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PERFORMANCE OF A HIGH PRESSURE HYDROGEN TIME PROJECTION CHAMBER*

T.J. Chapin, R.L. Cool, K. Goulianos,
J.P. Silverman, G.R. Snow, H. Sticker and S.N. White
The Rockefeller University, New York, NY 10021 USA

and

Y. H. Chou

Institute of High Energy Physics
Beijing, The People's Republic of China

Presented by: S.N. White

INTRODUCTION

We have been using a high pressure hydrogen filled timed projection chamber (TPC) in a Fermilab experiment (E-612) which is investigating the diffraction dissociation of photons on hydrogen, $\gamma p \rightarrow Xp$. In this paper we present details on construction and performance of the chamber and describe briefly the experiment for which it was designed.

The chamber acts both as target and as track detector of recoil protons. It is used to measure the polar angle, θ, and dE/dx of protons with $10 < T < 50$ MeV and $45^0 < \theta < 90^0$. The energy of protons is determined by stopping them in plastic scintillation counters located inside the high pressure vessel.

The experiment is operating in Fermilab's tagged photon beam ($20 \leq p_\gamma \leq 170$ GeV/c) which provides a flux of $1\text{-}2 \times 10^6$ tagged photons per pulse with a momentum resolution of $\pm 2\%$. The variables t and M_x^2 are determined from the measured quantities p_γ, T and θ as follows:

$$t = -2M_p T$$

$$M_x^2 = 2p_\gamma \sqrt{|t|}(\cos\theta - \sqrt{|t|}/2M_p)$$

Figure 1 shows the mass spectrum expected from 50 GeV photons. A pressurized target and good detector coverage are needed to obtain a useful event rate. Good mass resolution is essential to the study of the resonances. A $\Delta M_x^2/M_x^2 = \pm 0.03$ may be obtained in the region $0.05 < M_x^2/s < 0.1$ with $\Delta t = 0.002$ $(\text{GeV/c})^2$ and $\Delta\theta = 5$ mr. The latter is limited by multiple coulomb scattering in the target-detector combination. For this reason, a liquid target would be inadequate and a low Z drift chamber gas is desirable. The TPC that we have built is a target-detector combination that satisfies these requirements.

TREAD (The Recoil Energy and Angle Detector)

The recoil detector consists of two identical endcap assemblies mounted on a 26" I.D. × 84" long stainless steel tube. A schematic drawing is shown in Figure 2. The vessel may be pressurized up to 20 atm with hydrogen. The beam enters through a 2" dia. × 0.030" thick hemispherical beryllium window. Recoil protons from interactions of the beam with the hydrogen are stopped in 1 1/8" thick scintillation counters placed 9" away from the axis inside the high pressure vessel. The energy of the protons is determined from the counter pulse heights. Particles penetrating these counters register on anti-counters. The photon dissociation products exit through an 8" dia. × 0.080" thick aluminum window (not shown in the figure).

The ionization electrons generated along the path of the recoil proton drift along axial electric field lines towards a ground plate where they are detected by a set of concentric octagonal sense wires. Typically, at 15 atm of hydrogen with E = 2kV/cm drift field the drift velocity is 0.5 cm/μsec. The sense wires and associated electronics record the time and measure the amount of the ionization as it arrives. Time differences between sense wires are then translated into polar angles and pulse heights into dE/dx. From dE/dx and T (recoil energy measured by pulse-height counters) the mass of the recoil may be calculated.

Because the drift velocity of electrons in hydrogen is a function of the ratio of E to the gas density, angle measurements of the required accuracy demand tolerances on the electric field, temperature and pressure on the order of 0.1%. The temperature is maintained constant by an automatically controlled heating jacket surrounding the vessel. A pressure transducer controlled with

preset limits activates input and exhaust solenoid valves to keep the pressure within tolerances. In practice, allowing the gas to leak at a constant rate maintains the pressure within 0.01 psi of the low set limit. Finally, the electric field is kept uniform by two "cages" of field-shaping concentric metal rings. The outer cage consists of 48 rings made of 1/8" copper wire and connected by a bleeder chain of 48 × 100 MΩ metal film resistors. These rings are insulated from the wall of the vessel by a 1/2" thick polyethylene tube. The thickness of the wire was chosen to prevent corona discharge. Since the inner cage is located in an already uniform electric field, thin (0.002" diameter) wires were used for its construction.

The sense wires which are stainless steel or nichrome (35μ diameter) operate at 6.4 to 8 kV. They are located in the centers of 1/4" square grooves machined on the face of a 1/2" thick aluminum plate. With this arrangement, a track segment approximately equal to the width of the groove is focused onto each sense wire.

The drift time and gain stability of the TPC are monitored by ^{244}Cm α-sources positioned so as to leave ionization tracks directly over one wire of each sense wire plate. ZnS scintillation counters detect the α particles and provide a zero-time reference for drift velocity monitoring. Drift velocity measurements obtained in this manner are shown in Figure 3. We find that drift velocities scale as E/p to ± 2% over this pressure range.

SENSE WIRE GAIN

The sense wire gain in hydrogen was measured, prior to building TREAD, in a simple proportional counter consisting of an anode wire stretched along the axis of an 0.5" I.D. aluminum cylinder. Measurements were carried out

with 20μ and 50μ diameter sense wires at pressures from 5 to 15 atm. We have calculated the sense wire gain by integrating the first Townsend coefficient, α ,

$$\ln G = \int_{r_1}^{r_2} \alpha(r)\, dr$$

from the anode (r_1) to the cathode (r_2) using a simple approximation for α suggested by low pressure measurements[1]:

$$\alpha/p = 5.1 \exp(-139\, p/E(r)\ \mathrm{cm}^{-1}\cdot\mathrm{torr}^{-1}$$

where p/E is expressed in $\mathrm{torr}\cdot\mathrm{V}^{-1}\cdot\mathrm{cm}$. Our measurements agree well with the pressure and voltage dependence of the gain predicted in this manner. This is illustrated in Figure 4 which shows a comparison with our measurements at a gain of 10^4.

The maximum gain in the test counter and in TREAD was found to be in the range $2\text{-}5 \times 10^4$, essentially independent of sense wire diameter and gas pressure.

ELECTRON ATTACHMENT

Our gas purification system (Fig. 5) was designed primarily to remove oxygen impurities, since O_2 is expected to be the main electro-negative contaminant in the chamber. The chamber gas is recirculated at a rate of 3 volumes/hr. It passes through a "Deoxo" palladium catalyst which combines H_2 and O_2 to form water molecules which are subsequently adsorbed in a $4A^o$ molecular sieve. Under steady state conditions, we find that the pulse height attenuation with drift time is characterized by a decay constant of 1.8 msec. Using available data on three-body attachment[2] to O_2 impurities in H_2, this decay constant implies an oxygen level of < 1 part in 10^8.

SPATIAL RESOLUTION

Figure 6 shows the r.m.s. deviation of the drift time measured on a typical wire from fits to cosmic ray tracks passing through the axis of the chamber. Also shown is a fit of the form

$$\sigma^2 = \sigma_o^2 + \sigma_1^2 \cdot (\frac{Z}{1cm})$$

where $\sigma_o = 218$ μm and $\sigma_1 = 30$ μm.

The value of σ_o depends on the sense wire discriminator threshold. The second term is due to electron diffusion. The diffusion width along the drift direction, calculated from known transport coefficients[3)] in H_2, is $\sigma_D^2 = (68\mu m)^2 \cdot Z/1cm$. Due to statistics, for the sense wire threshold used in the cosmic ray data, we would expect an "ideal" $\sigma_1 = 0.3 \times 68 = 21\mu m$.

PERFORMANCE IN THE BEAM

During the previous run of the experiment, the chamber was operated at a sense wire gain of 1.5×10^2. At this gain, the total sense wire current was 2×10^{-8} Amps "on spill", caused primarily by low energy electrons produced in the beam halo. Under these conditions, we did not observe any deterioration of the chamber gain or spatial resolution due to space charge.

A scatter plot of sense wire pulse height vs. recoil kinetic energy obtained on-line is shown in Figure 7. The recoil proton band is clearly visible.

REFERENCES

* This research is supported in part by the United States Department of Energy.

1. D.J. Rose, Phys. Rev. 104, 273 (1956).

2. H. Shimamori and Y. Hatano, Chem. Phys. Lett. 38, 242 (1976).

3. L.G. Huxley and R.W. Crompton, *The Diffusion and Drift of Electrons in Gases* (Wiley, New York, 1974).

FIGURE CAPTIONS

Fig. 1 : Missing mass spectrum expected from 50 GeV photons.

Fig. 2a : TREAD.

Fig. 2b : TPC sense wire arrangement.

Fig. 3 : Drift velocity vs. E/p.

Fig. 4 : Voltage vs. Pressure at a fixed gain of 10^4.

Fig. 5 : The hydrogen purification system.

Fig. 6 : Resolution vs. drift distance.

Fig. 7 : dE/dx vs. recoil kinetic energy for raw events.

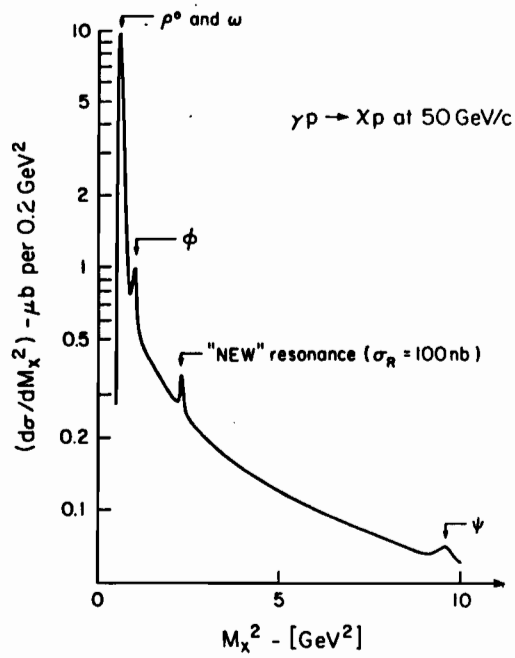
ρ° and ω
γp → Xp at 50 GeV/c
φ
"NEW" resonance (σ_R = 100 nb)
ψ
(dσ/dM_x²) - μb per 0.2 GeV²
10
5
2
1
0.5
0.2
0.1
0
5
10
M_x² - [GeV²]

FIGURE 1

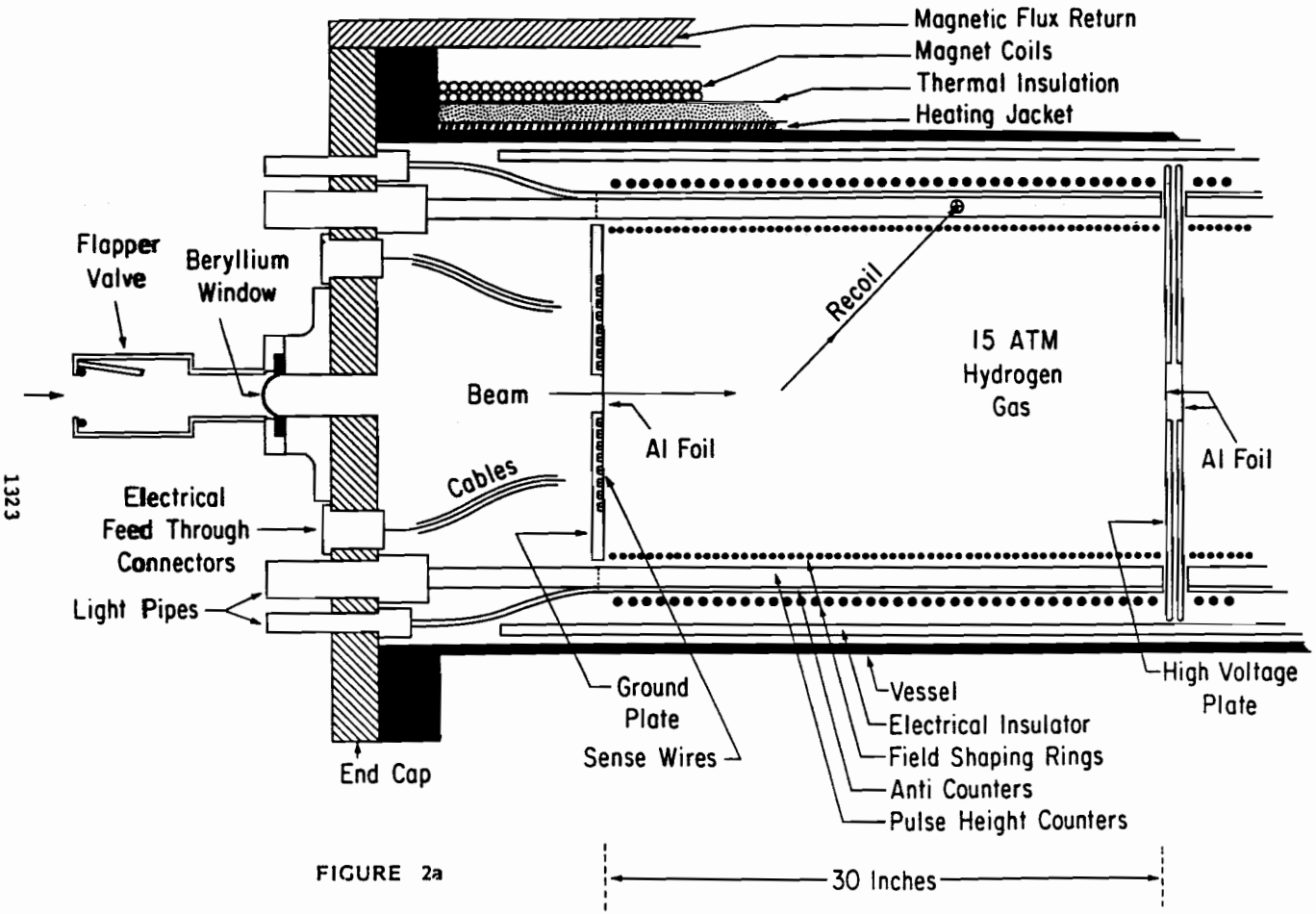
Magnetic Flux Return
Magnet Coils
Thermal Insulation
Heating Jacket
Flapper Valve
Beryllium Window
Recoil
15 ATM Hydrogen Gas
Beam
Al Foil
Al Foil
Cables
Electrical Feed Through Connectors
Light Pipes
Ground Plate
Sense Wires
Vessel
Electrical Insulator
Field Shaping Rings
Anti Counters
Pulse Height Counters
High Voltage Plate
End Cap
30 Inches

FIGURE 2a

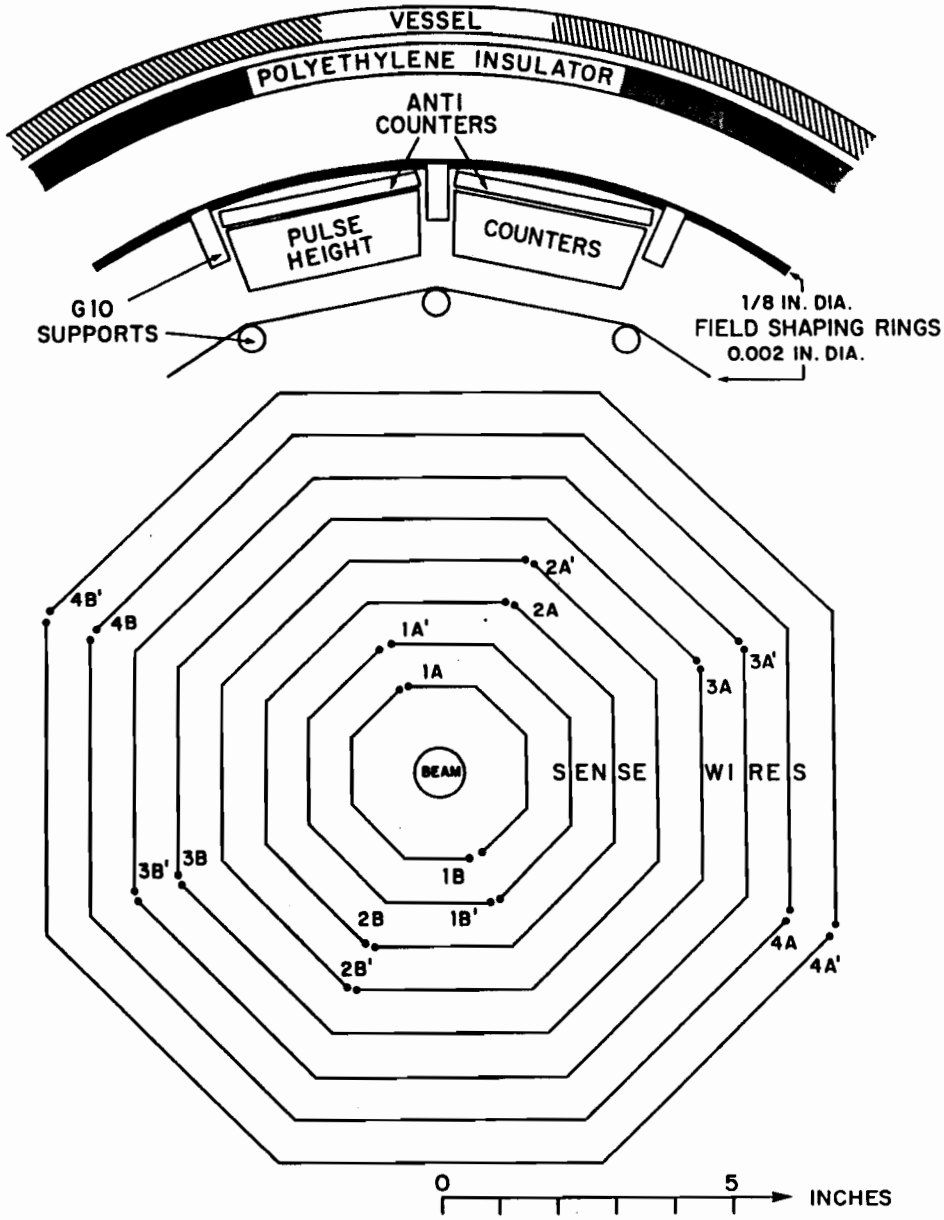
VESSEL
POLYETHYLENE INSULATOR
ANTI COUNTERS
PULSE HEIGHT
COUNTERS
G10 SUPPORTS
1/8 IN. DIA.
FIELD SHAPING RINGS
0.002 IN. DIA.
4B'
4B
3B'
3B
2A'
2A
1A'
1A
BEAM
1B
1B'
2B
2B'
3A
3A'
4A
4A'
SENSE WIRES
0
5
INCHES

FIGURE 2b

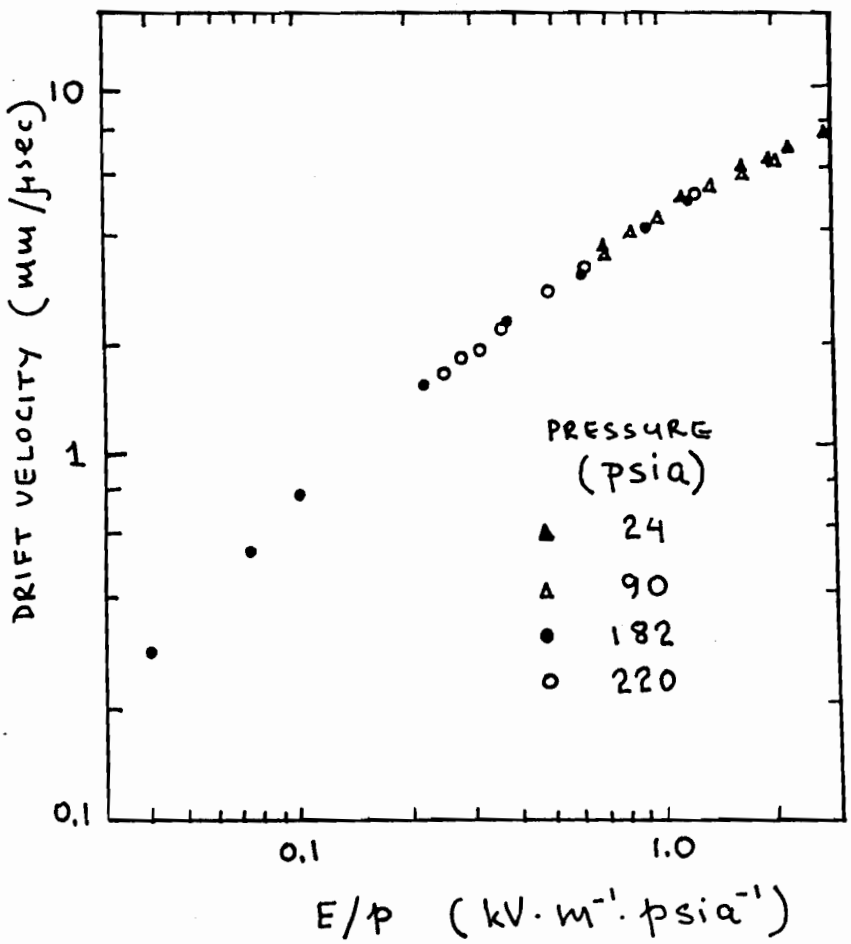
DRIFT VELOCITY (mm/μsec)
10
1
0.1
0.1
1.0
E/p (kV·m⁻¹·psia⁻¹)
PRESSURE
(psia)
24
90
182
220

FIGURE 3

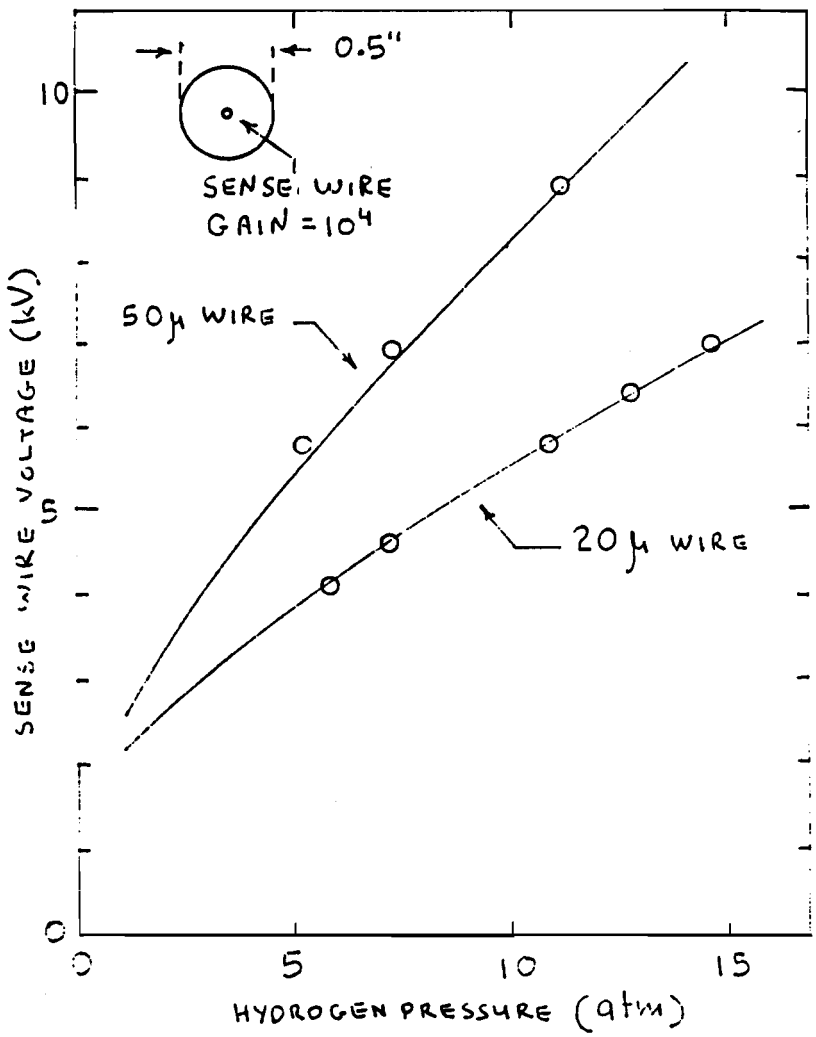
0.5"
SENSE WIRE
GAIN = 10^4
50μ WIRE
20μ WIRE
SENSE WIRE VOLTAGE (kV)
10
5
0
0
5
10
15
HYDROGEN PRESSURE (atm)

FIGURE 4

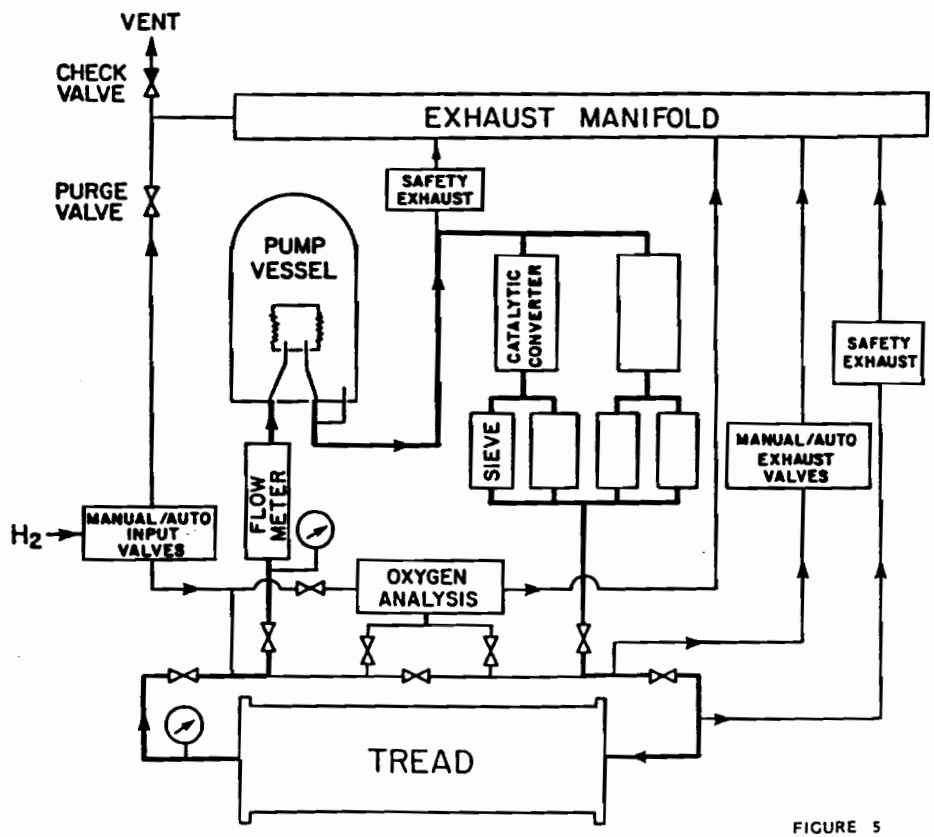
VENT
CHECK VALVE
PURGE VALVE
EXHAUST MANIFOLD
SAFETY EXHAUST
PUMP VESSEL
CATALYTIC CONVERTER
SIEVE
SAFETY EXHAUST
MANUAL/AUTO EXHAUST VALVES
FLOW METER
H_2
MANUAL/AUTO INPUT VALVES
OXYGEN ANALYSIS
TREAD

FIGURE 5

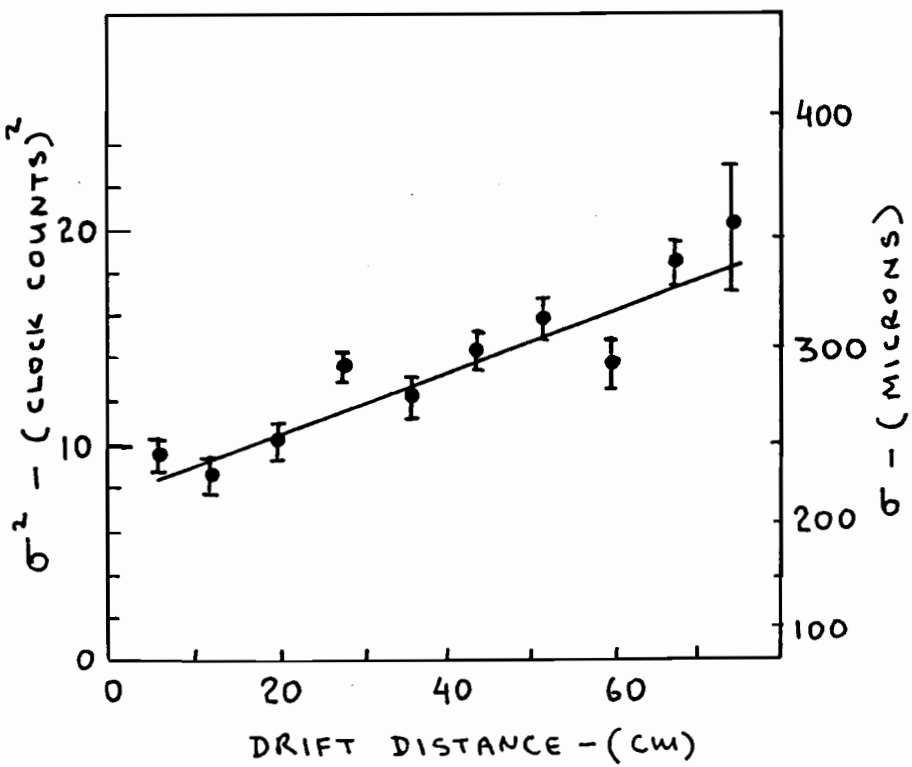
σ^2 - (CLOCK COUNTS)^2
0
10
20
σ - (MICRONS)
100
200
300
400
0
20
40
60
DRIFT DISTANCE - (CM)

FIGURE 6

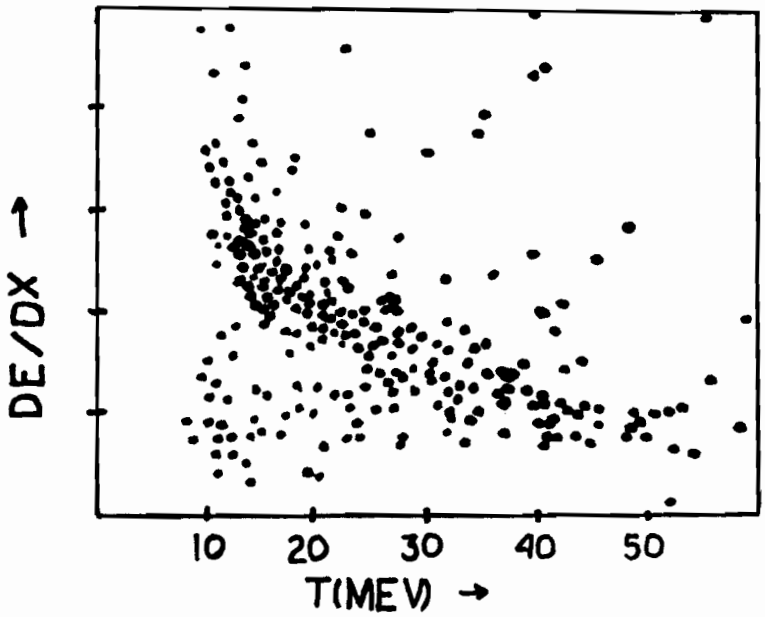

FIGURE 7