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EVIDENCE FOR INELASTIC PROPAGATORS
IN PROTON-DEUTERON ELASTIC SCATTERING AT $\sqrt{s} = 63$ GeV

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ABSTRACT

We report on experimental results on proton-deuteron elastic scattering at a centre-of-mass energy of $\sqrt{s} = 63$ GeV. The data were obtained using the Split Field Magnet detector at the CERN Intersecting Storage Rings. The t -dependence of the elastic differential cross-section, measured up to $-t = 2.0$ GeV², is compared with the prediction of an extended Glauber theory including contributions from inelastic intermediate states. Discrepancies of up to 30% with the basic theory are observed in the interference region. The inelastic contributions are essential for the detailed description of the data both in the single- and double-scattering regions.

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Measurements [1,2] of elastic scattering of high-energy protons on deuterons have been performed in the PS energy region for values of the invariant four-momentum transfer up to about 1.5 GeV^2 .

The success of Glauber theory [3] in describing the main features of this reaction implies that the structure observed in the differential cross-section can be interpreted as due to the effects of multiple diffractive collision processes. The data in general display a sharp forward peak dominated by the deuteron form factor and essentially associated with single nucleon-nucleon scattering, followed by a region of much shallower t -dependence as a result of double-scattering processes. The destructive interference of these two amplitudes at intermediate t -values around $-t \approx 0.3 \text{ GeV}^2$ is almost completely compensated by the quadrupole form factors of the deuteron.

The multiple scattering model, in itself valid in the limit of high energy and small scattering angles, contains a number of approximations; an intrinsic difficulty in any test of the Glauber model lies in our limited knowledge of the elementary nucleon-nucleon amplitude, in particular the t -dependence of the real to imaginary part. A correct treatment of double-scattering collisions requires, in addition, the inclusion of diagrams with inelastic intermediate states (IIS) [4].

In order to obtain new information on the dynamics of multiple scattering, and in particular on its energy-dependent terms, we have measured proton-deuteron elastic scattering at the CERN Intersecting Storage Rings at two different centre-of-mass energies. In the same experiment data on deuteron-deuteron elastic scattering were also collected, on which we report in the following letter.

We present here results in the range of momentum transfer $0.07 < -t < 2.0 \text{ GeV}^2$ at a centre-of-mass energy of $\sqrt{s} = 63 \text{ GeV}$, corresponding to incident proton momenta of $1034 \text{ GeV}/c$ in the deuteron rest frame, and we compare them with the predictions of an extended Glauber calculation including IIS contributions.

The data have been obtained using the Split Field Magnet detector (SFM) and correspond to an integrated luminosity of $14,443 \mu\text{b}^{-1}$.

The SFM detector has been described in detail elsewhere [5]; it consists of two symmetric forward magnetic spectrometers equipped with 10 multiwire proportional chambers each, complemented by downstream compensator magnets with four additional proportional chambers covering the small-angle region. The average magnetic field is 1.0 T, resulting in a momentum resolution for elastically scattered particles of $\Delta p/p = \pm 0.07$ at $\sqrt{s} = 63 \text{ GeV}$.

A two-step trigger selection operated first on the fast signals of the proportional chambers requiring at least one particle in each telescope and resulting in a rate roughly corresponding to the total pd cross-section. A slower decision was then performed on the memory levels of the chamber signals (with a decision time of about $2 \mu\text{sec}$) requiring a rough collinearity in the vertical plane and the absence of further background-associated tracks.

Given the sharp t -dependence of the cross-section and the reduced scale of t -values over which structures develop in pd scattering, events were only selected in the small compensator telescopes, and different scaling factors were applied to the triggers in different intervals of four-momentum transfer. The recorded events were analysed through a sequence of three reconstruction programs performing pattern recognition, track fitting in the magnetic field to a common vertex, and a four-constraint kinematical fit. Events having χ^2 -probability greater than 0.01 were accepted for further analysis (see Fig. 1a); the results presented here are based on a total sample of 205,600 events with 3496 events in the region above $-t = 0.4 \text{ GeV}^2$.

The presence of a coherently scattered final-state deuteron was imposed by requiring a measured momentum greater than $24 \text{ GeV}/c$ in the corresponding spectrometer arm, the break-up products peaking around $16 \text{ GeV}/c$. The strong coherence requirement implied by the deuteron form factor and the isospin selection rules which inhibit single π^0 production remove most of the inelastic contamination

from the interesting kinematical region. The residual background contamination, estimated by imposing a cut on the collinearity distribution, was found to be negligible, of the order of 1% at all t -values. The collinearity distribution for a sample of data is shown in Fig. 1b. Other background sources were below the 0.2% level.

The acceptance of the detector was calculated using a Monte Carlo simulation taking into account beam parameters, detector geometry and trigger conditions. In particular, absorption and scattering in the detector and in the ISR vacuum chamber were considered together with chamber inefficiencies and losses in the reconstruction and selection program chain. Excellent agreement was found between all simulated and reconstructed quantities (see Fig. 1).

The simulated events were used to determine the experimental t -resolution, which is about $\sigma_t = 0.009 \text{ GeV}^2$ at $-t = 0.1 \text{ GeV}^2$ and varies approximately as $|t|^{0.7}$. The absolute normalization was obtained by collecting monitor counts from two scintillation hodoscopes simultaneously with data taking. The monitor system was calibrated using the Van der Meer method [6]. The over-all systematic uncertainty of the results, including contributions from event sample selection and acceptance calculation is estimated to be $\pm 9\%$.

The elastic pd differential cross-section as a function of four-momentum transfer is shown in Fig. 2. The errors include a systematic t -dependent contribution estimated from a 15% uncertainty in the absorption path length of the outgoing particles traversing the vacuum chamber walls. The data display a very steep t -dependence in the single-scattering region, followed by a much weaker dependence in the interference and double-scattering regions. If we describe the local properties of the differential cross-section by a single exponential with slope b we get $b = 27.9 \pm 0.27 \text{ GeV}^{-2}$ for $0.08 < -t < 0.14 \text{ GeV}^2$ and $b = 5.4 \pm 0.06 \text{ GeV}^{-2}$ for $0.73 < -t < 2.0 \text{ GeV}^2$.

It is well known that these gross features are reproduced by the Glauber theory [3,7], as recently found in a similar ISR experiment [8]. It is however

important at these extremely high energies to include in the theory the so-called inelastic shadow correction [4,9,10]. This corresponds to adding to the Glauber double-scattering amplitude the contribution of the intermediate inelastic states:

$$f_{\text{double}} = f_G + f_{\text{IIS}}$$

$$f_{\text{IIS}} = \frac{i}{2\pi p_\ell} \int d^2 q'_T \sum_n f_n \left(\frac{\vec{q}_T}{2} - \vec{q}'_T \right) f_n \left(\frac{\vec{q}_T}{2} + \vec{q}'_T \right) S(\vec{q}'_T, q_L) +$$

$$+ \frac{i}{2\pi p_\ell} \sum_{ijk} \eta_k e^{-i\pi\beta_k(q^2/4)} \int \Delta F_6^{ijk}(s+i\epsilon, s-i\epsilon, M^2) S(\vec{q}'_T, q_L) d^2 q'_T dM^2 \quad (1)$$

$$(q^2 = -t)$$

where $S(q)$ is the deuteron charge form factor and $q_L = (M^2 - m^2)/2p_\ell$, p_ℓ being the equivalent laboratory momentum of the incident proton. ΔF_6^{ijk} is the discontinuity of the triple-Regge amplitude [11], β_k the trajectory of the k^{th} Regge pole and η_k its signature. The discontinuity ΔF_6^{ijk} is connected at $q^2 = 0$ to the inclusive cross-section for $pp \rightarrow pX$

$$\Delta F_6^{ijk} = \frac{p_\ell^2}{\pi} \frac{d\sigma^{ijk}}{dt dM^2} . \quad (2)$$

For $q^2 \neq 0$, there are multiplicative factors taking into account that for the i^{th} Reggeon $m_i^2 = -q^2$.

In the first term we sum over all the discrete states of the diffractive spectrum; since the low mass resonances are embedded in the Deck continuum [12], we have represented the first term of f_{IIS} as the mass integration of a Breit-Wigner form plus a $1/M^2$ term [13].

The parameters for the triple-Regge fit of the inclusive cross-section for $pp \rightarrow pX$ are taken from a fit of Fermilab and ISR data by Field and Fox [14].

In the Glauber formula we have used as elementary nucleon-nucleon amplitude the form:

$$f(q) = \frac{p_0}{4\pi} \sigma_{\text{tot}} (i + \rho) e^{-bq^2} \quad (3)$$

with the break of the elastic scattering slope b at $q^2 = 0.15 \text{ GeV}^2$ [15]; σ_{tot} and ρ are taken from ISR data [16]. The deuteron form factors have been calculated using the McGee wave function [17].

It is important to notice that the prediction of the full theory does not depend on free parameters, but is completely determined by the input experimental data. The results of this calculation, folded with the experimental t -resolution, are compared with the data in Figs. 2 and 3. The complete theory yields an absolute prediction which describes very accurately the pd differential cross-section over more than six decades.

As shown in Figs. 3a and b, adding the inelastic shadow scattering is essential to get in detail the impressive agreement of Fig. 2. The region below $-t = 1.0 \text{ GeV}^2$ turns out to be particularly sensitive to the inelastic shadow correction, which is negative for $-t < 0.3$ and positive for $-t > 0.3$, as clearly displayed by the plot of $(d\sigma/dt)/(d\sigma/dt)_{\text{Glauber}}$ in Fig. 3b. Figure 3a shows also that the contributions of the discrete spectrum and of the continuum are equally important for the description of the data. This opens up a new possibility for an independent test of triple-Regge parametrizations [18].

The data shown in Figs. 3a and 3b give clear evidence for the existence of sizeable inelastic shadow effects in proton-deuteron high-energy scattering; they also provide a detailed t -dependent test of this extended Glauber theory not otherwise possible through the measurement of total cross-section defects [19]. Indeed weights and phases of the triple-Regge terms in expression (1) are different from those at $t = 0$; this implies a sensitivity of this experiment to the triple-Regge parameters different from that of total cross-section defects and inclusive scattering data.

Further experimental results at a different energy and a more detailed theoretical analysis will be the subject of a forthcoming paper [18].

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REFERENCES

- [1] F. Bradamante et al., Phys. Letters 32B (1970) 303, and references therein.
- [2] U. Amaldi et al., Nuclear Phys. B39 (1970) 39.
- [3] C. Michael and C. Wilkin, Nuclear Phys. B11 (1964) 99.
V. Franco and R.J. Glauber, Phys. Rev. Letters 22 (1969) 370.
G. Alberi and L. Bertocchi, Nuovo Cimento 63A (1969) 285.
- [4] E.S. Abers et al., Nuovo Cimento 42A (1966) 363.
- [5] R. Bouclier et al., Nuclear Instrum. Methods 115 (1974) 235.
- [6] S. Van Der Meer, CERN Internal Report ISR-PO/68-31 (1968).
- [7] R.J. Glauber, *in* Lectures in theoretical physics (eds. W.E. Brittin et al.)
(Interscience, NY, 1959), Vol. 1, p. 315.
- [8] J.C.M. Armitage et al., Nuclear Phys. B132 (1978) 365.
- [9] G. Alberi and L. Bertocchi, Nuovo Cimento 61A (1969) 203.
- [10] V.N. Gribov, Zh. Exper. Teor. Fiz. 56 (1969) 892.
- [11] G. Alberi and F. Baldracchini, Preprint TH.2443, CERN, December 1977, to
be published in Nuclear Phys. B.
- [12] S. Drell and K. Hiida, Phys. Rev. Letters 7 (1961) 199.
R. Deck, Phys. Rev. Letters 13 (1964) 169.
E.L. Berger, Phys. Rev. 166 (1968) 1525.
- [13] S. Hendrick et al., Phys. Rev. D 11 (1975) 536.
- [14] R.D. Field and G.C. Fox, Nuclear Phys. B80 (1974) 367.
- [15] G. Giacomelli, Phys. Report 23C (1976) 182.
- [16] U. Amaldi et al., Phys. Letters 44B (1973) 111.
- [17] J.I. McGee, Phys. Rev. 151 (1966) 772.

- [18] G. Goggi et al., Inelastic intermediate states in proton-deuteron and deuteron-deuteron elastic collisions at the ISR, to be submitted to Nuclear Phys. B.
- [19] A.S. Carroll et al., Phys. Rev. Letters 33 (1974) 929; Phys. Letters 61B (1976) 303.

Figure captions

- Fig. 1 : a) Experimental χ^2 distribution for a sample of events. The curve is the normalized Monte Carlo simulation. In the inset the χ^2 distribution after the probability cut is compared with the theoretical distribution for four degrees of freedom.
- b) Experimental collinearity distribution and the corresponding (normalized) Monte Carlo curve.
- Fig. 2 : Differential cross-section for pd elastic scattering at $\sqrt{s} = 63$ GeV. The curve is the absolute prediction of the modified Glauber model described in the text convoluted with the experimental resolution.
- Fig. 3 : a) The elastic differential cross-section in the interference region. The solid line is the full model, the dashed line the pure Glauber term. Also shown is the contribution of the resonance part of the inelastic intermediate states (dotted line).
- b) The elastic differential cross-section normalized to the Glauber term. The line is the prediction of the model including inelastic intermediate states.

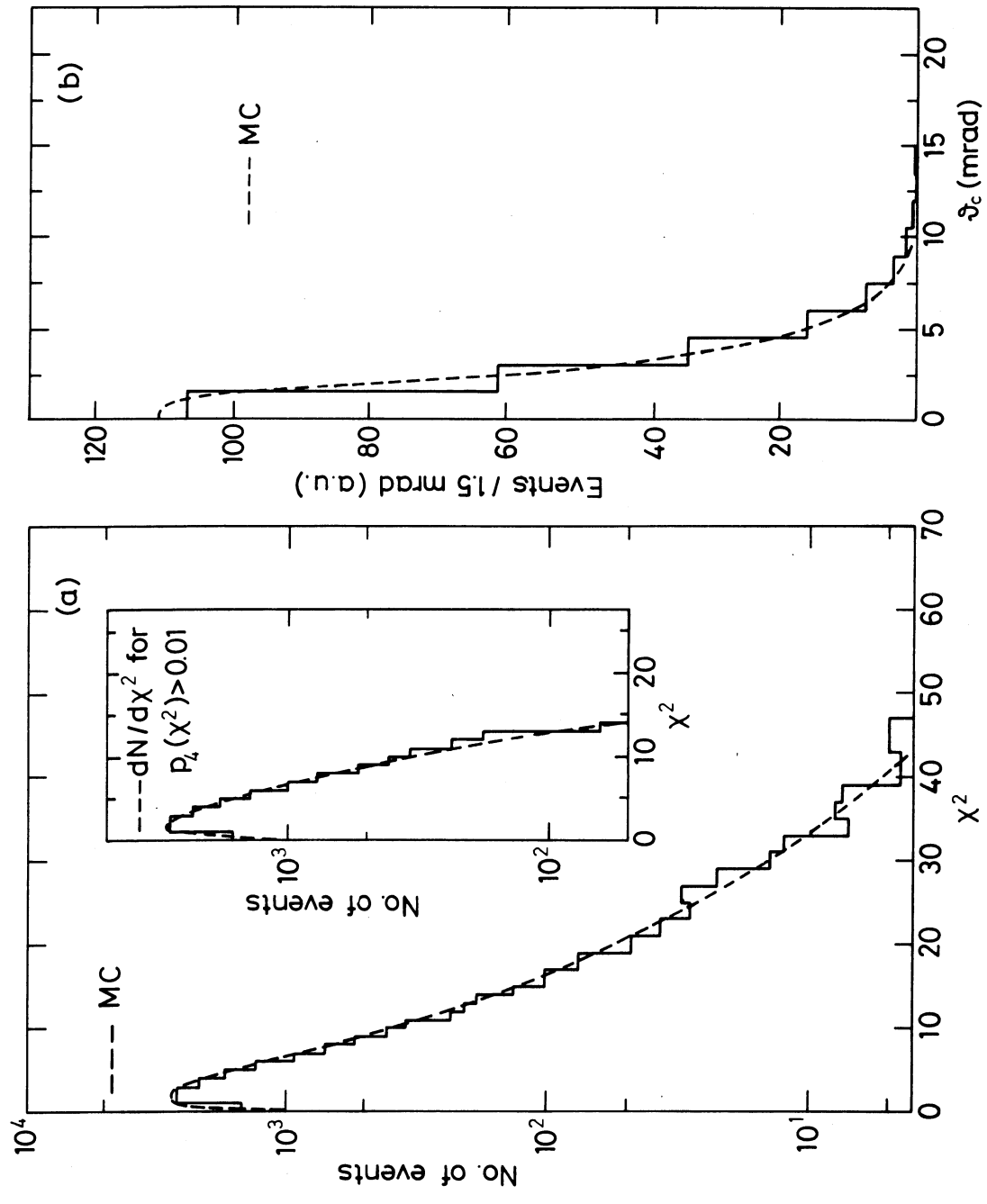


Fig. 1

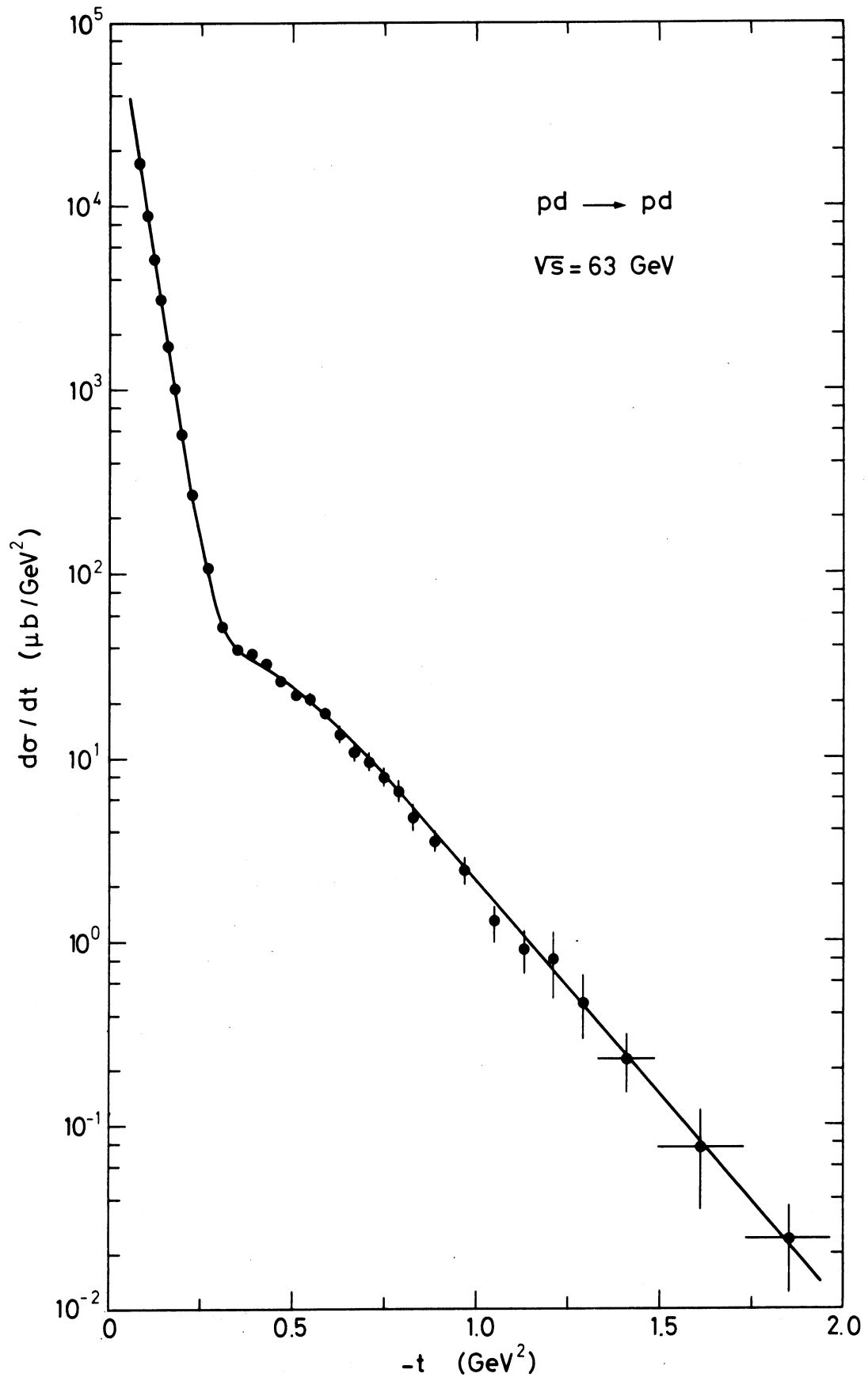


Fig. 2

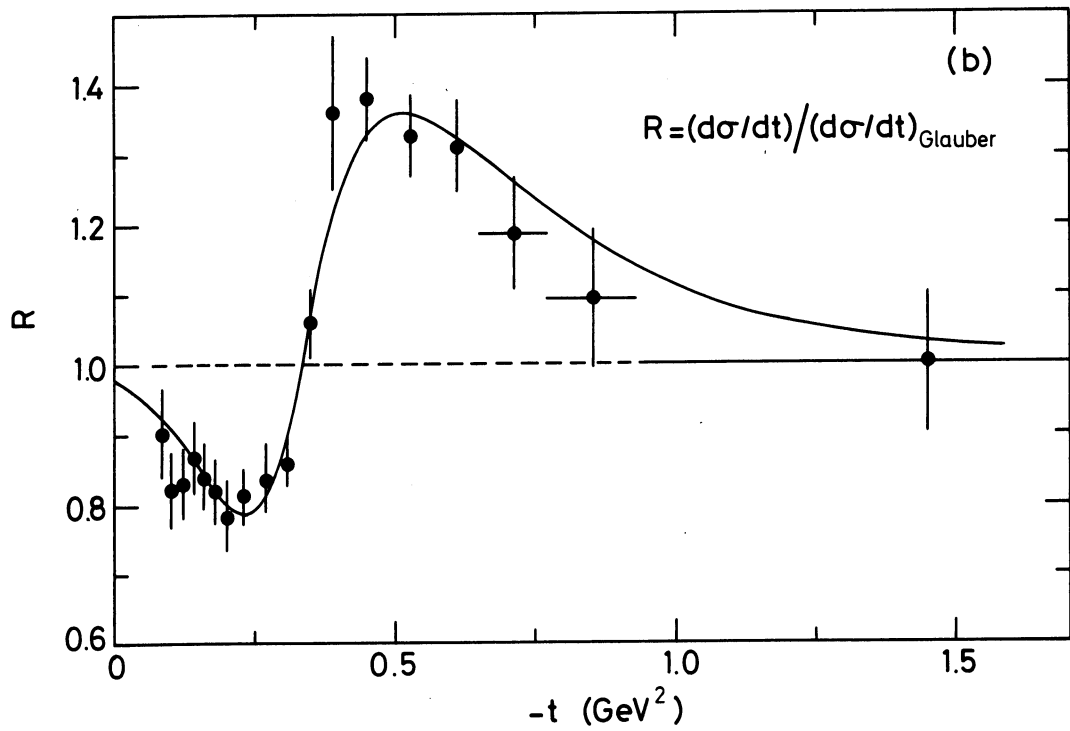
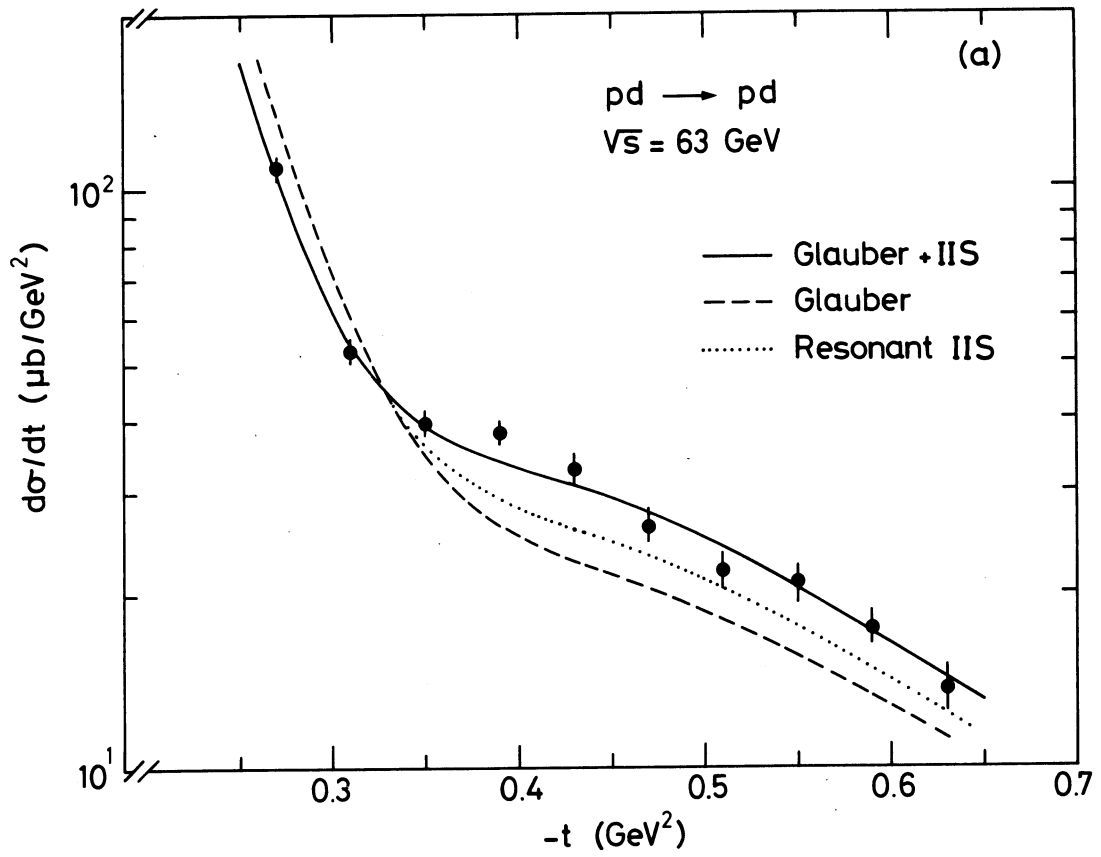


Fig. 3