NAL PROPOSAL No. 186

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A PROPOSAL TO STUDY SMALL ANGLE PROTON-DEUTERON SCATTERING

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ABSTRACT

We propose an extension of the present p-p small angle scattering experiment to a measurement of p-d scattering using a deuterium gas jet. In 400 hours of beam time we will measure as a function of energy

(a) the slope of the small angle p-d scattering

(b) the real part of the forward p-d scattering

(c) the total p-d cross section

(d) the coherent diffraction dissociation of protons on deuterons.

No new apparatus is required or need be installed for the performance of this experiment.

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STUDY OF SMALL ANGLE PROTON-DEUTERON SCATTERING

The USA-USSR collaboration is presently measuring the small angle elastic p-p scattering using a hydrogen gas jet. In an early phase of this experiment the scattering has been measured using a polyethylene foil. From the data it was possible to obtain the energy dependence of the p-p total cross section (Fig. 1) and the slope parameter for the elastic diffraction peak (Fig. 2). It is expected that the gas jet measurements will significantly improve the errors on these data points; in addition the real part of the forward scattering will be extracted.

We wish to propose an extension of this work to a deuterium target, in order to investigate the following phenomena:

(a) the slope of the small angle p-d nucleon scattering

(b) the real part of forward p-d scattering

(c) the total cross section for p-d scattering

(d) the coherent diffraction of protons from deuterons.

From measurements (a), (b) and (c) one obtains information on the corresponding process for proton-neutron interactions by using appropriate theoretical models (Glauber theory). For process (d) the main interest lies in examining the mass spectrum (continuous and discrete) into which a proton can dissociate. The use of a deuterium target, and the detection of the recoil deuteron are ideally suited for such investigations. This is because by detecting the recoil (1) Very low transverse momenta can be measured with good t-resolution. (2) Detection of the deuteron automatically guarantees the coherence of the interaction. (3) Coherence restricts the quantum numbers exchanged. Most importantly however, when exploring the diffractive cross section in the continuum the detection of the deuteron permits the separation of signal from non-diffractive background.

Next we wish to emphasize that the value of these measurements is greatly enhanced by the availability of variable incident energy. Indeed, the energy dependence of the cross sections for the processes (a) through (d) measured in a single experiment and with the same apparatus is perhaps of more importance than the absolute value itself. This is clearly evidenced by our data on the p-p diffraction slope where it is our belief that the ultimate distinction between continuing shrinkage or saturation of the process will be obtained by the forthcoming NAL data, in spite of the existence of data points from the ISR. We recall that at NAL we can cover the energy range from 10 to 400 GeV which corresponds to a change in s by a factor of 40.

The experimental apparatus to be used will be identical to the present apparatus except for a modification of the existing ion guide so as to reach to 45° angles. This modification does not affect in any way the space available at the C-zero section. Positive identification of the deuterons will be achieved through the use of thin dE/dx detectors in combination with a thicker, E detector. The formation and trapping of the deuterium jet has already been accomplished. Furthermore the operation of the jet does not affect the operation of the accelerator. The electronic equipment and PDP-11 computer used in the present setup are equally adequate for the proposed measurements. To sum up: No new equipment is required and the measurements could, in principle, start immediately. Furthermore all the programming and experience of the group in recoil detection can be transferred to the new measurements.

The counting rates for the elastic scattering processes are adequate at a circulating beam intensity of 10^{10} protons/pulse. For the inelastic processes the diffractive cross section is constant with energy so that we assume

$$\frac{d\sigma}{dt\,dM} = [10 \text{ mb}/(\text{GeV}/c)^2 - \text{GeV}] \times A^2$$

Using

$$\Delta t = 10^{-4} \, (\text{GeV}/c)^2$$

$$\Delta M = 4 \quad \text{GeV}$$

$$\Delta\phi/2\pi = 4 \times 10^{-4} \quad (1 \text{ cm}^2 \text{ detector at 2m at } 45°)$$

one obtains

$$\Delta\sigma = 10^{-32} \text{ cm}^2$$

Finally a circulating beam of 10^{11} and a 200 m sec jet pulse (3×10^{17} atoms/cm^3) yields 3 events/pulse - detector

Some kinematic parameters for a detector placed at $\varphi = 45^{o}$ are shown in Table I. Since we will use an array of 12 detectors we can expect 10^{6} diffractive events in 100 hours of running.

Concerning the total cross section measurements, these depend critically on adequate monitoring of the beam-jet overlap (interaction) rate. With the foil target the beam intensity was monitored by an induction torroid, since the foil density was known. For the gas jet we are presently planning to measure the proton-electron scattering at 45^{o} which yields ~ 1 MeV electrons. Conventional monitoring techniques (i.e. scintillator and Cerenkov telescopes) are also being used.

We request a total of 400 hours of beam time in order to run with a deuterium jet. This should provide accurate data for the sets of measurements (a) through (d) at approximately eight energies between 20 and 200 GeV. When the accelerator operates at higher energies data will be preferably taken above 200 GeV.

The attached figures 1-4 show the data that have been obtained in the present experiment using a thin polyethylene foil.

TABLE I

Example of Kinematic Parameters for Diffractive Scattering of Protons on Deuterons

Incident energy:	200 GeV
Deuteron recoil angle:	$\varphi = 45^{\circ}$
Detector area:	$1 cm^2$ at 2m

	M_x (GeV)	$\cos\varphi_{min}$ (1)	t (2) $(GeV/c)^2$	T_d (3) (MeV)	Δt $(GeV/c)^2$	dm_x (4) (GeV)	$(q^2R^2/3)$ (5)
detector placed closer to 90°	1	0.02	0.2×10^{-6}	0.05×10^{-3}	-	2.5	-
	2	0.09	0.1×10^{-3}	0.025	10^{-6}	0.3	0.004
	3	0.14	0.8×10^{-3}	0.2	10^{-5}	0.09	0.03
	4	0.19	2.8×10^{-3}	0.7	0.3×10^{-4}	0.04	0.10
accessible	5	0.25	7.2×10^{-3}	1.8	0.7×10^{-4}	0.02	0.27
	6	0.30	15.0×10^{-3}	3.7	1.5×10^{-4}	0.011	0.6
	7	0.35	0.03	7.5	3.0×10^{-4}	0.007	1.1
	8	0.40	0.05	12.5	5.0×10^{-4}	0.005	1.8
	9	0.45	0.08	20.0	8.0×10^{-4}	0.003	3.0
	10	0.50	0.120	30.0	12.0×10^{-4}	0.002	4.6

(1) The angle φ is measured from 90°. φ_{min} is the angle where the Jacobian peak appears.

(2) Momentum transfer for 45° recoil. The low-t branch is shown.

(3) We consider 1 MeV as the limit of our measurable energy; therefore at 45° and 200 GeV energy the higher mass range $5 < m_x < 10$ GeV is explored. The lower masses are measured at 45° with lower incident energy as well as by the detectors located closer to 90°.

(4) The mass resolution is calculated on the basis of a 50 keV energy resolution in the detectors.

(5) The form-factor squared for deuteron break up is exp $(q^2R^2/3)$. Note that significant damping of the cross section does not appear until $m_x \sim 8$ GeV.

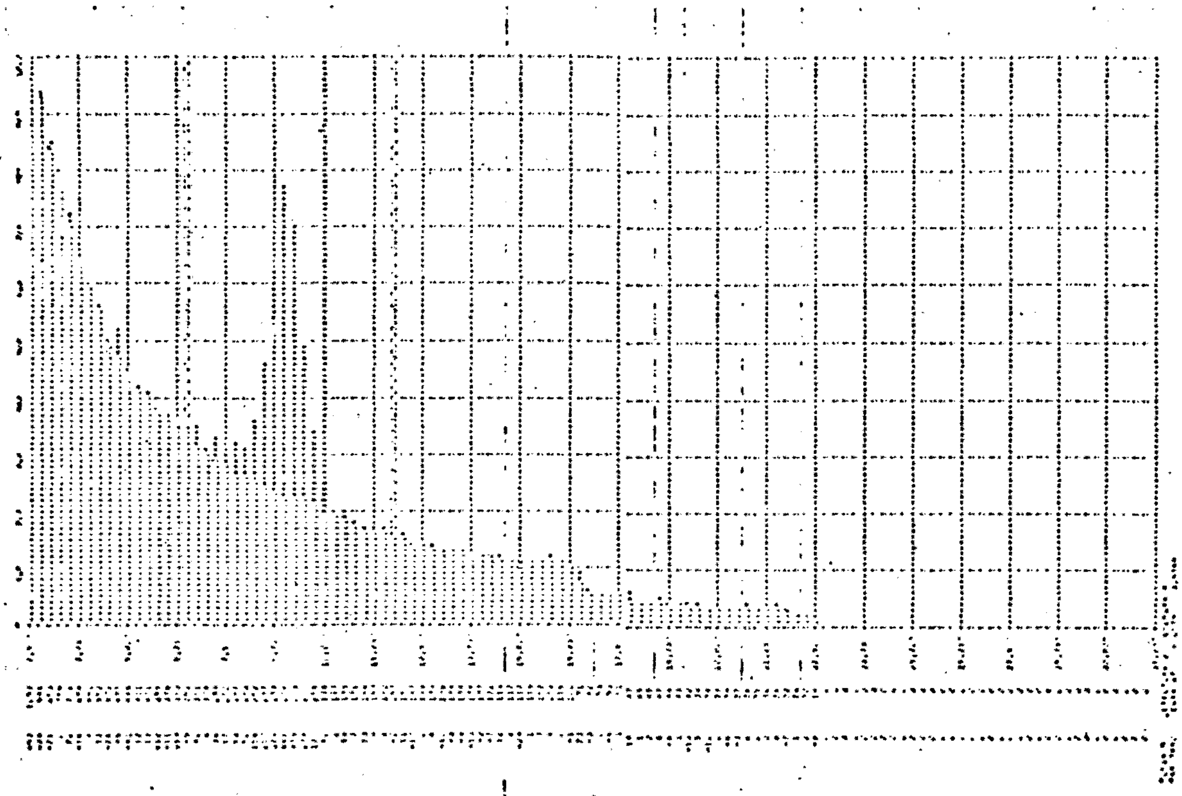
Figure Captions

Fig. 1 Typical elastic peaks from p-p scattering.

Fig. 2 The differential cross section $d\sigma/dt$ elastic p-p scattering at eight incident energies.

Fig. 3 The energy dependence of the slope parameter b(5).

Fig. 4 The total cross section for p-p elastic scattering.


(a)

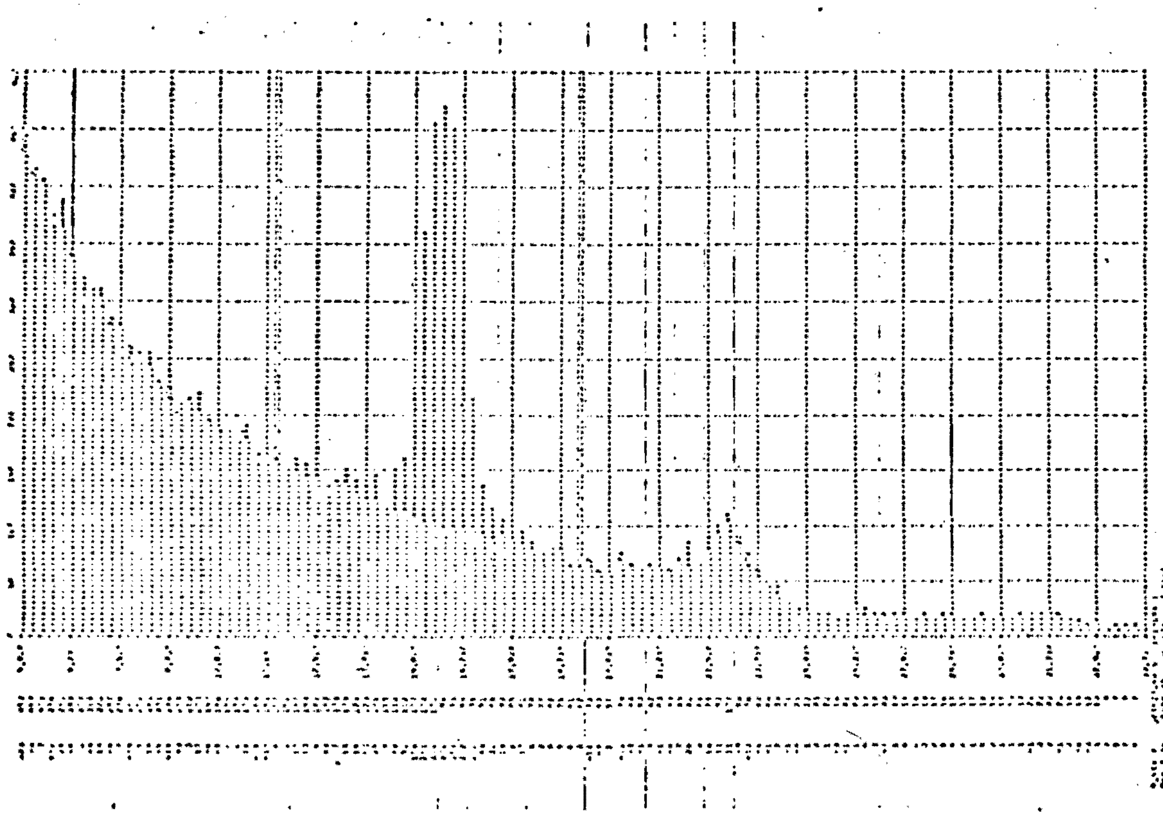
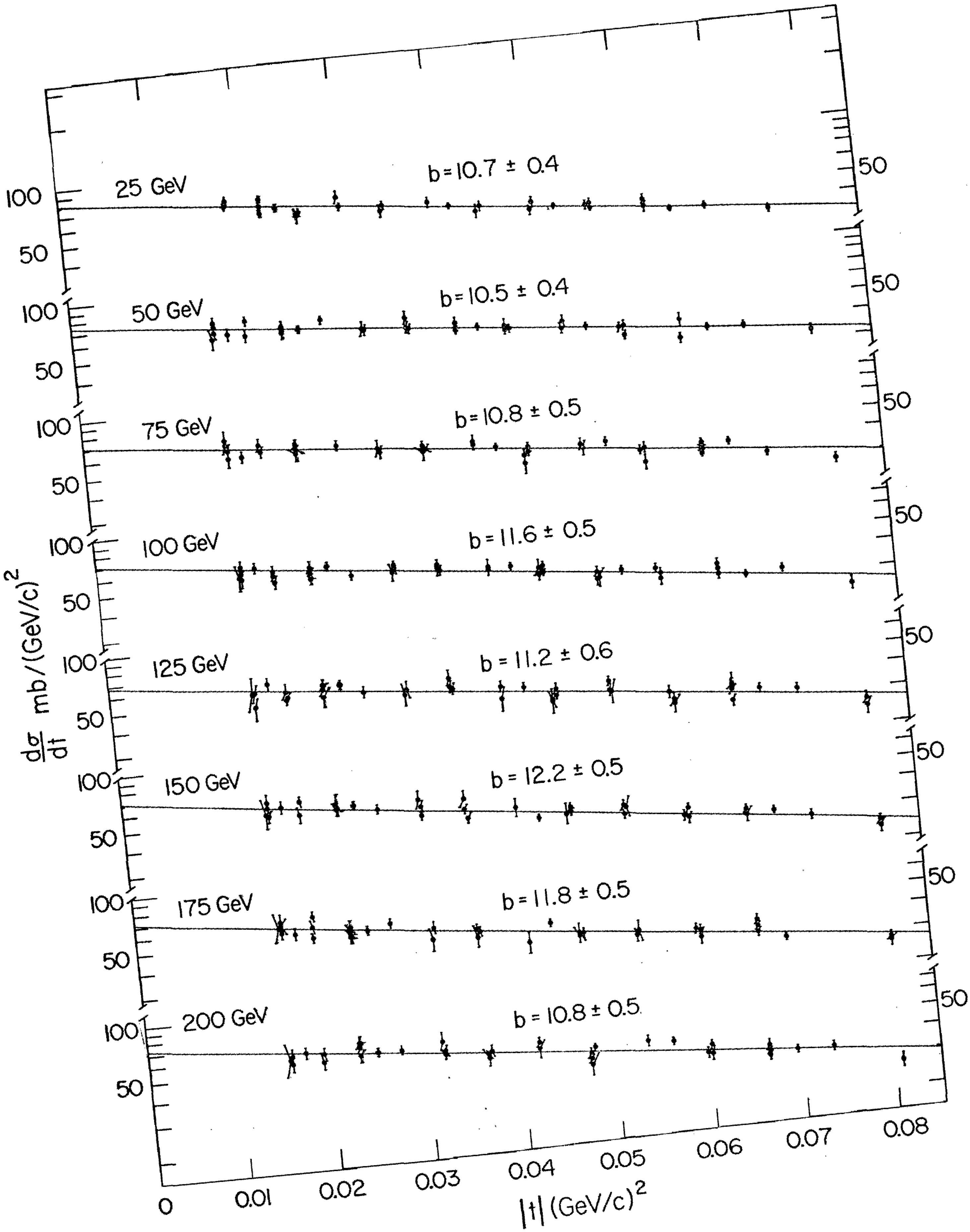

(b)

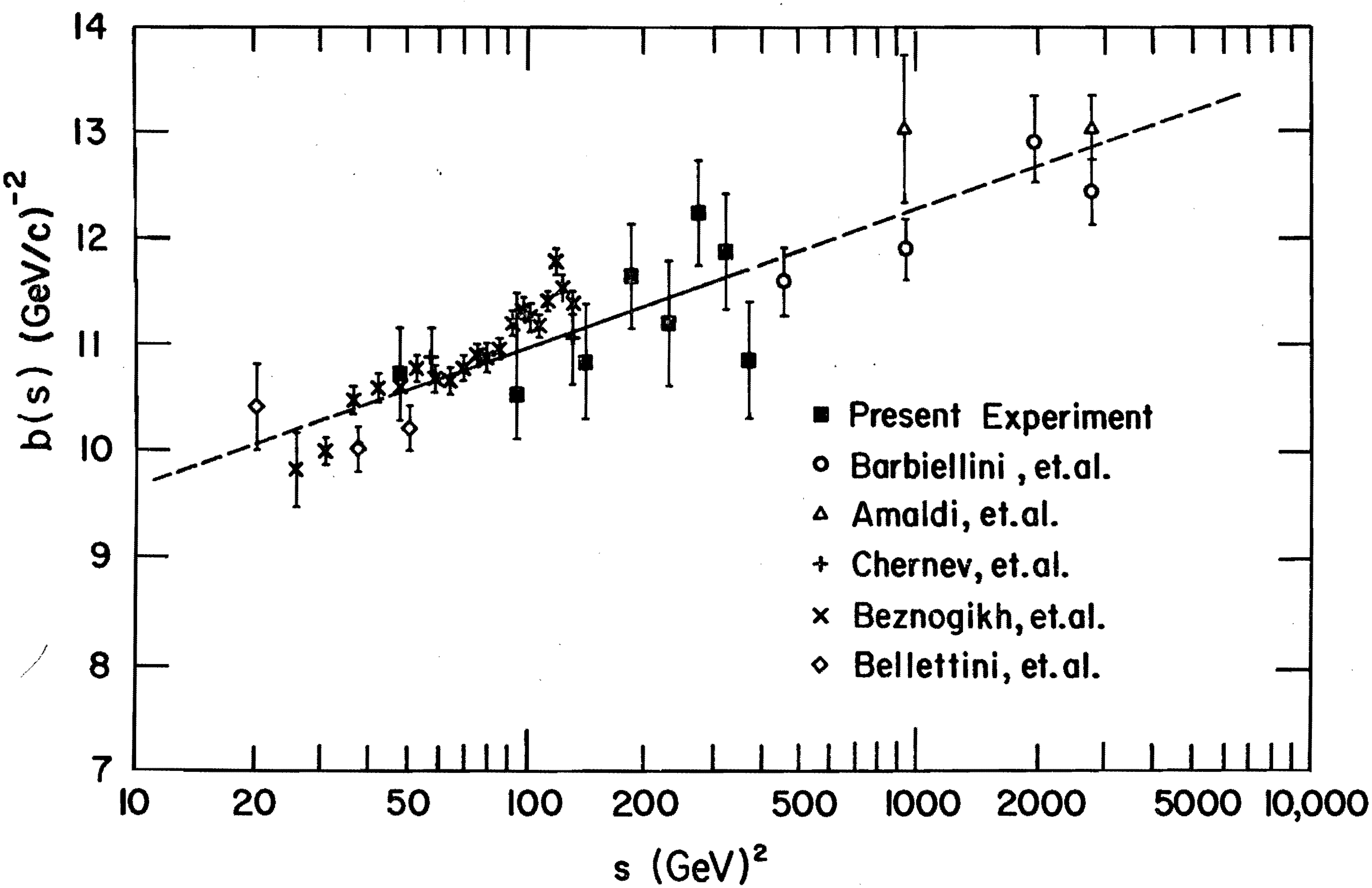
Fig. 1

Figure 2



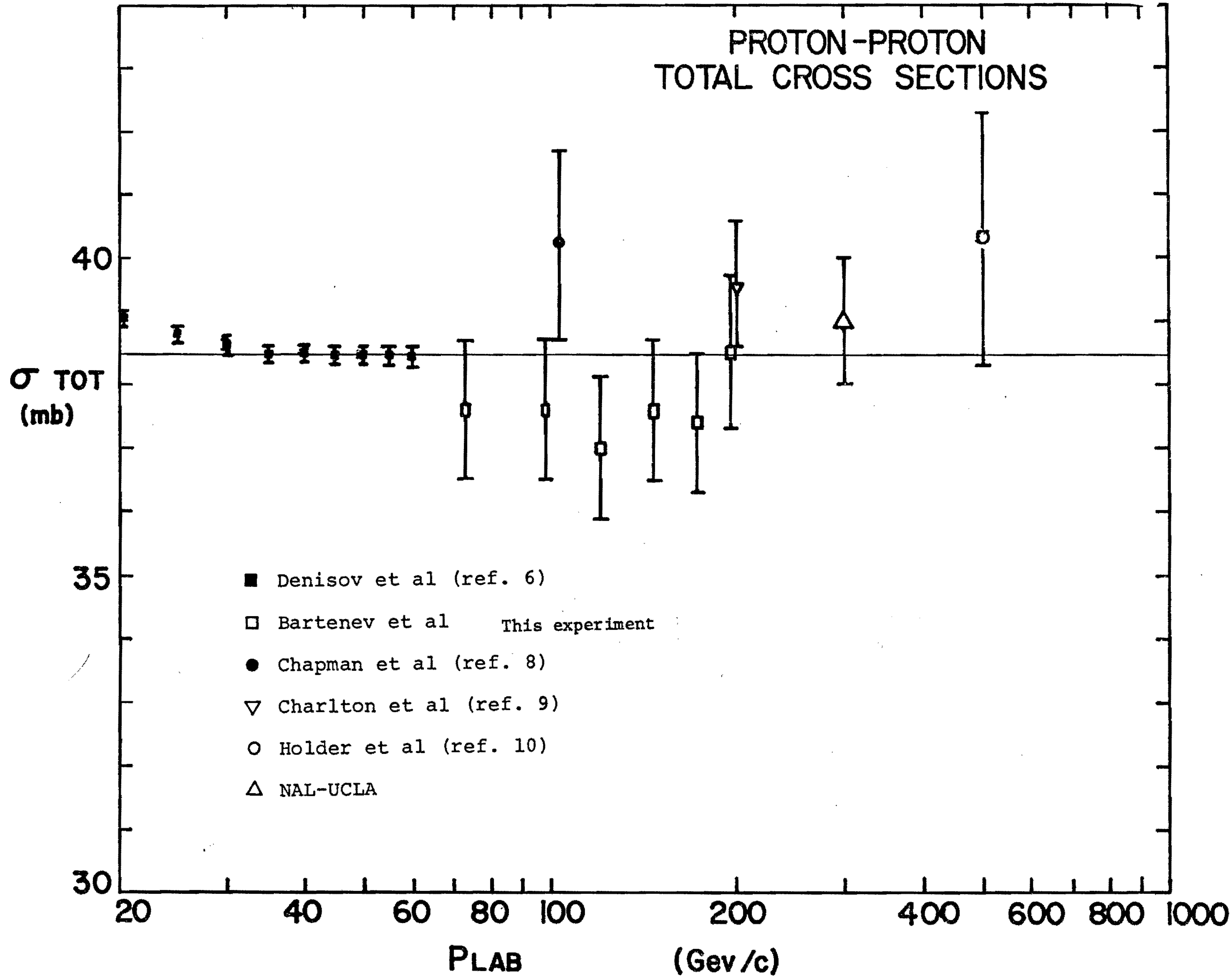
25 GeV
b = 10.7 ± 0.4
50 GeV
b = 10.5 ± 0.4
75 GeV
b = 10.8 ± 0.5
100 GeV
b = 11.6 ± 0.5
125 GeV
b = 11.2 ± 0.6
150 GeV
b = 12.2 ± 0.5
175 GeV
b = 11.8 ± 0.5
200 GeV
b = 10.8 ± 0.5
100
50
dσ/dt mb/(GeV/c)^2
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
|t| (GeV/c)^2

Figure 3



14
13
12
11
10
9
8
7
b(s) (GeV/c)^-2
10
20
50
100
200
500
1000
2000
5000
10,000
s (GeV)^2
Present Experiment
Barbiellini , et.al.
Amaldi, et.al.
Chernev, et.al.
Beznogikh, et.al.
Bellettini, et.al.

Figure 4


PROTON-PROTON
TOTAL CROSS SECTIONS
σ TOT
(mb)
40
35
30
Denisov et al (ref. 6)
Bartenev et al
This experiment
Chapman et al (ref. 8)
Charlton et al (ref. 9)
Holder et al (ref. 10)
NAL-UCLA
20
40
60
80
100
200
400
600
800
1000
PLAB
(Gev/c)