A Proposal to Study pp Elastic and pd Coherent Scattering

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ABSTRACT

Using the E198 spectrometer and warm jet target at the Internal Target Area we propose to measure the differential cross sections for 1) pp elastic scattering for $2 < -t < 5$ GeV^2, 2) pd elastic scattering for $0.7 < -t < 3$ GeV^2 and 3) pd → Xd coherent inelastic scattering for $0.7 < -t < 3$ GeV^2 and $M_X{}^2/s < 0.2$. These cross sections would be measured at incident proton energies from 30 to 300 GeV.

Glauber-Gribov analyses of pd → pd data in the double scattering region would provide a check on existing calculations of absorptive corrections to pp → pp cross sections. Analyses of pd → Xd data with pp → pX data could provide much better estimates of the triple-Pomeron coupling than those obtained from pp → pX data alone. The reaction pd → N*d can be used to study N*-nucleon scattering.

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I. INTRODUCTION

Since the current proposal is to a large degree an extension of E198, it is appropriate to say briefly what we have accomplished in that experiment.

The prime objective of E198 was to study in detail how the dip in $d\sigma/dt$ for pp elastic scattering develops with increasing energy. We have taken data up to $-t = 2$ GeV^2 and $E = 280$ GeV (the lowest ISR energy at which pp elastic data were taken[1]). Our cross sections at three representative energies are shown in Fig. 1(a). The lowest data point at $-t \simeq 1.5$ GeV^2 and $E = 200$ GeV with an error of ±50% came from 15 events. We have 5 times more data in this region which is being analyzed so that the error on this point will probably shrink by a factor of ∿4. We have data, not yet fully analyzed, with comparable statistics at incident energies from 30 to 280 GeV at 20 GeV intervals.

For purposes of comparison, we show in Fig. 1(b) the data of E7 (Akerlof et al.[2]) at 100 and 200 GeV and of Allaby et al.[3] at 24 GeV. The improvement in the accuracy of the high energy E198 cross sections as compared to earlier measurements is evident and will become more so when the unanalyzed data are added.

The acceptance of our spectrometer was such that during our elastic runs we also collected inelastic events with $x = 1 - M_X^2/s > 0.95$, i.e., we have missing mass spectrum for $pp \to pX$ from $M_X^2 \simeq 2.5$ GeV^2 at 30 GeV to $M_X^2 \simeq 25$ GeV^2 at 280 GeV incident energy. These spectra include obvious N*'s (see Fig. 2) for which we plan to obtain $d\sigma/dt$'s.

We also ran a few days with a deuterium target to study pd coherent scattering in the double scattering region (see Fig. 3). Very preliminary analyses indicate that the elastic pd cross section at fixed t drops approximately with increasing energy as does the square of the pp elastic cross section at $t_{pp} = t_{pd}/4$. This result needs to be confirmed by further measurements.

Although the study of pd coherent scattering was part of our original E198 proposal, we made only exploratory measurements in order not to compromise our pp elastic measurements given limited running time. We feel we now have definitive pp elastic cross sections in the region of the dip and would now like to extend these to higher $|t|$ as well as start a systematic study of pd coherent scattering.

II. PHYSICS JUSTIFICATION

1. Elastic pp Scattering

The differential cross section at $-t = 2\ GeV^2$ as measured by E198 drops by a factor of $\sim$10 between E = 30 and 100 GeV and by a factor of $\sim$3 between E = 100 and 200 GeV.

The ISR cross section[1] on the other hand rises by a factor of $\sim$1.5 between E_{lab} = 280 and 2050 GeV (see Fig. 4). This rise however is apparently related to the shift of the dip to lower $|t|$ with increasing energy. For $|t| > 2.5\ GeV^2$ there is no energy dependence in the ISR cross sections. At Fermilab preliminary analysis of E177 data[4] indicates a factor of $\sim$2 drop in $d\sigma/dt$

between E = 200 and 400 GeV at all t in the region $5 < -t < 10$ GeV^2.

For these data to be consistent, the drop measured by E177 must occur between E = 200 and ∿300 GeV or there is some new mechanism setting in at $|t| > 5$ GeV^2 or both.

Clearly, measurements of $d\sigma/dt$ in the region $2 < -t < 5$ GeV^2 and $30 < E < 300$ GeV, as we propose, with an emphasis on the s-dependence, would go a long way in tying together existing data and, hopefully, in understanding the nucleon-nucleon interaction.

2. Coherent pd Scattering

Simple Glauber theory, in which the proton rescatters elastically (Fig. 5c), predicts an s-dependence for pd elastic scattering in the double scattering region which goes like the square of pp elastic scattering at $t_{pp} = t_{pd}/4$, i.e., pd shrinkage would go like pp shrinkage squared. As s increases, inelastic rescattering channels (Fig. 5d) would begin to contribute and increase or decrease the shrinkage, depending on their phase. Hence measurements of pd elastic scattering at $|t| > 0.5$ GeV^2 and large s would be a check on the relative phases of elastic and inelastic amplitudes. Moreover, the calculation of pd elastic scattering cross sections at $|t| > 0.5$ GeV^2 (Figs. 5c or e) using the Glauber-Gribov technique, and comparison with measured data, would test theories of Regge cuts based on Reggeon calculus.[5] This is due to the similarity between the absorptive correction for pp → pp scattering (Fig. 5b) and the leading term (Fig. 5c) for pd → pd scattering.

In the reaction pd → N*d (Fig. 5g), where the N* in the final state is inferred by plotting the missing-mass recoiling off the deuteron, one could, using Glauber theory, make fairly precise measurements of N*-nucleon elastic scattering[8] and determine the N*-Pomeron coupling and N* total cross section.

The cross section for the reaction pd → Xd in the triple-Regge region can be represented by the diagrams shown in Figs. 5j and k. In the coherent double scattering region, $|t| > 0.5\ GeV^2$, the second term (Fig. 5k) becomes the dominant term since the first (Fig. 5j) leads to break-up of the deuteron. This term (Fig. 5k) is of the type that form the absorptive corrections, e.g. Fig. 5i, in the pp → pX cross section. In triple-Regge analyses of pp → pX data, the absorptive corrections, which are now thought to be large[6], have usually been neglected, resulting in an underestimate of the triple-Regge coupling strengths. Measuring pd → Xd inclusive cross sections would therefore be a logical second step in attempting to determine triple-Regge couplings.[7] The pd → Xd cross sections can be viewed as the "corrections" that are needed to extract triple-Regge couplings from pp → pX data.

Summarizing, Glauber-Gribov analyses of pd → pd data would provide a check on existing calculations of absorptive corrections to pp → pp cross sections and analyses of pp → pX <u>and</u> pd → Xd data could provide much better estimates for triple-Regge coupling strengths than those obtained from pp → pX data alone. In Gribov's Reggeon field theory the triple-Pomeron coupling plays a central role much like that of the electric charge in quantum electrodynamics, thus the importance of determining the triple-Pomeron coupling need not be stressed.

III. EXPERIMENTAL EQUIPMENT AND METHOD

1. Apparatus

The equipment needed to make the proposed measurements is the same as that used in E198 which is shown in Fig. 6. For E198 we had originally intended to use two bending magnets to improve the mass resolution by a factor of two but this was never realized. Instead, to measure elastic pp cross sections at energies above 150 GeV, we detected the second proton in a 60-element scintillator hodoscope which was next to the beam pipe and 76 feet downstream of the target. In the region of the dip, where the elastic signal was small compared to inelastic events, we made a mass cut around the proton in the missing mass spectrum, assumed the event was elastic, predicted the location of the second proton in the downstream hodoscope and looked for it in that element. Several correlated distributions in both "arms" are shown in Figs. 7b and c. We propose to use the same technique to measure both pp elastic scattering at high $|t|$ and pd elastic scattering. After the dip at $-t \simeq 1.5$ GeV^2 there appear to be no problems in distinguishing pp elastic events from background (see Fig. 7). There also appear to be no problems in identifying pd elastic events (see Fig. 3).

2. Technical Requirements

The pd data will be taken with the same dipole bend angle (25°) as in E198. A cable tray (non-accelerator) will have to be re-routed to allow the main spectrometer to reach higher lab angles (lower $|t|$).

The pp runs will require the dipole bend angle to be halved (to $12\frac{1}{2}^{\circ}$). The maximum $|t|$ transmitted through the magnet at the present angle of 25^{o} is ~ 2.2 GeV^2. Provisions for changing the bend angle have been built into the spectrometer.

The MWPC's and associated readout logic (provided by University of Rochester) and PDP 11/45 (provided by Rutgers University) used for E198 would remain at Fermilab to do this proposed experiment. If approved, the major requirement of Fermilab would be to provide ~ 40 ℓ/hr of liquid helium for the superconducting magnets.

3. Data Rates

Typical luminosities and spectrometer acceptances can easily be determined empirically using E198 data rates and known cross sections. After the second maximum in pp elastic scattering, $d\sigma/dt$ goes like e^{bt} where $b \simeq 2$. Keeping in mind that halving the dipole bend angle approximately doubles $\Delta\theta$ and that Δt increases with $|t|$ for fixed $\Delta\theta$, we estimate that it would require 20 hrs. to collect 100 elastic events at $-t = 4$ GeV^2 and $E = 200$ GeV ($d\sigma/dt \simeq 0.5$ nanobarns/GeV^2).

The s and t dependence of pd elastic scattering at high energies is less well known. Using low energy data and our preliminary measurements we estimate, conservatively, that to collect 100 elastic pd events at $-t = 2$ GeV^2 and $E = 100$ GeV would require ~ 5 hrs.

The number of data points at high $|t|$ will necessarily be less dense than those at low $|t|$. To make reasonable measurements over the proposed kinematic regions we feel would require 900 hours of running time.

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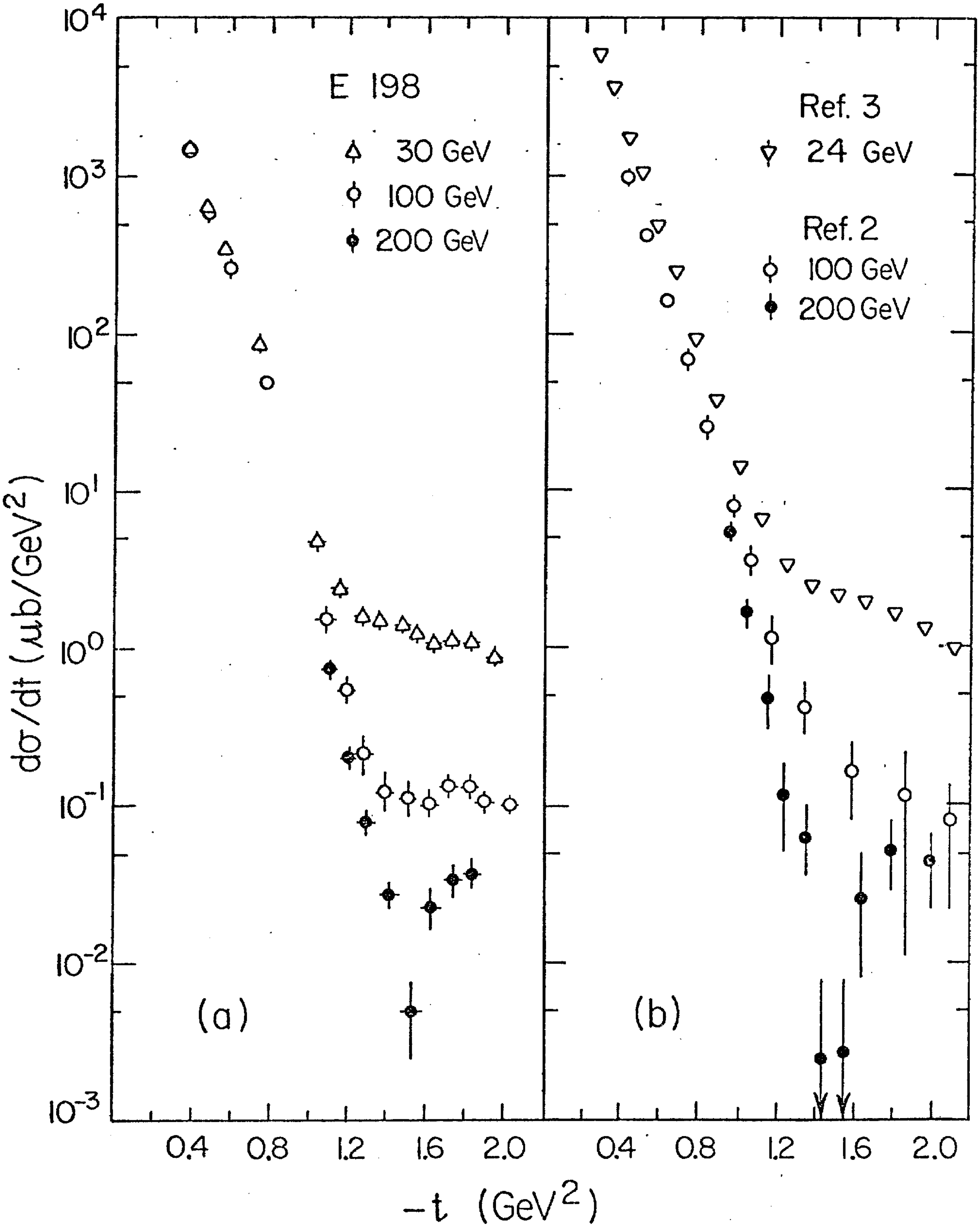


Fig. 1(a): Differential cross sections for the reaction $pp \to pp$ as measured by E198. Full Δt and ΔE bites are 0.06 GeV^2 and 20 GeV respectively. The cross sections were calculated from a 20% sample of the total data taken. When the full data set is analyzed we hope to have cross sections at every 20 GeV interval between 30 and 280 GeV with errors approaching those of the 30 GeV data shown.

Fig. 1(b): Cross sections measured in earlier experiments.

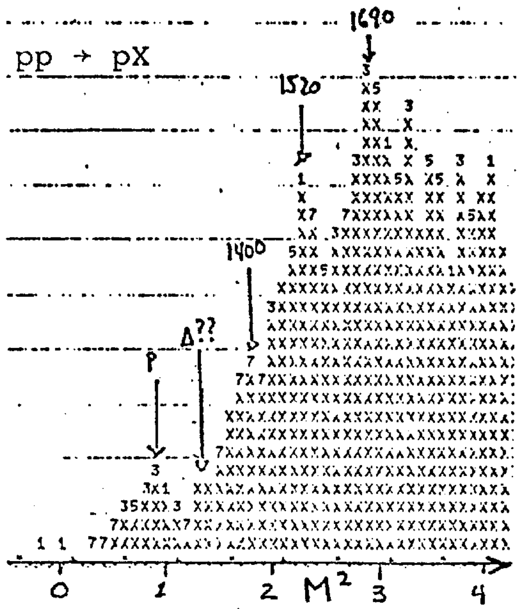


Fig. 2. Missing mass spectrum measured by E198 at $-t = 1.6\ \mathrm{GeV}^2$ and E = 100 GeV.

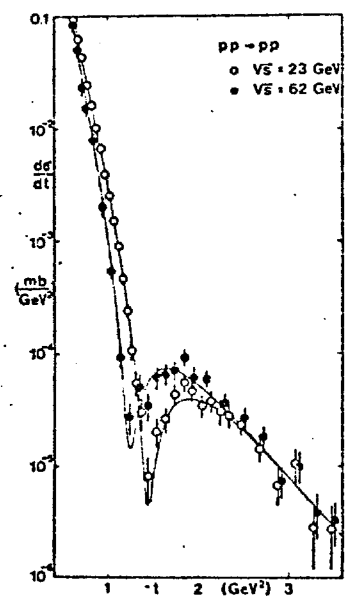


Fig. 4. ISR data (Ref. 1) at equivalent $E_{lab} = 280$ and 2050 GeV showing energy independence for $-t > 2.5\ \mathrm{GeV}^2$.

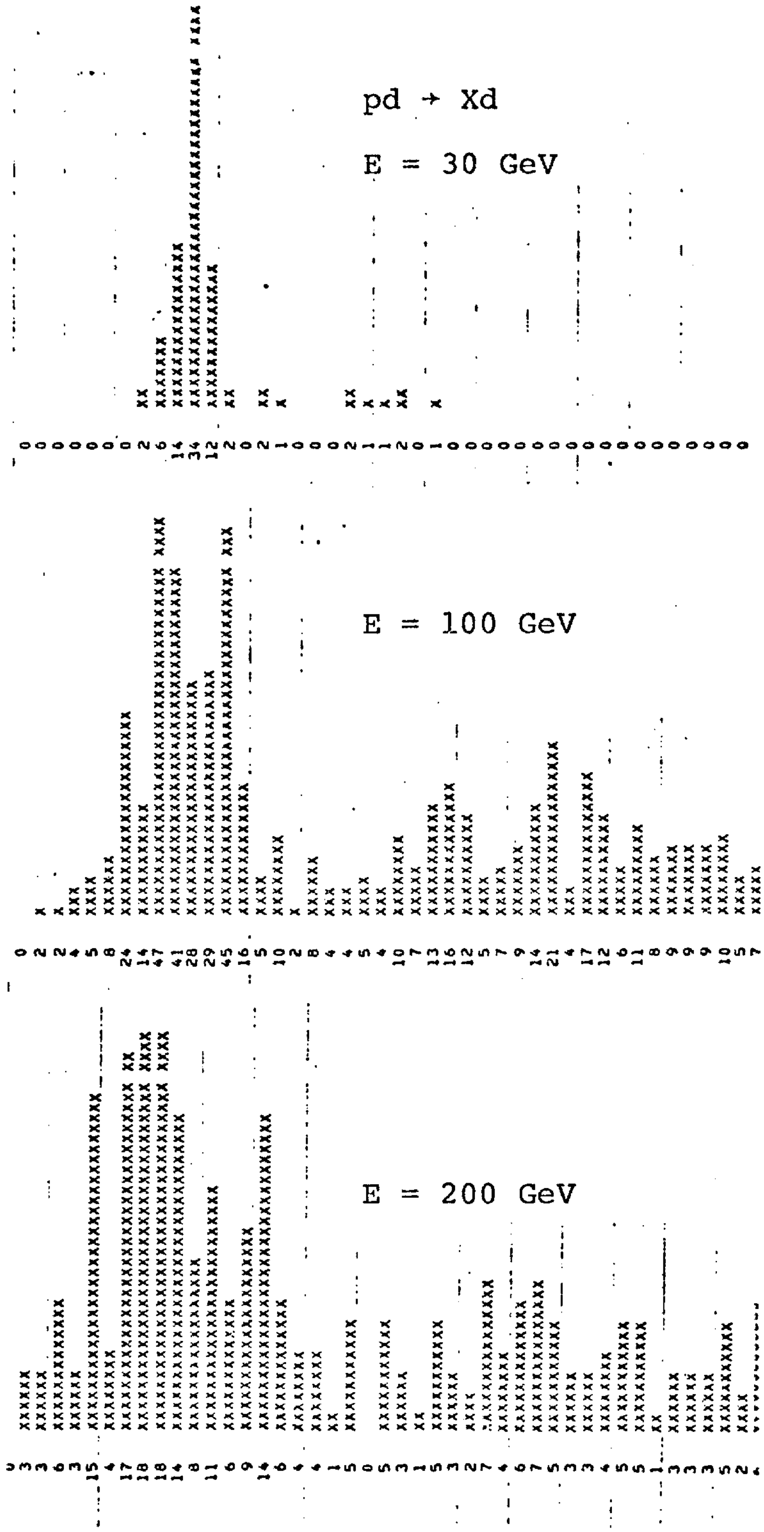
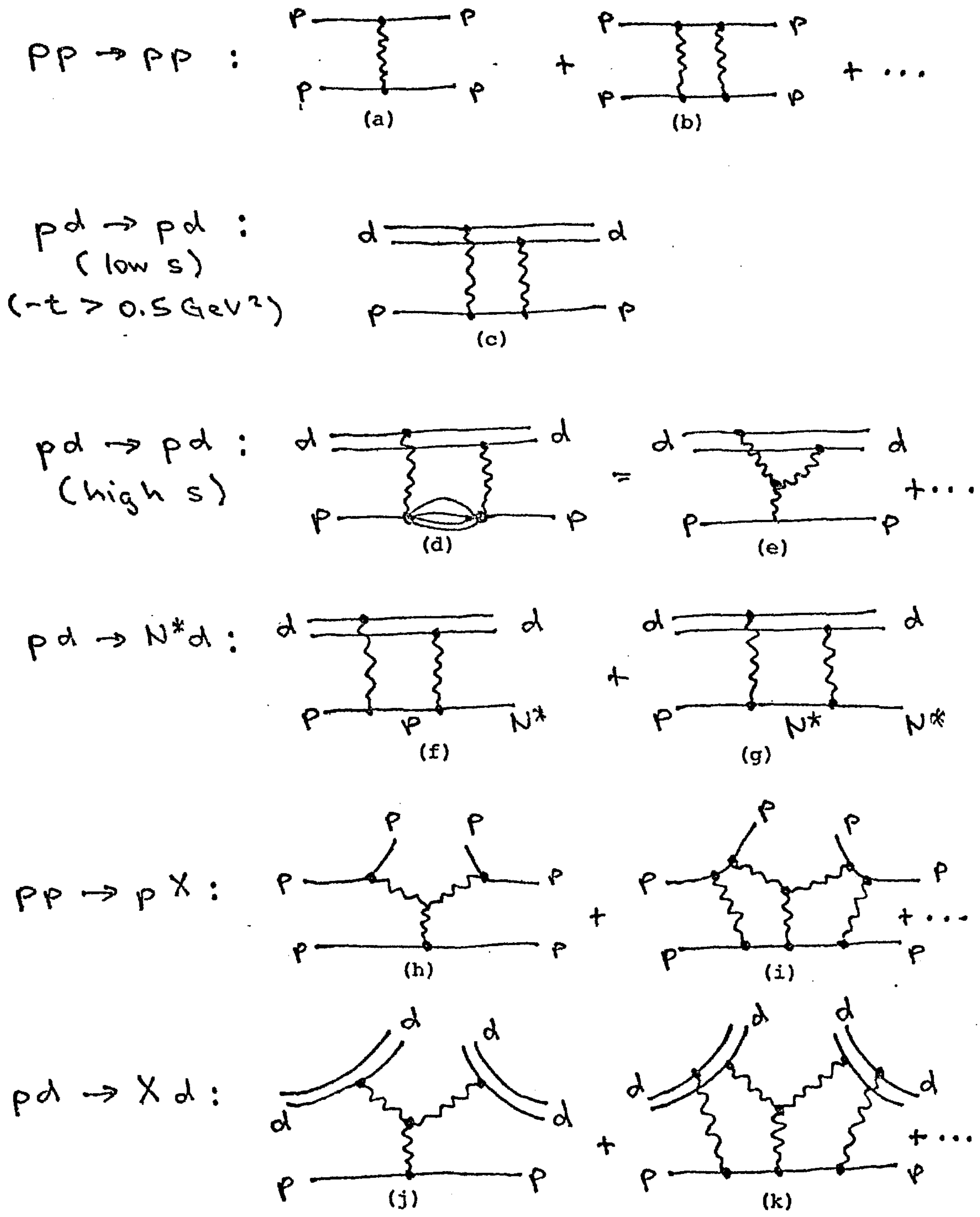


Fig. 3. Spectra of missing mass recoiling off the deuteron in pd coherent scattering at $-t = 1.3\ \mathrm{GeV}^2$ and three incident energies.



<u>Fig. 5</u>. Diagrams representing reactions discussed in text.

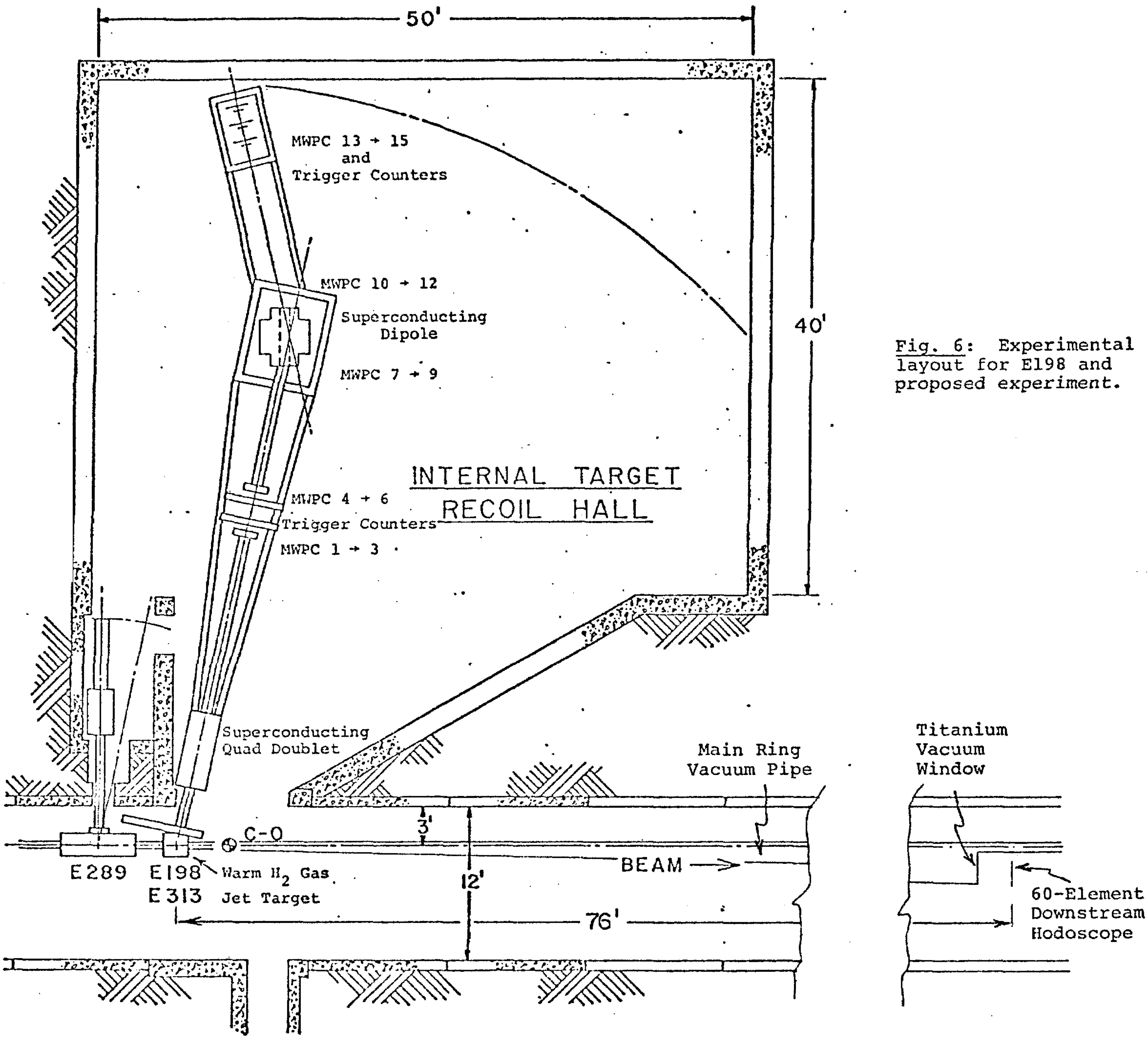
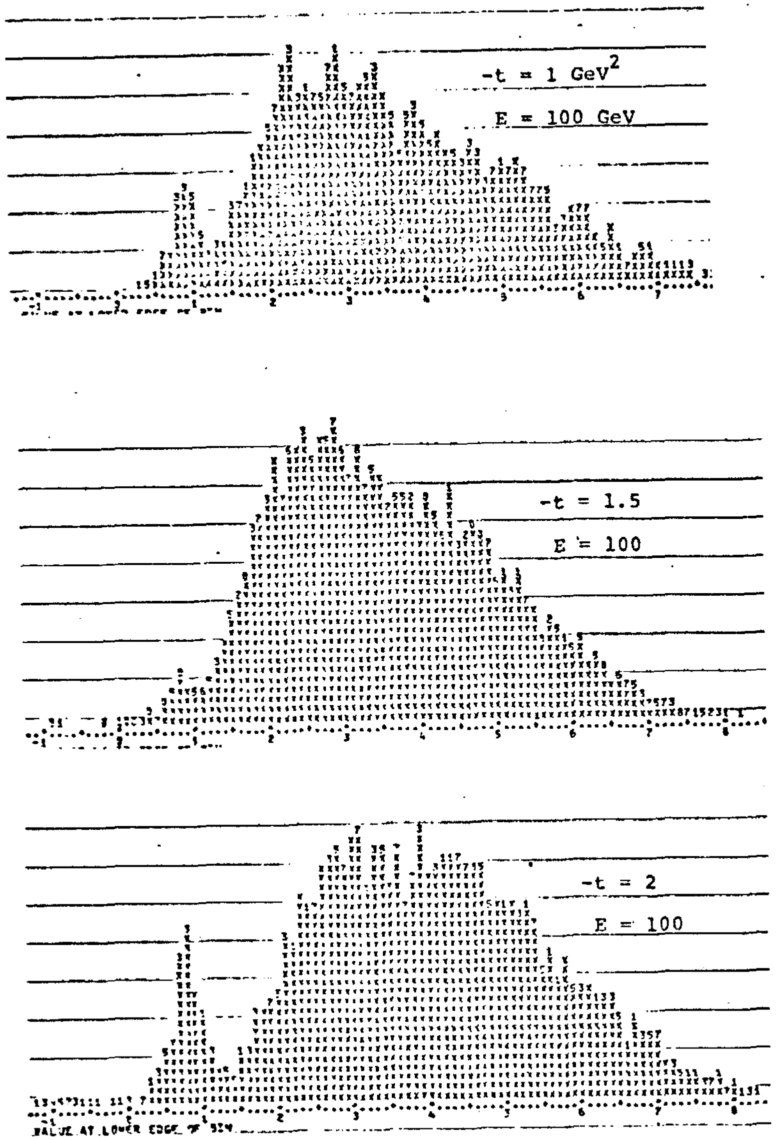
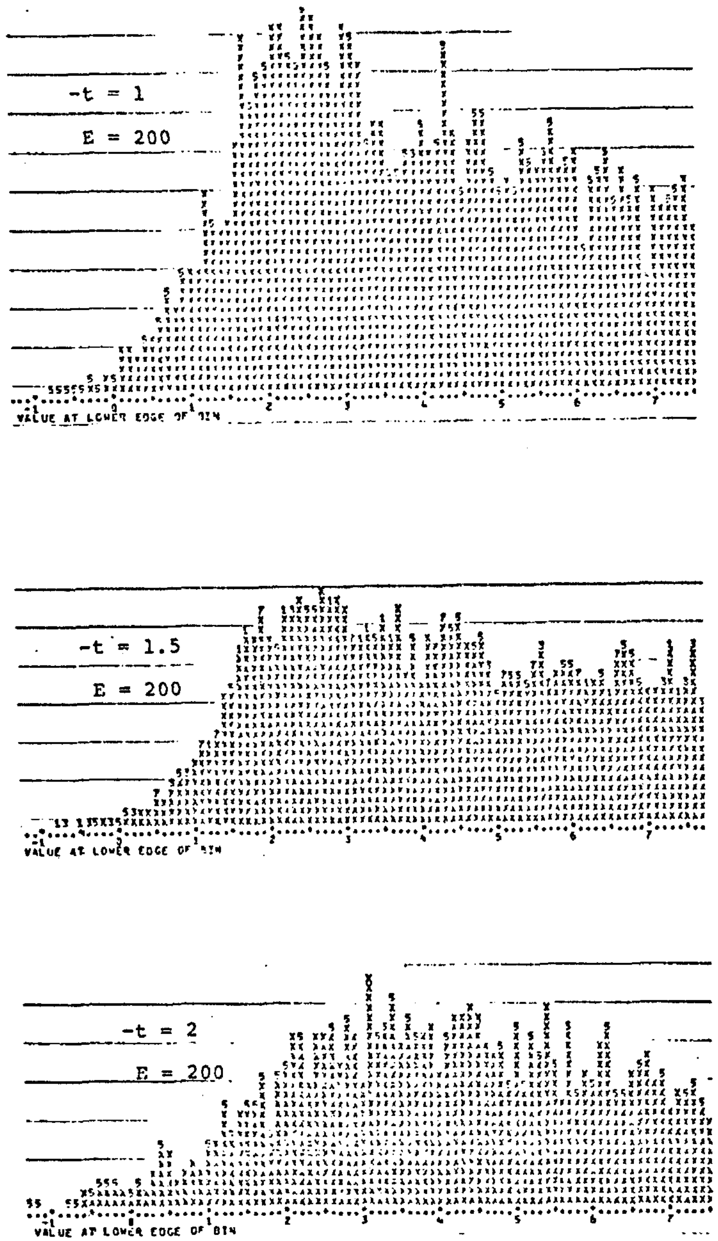


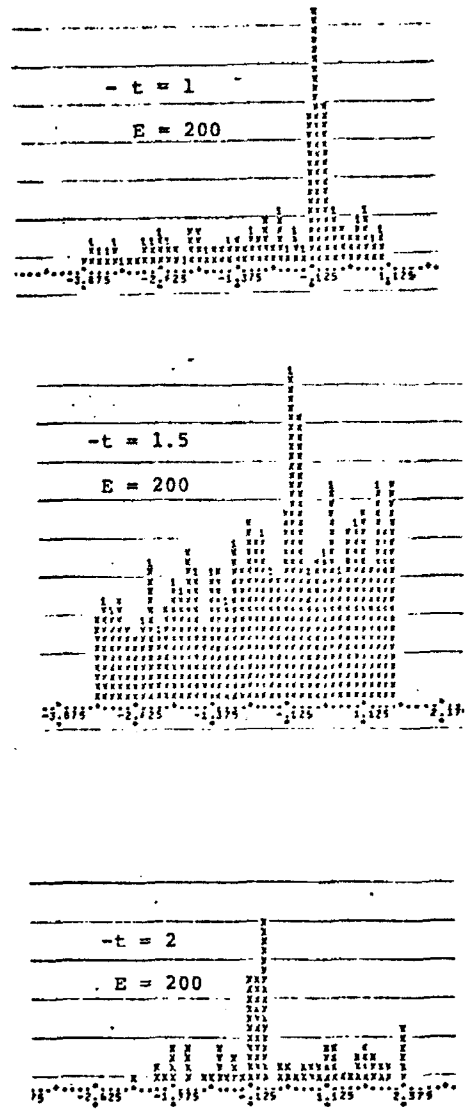
Fig. 6: Experimental layout for E198 and proposed experiment.



(a)



(b)



(c)

Figs. 7(a): Missing mass spectra for $pp \to pX$ at E = 100 and -t = 1.0, 1.5 and 2.0 GeV^2.

(b): Same spectra at E = 200.

(c): Angular distributions of hits in downstream hodoscope corresponding to elastic events in Figs. 7(b).

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