made in opposite segments. For the e^+e^- case the coincidence would also be made in opposite segments but on opposite sides of the dipole.

If the polarization of the low energy electron beam could be changed on a short-time scale like 1 sec, a measurement of the polarization could be made by comparing the parallel to the anti-parallel case. For 100% polarizations this is

$$\frac{d\sigma\,(P_1 \parallel P_2)}{d\sigma\,(P_1 \parallel -P_2)} = 8$$

for the longitudinal case but only 1.2 for the transverse case. Thus although the difference for the transverse case is smaller, it is still significant.

COUNTING RATE

The following calculations are for polarizations measurements at the interaction point. The average count rate per second is

$$C = L\,\frac{N_t}{N}\,\overline{\left(\frac{d\sigma}{d\Omega}\right)}\,\Delta\Omega$$

where L is the e^+e^- luminosity,

N_t is the number of target electrons in the effective area of the 15 GeV electron beam ($\approx 0.001 \times 0.12 \approx 10^{-4}$ cm^2) and in the target electron beam effective bunch length L_B,

and N is the number of 15 GeV electrons per bunch and is about 1.5×10^{12}.

For $N_t = 10^9$ and $\Delta\Omega = 2\pi sr$ the count rate is 4/sec for e^-e^- and 1/sec for e^+e^-. $N_t = 10^9$ corresponds to an electron density of about $\frac{10^{13}/cm^3}{L_B}$.

The time, T, to measure the polarization of the 15 GeV beam, P_1, to an accuracy ΔP_1 is

$$T = \frac{1}{(A_{sy})^2}\,\frac{1}{C}\,\frac{1}{\Delta P_1}\,\frac{1}{P_2^2}$$

where P_2 is the polarization of the target beam and C is the count rate using

$\left(\overline{\frac{d\sigma}{d\Omega}}\right)$ averaged over solid angle. Hence

$$\left(\overline{\frac{d\sigma}{d\Omega}}\right)(A_{sy})^2(P_2^2)$$

is a measure of the counting time required. Thus for the rates given above this would permit a 10% measurement of the polarization in a few minutes.

If the polarization is measured at a position other than the interaction point, the count rate is the same providing the target electron density is kept the same ($10^{12}/cm^3$) over the area of the 15 GeV beam.

POLARIZED ELECTRON SOURCES

a) Current techniques are not able to produce the required polarized electron intensity. The technology is improving rapidly and may eventually reach the required currents.

b) It might be possible to reach the required current by storing low energy electrons moving perpendicular to the 15 GeV beam.

c) It is possible to produce atomic beams containing polarized electrons. Lithium beams of 10^{10} atoms/cm^3 = 3×10^{10} electrons/cm^3 can be produced but with only one electron in three polarized. This would reduce the asymmetry by three. If a bunch length L_B of 100 cm is used, the count rate for e^-e^- is about 1/sec. An improvement in the atomic beam intensity of 3 to 10 would give a practical count rate.

REFERENCES

1. V. N. Baier, XLVI Corso Scuola International di Fizica "Enrico Fermi", 4 (1969), Academic Press.

2. A. I. Akhiezer and V. B. Berestetski, Quantum Electrodynamics, Interscience Publishers, 1965.

3. W. H. McMaster, Rev. Mod. Phys. 33 (1962) 8.

4. R. Schwitters and B. Richter, SPEAR-175, unpublished.

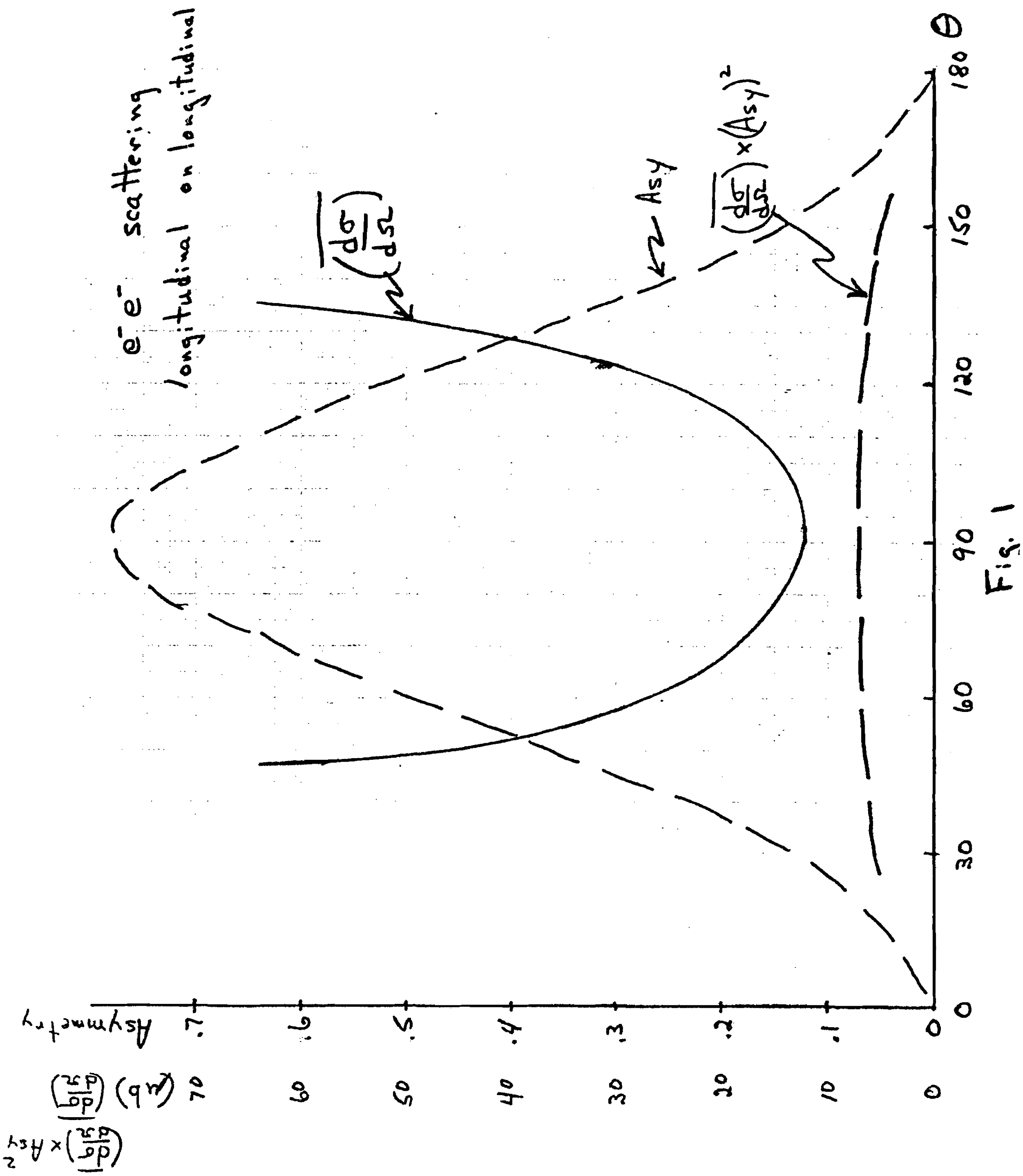
e⁻e⁻ scattering
longitudinal on longitudinal
$\overline{\frac{d\sigma}{d\Omega}}$
Asy
$\overline{\frac{d\sigma}{d\Omega}} \times (Asy)^2$
θ
0
30
60
90
120
150
180
Asymmetry
0
.1
.2
.3
.4
.5
.6
.7
$\overline{\frac{d\sigma}{d\Omega}}$ (μb)
$\overline{\frac{d\sigma}{d\Omega}} \times Asy^2$
0
10
20
30
40
50
60
70

Fig. 1

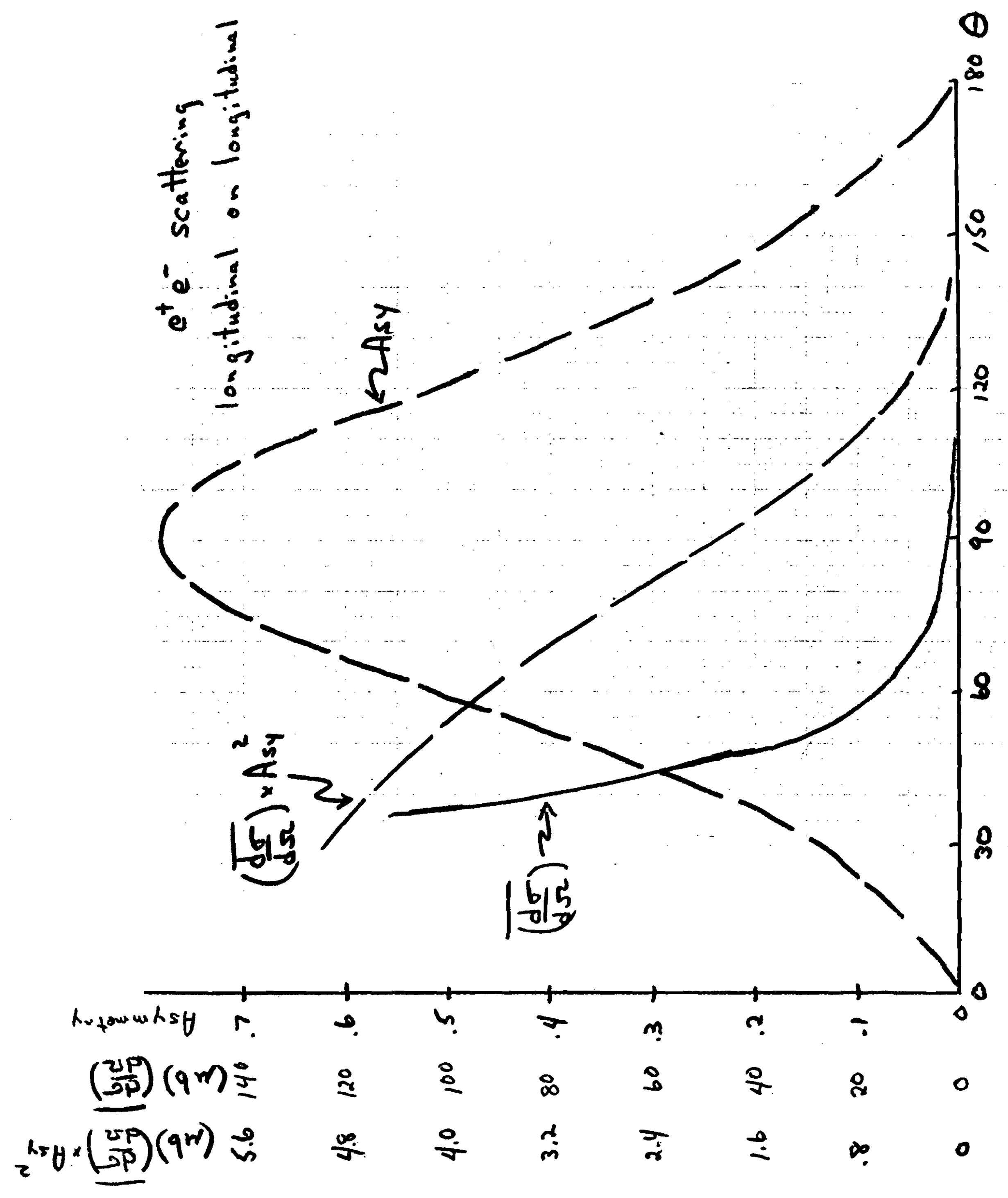
e+e- scattering
longitudinal on longitudinal
Asy
$\overline{\left(\frac{d\sigma}{d\Omega}\right)} \times Asy^2$
$\overline{\left(\frac{d\sigma}{d\Omega}\right)}$
θ
0 30 60 90 120 150 180
Asymmetry
0 .1 .2 .3 .4 .5 .6 .7
$\overline{\left(\frac{d\sigma}{d\Omega}\right)}$ (μb)
0 20 40 60 80 100 120 140
$\overline{\left(\frac{d\sigma}{d\Omega}\right)}$ (μb) × Asy²
0 .8 1.6 2.4 3.2 4.0 4.8 5.6

Fig. 2

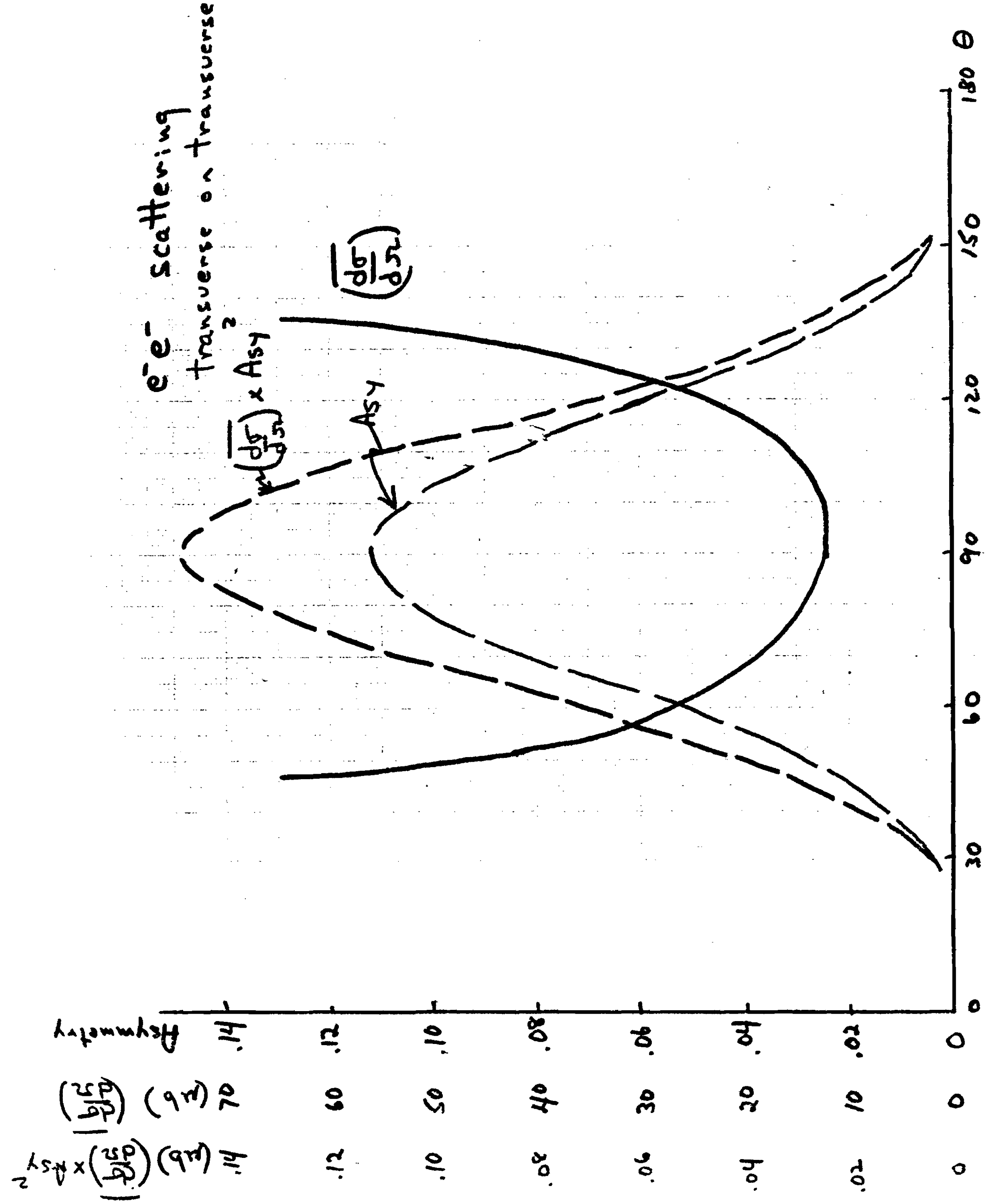
e⁻e⁻ scattering
transverse on transverse
dσ/dΩ
(dσ/dΩ) × Asy²
Asy
0
30
60
90
120
150
180
θ
Asymmetry
.14
.12
.10
.08
.06
.04
.02
0
70 (μb) (dσ/dΩ)
60
50
40
30
20
10
0
.14 (μb) (dσ/dΩ) × Asy²
.12
.10
.08
.06
.04
.02
0

Fig. 3

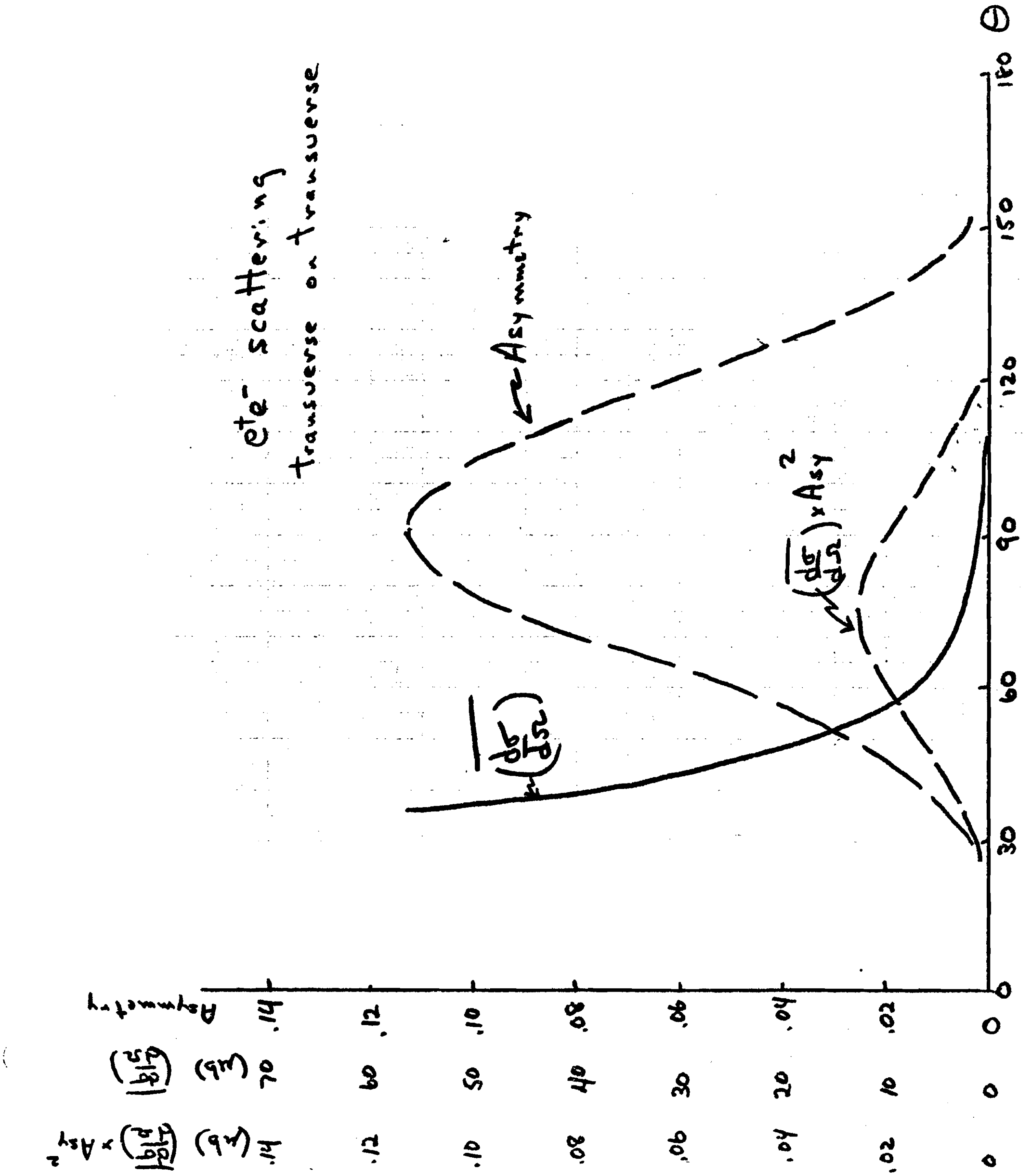
e+e- scattering
transverse on transverse
Asymmetry
$\overline{\left(\frac{d\sigma}{d\Omega}\right)}$
$\overline{\left(\frac{d\sigma}{d\Omega}\right)} \times Asy^2$
Θ
0
30
60
90
120
150
180
Asymmetry
0
.02
.04
.06
.08
.10
.12
.14
(μb) $\overline{\left(\frac{d\sigma}{d\Omega}\right)}$
0
10
20
30
40
50
60
70
(μb) $\overline{\left(\frac{d\sigma}{d\Omega}\right)} \times Asy^2$
0
.02
.04
.06
.08
.10
.12
.14

Fig. 4

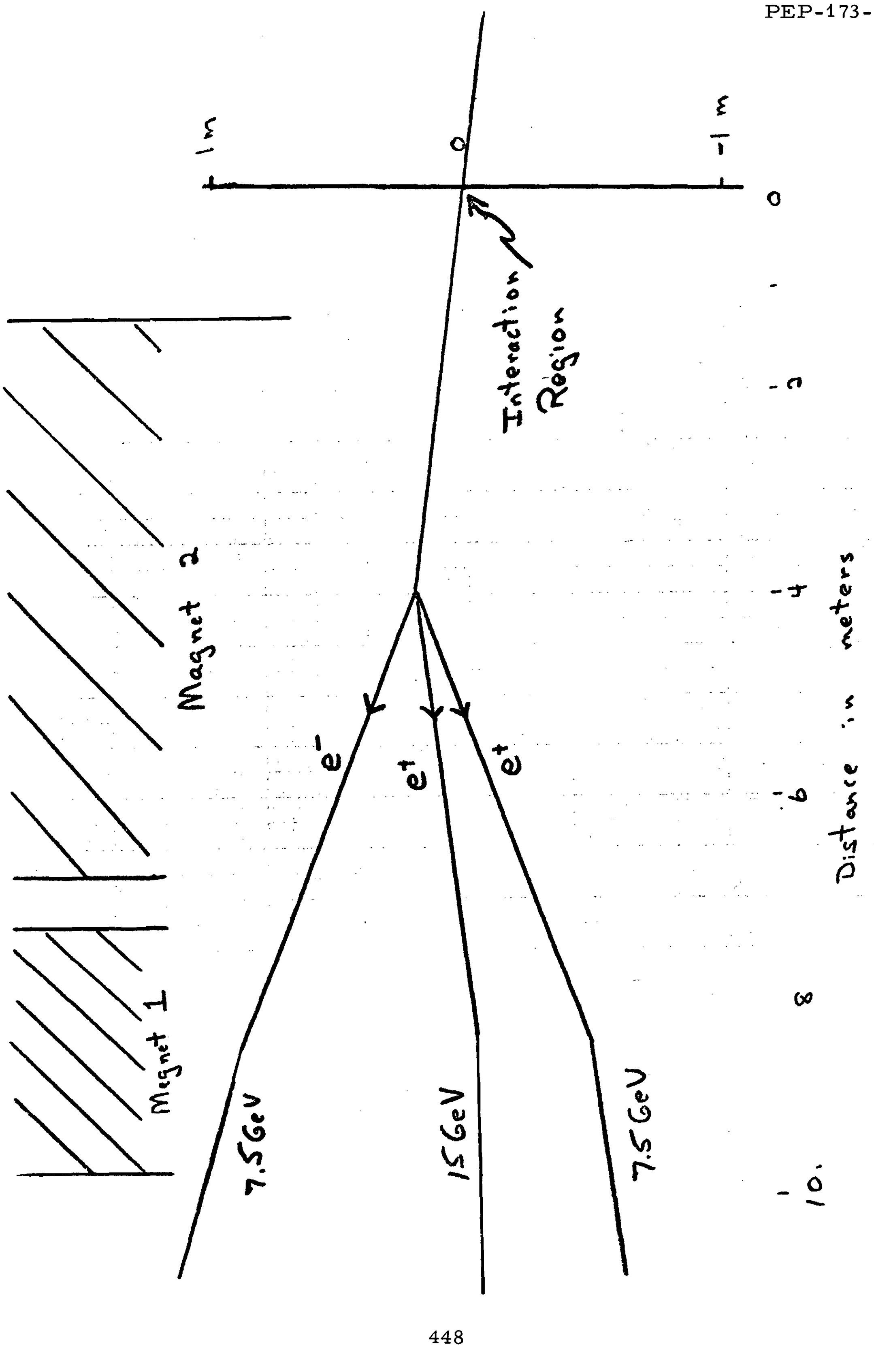
1 m
0
-1 m
Interaction Region
Magnet 2
Magnet 1
e⁻
e⁺
e⁺
7.5 GeV
15 GeV
7.5 GeV
0
2
4
6
8
10.
Distance in meters

Fig. 5

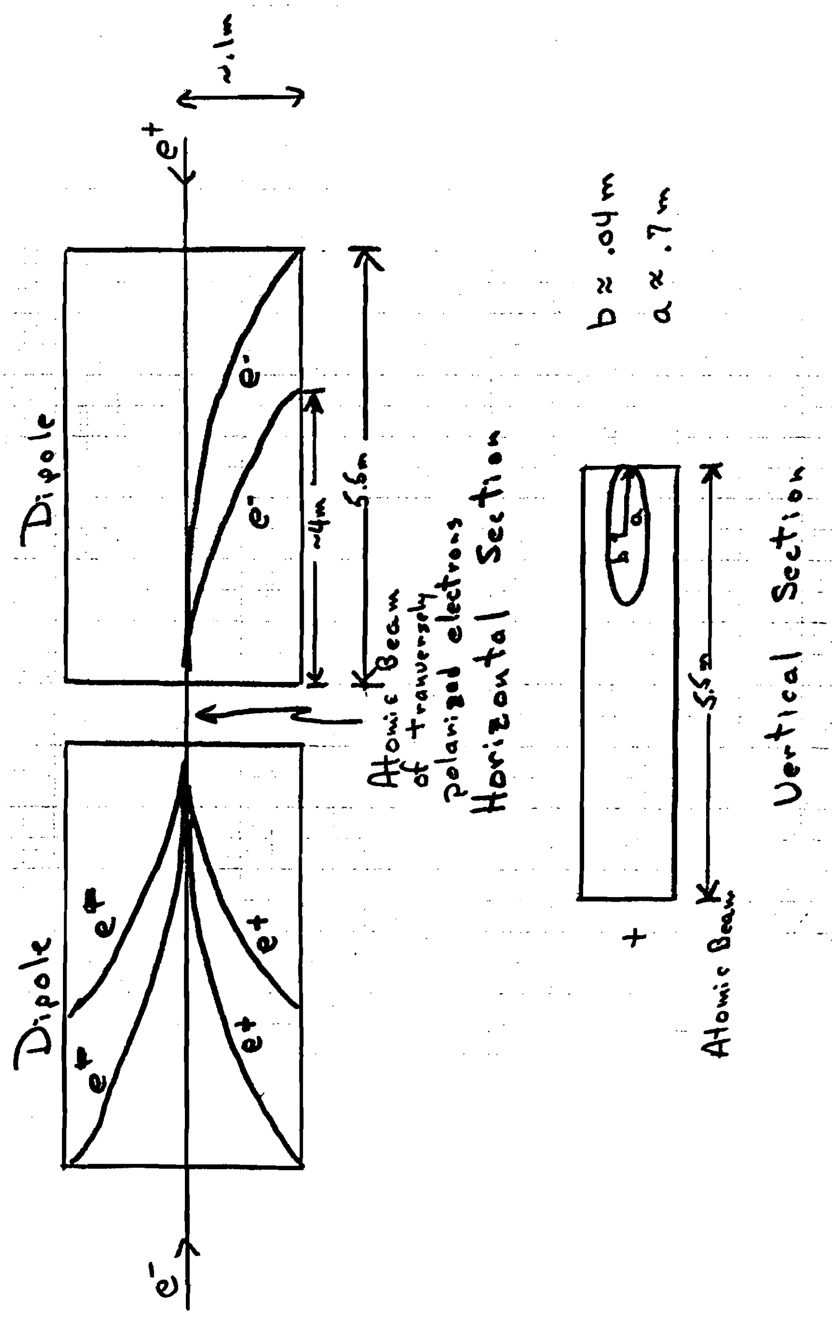
e+
e-
~.1m
Dipole
Dipole
5.5m
~4m
Atomic Beam of transversely polarized electrons
Horizontal Section
b ≈ .04m
a ≈ .7m
5.5m
Atomic Beam
Vertical Section

Fig. 6