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A MEASUREMENT OF ALPHA-ALPHA ELASTIC SCATTERING AT THE CERN ISR

The Axial Field Spectrometer Collaboration

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ABSTRACT

We present measurements of the $\alpha\alpha$ elastic scattering differential cross-section at $\sqrt{s} = 126$ GeV in the range $0.05 < |t| < 0.19$ (GeV/c)². The data give an improved definition of the first cross-section minimum at $|t| = 0.098$ (GeV/c)² and are consistent with theoretical models of nucleus-nucleus scattering. The $\alpha\alpha$ total cross-section obtained by extrapolation to the optical point is 280 ± 70 mb.

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I. INTRODUCTION

The physics processes of $\alpha\alpha$ scattering are determined by a combination of the internal nuclear structure and the basic nucleon-nucleon interaction. It is thus of interest to examine the fundamental properties of elastic scattering and total cross-sections for this simple nucleus at high energies, where the generalised Glauber model is expected to be quantitatively correct.

Two previous measurements of the $\alpha\alpha$ differential cross-section for elastic scattering have been made at the ISR at $\sqrt{s} = 126$ GeV. Ambrosio et al. [1] covered the region $0.05 \leq |t| \leq 0.72$ (GeV/c)² with a t -resolution of ± 0.02 (GeV/c)², while measurements at $|t| > 0.2$ (GeV/c)² have been made with the S.F.M. detector [2]. The highest energy fixed target experiment of Berger et al [3] obtained data at $\sqrt{s} = 8.8$ and 8.4 GeV over the range $0.05 \leq |t| \leq 0.77$ (GeV/c)².

The present data come from the final ISR period of α -particle collisions in 1983. The trajectories of the scattered α -particles were recorded in small forward drift chambers, originally designed as part of an experimental search for glueball states produced by pomeron-pomeron interactions[4]. The $|t|$ range covered by these chambers for $\alpha\alpha$ elastic scattering, though small ($0.05 - 0.19$ (GeV/c)²), includes the interesting region of the first minimum in the differential cross-section, and the resolution in t of ± 0.005 (GeV/c)² represents a significant improvement over previous data.

II APPARATUS

The measurements were made using a small part of the apparatus of the Axial Field Spectrometer, AFS [5]. The trajectories of the scattered α -particles were measured by small drift chamber telescopes installed ~ 9 m from the intersection region above (UP) and below (DOWN) each downstream beam pipe, as shown in Fig. 1. Two scintillation counters approximately 30mm x 30mm in size at the front and back of each telescope provided a trigger for the reaction. The scintillators were equipped with

ADC's, and the pulse heights were recorded on tape. The thresholds were set above the peak of the pulse height distribution for protons, and a typical pulse height spectrum for triggered events is shown in Fig. 2, illustrating the clean separation of the α -particle signal. A further off-line cut was made about the α -peak. The trigger required a coincidence between the two scintillators in an UP arm and in the DOWN arm on the other side of the intersection region, which defined the kinematics for an elastic event.

Most of the solid angle outside the forward drift chambers and scintillators was covered by a 44-scintillator central cylindrical barrel hodoscope surrounding the beam pipe (Fig. 1) and a further 100 scintillation counters. The OR of these counters was used as a veto in defining elastic events.

The forward drift chambers are described in [6]. Each had four horizontal sense wires and measured the vertical drift distance with a precision of $\sigma \sim 120\mu\text{m}$ per wire. The wires were equipped with charge division readout to give the horizontal position to $\sigma \sim 1.2\text{mm}$. A final state α -particle passed through the ISR vacuum for $\sim 8\text{m}$ before emerging through a 0.2mm stainless steel window in a transition from a circular to an elliptical beam pipe. The material (vacuum window and scintillator) before the first drift chamber gave rise to a mean α -particle multiple scattering angle of 0.08mr.

III DATA ANALYSIS

The results presented come from 40,000 triggers where both final state particles are identified as α -particles after applying the scintillator pulse height cuts. Straight lines were fitted in the x-z and y-z planes (Fig. 1) to the drift chamber coordinates, with the requirement that two or more coordinates came from each of the three chambers in a triggered arm. Cuts were imposed to define a fiducial area within the triggering scintillators for the purpose of acceptance and cross-section calculations. The (x,z) coordinate of the interaction was determined from the intersection of the trajectories of the two scattered particles, and cuts were made on the vertex position of the event. The incident α -particle momenta were corrected for the known correlation between momentum and position in the beam. At this stage 30,000 events remained for further analysis.

The incident α -particle momentum vectors and the final α -particle directions were used in a 2-constraint kinematic fit to the elastic hypothesis. For the final unfitted angles, dx/dz was determined to a precision of ~ 1.0 mr from the drift chamber coordinates alone. The more critical dy/dz was obtained to a precision of ~ 0.25 mr from the average y coordinate of the fitted line in the drift chamber telescope, and the average y of the primary vertex. A correction was made for the 2mm vertical displacement of a 63 GeV α -particle after passage through the A.F.S. and a downstream compensating magnet. This method for determining dy/dz was preferable to the use of drift chamber coordinates alone, as it made negligible the effects of multiple and small angle scattering, δ -ray production and any systematic errors in the angles of those tracks crossing drift chamber sense wire planes. 92% of the events gave good fits to the elastic hypothesis, and a resolution in t of ± 0.005 (GeV/c)² was obtained from the fitting procedure.

IV CORRECTIONS AND NORMALISATION

A correction of 9.5% has been applied to the fitted number of events to allow for estimated chamber, scintillator and reconstruction inefficiencies. A Monte Carlo calculation has been made of the acceptance of the forward arm telescopes for elastic scattering, using beam profiles determined from inelastic $\alpha\alpha$ data taken in the AFS during the same run. The acceptances for the 'UP-DOWN' and 'DOWN-UP' triggers are shown in Fig. 3. Absolute cross-sections were then calculated using the known luminosity, $\sim 8 \times 10^{28} \text{ cm}^{-2} \text{ s}^{-1}$, and the experimental livetime. We estimate an overall scale error of $\pm 20\%$ to cover uncertainties in these quantities, in the correction for inefficiencies, and in the acceptance calculation (the dominant contributions are $\pm 10\%$ from the integrated luminosity and $\pm 15\%$ from the acceptance).

A possible source of background in the data satisfying the scintillator pulse height cuts could come from the reaction $\alpha\alpha \rightarrow \alpha\alpha^*$, with the excited α^* subsequently decaying into ${}^3\text{He} + n$. However, on the basis of measurements at low energy [3,7] and the angular constraints imposed on our data by fitting, we estimate that this background is at an insignificant, $< 3\%$, level.

V RESULTS

The results for the $\alpha\alpha$ elastic differential cross-section are tabulated in Table 1 and shown in Fig. 4(a), where they are compared with a previous ISR measurement of Ambrosio et al. [1] at $\sqrt{s} = 126$ GeV and with the data of Berger et al. [3] at 8.4 and 8.8 GeV. The agreement between our data and that of Ambrosio et al. above $|t| = 0.14$ $(\text{GeV}/c)^2$ is excellent, but our superior t resolution (± 0.005 $(\text{GeV}/c)^2$, compared with ± 0.02 $(\text{GeV}/c)^2$ in [1]) results in a considerably better definition of the first dip in the differential cross-section at $|t| = 0.098 \pm 0.002$ $(\text{GeV}/c)^2$. A dip is also seen in the low energy data at a similar t value.

We have calculated the magnitude of the $\alpha\alpha$ total cross-section from the optical theorem (under the assumption of a purely imaginary forward amplitude) by fitting the 5 data points below $|t| = 0.075$ $(\text{GeV}/c)^2$ to an exponential Ae^{bt} . This forward region of t was used as the cross-section falls more steeply towards the dip for $|t| > 0.075$ $(\text{GeV}/c)^2$. We obtain a slope $b = 72 \pm 6$ $(\text{GeV}/c)^{-2}$ and a total cross-section of $\sigma_T = 280 \pm 70$ mb, where the error includes both the statistical and scale uncertainties. The result agrees well with the value of 250 ± 50 mb previously obtained at $\sqrt{s} = 126$ GeV [1]. The optical model relates the slope b at small $|t|$ to the $\alpha\alpha$ interaction radius, R . The scattering amplitude is given by the Fourier-Bessel transform of the nuclear matter profile, $r(a)$, with respect to the impact parameter a . For a Gaussian profile of the form

$$r(a) \propto \exp(-a^2/R^2)$$

the differential cross-section is [8]

$$d\sigma/dt \propto \exp(R^2 t/2)$$

Our measured value of b corresponds to an interaction radius of $R = 2.4 \pm 0.1$ fm.

In Fig. 4(b) we compare our data with the predictions of two model calculations based upon the generalized Glauber theory for multiple scattering. The Franco and Varma model [9] is evaluated at 2.1 GeV/nucleon and that of Czyz and Maximon [10] at several GeV/nucleon. For the constituent scattering, the nucleon-nucleon amplitudes are defined

by the total cross-section, σ_{NN} , the ratio ρ_{NN} of the real to imaginary part of the elastic amplitude, and the slope B_{NN} of the elastic differential cross-section. Both models use Gaussian functions to describe the single particle density within the nucleus, and incorporate centre of mass correlations. Czyz and Maximon evaluate the full Glauber multiple scattering series, while Franco and Varma approximate the sum by expanding a rapidly converging optical phase shift function. The forward differential cross-section is dominated by single nucleon-nucleon scattering, and the first dip arises from the destructive interference of the single and double scattering terms in the amplitude. The position of this minimum is seen to be well reproduced by both calculations. Its depth is a more sensitive function of the input parameters (which were not optimized for our energy) and of the details of the model. Nevertheless, our data are in general agreement with these calculations, and support the validity of the Glauber multiple scattering theory.

VI SUMMARY

We have presented an improved measurement of the $\alpha\alpha$ elastic differential cross-section at $\sqrt{s} = 126$ GeV in the region of t that contains the first minimum. A comparison with low energy results indicates only a weak s -dependence of the cross-section, and our data are in general quantitative agreement with calculations based upon the generalised Glauber theory of interactions between nuclei.

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TABLE 1

The $\alpha\alpha$ elastic differential cross-section at $\sqrt{s} = 126$ GeV.

The errors quoted are statistical.

There is an additional estimated uncertainty in scale of $\pm 20\%$

$-t$ (GeV/c) ²	$\frac{d\sigma}{dt}$ mb (GeV/c) ⁻²	$-t$ (GeV/c) ²	$\frac{d\sigma}{dt}$ mb (GeV/c) ⁻²
0.0525	93.8 \pm 5.0	0.1225	6.3 \pm 0.3
0.0575	59.6 \pm 2.0	0.1275	6.6 \pm 0.3
0.0625	45.3 \pm 1.0	0.1325	6.8 \pm 0.3
0.0675	32.2 \pm 0.7	0.1375	6.7 \pm 0.3
0.0725	20.5 \pm 0.6	0.1425	7.1 \pm 0.3
0.0775	12.4 \pm 0.4	0.1475	7.4 \pm 0.3
0.0825	7.5 \pm 0.3	0.1525	6.8 \pm 0.3
0.0875	5.1 \pm 0.3	0.1575	6.8 \pm 0.3
0.0925	3.7 \pm 0.2	0.1625	6.2 \pm 0.3
0.0975	3.6 \pm 0.2	0.1675	5.3 \pm 0.3
0.1025	3.3 \pm 0.2	0.1725	4.8 \pm 0.3
0.1075	4.1 \pm 0.2	0.1775	4.5 \pm 0.3
0.1125	4.9 \pm 0.2	0.1825	3.5 \pm 0.4
0.1175	5.7 \pm 0.2	0.1875	3.8 \pm 0.5

FIGURE CAPTIONS

Fig. 1 Schematic side view of the apparatus. Only the right-hand forward detectors are shown; the apparatus is left-right symmetric.

Fig. 2 Typical scintillator pulse height distribution for triggered events.

Fig. 3 The acceptance in t for the UP-DOWN and DOWN-UP triggers (see text for notation).

Fig. 4(a) The measured $\alpha\alpha$ elastic scattering differential cross-section. The errors shown are statistical. There is an additional estimated uncertainty in the scale of $\pm 20\%$. The dashed curve is to guide the eye. Also shown are data from refs [1,3].

Fig. 4(b) A comparison between the $\alpha\alpha$ elastic scattering differential cross-section and the model calculations of Franco and Varma [9] and Czyz and Maximon [10]. The nucleon-nucleon parameters used were,

respectively, $\sigma_{NN} = 42.4$ mb, $\rho_{NN} = -0.28$, $B_{NN} = 6.2$ (GeV/c)⁻² and $\sigma_{NN} = 41$ mb, $\rho_{NN} = -0.3$, $B_{NN} = 10$ (GeV/c)⁻².

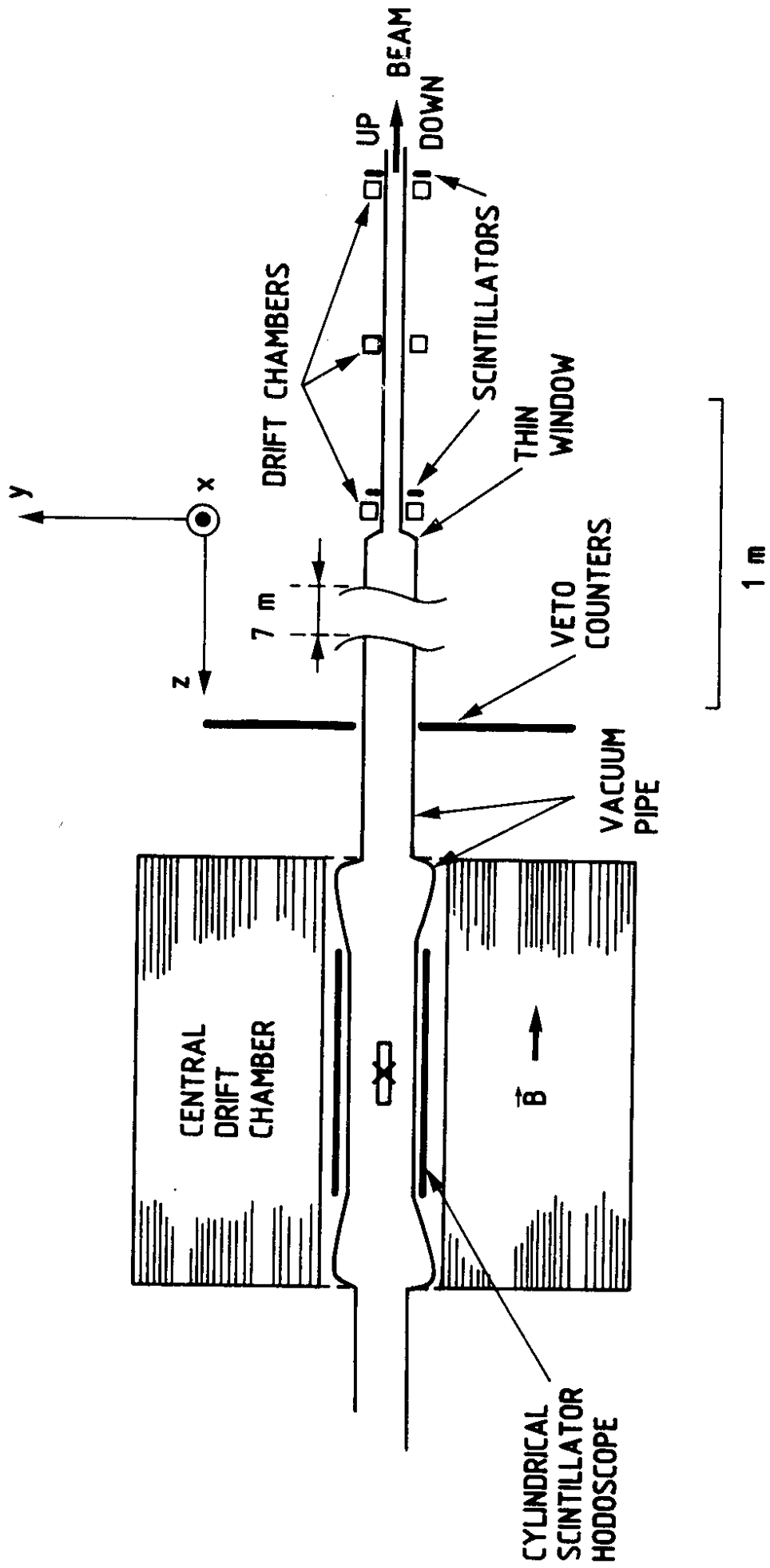


Fig. 1

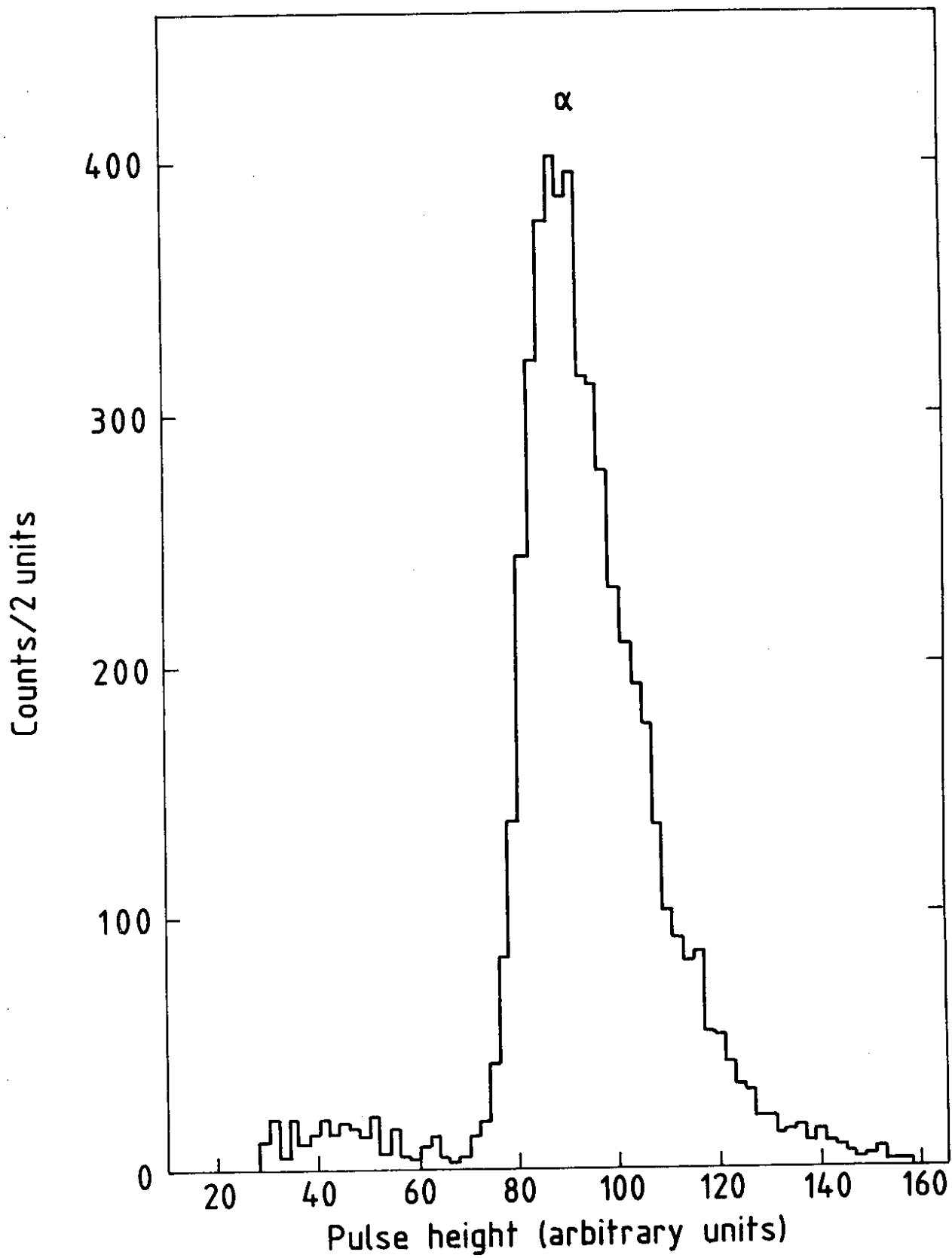


Fig. 2

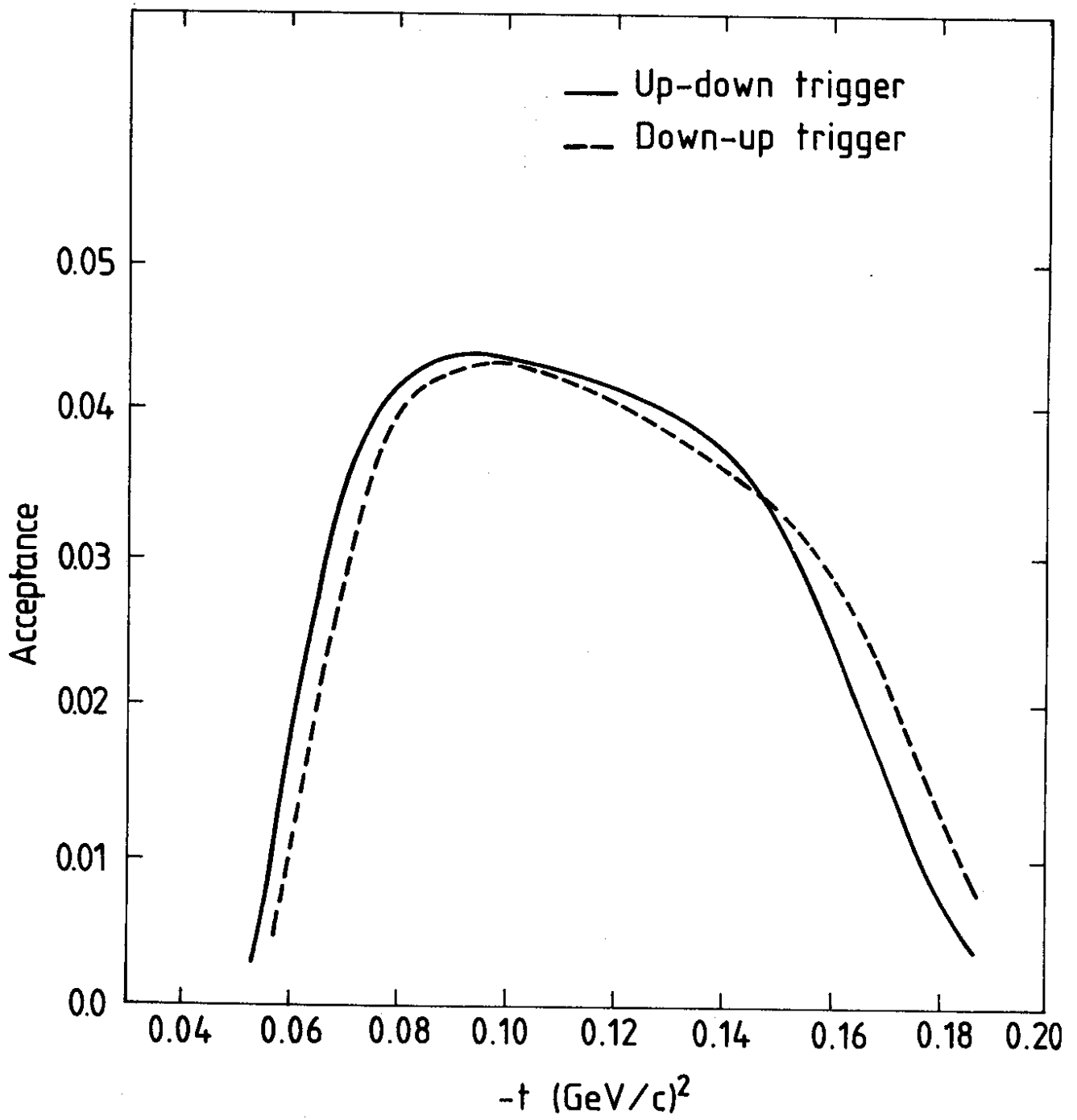


Fig. 3

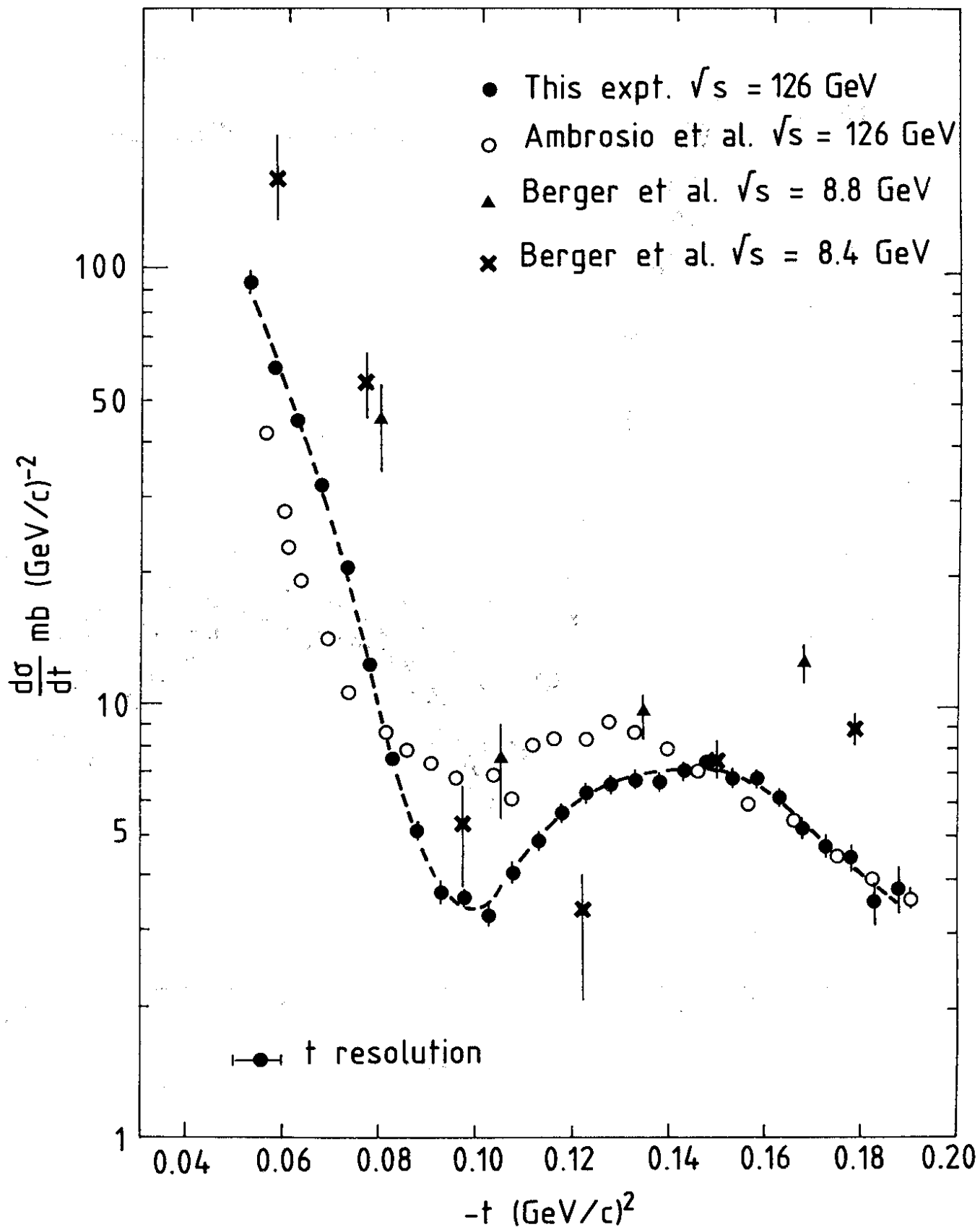


Fig. 4a

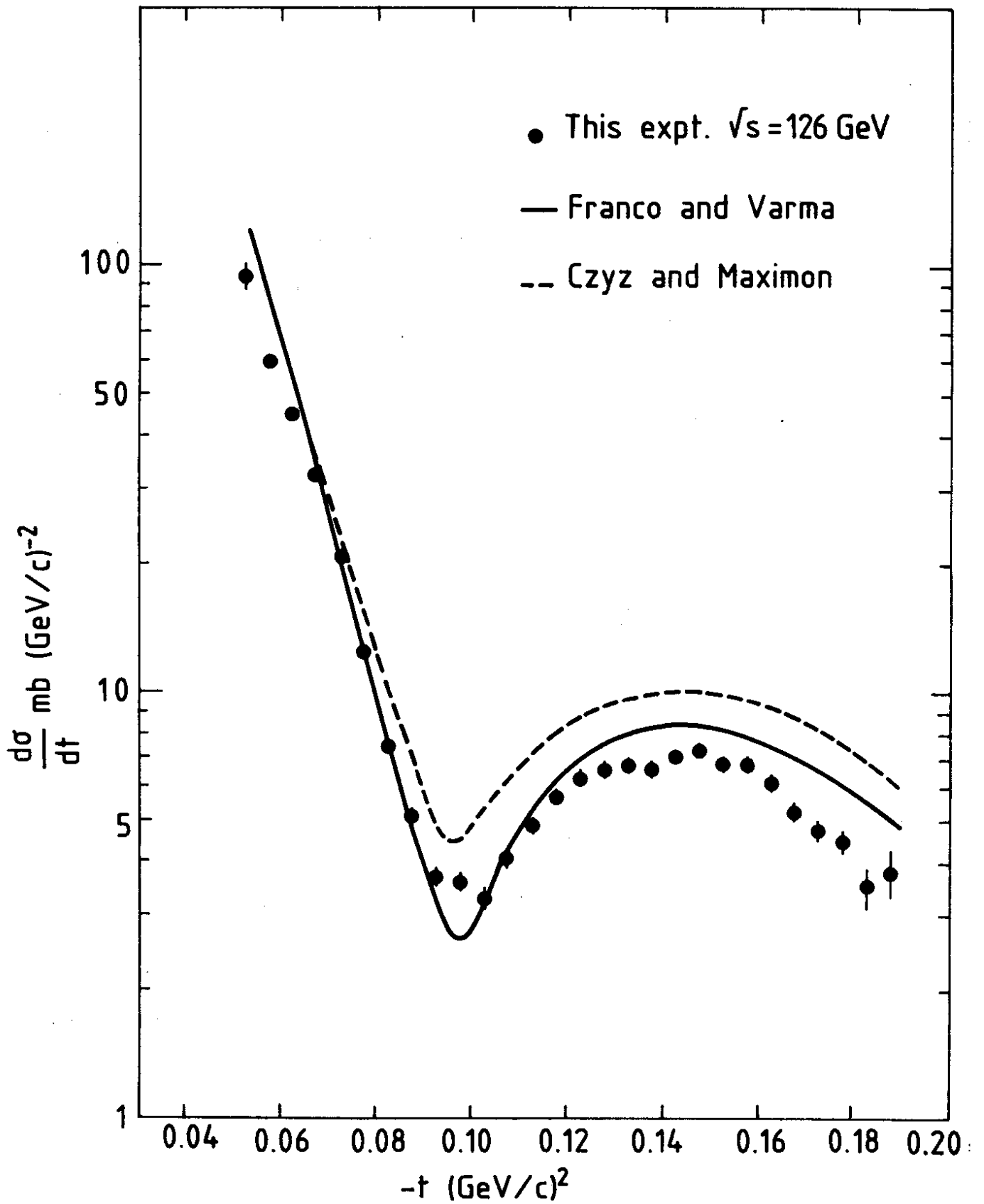


Fig. 4b