PROPOSAL

Elastic Scattering and Diffraction Dissociation at Small Momentum Transfer for $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$ and n.

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ABSTRACT

A simple apparatus is proposed for measuring the energies, angles, and identity of recoil p or d at small $|t|$ from a gas target. Large solid angle coverage and target length are capable of extending pp and pd gas jet measurements to $\pi^{\pm}$, $K^{\pm}$, $\bar{p}$ and n using typical FNAL existing beams. In addition, the recoil detector will label each diffractively produced state with M_x, $|t|$ and $\hat{n}$, the normal to the production plane, for study by downstream apparatus. Since diffractively produced states at very low $|t|$ carry the same quantum numbers as the incoming particle, each final state of mass M_x is labeled as to isospin, parity and strangeness. The variety of quantum numbers provided by existing beams then allows a sensitive method of searching for new particles within specified mass ranges with specific quantum numbers. Apart from the particle search potentiality, the systematic study of the important diffraction dissociation production process itself with a variety of incoming particles is emphasized. In addition to measuring $d^2\sigma/dM_x{}^2d|t|$ as a function of s, $|t|$ and $M_x{}^2$ for inelastic processes, $d\sigma/d|t|$ for elastic scattering will be measured in the range $0.01 \lesssim |t| \lesssim 0.12$ $(GeV/c)^2$.

Recent experiments at FNAL and the CERN ISR have shown that, for p-p interactions, a sizeable fraction of the total inelastic cross section arises from the coherent diffraction dissociation process. The data for pp and pd collisions at low $|t|$, which cover a considerable range in s, t, and M_x^2, display a number of extremely interesting regularities[1]. Several recent attempts have been made to interpret this information[2], usually on the basis of Regge models. These attempts have had a considerable degree of success, but the difficulties and failures are in many ways the most interesting aspect. Most current models correlate the diffraction dissociation of the proton to that of other hadrons. It has become evident that data for other hadrons of a quality and extent similar to that now available for protons would provide crucial tests of our understanding of this important process.

It is also well-known that the coherent diffraction dissociation process is an abundant source for the production of resonances. A systematic study of the decay products of the diffractive states may therefore be a most promising way to search for new phenomena. This is particularly true since the mass and quantum numbers of these states are labeled. This situation is to be contrasted with the usual situation in searching for new states in strong interactions when all quantum numbers and a wide range of mass states are available. The selectivity introduced by the production requirements is an effective tool to reduce background from unwanted processes.

The technique of measuring the energy, production angle and identity of recoil particles from a low density gas jet of hydrogen and deuterium has

successfully provided detailed data for scattering and production processes by protons at low $|t|$. The internal gas jet target of the USA-USSR collaboration has provided interesting and accurate data for elastic scattering[3], the ratio of real to imaginary amplitudes[4], and diffraction dissociation[5,6] as a function of s, $|t|$ and M_x . Unfortunately the gas jet, solid-state-detector apparatus in its present form is limited for a variety of reasons to the use of incoming protons in the internal beam.

Analysis of the diffraction dissociation of the proton from low t data where the process is coherent has shown important regularities[7]. It has also demonstrated several experimentally important features: (i) that measurements at low $|t|$ are essential both because the bulk of the cross section is concentrated there and because it is important to assure that the process is coherent, (ii) that measurements must be available over a wide range of the variables s, t and M_x^2, and (iii) that measurements for hadrons with quantum numbers other than those of the proton will increase dramatically the power of the data for studying the structure of hadrons and their interactions.

In addition to the production process itself, we can study the diffractively produced final states. At FNAL momenta, the decay products of these states are typically concentrated in a small cone near the forward direction and thus accessible to measurement with downstream apparatus of moderate scale.

In the following sections we describe the apparatus and proposed program to make the measurements outlines above.

I. Recoil Detector -

The heart of the experiment is the apparatus to detect and measure the variables of the low energy recoiling proton (deuteron). Since the kinetic energy $T = |t|/2m_T$, for $|t| < 0.1(\mathrm{GeV}/c)^2$ we will be interested in $T \lesssim 50$ MeV. For these energies, the target must be a low density gas and the detector elements must have thin walls to minimize coulomb scattering which will limit the angular resolution. In addition, we consider it important that the target be a pure gas (H_2 or D_2). A pure target eliminates the uncertainties introduced by background subtractions and simplifies the identification of the recoil particle.

A schematic plan view and elevation view of the detector are shown in Figs. 1 and 2. The target chamber between drift wire chambers (DWC) 1 and 1' and the space between DWC 1 and DWC 2 (also between 1' and 2') are filled with atmospheric pressure $H_2(D_2)$. The density $\rho \cong 10^{-4}$g cm^{-3}.

DWC's 1, 1', 2, and 2' have 0.25" gaps filled with the standard mixture of argon and isobutane gas at near atmospheric pressure. The windows are half mil thick mylar (aclar). The sense wires are stretched vertically with a spacing of 2.0" (the maximum drift distance is 1.0"). Each sense wire consists of a closely spaced pair (4 mil spacing) of gold plated tungsten wires, each 0.8 mils in diameter. The drift field is produced by 2 mil Be-Cu wires spaced 87 mils apart. The closely spaced sense wire pair resolves right left ambiguities[8]. The anticipated space resolution is ±6 mils. The accuracy in the angle (θ_{proj}) projected on the horizontal plane is then ±1.5 mrad.

PWC's 3 and 3' are proportional wire chambers with 0.25" gaps. The sense wires are stretched horizontally with a spacing of 0.1". These chambers serve a dual purpose: (1) they measure the vertical position to ± 0.05" and (2) they provide a measurement of the ionization loss (dE/dx) in order to identify the stopping particle. Since the vertical angle is never greater than 30^0, PWC 3 and the known beam position measure the angle ϕ sufficiently well to obtain the space angle θ from θ_{proj} without increasing its error appreciably.

The scintillation counter hodoscopes H and H' each consist of ≈ 6 1" thick plastic counters. The pulse height from each counter is recorded. Directly behind H and H' are anti-coincidence counters N and N' which will allow us, on- or off-line, to select only those particles ($T \lesssim 50$ MeV for protons) which stop in H or H'. The combination of dE/dx from DWC 3, pulse height from H and the anti-coincidence from N will allow us to select stopping protons (deuterons) cleanly and measure their kinetic energies. The selectivity for elastic scattering or diffraction dissociation against background is also enhanced by requiring no particles, other than the stopping one, within the two spectrometers.

A thin (~ 0.1") scintillator B defines the beam ahead of the detector, and the anti-coincidence counter A protects the detector from background due to particles which arrive time coincident with a beam particle. Counter A is put in time coincidence with the Cerenkov system pulses which define the nature of the incoming beam particle (see Section IV).

All electronic signals are sent to a PDP11/20 computer for recording, monitoring and on-line processing.

We note additionally a few possible alternatives for improvement of the recoil detector which are under active study: (i) the use of He gas instead of Argon gas in the DWC's which could reduce multiple scattering and improve resolution, (ii) the use of difference amplifiers or delay lines in DWC 1 to measure vertical position, and (iii) the use of liquid argon counters to replace H and H' for pulse height measurement.

II. Rates and Resolution -

A. Rates

We assume a total charged particle beam rate of $\approx 5\times10^6$ particles per accelerator pulse which is $\approx 10^6$ sec^{-1}. For each recoil detector with an effective target fiducial length of 40cm, the target contains 3.6×10^{-3} g cm^{-2} of H_2 at atmospheric pressure. We will use incoming protons in the calculated rate example since all of the data is now known: $\sigma_T(pp) \cong 40$ mb, $\sigma_{el}(pp) \cong 7$ mb, the single diffraction dissociation cross section, integrated over t, is $d\sigma/dM_x^2 = 0.7/M_x^2$ mb/(GeV)^2. The total interaction rate per second is:

$$N_T = 10^6 \times 6 \times 10^{23} \times 3.6 \times 10^{-3} \times 40 \times 10^{-27} \cong 86 \text{ sec}^{-1}$$

the total detected elastic rate ($\Omega = 4\pi/3$) is approximately

$$N_{el} = 10^6 \times 6 \times 10^{23} \times 3.6 \times 10^{-3} \times 7 \times 10^{-27} \times 0.33 \cong 5 \text{ sec}^{-1}$$

the total detected diffraction dissociation rate per (GeV)^2 at M_x^2 is approximately:

$$d\sigma/dM_x^2 = (10^6 \times 6 \times 10^{23} \times 3.6 \times 10^{-3} \times 0.33 \times 0.7)/M_x^2 = 0.5/M_x^2 \text{ sec}^{-1} \text{ GeV}^{-2}$$

Thus a day of running will yield about 4×10^5 elastic events and $4 \times 10^4/M_x^2$ diffraction dissociation events per (GeV)^2 bin at M_x^2. Depending on beam momentum, the events in a given run are divided between π, K and p in varying proportion.

B. Resolution

The resolution in the measurement of M_x is dominated by the uncertainties in the angle θ introduced by multiple coulomb scattering. Scattering in DWC 2 may be neglected since the lever arm is negligible. Except for $\approx$ 2% of the particles which strike the Cu wires, 98% of the particles pass through $\approx 10^{-4}$ radiation lengths of material which is comprised of H_2 and the windows and gas of DWC 1. The uncertainty in the projected scattering angle is

$$\theta_{proj} = 15\ (10^{-4})^{1/2}/p\beta = 0.15/p\beta \qquad p \text{ in MeV/c}$$

since

$$\Delta M_x^{\ 2} = 2p_o\sqrt{|t|}\ \Delta\theta$$

where p_o is the incoming beam momentum and for slow protons $p\beta \cong |t|/m$

$$\Delta M_x^{\ 2} = 0.3 \times 10^{-3}\ mp_o/(|t|)^{1/2} \quad \text{GeV}^2$$

Typical values of ΔM_x for recoil protons are given in the following Table:

M_x(GeV)	ΔM_x(MeV)
1.5	100
3.0	50
5.0	33
7.5	20

The error introduced in ΔM_x by coulomb scattering at $|t| = 0.04$ and $p_o = 200$ at typical values of M_x .

III. Downstream Detector -

A. Phase I

In the first phase of the proposed program (see Section IV), we propose to place a simple detector capable of recording the number and position of charged particles and γ-rays in a plane perpendicular to the beam ≈ 10 meters downstream of the recoil detector. Each event triggered by the recoil detector is labeled by M_x, $|t|$ and incoming particle type. Thus for each category multiplicities and angular distribution can be studied. The detector would be an array of wire chambers followed by a Pb-scintillator sandwich. The Pb-scintillator would leave a hole for passage of the primary beam. The beam itself would pass only the small amount of material of the WC and would thus be almost unaffected and available for subsequent use. In Phase I, momentum of secondaries is not measured. However, the energy of γ-rays can be estimated from the Pb-scintillator sandwiches. The possible use of Pb-glass in Phase I is being considered to achieve better energy resolution. For simple configurations, some additional information can be deduced. For example, the elastic scattering identification of the recoil detector can be checked and confirmed.

B. Phase II

The precise design of a Phase II downstream detector will depend upon the results of Phase I. Clearly, momentum and energy (for γ-rays) will be included. Thus a magnet and Pb-glass or calorimeter type detectors are required. The extent to which a practicable device to identify the outgoing particles can be designed is highly dependent on the results of Phase I. For these reasons, the Phase II detector is not specified at this time.

IV. Beam and Space Requirements -

The apparatus of Phase I is small and highly portable. For example, space in most beam tunnels is adequate. The material placed in the beam is roughly the equivalent of one normal scintillation counter so that the degradation of the beam quality downstream is negligible. Thus this apparatus can be used upstream of most other experiments without interference. Longitudinally we require a free beam space of ≈ 50 feet in which the beam diameter is $\lesssim 1''$.

In principle, any high intensity charged beam in which Cerenkov counters are installed for particle identification can be used. Use of signals from the Cerenkov counters is required, but can be shared with a downstream experiment. We would prefer, for example, beam 1 or beam 6 in the meson area initially. Although the recoil detector is designed also for neutral beams if a calorimeter is added downstream, we prefer to do initial testing and running in a charged beam.

Control electronics and computer require space for about four normal racks. They may be located at any distance from the detector.

V. Equipment and Services -

A. Apart from use of a beam in which Cerenkov counters are installed, no equipment is requested from FNAL. All electronics, detectors and computer will be furnished by Rockefeller University for Phase I.

B. All data analysis will be performed on Rockefeller University computers.

C. A low pressure gas dump line from the area of the recoil detector to an area in which small quantities of hydrogen gas can be safely vented to the atmosphere is required. Hydrogen gas near atmospheric pressure is used for filling and purging the target volume. No appreciable safety hazard is foreseen.

D. A prototype recoil detector is now under construction and will be finished by the end of 1975.

VI. Summary -

We request approval for 1000 hours of running in a suitable charged particle beam for Phase I of this experiment. The specific program is to measure the following: (i) $d^2\sigma/d|t|dM_x^2$ for $50 < s < 400$ GeV^2, $0.01 \lesssim |t| \lesssim 0.12$ (GeV/c)^2 and $M_p^2 < M_x^2 < 0.15\ s$ for each particle type, (ii) $d\sigma/d|t|$ for elastic scattering over the same ranges of s and t for each particle type and (iii) multiplicities and angular distributions for charged particle and γ-ray secondaries of diffraction dissociation states together with γ-ray energies. The apparatus can be ready for installation in early 1976. A proposal for Phase II will be made at a later time.

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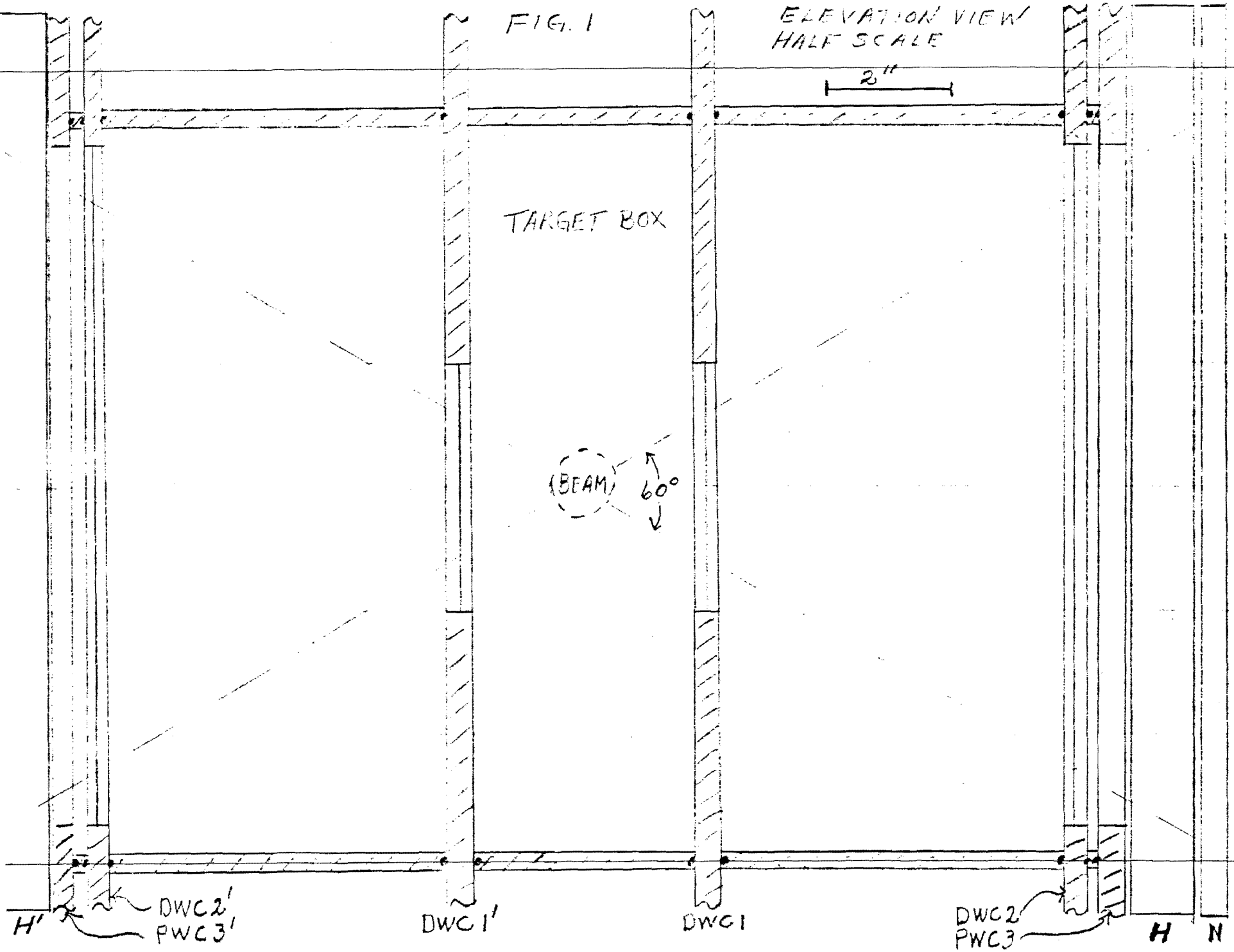
FIG. 1
ELEVATION VIEW
HALF SCALE
2"
TARGET BOX
BEAM
60°
H'
DWC2'
PWC3'
DWC1'
DWC1
DWC2
PWC3
H
N

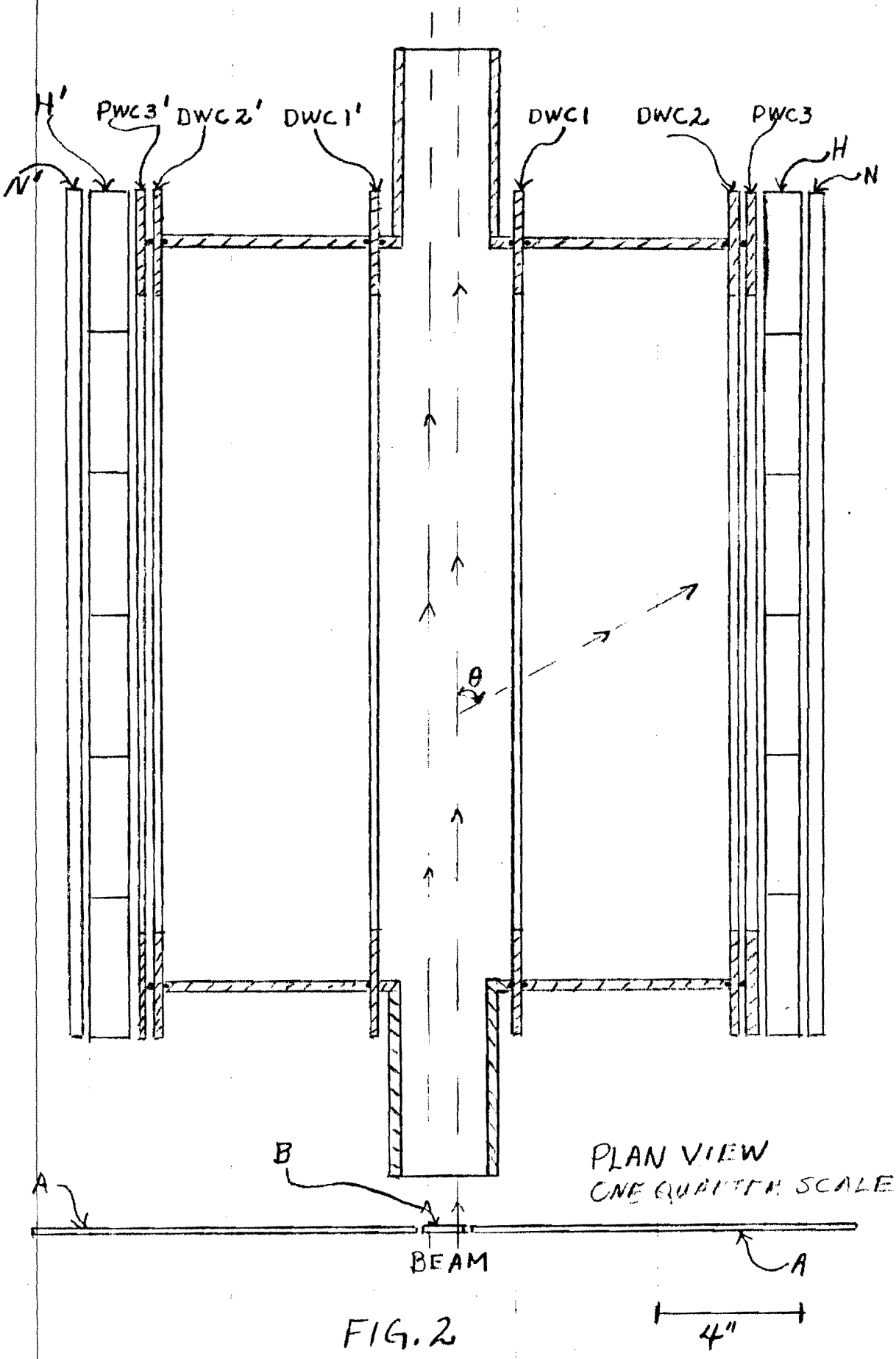
H'
PWC3'
DWC2'
DWC1'
DWC1
DWC2
PWC3
H
N
N'
θ
B
A
BEAM
A
PLAN VIEW
ONE QUARTER SCALE
4"

FIG. 2