681

Proposal to Measure Proton-Proton and Proton-Deuterium Elastic and Inelastic Cross Sections in the 0.4 TeV/c $\leq p_{inc} \leq$ 1 TeV/c Beam Momentum Range.

This proposal is

submitted by scientists at

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Abstract

We propose to study p-p and p-d elastic scattering in the Coulomb interference and intermediate momentum transfer regions; $0.001 \leq q^2 < 0.15$ $(GeV/c)^2$. The experiment will be performed at the Internal Target Laboratory. We will build a new gas jet target. Applying fast double differential pumping techniques, the new target system will have superior characteristics (speed, pressure differential, cleanliness) to any previous gas jet target. For intermediate momentum transfer polyethylene rotating targets will be used.

Novelties of the proposed experiment are:

(a) High data rate.

(b) Excellent energy resolution (40 KeV) in the Coulomb interference region.

(c) Excellent angular resolution (0.05 mrad).

(d) Using H_2-D_2 gas mixtures we will be able to cross normalize accurately the p-p and p-d elastic scattering for a wide range of incident beam momenta; $0.4 \leq p_{inc} < 1$ TeV/c.

(e) A new gas target, with an order of magnitude less time averaged pressure than the presently operating system, thus the experiment can be done in a parasitic mode.

From the data we will extract:

(a) The q^2 dependence of the logarithmic slope; $\frac{d}{dq^2}\left[\ln \frac{d\sigma}{dq^2}\right]$.

(b) The real part of p-p and p-d forward elastic scattering amplitude.

(c) Test the predictions of the additive quark model.

(d) Determine the dependence of the missing mass cross section on beam momentum, q^2, and the missing mass which recoils from the detected slow inelastic proton and deuteron.

The significance of the proposed experiment lies not only in the measurement of fundamental quantities but in the fact that the data will be measured in one experiment using the same geometrical setup over a wide range of beam momenta, momentum transfers, for isospin half and zero targets.

This experiment will be the first to demonstrate the feasibility of the gas jet internal targets in the energy doubler. Thus we wrote a modest proposal as far as the scope of this experiment (t-range, statistics, energies, targets, beam particles) is concerned. We could, for example, easily extend our t-range to $t = -0.5$ by adding scintillators behind our silicon detectors. In a later experiment we also hope to measure pHe, $\bar{p}$He, $\bar{p}p$ and $\bar{p}d$ elastic scattering and determine $\frac{d\sigma}{dt}(\bar{p}X) - \frac{d\sigma}{dt}(pX)$ where X denotes p, d and He.

The experimenters will provide the complete data acquisition system (Bison Box, PDP-11 computer, disc drives, tape drives), vacuum gauges (thermocouple, cold cathode gauges and controllers), detectors and some of the electronics. We request three months of setup, testing, and 950 hours of running time.

I. Introduction

Sophisticated and elaborate models[1-4] and high statistics experiments[5,6] have established particle exchange as the mechanism for resonance production. With the advent of the absorptive Regge models[7], particle exchange has been accepted as the valid description of reactions in which objects with non-vacuum quantum numbers were exchanged. Prior to the availability of high energy beams (p_{inc} > 30 GeV/c) it was primarily the π^+-p polarization experiments[8] that demanded the introduction of an imaginary amplitude without much momentum transfer ($t = -q^2$) or total energy ($\sqrt{S}$) dependence. Furthermore the approximate constancy[9] of $\frac{d\sigma}{dt}$(pp) at t = 0 also supported this point of view. There have been a series of theoretical papers attempting to treat this amplitude either as another Regge trajectory[10] (the Pomeron), or as a manifestation of multiple, constituent scattering of two identical composite objects[11]. The striking prediction of the latter model was the existence of diffraction zeroes in the elastic differential cross section. High energy experiments did verify the existence of sharp dips in proton-proton elastic scattering[12,13]. Recent successes of gauge theories[14] have given new impetus to describing high energy reactions in terms of quark-quark[15] scattering. Thus it is tempting to identify the proton constituents in the Chou-Yang model[11] with quarks[16]. The Fermilab-Yale collaboration[17] fitted their elastic events with the forms given in Reference 16 (the additive quark model) and obtained a good fit.

Another interesting concept, stimulated by the constituent picture, is geometrical scaling[22]. It relates those parameters which we will be able to measure; σ_{el}, σ_{total}, and elastic slopes.

We will test the predictions of the above constituent models in

a single experiment at four energies separated by about 150 GeV/c beam momentum intervals.

II. Physics Justification of the Proposed Experiment

As discussed in the introduction, the nature of elastic and diffractive inelastic scattering is still not understood. Since these two processes comprise a large fraction of the high energy total cross section, it is important to study experimentally the energy and momentum transfer dependence of these amplitudes. Experimental proof that high energy elastic scattering is a manifestation of coherent quark-quark scattering would have fundamental importance.

The nature of slope increase going from p-p to p-d elastic scattering as well as the effects of inelastic screening is not understood.

The real part of the forward p-p elastic scattering amplitude (ρ) is a basic quantity in any high energy collision because of unitarity.

In measuring elastic cross sections we will obtain the inelastic cross section concurrently with the elastic cross sections. The fall off of $\frac{d^2\sigma}{dM^2dt}$ with M^2 and t will be measured and compared with theoretical models.

The present status of the experimental determination of the above quantities is the following; the elastic slopes[18], (ρ) the real part of the forward scattering amplitudes[19], in p-p scattering and the diffractive inelastic excitations[20] in p-p and p-d interactions have been measured at FNAL Internal Target Laboratory up to 400 GeV/c.

At larger q^2 values, p-p elastic cross sections were measured at 50 and 175 GeV/c by Ayres, et al[21]. They tested the validity of geometrical scaling model[22], which is one of the goals of this experiment. Determination of ρ in the Coulomb interference region has been done by L. A. Fajardo et al.[23] at 200 GeV/c. The data was analyzed in terms of q-q scattering amplitude.

At ISR the real part, ρ, has been measured by Amaldi et al[24]. They

chose their energies in 500 GeV/c steps. Thus we selected our energies such a way that at 400 GeV/c our data will overlap with earlier Internal Target measurements, two points will be in a hitherto unexplored regime (600 and 800 GeV/c) and the 1000 GeV/c point will overlap with that of Ref. 24.

The familiarity of the authors with the operation of the accelerator, the main ring vacuum system, cryogenics, as well as the participation in earlier internal target experiments, will be important assets in working in the more demanding environment of the Tevatron. In addition to the rewards of measuring some fundamental quantities in a new energy range, this experiment will evaluate the feasibility of operating an internal target in the Tevatron.

III. Experimental Details

A. Vacuum System

The experimental apparatus will be located at the Internal Target Laboratory in the high momentum transfer, elastic scattering spectrometer room. The schematic drawing of the setup is shown in Fig. 1. Since the time average pressure at the entrance to the Lambertson magnets must be of the order of 10^{-6} Torr and oil free, we designed an elaborate differential pumping scheme, shown in Fig. 2. The tests are underway with an existing model of Lambertson magnet to see how rapidly the Lambertson magnets can recover to 10^{-8} Torr after a long exposure to H_2 at 10^{-6} Torr pressure.

The box which housed the De Laval nozzle is called the target box (TB). The TB will form a part of the doubler vacuum pipe and will be located in the opening between the spectrometer room and the main ring tunnel as in Fig. 2. The TB is separated into two compartments, connected by a conical hole. The proton beam passes through the upper chamber referred to as chamber "A". The lower chamber (chamber "B") is connected to a 1000 liter buffer volume, which is pumped by four 4000 liter/sec diffusion pumps (see Fig. 3). About 80% of the injected target gas (~ 2 Torr-ℓ in 1 sec) passes through the conical hole into chamber B and thus into the buffer volume. The large pumping speed brings the pressure in the buffer volume to 10^{-6} Torr within 2 seconds. The remaining portion (~ 0.4 Torr-ℓ) of gas remains in the target box "A" and is pumped by two 2000 ℓ/s horizontal turbo molecular pumps. The conical hole between boxes A and B is closed when the jet is not pulsing to inhibit molecular flow. The buffer volume will contain a liquid nitrogen cooled baffle to prevent the oil from the diffusion pumps entering chamber A. According to our design, the maximum pressure in the target box at any time will be of the order of 1×10^{-4} Torr.

This pressure surge in the target box will be brought down to 10^{-6} Torr within 200 ms after the pulse ends. To arrest the propagation of the pressure wave, upstream and downstream from the TB in the main ring vacuum pipe, two differential pumping systems will be placed symmetrically around the TB as shown in Fig. 2. Each one is constructed from a vacuum box of 150 ℓ, which substitutes for regular vacuum pipe, to which a 2000 liter/sec turbo molecular pump is attached.

Due to the large pumping speed and the small diameter (2.5") of the beam pipes that connects the TB to the pumping boxes, the time average pressure at the Lambertson magnets will be kept at the level of 10^{-6} Torr. This means that the pressure in the target box, averaged over an accelerator cycle, will be an order of magnitude lower than in the system presently in operation.

The jet nozzle will be electrically insulated and we will have the option of applying variable positive voltage on it to minimize electron production by gas discharge. To remove the electron gas we will install a 1 KeV split cathode clearing electrode. The nozzle diameter will be decreased to 1 mill and the input pressure will be about 100 PSIA, to ensure better collimated jet. With the above innovations we will alleviate the increase of beam instability caused by electron oscillations.

B. Detector System

We will construct a matrix of apertured detector holders of 35 elements. Twenty-five silicon detectors will be placed in these holders in several configurations, depending on the momentum transfer region under study. A possible configuration is shown in Fig. 4. Since there is no charged nucleon background when hydrogen gas target is used, a single detector is used in each location. All detectors will have the same 20 x 5 mm^2

apertures but will have various thickness from 5 μm to several thousand μm. They will be used either as a ΔE or as an E detector. The array will be able to sweep out the $88° < \theta < 90°$ angular interval, where θ is measured from the beam direction. The detector holder matrix will be located 7 meters from the jet.

C. Jet Structure

During the 30 sec ramp we will pulse the jet at 4 energies for 1 sec. Thus we plan to collect data at 400, 600, 800, and 1000 GeV/c.

D. Data Rate and Time Request

Using $d\sigma/d\Omega_{lab} = 3.6$ mb/ster we predict 1.8 recoils/sec/detector. We plan to have a $\sqrt{N}/N = 1\%$ statistical accuracy, i.e. 10000 elastic recoil at a given energy. We intend to run at 5 different angle settings. Thus the required time is 27770 sec. Using a 1 minute repetition rate we need 27770 sec equivalent to 500 hours. Thus we request 550 hours of running time with a pure hydrogen jet. Since the cross section for proton deuterium scattering is about a factor of four times larger we request 200 hours of running time to study p-d collisions. To cross normalize the proton and deuterium results we will run a H_2(50%) - D_2(50%) mixture for 200 hours. Thus we request a total of 950 hours of running time.

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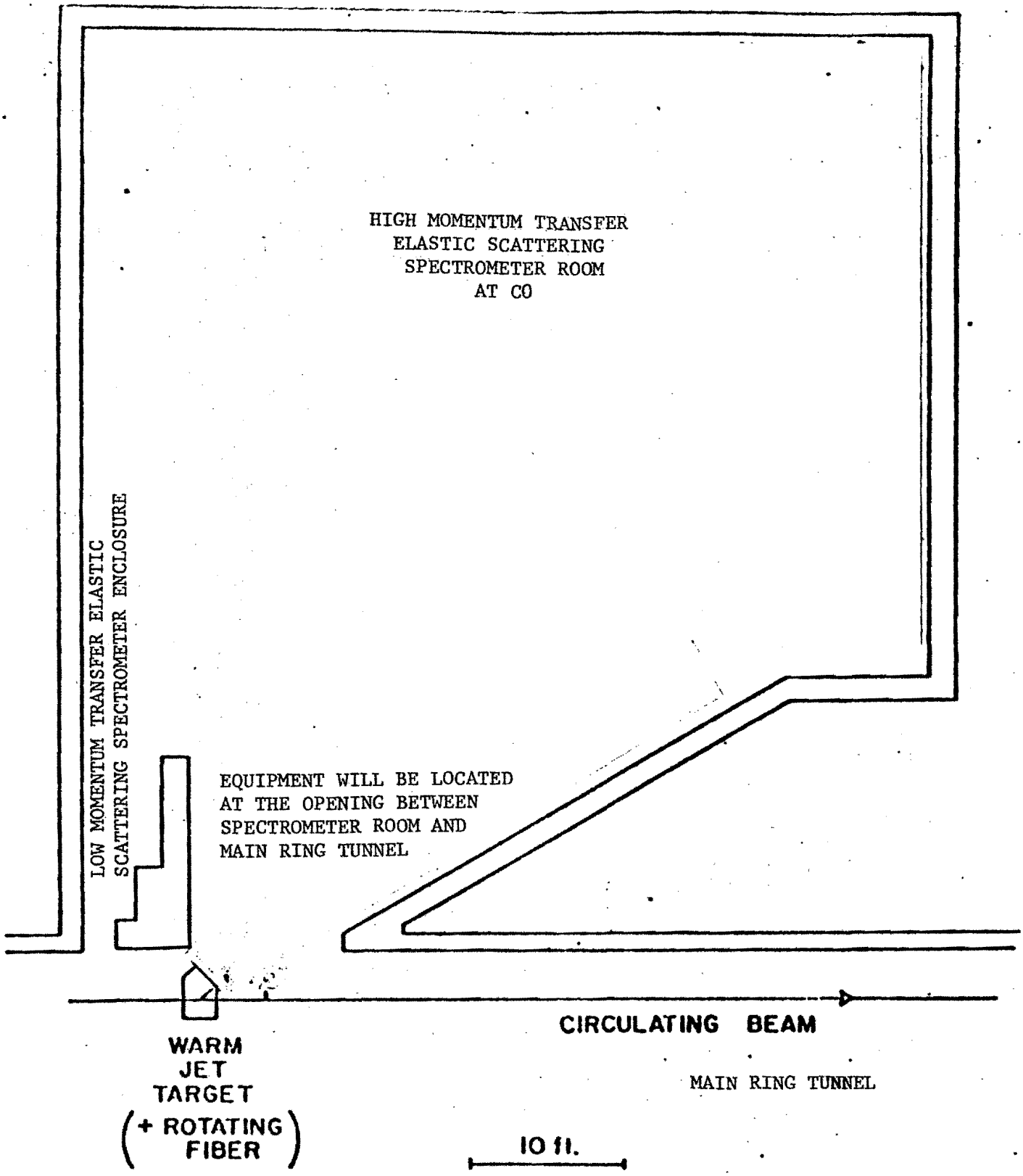
HIGH MOMENTUM TRANSFER
ELASTIC SCATTERING
SPECTROMETER ROOM
AT CO
LOW MOMENTUM TRANSFER ELASTIC
SCATTERING SPECTROMETER ENCLOSURE
EQUIPMENT WILL BE LOCATED
AT THE OPENING BETWEEN
SPECTROMETER ROOM AND
MAIN RING TUNNEL
CIRCULATING BEAM
WARM
JET
TARGET
(+ ROTATING
FIBER)
MAIN RING TUNNEL
10 ft.

Figure 1

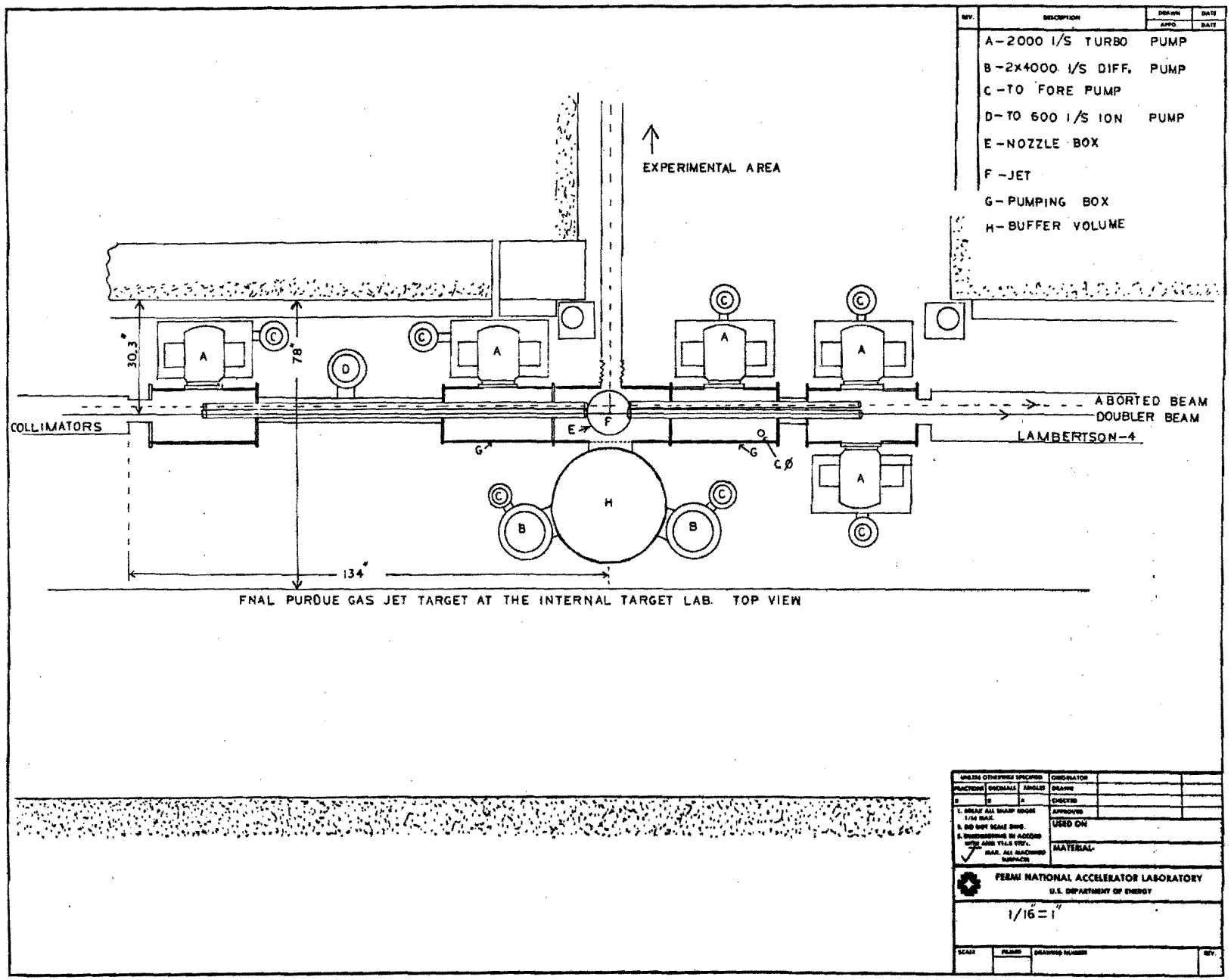
A-2000 I/S TURBO PUMP
B-2x4000 I/S DIFF. PUMP
C-TO FORE PUMP
D-TO 600 I/S ION PUMP
E-NOZZLE BOX
F-JET
G-PUMPING BOX
H-BUFFER VOLUME
EXPERIMENTAL AREA
ABORTED BEAM
DOUBLER BEAM
LAMBERTSON-4
COLLIMATORS
30.3"
78"
134"
FNAL PURDUE GAS JET TARGET AT THE INTERNAL TARGET LAB. TOP VIEW
FERMI NATIONAL ACCELERATOR LABORATORY
U.S. DEPARTMENT OF ENERGY
1/16" = 1"

Figure 2

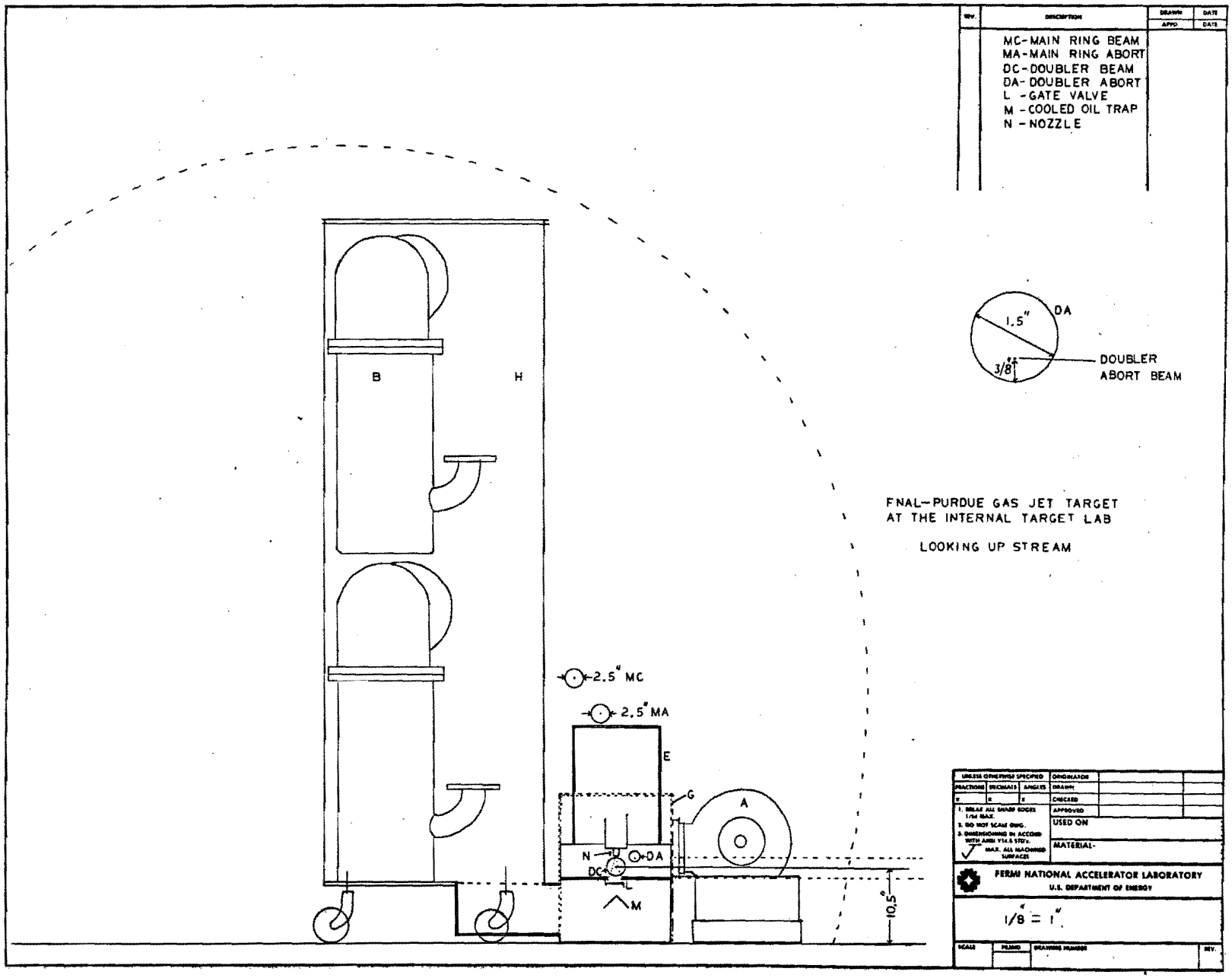
MC-MAIN RING BEAM
MA-MAIN RING ABORT
DC-DOUBLER BEAM
DA-DOUBLER ABORT
L -GATE VALVE
M -COOLED OIL TRAP
N -NOZZLE
B
H
E
G
A
N
DA
DC
L
M
2.5" MC
2.5" MA
10.5"
1.5"
DA
3/8"
DOUBLER
ABORT BEAM
FNAL-PURDUE GAS JET TARGET
AT THE INTERNAL TARGET LAB
LOOKING UP STREAM
FERMI NATIONAL ACCELERATOR LABORATORY
U.S. DEPARTMENT OF ENERGY
1/8" = 1"

Figure 3

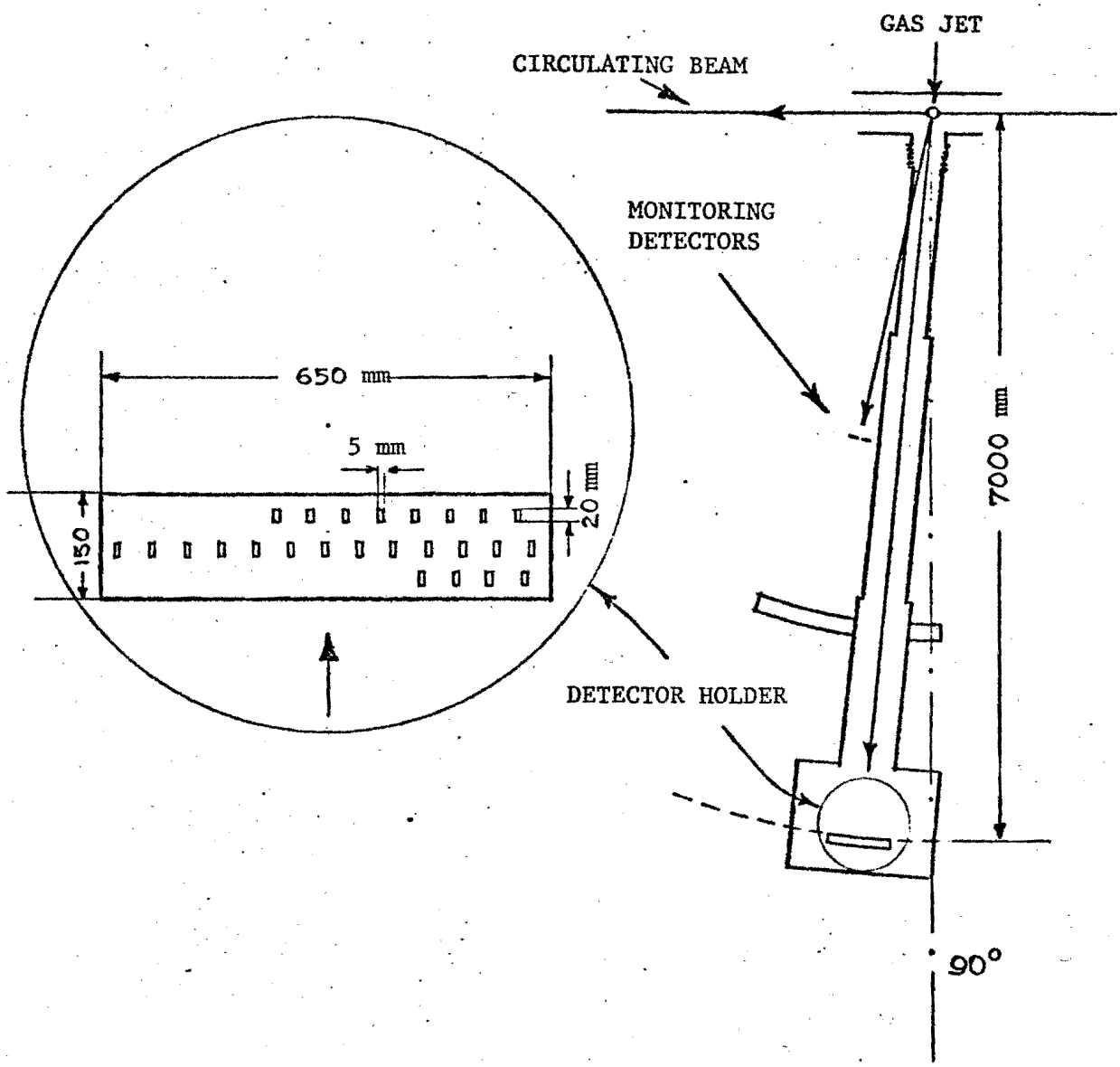

Fig.4 A sketch of the detector carrige and the detector holder. Distances are given in millimeters.