A COMPACT MAGNETIC DETECTOR FOR μ^+-μ^- ASYMMETRY MEASUREMENTS AND LONGITUDINAL POLARIZATION UTILIZATION AT PEP

U. Camerini, D. B. Cline, J. G. Learned, L. K. Resvanis, P. J. Wanderer

ABSTRACT

A compact-spherically symmetric detector designed to observe single and dimuon final states is described. The detector is sufficiently compact to fit into the interaction region for which longitudinally and transversely polarized beams will be available. The usefulness of the detector to successfully search for the asymmetry resulting from weak-electromagnetic interference and from higher order electromagnetic processes is studied with Monte Carlo simulated experimental data.

The iron ball detector proposed for the SPEAR 7 experiment is easily adapted to experiments at PEP. A drawing of the detector is shown in Fig. 1. The major properties of the detector are listed in Table 1. Devices of this sort may be useful for new particle searches but are primarily designed to measure the μ^+-μ^- asymmetry that is expected to arise from weak-electromagnetic interference.

This detector is also sufficiently compact to fit into the small interaction region that would be available for longitudinally polarized beams and is shown schematically in Fig. 2 (the bending magnets are roughly scaled from the note of Schwitters and Richter). The longitidinal polarization will be primarily useful for observing parity violating weak interaction effects and for testing μ-e universality. A simple scheme for classifying the information content in the beam polarization for tests of C, P, T is given in Table 2.

Tests of parity violating and μ-e universality invariably require the comparison of cross-sections for polarized and unpolarized incident beams and are thus very sensitive to systematic experimental errors. One scheme that could overcome these effects involves the collision of separate polarized and unpolarized bunches of electrons with unpolarized positron bunches and a direct comparison of rates. It would still be necessary even with this scheme to measure the luminosity of individual bunches.

Monte Carlo experiments have been carried out for PEP energies and with the momentum resolution of the magnetic iron ball. 10,000 event samples were generated at three s values (900, 400 and 100 GeV^2) using the weak coupling constant from the Weinberg model. We note that this is approximately independent of the Weinberg angle and perhaps represents a conservative estimate for the effect to be expected. Higher order electromagnetic interactions also produce fore-aft asymmetry and this was included in the Monte Carlo experiment. Table 3 and Fig. 3 give the values of the weak and electromagnetic asymmetry for various $|z|$ (= $|\cos\theta|$) and ϕ = 0. The resultant asymmetry that is observed for a 10,000 event experiment in z and ϕ bins is shown in Table 4. The only statistically significant asymmetry that is observed is in the lowest z bins and arises from the radiative corrections. Clearly the extraction of the weak asymmetry even at PEP will require a substantial background subtraction and needs a good understanding of the radiative corrections. In our opinion the radiative contribution must be experimentally measured. Four ways are possible: (1) change the beam energy to reduce the weak interaction effect, (2) study the small (z) region where the radiative corrections dominate, (3) use the transverse beam polarization which allows an approximate separation of the weak and electromagnetic effects even at $|z| \sim 1$, and (4) decrease the resolution of the detector which results in an attendent decrease in the radiative corrections. Possibly all four methods will be necessary to reach a definitive conclusion that weak interactions have been seen at PEP.

In Fig. 4 is shown the χ^2 that is obtained for the Monte Carlo experiments when fit to the hypothesis of no weak interaction; with and without beam polarization. The χ^2 reaches the 2σ level at about 6×6 GeV^2 for 10,000 event experiments.

Figure 5 shows the error in the resulting weak interaction parameter (assumed to be equal to 1) at the various energies for 10,000 event experiments. Figure 6 shows the errors that would be obtained in the weak coupling strength at the various energies compared to the values at 15×15 GeV^2. The linear rise in s is a direct consequence of the locality of weak interaction and might be violated at PEP energies. Furthermore, a non-linear s dependence would result from the existence of a massive neutral intermediate boson. The effects of this boson on the asymmetry for various masses is shown in Fig. 6. 10,000 event experiments would distinguish masses up to $\sim$50 GeV but in the 80-100 GeV mass range 100,000 event experiments would likely be needed as well as a very good understanding of the background from systematic errors as well as the radiative corrections.

Obviously if the radiative corrections are not exactly as expected from theory, the data will have to be used to simultaneously extract weak and radiative corrections and will increase the statistical errors.

Table 1

Magnetic Iron Ball Detector at PEP

Properties of Ball Detector:

1. Symmetric magnetic field.
2. Close packed, high density detector to minimize $\pi \to \mu$ decay.
3. Covers 98% of solid angle and large range of θ, all of ϕ - measure θ down to 10°.

Parameters of Ball:

1. 19 KG field.
2. Outer radius 4', inner radius 1'.
3. 51 radiation lengths.
4. 7.2 collision lengths.
5. 66 tons of Fe.
6. Fits well into small interaction region.
7. $\delta\theta$ magnetic deflection for 15 GeV μ is 40 mr.
8. $\delta\theta$ multiple scattering for 15 GeV μ is 8 mr.
9. The resulting $\delta E/E$ for a dimuon final state is $\simeq .15$.

Table 2

Weak Interaction Information with Polarized e^+, e^- Beams for the Process $e^+e^- \rightarrow \mu^+\mu^-$

	e^+, e^- Polarization Vectors	Other Vectors	Correlation Functions Possible	Symmetry Tests
I	None	$\vec{p}_{e^-} = -\vec{p}_{e^+}$	$\langle \vec{p}_{e^-} \cdot \vec{p}_{\mu^+} \rangle$	C
		$\vec{p}_{\mu^+} = -\vec{p}_{\mu^-}$	$\langle \vec{p}_{e^-} \cdot \hat{\sigma}_{\mu^\pm} \rangle$	P
		$\hat{\sigma}_{\mu^+}$, $\hat{\sigma}_{\mu^-}$		
		(4 indepen-	$\langle \vec{p}_{\mu^-} \times \hat{\sigma}_{\mu^+} \cdot \hat{\sigma}_{\mu^-} \rangle$	P, T
		dent vectors)	$\langle \vec{p}_{e^-} \times \hat{\sigma}_{\mu^-} \cdot \hat{\sigma}_{\mu^+} \rangle$	P, T
II	Transverse Natural Polarization	$\vec{p}_{e} = -\vec{p}_{e^+}$	Same as I	C, P, T tests
	$\hat{\sigma}_{e^+} = -\hat{\sigma}_{e^-}$	$\vec{p}_{\mu^+} = -\vec{p}_{\mu^-}$	$\langle \hat{\sigma}_e \cdot \vec{p}_e \rangle = 0$	P
		$\hat{\sigma}_{\mu^-}$, $\hat{\sigma}_{\mu^+}$	$\langle \vec{p}_\mu \times \vec{p}_e \cdot \hat{\sigma}_e \rangle$	T
		(5 indepen-	$\langle \hat{\sigma}_\mu \times \hat{\sigma}_{e^+} \cdot \hat{\sigma}_{e^-} \rangle$	T
		dent vectors)	$\langle \vec{p}_\mu \cdot \hat{\sigma}^T \rangle = 0$ for weak interactions	
III	One Beam Transverse One Beam Longitudinal (or one beam longitudinal, the other unpolarized)	$\vec{p}_{e^-} = -\vec{p}_{e^+}$	Same as I	
	$\hat{\sigma}^T_{e^\pm}$, $\hat{\sigma}^L_{e^\mp}$	$\vec{p}_{\mu^+} = -\vec{p}_{\mu^-}$	$\langle \sigma^T \cdot \sigma^L \rangle = 0$	
	$\sigma^T_{e^\pm} \cdot \sigma^T_{e^\mp} = 0$	$\hat{\sigma}_{\mu^+}$, $\hat{\sigma}_{\mu^-}$	$\langle \hat{p}_\mu \times \hat{\sigma}_{e^+} \cdot \hat{\sigma}_{e^-} \rangle$	P, T
			$\langle \hat{p}_\mu \cdot \hat{\sigma}^{T,L}_{e^+} \rangle$	P
		(6 indepen-	$\langle \vec{p}_e \times \hat{\sigma}^L_e \cdot \hat{\sigma}^T \rangle$	P, T
		dent vectors)	$\langle \vec{p}_e \times \vec{p}_\mu \cdot \hat{\sigma}^T_e \rangle$	T
IV	Both Beams Longitudinally Polarized	$\vec{p}_{e^-} = -\vec{p}_{e^+}$	Same as I	
		$\vec{p}_{\mu^+} = -\vec{p}_{\mu^-}$	$\langle \vec{p}_\mu \cdot \hat{\sigma}^L \rangle$	P

$\hat{\sigma}^L_{e^\pm}$, $\hat{\sigma}_{e^\mp}$	$\hat{\sigma}_{\mu^+}$, $\hat{\sigma}_{\mu^-}$	$\langle\vec{p}_\mu \times \hat{\sigma}^L_e \cdot \hat{\sigma}^L_e\rangle$	T, P
$\langle\sigma^L_{e^\pm}\hat{\sigma}^L_{e^\mp}\rangle = +1$	(6 independent vectors)	$\langle\vec{p}_e \cdot \sigma^L_e\rangle$	P

Notes on the Table

1. C can be tested with no polarization, but P and T always require either initial lepton polarization or final μ polarization.
2. The simplest test of T can be made with a transverse $e^\pm$ polarization beam.
3. The simplest test of P separately requires at least one beam be longitudinally polarized or that the outgoing μ polarization be measured.
4. The simplest test of T separately requires one beam transversely polarized and $\vec{p}_\mu$, $\vec{p}_e$ or both beams transverse and measurement of the outgoing μ polarization vector.

Table 3

15 × 15 GeV
P = 0.924
ε = .1

	$\phi=0$			$\phi=\pi/2$		
$\lvert z\rvert$	D^{EM}	D^{WEM}	D^{Σ}	D^{EM}	D^{WEM}	D^{Σ}
.0	.0	.0	.0			
.1	.61	-9.1	- 8.5	.97	- .07	.17
.2	1.4	-13.6	-12.2	1.9	-1.6	.36
.3	2.5	-14.4	-11.9	3.0	-2.4	.61
.4	3.6	-13.5	- 9.9	4.1	-3.2	.94
.5	4.9	-12.3	- 7.4	5.4	-3.9	1.4
.6	6.4	-11.0	- 4.7	6.8	-4.7	2.1
.7	8.2	- 9.9	- 1.7	8.5	-5.5	3.1
.8	10.6	- 9.0	1.6	10.8	-6.2	4.7
.9	19.5	- 8.2	6.3	14.7	-6.8	7.8
1.0	40.9	- 7.5	33.4	40.9	-7.5	33.5
		sign changes			sll one sign	

Table 4

	0	π/2	π	3/2 π
.05	0.1 ± .07	.01 ± .04	-.01 ± .07	-.003 ± .04
.15	.02 ± .07	-.028 ± .04	-.03 ± .07	-.02 ± .04
.25	- .07 ± .07	.007 ± .04	-.009 ± .07	.06 ± .04
.35	.024 ± .06	.009 ± .04	-.04 ± .07	-.05 ± .04
.45	- .05 ± .05	.05 ± .04	.13 ± .06	.05 ± .04
.55	- .088 ± .05	.01 ± .04	-.02 ± .05	.04 ± .04
.65	.066 ± .05	.04 ± .04	.01 ± .05	.02 ± .04
.75	.027 ± .045	.001 ± .04	-.004 ± .04	-.007 ± .04
.85	.09 ± .04	.09 ± .04	.02 ± .04	.03 ± .04
.95	.11 ± .04	.06 ± .04	.12 ± .04	.09 ± .04

Monte Carlo simulation of an $e^+e^- \to \mu^+\mu^-$ experiment at PEP - The forward backward asymmetry as a function of z and ϕ for 10,000 Events. P = 0.924 and ε = 0.1 are assumed.

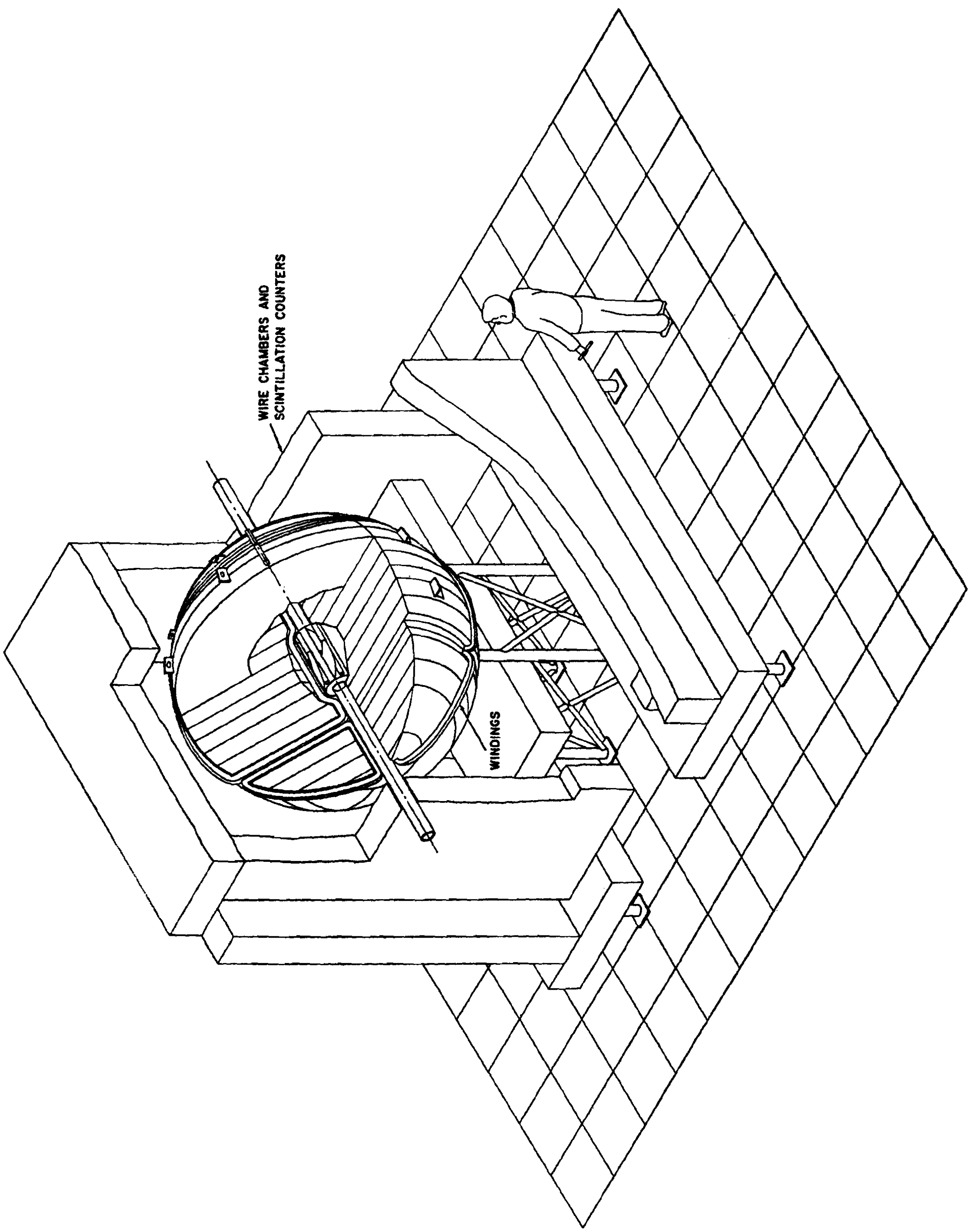


FIG. 1

MAGNETIC IRON BALL IN A HIGH LUMINOSITY REGION WITH LONGITUDINAL BEAM POLARIZATION

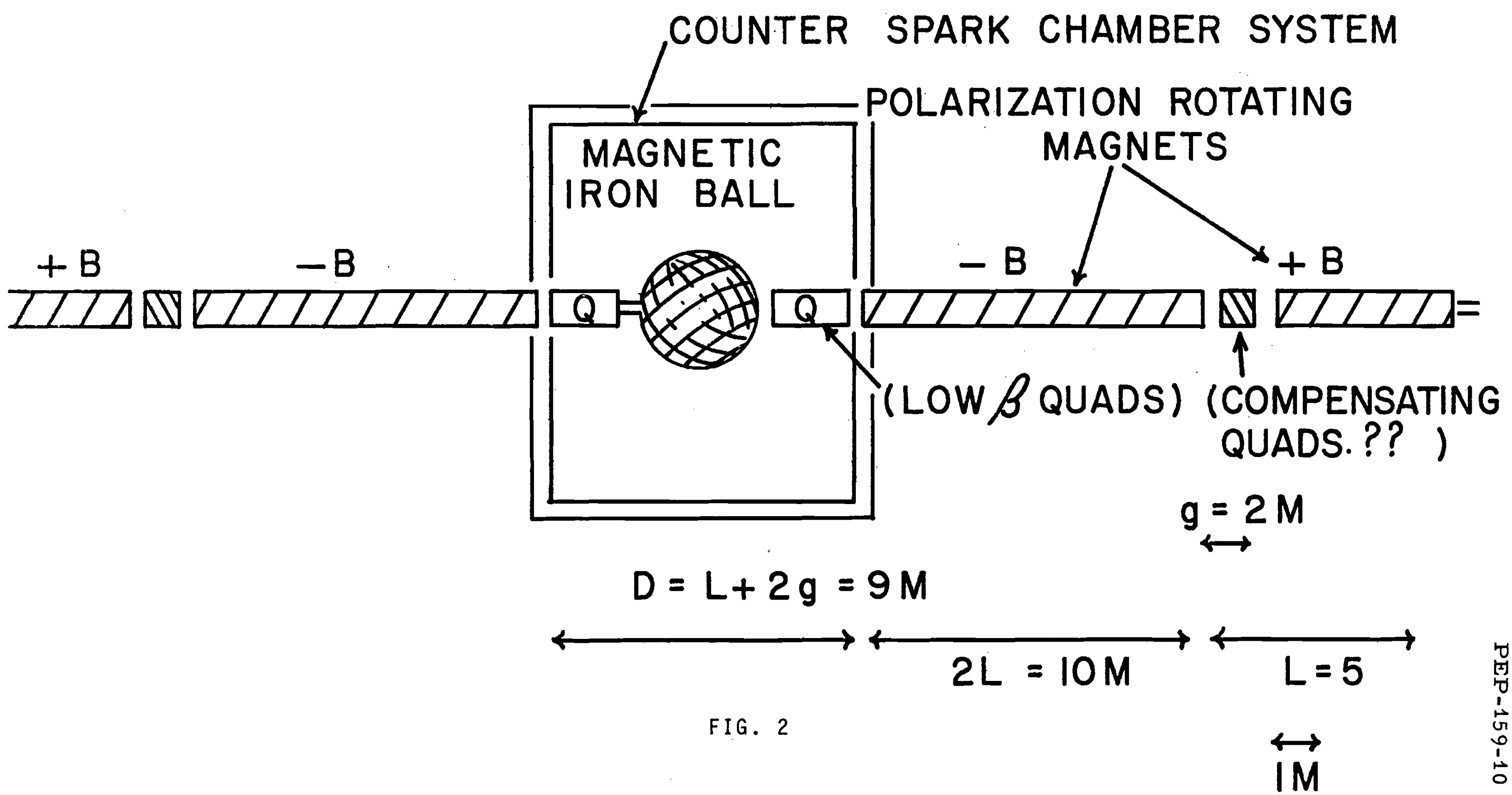


FIG. 2

PEP-159-10

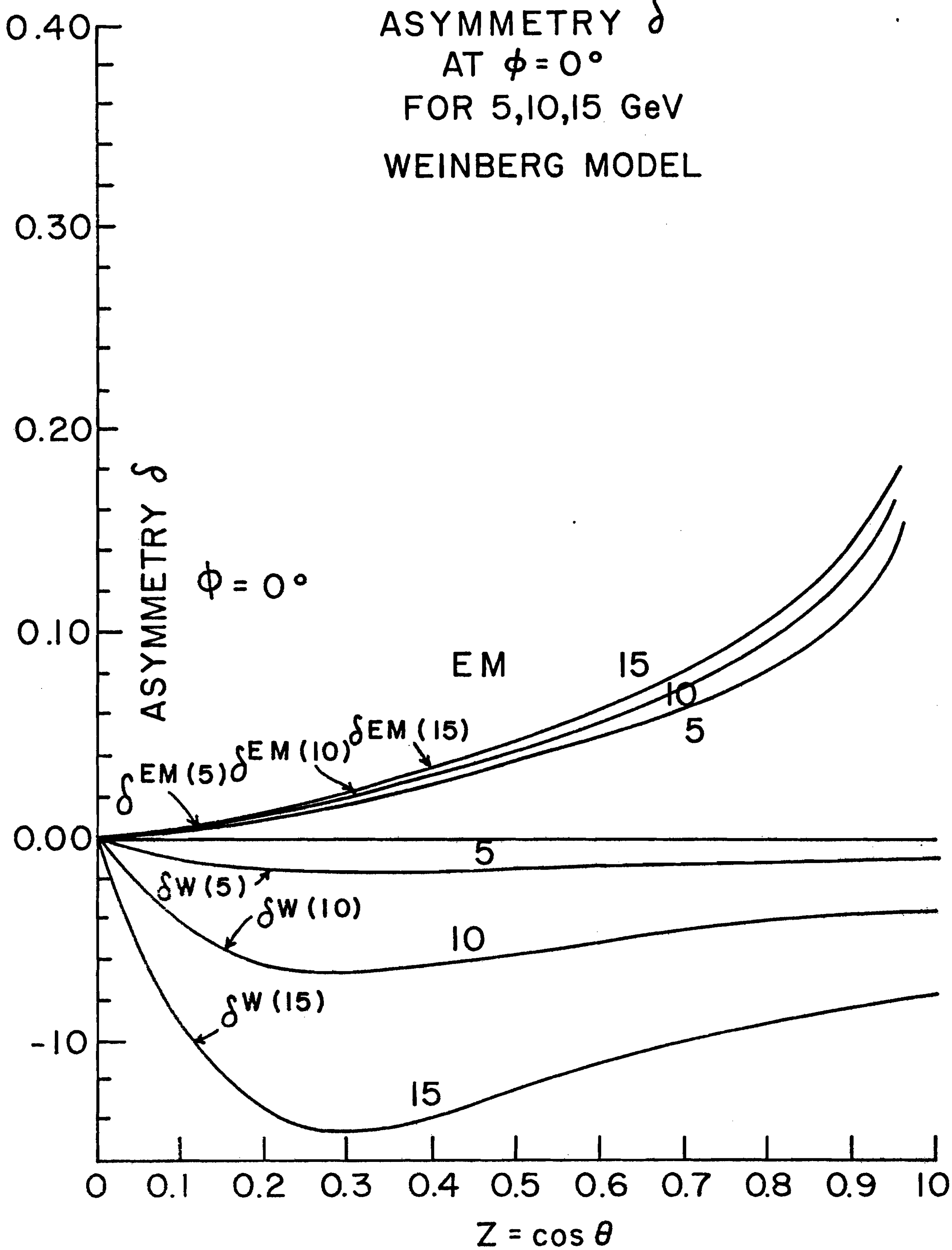
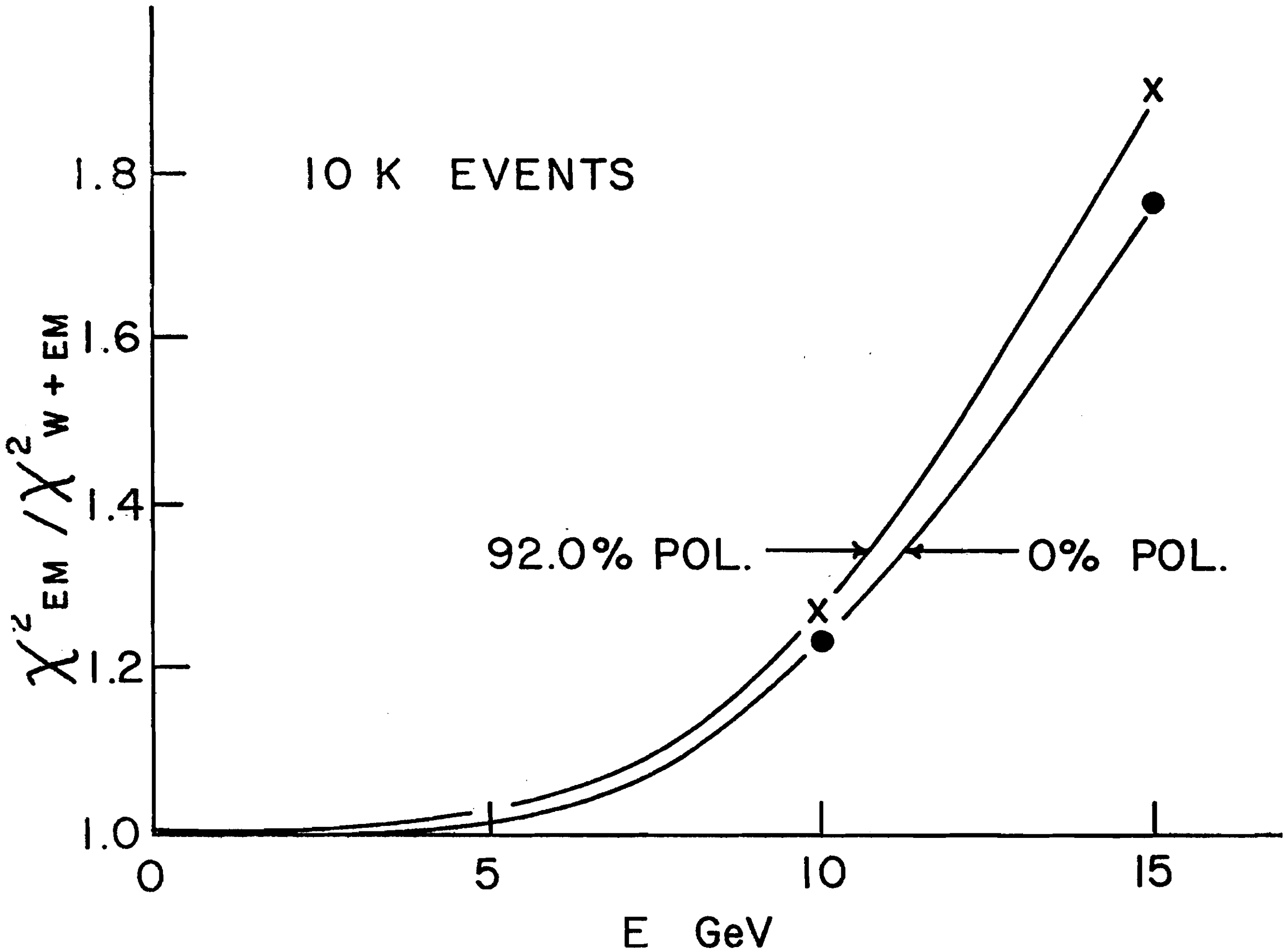

ASYMMETRY δ
AT φ = 0°
FOR 5,10,15 GeV
WEINBERG MODEL
0.40
0.30
0.20
0.10
0.00
-10
ASYMMETRY δ
φ = 0°
EM
15
10
5
δEM (15)
δEM (10)
δEM (5)
5
δW (5)
δW (10)
10
δW (15)
15
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
10
Z = cos θ

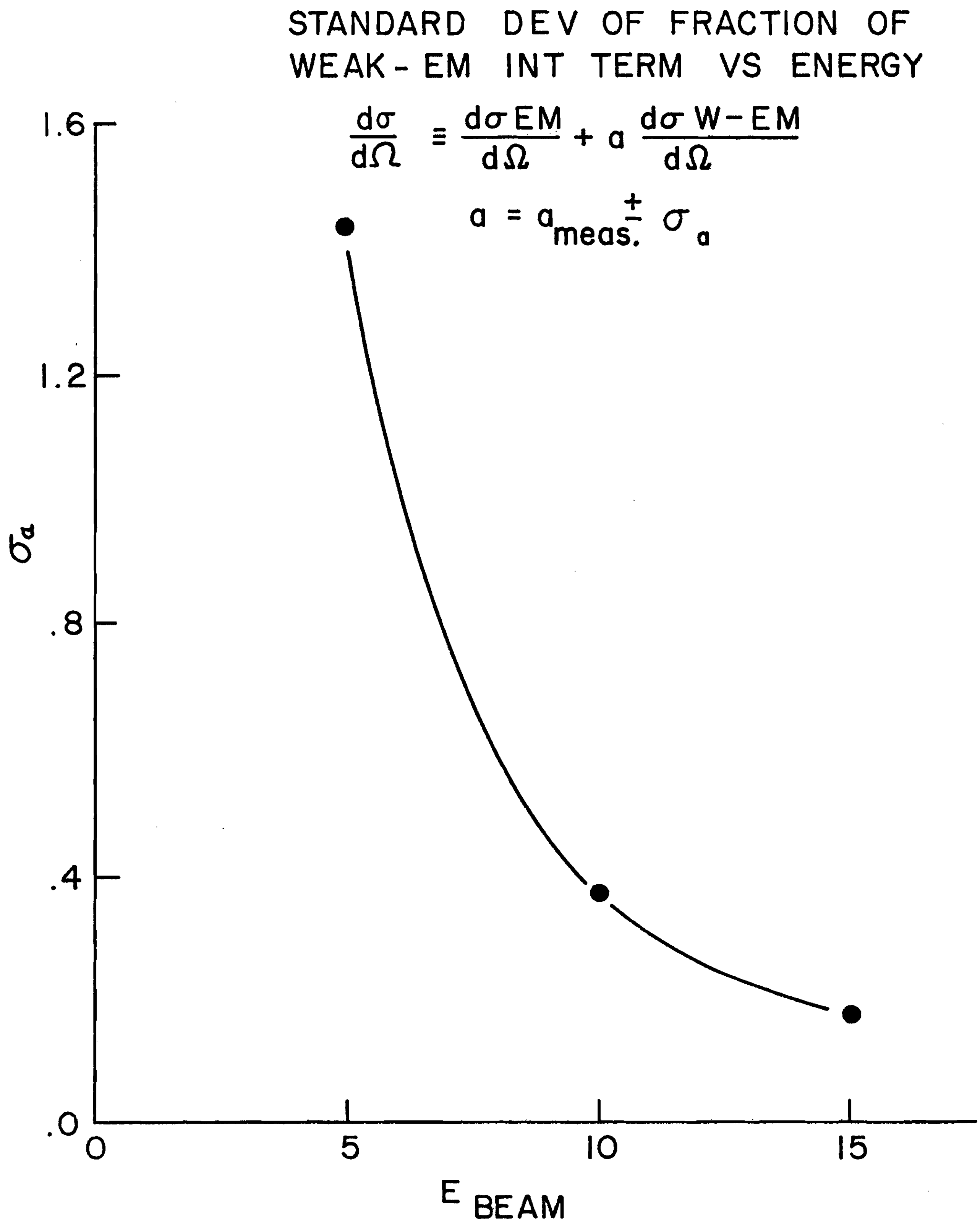
FIG. 3



FITTING TO THE MEASURED ASYMMETRY; RATIO OF χ^2 FOR FITS TO MONTE CARLO DATA WITH ELECTROMAGNETIC TERMS ONLY AND FIT INCLUDING WEAK ELECTROMAGNETIC INTERFERENCE. CALCULATED FOR 10 K EVENTS, 40 DEG. OF FREEDOM. $\mu\mu$ ENERGY RESOLUTION IS 10%

FIG. 4

FIG. 5


STANDARD DEV OF FRACTION OF
WEAK-EM INT TERM VS ENERGY
$\frac{d\sigma}{d\Omega} \equiv \frac{d\sigma EM}{d\Omega} + a \frac{d\sigma W-EM}{d\Omega}$
$a = a_{meas.} \pm \sigma_a$
1.6
1.2
.8
.4
.0
σ_a
0
5
10
15
E BEAM

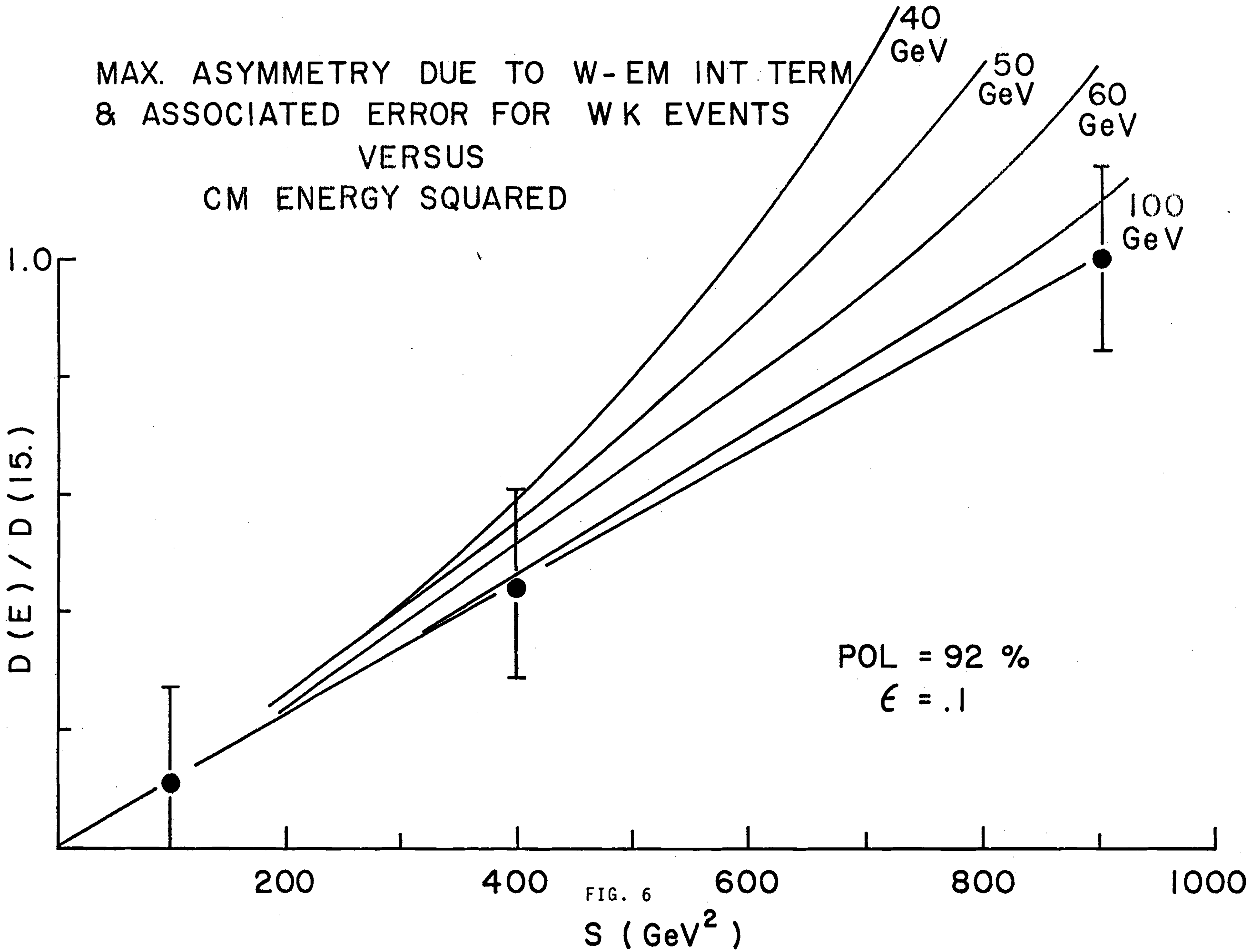


FIG. 6

PEP-159-14