TRN AU8105005

UM-P-79/16.

# CURRENT - CURRENT INTERACTION PICTURE
# FOR PROTON PROTON SCATTERING

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Abstract:

We propose that color current - color current interaction is responsible for small angle elastic proton proton scattering at asymptotic energy. Excellent fits are obtained for all data above 12 GeV/c which covers twelve orders of magnitude.

The nucleon - nucleon interaction is one of the most studied subjects i particle physics, both theoretically and experimentally. At low energy (< 1 GeV), the nucleon - nucleon interaction is known to be complex. However there is always a hope that at high energy the nucleon - nucleon interaction may become simple again in small angle scattering region. We propose that currents, which play a central role in electromagnetic and weak interaction may occupy an equally important position in nucleon - nucleon interaction. Specifically, the color current is responsible for the elastic asymptotic proton - proton scattering [1], and the flavor current is responsible for the decreasing energy dependent term. The S-matrix in the eikonal picture exponentiates to be:

$$S(\underset{\sim}{b},\underset{\sim}{s}) = \exp(-2\pi\mu_0(s)\iint d^3x'd^3x j_0^{\alpha}(x) j_0^{\alpha}(x)\Delta(x'-x) - 2\pi\mu_1(s)\iint d^3x'd^3x\, j_0^{(I=1)}(x)\, j_0^{(I=1)}(x)\, \Delta^{(1)}(x'-x)]$$

where $j_0^{\alpha}$ is the time component of the color current, $j_0^{I=1}$ is the time component of the isovector current, and $\Delta,\Delta^{(1)}$ are interaction kernels.

Our theoretical motivations for proposing this particular model may be summarized as follows: (1) It is the natural quantized version of the Chou-Yang model[2].

(2) QCD theory for strong interaction strongly suggests that color current may play a very important role.

(3) The value of the eikonal picture has been demonstrated already for QED[3], and it has recently been shown to hold also for Yang-Mills Gauge theories.

Our particular formulation employs the following simplifications:

$$< p'|j_o^{\alpha}|p > = < p'|j_o^{\alpha'}|p > = < p'|j_o^{(I=0)}|p >$$

$$= \left\{ \frac{m^2}{p_o p_o'} \right\} \bar{u}(p') \left\{ F_1^{s}(q^2)\gamma_4 + F_2^{s}(q^2) \frac{1}{2m} \sigma_{i4} q_i \right\} u(p)$$

where we have identified the color current form factors with the isoscalar form factors $F_1^s$ and $F_2^s$ [5].

The I = 1 term makes use of the isovector form factors. All the form factors are well known experimentally through electromagnetic interaction.

The interaction Green's function $\Delta^{(0,1)}$ is approximated by a $\delta$ -function, $\delta^2(\underset{\sim}{b} - \underset{\sim}{k} + \underset{\sim}{k}')$.

The model makes no predicition as to the s-dependence, but the t-dependence is completely specified by the proton form factors. The color exchange term, $\mu_o$, is determined by the normalization point of the total cross section. The energy-dependent term, $\mu_1(s)$, which has a phase, is fitted to data and is the only adjustable parameter in the theory.

This phenomenological model is used to fit the experimental data [5,6,7] for pp elastic scattering for Lab. momenta from 10 GeV/c up to $10^3$ GeV/c. Figures 1. and 2. show the differential cross sections for 12, 150, 200, 300 and 1500 GeV/c. The model provides good fits to all small angle data, which for ISR data includes the region $-t \sim 10$ GeV$^2$. The data extends over 12 orders of magnitude and the maximum deviation from experimental number is not more than 30% [1].

in particular it is worth noting that the model reproduces the change of slope at $-t = 1.0\ GeV^2$ for $P_{Lab} = 12$ GeV/c and the positions and magnitudes of the dips at $P_{Lab} = 150$ and 300 GeV/c. The second dip, at $-t \sim 3.5\ GeV^2$, is masked by the energy dependent term $\mu_1$. It is expected that if the value of $\mu_1$ decreases like $\frac{1}{s^{1/2}}$ the dip will reveal itself at ISABELLE energies. If $\mu_1$ decreases even less than $1/\sqrt{s}$, a shoulder type structure will emerge.

The Polarization Parameter can also be calculated from the above model. It is essentially due to the interference between the color current-color current and the flavor current-flavor current (I = 1) interaction terms. The results are shown in fig. 2.

In calculating the numerical fit for the color current-color current interaction the spin non-flip term is included to 9th order but the spin flip term only to 1st order. We only include flavor current-flavor current interaction to the first order, so we cannot, at this moment, reliably predict the spin parameters, A and $C_{nn}$, especially at low energy where the flavor current with a much larger spin flip term plays a more important role.

From the success with which both differential cross section and polarization data are fitted, it is interesting to speculate on the correctness of the current-current interaction picture for proton-proton scattering through considering the significance of the spin-flip term at high energy, say that achieved by the ISABELLE accelerator.

The spin-dependent cross sections given in fig. 4 may be better examined from their formulation in terms of the Wolfenstein Parameters[8].

$$\frac{d\sigma}{dt}\ (\uparrow\downarrow) = \pi|a - m|^2$$

$$\frac{d\sigma}{dt}\ (\uparrow\uparrow) = \pi(|a + m|^2 - 2\mathrm{Rec}(a - m)^* + 4|c|^2)$$

$$\frac{d\sigma}{dt}\ (\downarrow\downarrow) = \pi(|a + m|^2 + 2\mathrm{Rec}(a - m)^* + 4|c|^2)$$

Without a spin-flip term these cross sections are identical as implied in a pure scalar theory, but they show considerable structure in the current - current interaction picture.

The exact numerical values presented in fig. 4 of course depend sensitively on the parameters we assume and the omission of higher order spin-flip term. However these qualitative features of the three cross sections seem rather stable: For example, the first and second dip of mixed spin cross section $\frac{d\sigma}{dt}(\uparrow\downarrow)$, the first dip and then the first maximum for the parallel spin cross section are insensitive to the exact value of the energy dependent term ($\mu_1$). The three spin correlated cross sections are approximately the same for $|t|$ values smaller than the position of the first dip, but deviates after the occurence of the first dip. We hope this can be tested soon.

In conclusion, the excellent fits that we obtain seem to suggest that the color currents occurring in quantum chromodynamics may indeed play a crucial role in explaining the hadron scattering processes in a quantitative way.

References

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Figure Captions

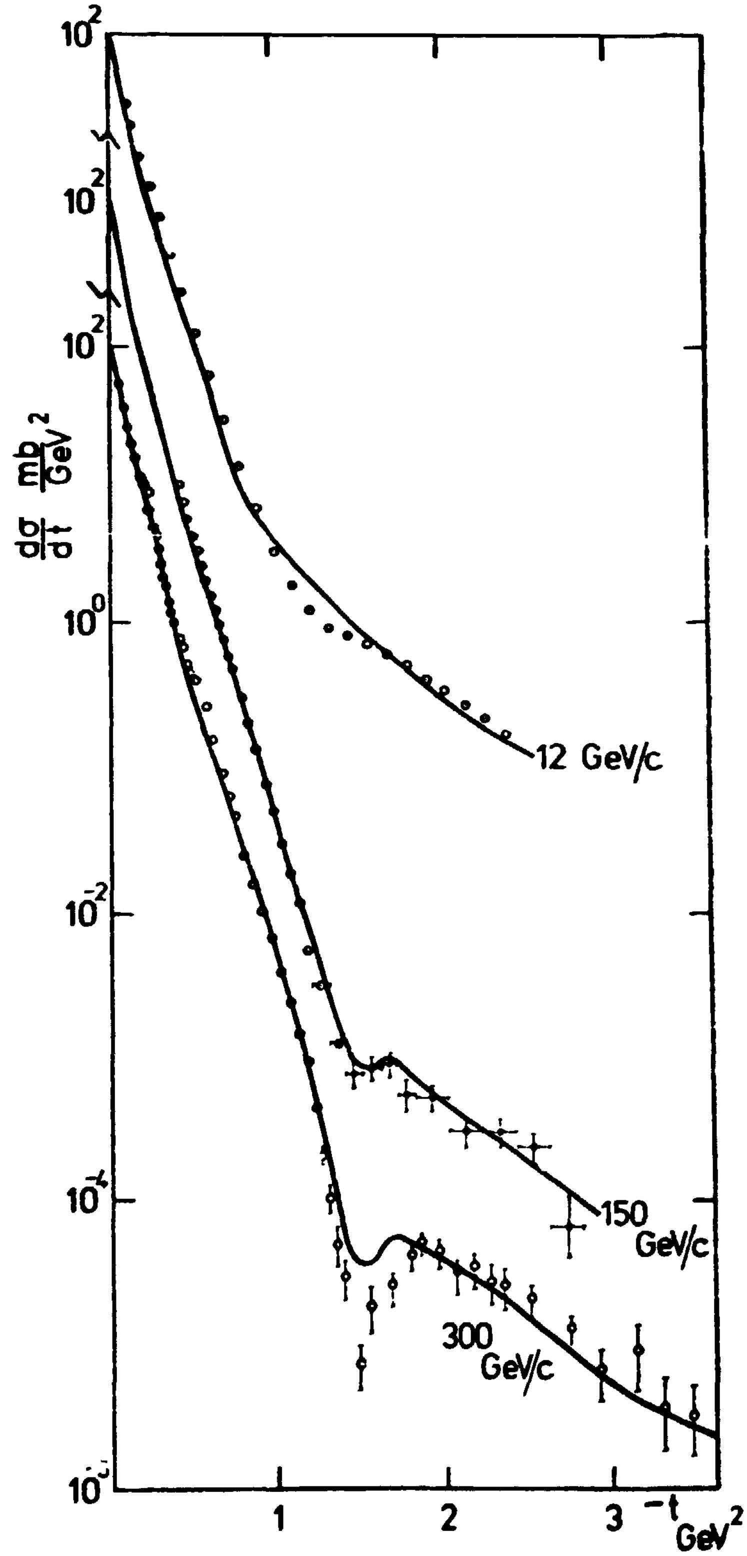
Fig. 1. Theoretical curves for pp elastic scattering differential cross section data at lab momenta 12, 150 and 300 GeV/c. Data is from reference 2 and the total cross sections used to fix $\mu_o$ were 39mb, 38mb and 39.1mb respectively. The values of $\mu_1$ employed were 1.15, 0.15 and 0.106 $GeV^{-2}$.

Fig. 2. Theoretical fit to pp elastic scattering differential cross section data at ISR energies. The fit to data at $P_{Lab}$ = 200 GeV/c is included for comparison. Experimental data is from references 2 and 3. A total cross section of 42.8mb was used to obtain the ISR fit, and 38.9mb for the 200 GeV/c fit. The values of $\mu_1$ used were 0.100 for ISR and 0.110 for 200 GeV/c.

Fig. 3. Theoretical fits to pp elastic scattering Polarization data at lab momenta 12, 150 and 300 GeV/c. Note that $\mu_o$ and $\mu_1$ are not free parameters. They are fixed by the total cross sections and differential cross sections respectively. The phase, $\phi$, is also restricted by the differential cross section data. At small cross momentum phase variation can produce a change of 15% in the theoretical fit to $\frac{d\sigma}{dt}$. At larger $P_1^2$ phase variation can affect the differential cross section by a factor of 2, and even 3 in the dip region. In summary: the differential cross section restricts the possible choice of phase and it is most encouraging that the phase values employed to fit differential cross section data are entirely consistent with the Polarization data.

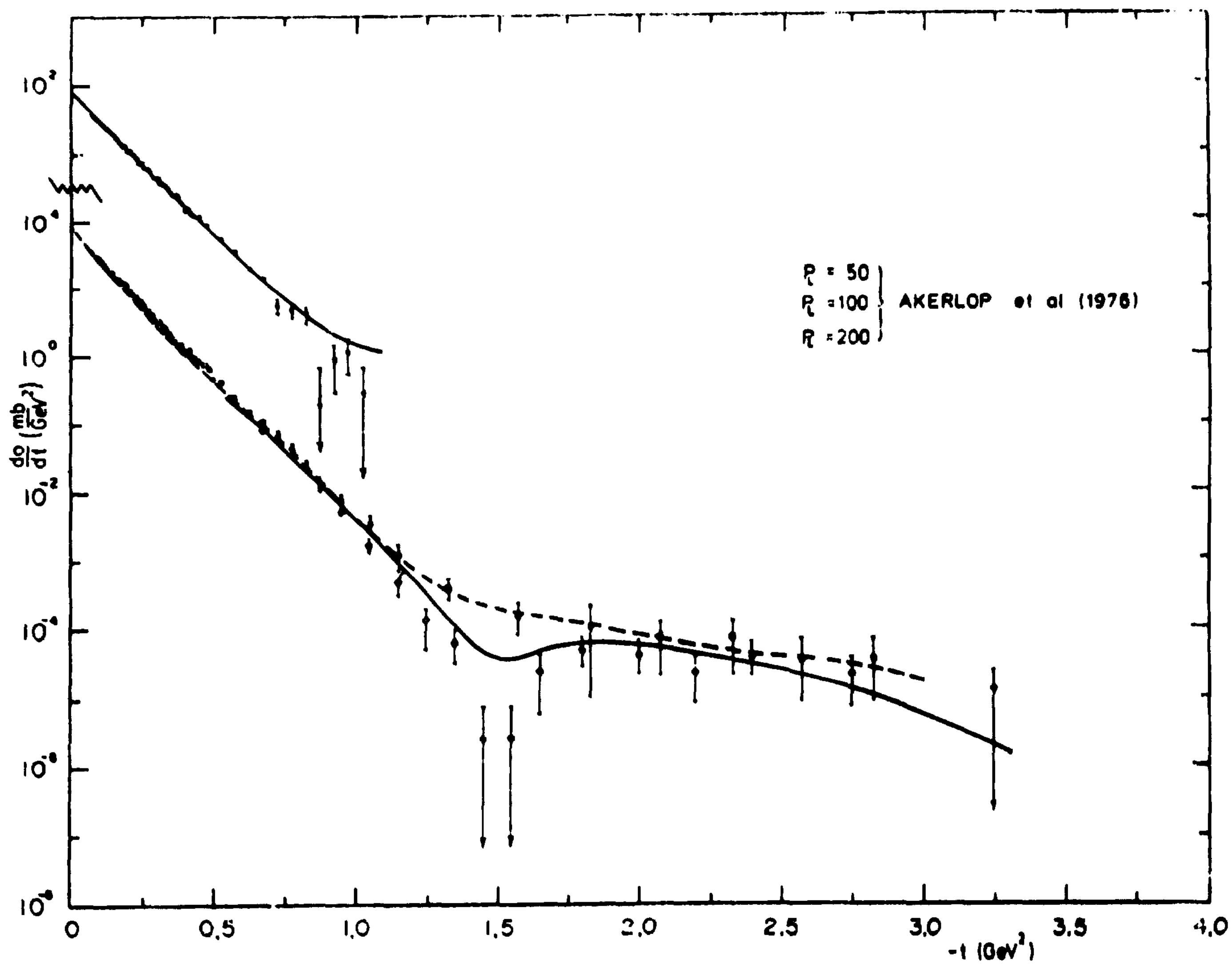
Fig. 4. Theoretical curves for spin-parallel and spin-anti- parallel differential cross sections at ISABELLE energy. A total

cross section of 83.1mb was used to fix $\mu_0$ and a value at 0.08 $GeV^{-2}$ used for $\mu_1$. This latter value was obtained by extrapolating the apparent trend in $\mu$ to higher energy. Phase values were determined on the assumption that the same regularity observed at lower energies could be assumed for very high energies.

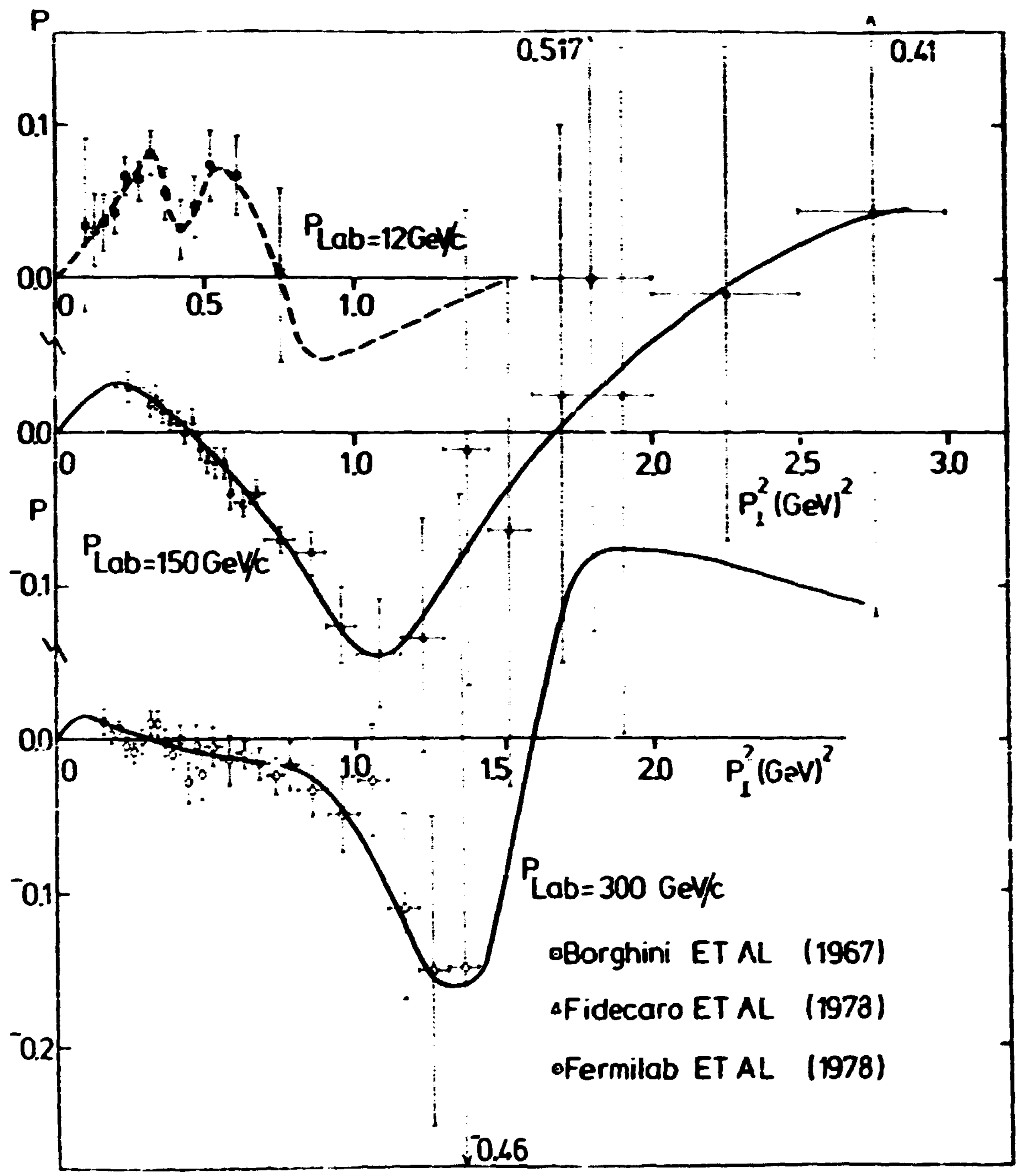


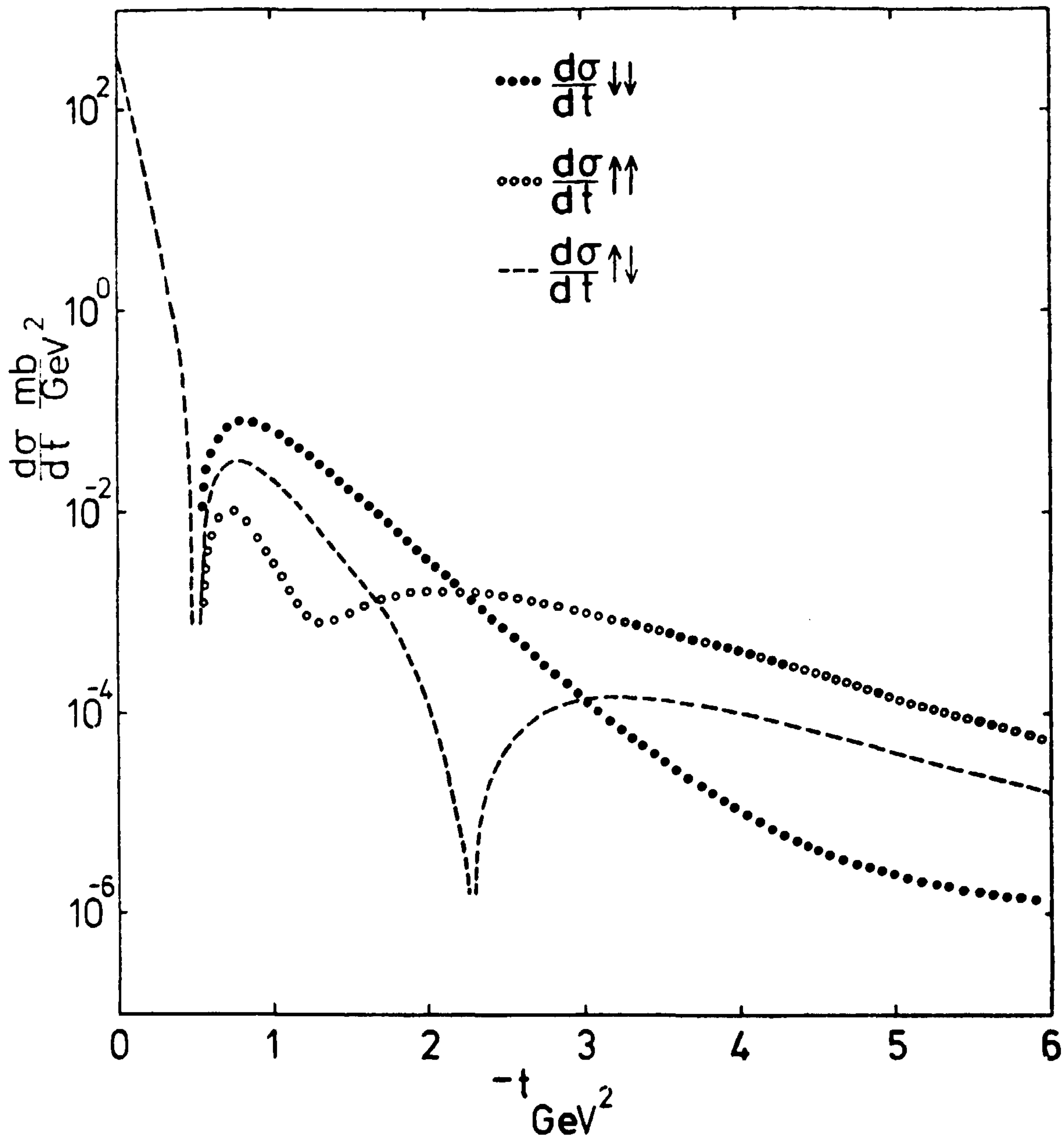
$10^2$
$10^2$
$10^2$
$10^0$
$10^{-2}$
$10^{-4}$
$\frac{d\sigma}{dt}$ $\frac{mb}{GeV^2}$
12 GeV/c
150 GeV/c
300 GeV/c
1
2
3
$-t$ $GeV^2$

Fig.



10²
10⁰
10⁻²
10⁻⁴
10⁻⁶
10⁻⁸
dσ/dt (mb/GeV²)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
-t (GeV²)
P_L = 50
P_L = 100
P_L = 200
AKERLOF et al (1976)


P
0.1
0.0
0.517
0.41
$P_{Lab}$=12GeV/c
0
0.5
1.0
1.5
2.0
2.5
3.0
$P_\perp^2$ (GeV)$^2$
P
$P_{Lab}$=150GeV/c
-0.1
$P_{Lab}$=300 GeV/c
-0.2
$P_\perp^2$ (GeV)$^2$
-0.46
▫Borghini ET AL (1967)
▵Fidecaro ET AL (1978)
∘Fermilab ET AL (1978)



dσ/dt ↓↓
dσ/dt ↑↑
dσ/dt ↑↓
dσ/dt mb/GeV^2
10^2
10^0
10^-2
10^-4
10^-6
0
1
2
3
4
5
6
-t GeV^2