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## Measurement of small angle alpha-alpha and alpha-proton elastic scattering at the CERN Intersecting Storage Rings

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### ABSTRACT

We measured the elastic scattering of  $aa$  at  $\sqrt{s} = 126$  GeV and of  $ap$  at  $\sqrt{s} = 89$  GeV. In  $aa$ ,  $d\sigma/dt$  exhibits a slope parameter  $b = 100 \pm 10$  (GeV/c)<sup>-2</sup> for  $|t| < 0.1$  (GeV/c)<sup>2</sup>. Minima are observed at  $|t| = 0.09$  (GeV/c)<sup>2</sup> and  $|t| = 0.4$  (GeV/c)<sup>2</sup>. In  $ap$ ,  $b = 41 \pm 2$  (GeV/c)<sup>-2</sup> for  $|t| < 0.2$  (GeV/c)<sup>2</sup>, and a minimum is observed at  $|t| = 0.20$  (GeV/c)<sup>2</sup>. Results for  $pp$  elastic scattering at  $\sqrt{s} = 63$  GeV agree with previous ISR experiments.

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This letter presents results of measurements of elastic  $aa$  and  $ap$  scattering at small four-momentum transfer [ $0.05 < |t| < 0.8$  (GeV/c)<sup>2</sup> for  $aa$  and  $0.05 < |t| < 0.25$  (GeV/c)<sup>2</sup> for  $ap$ ]. These measurements were performed in July-August 1980 at the CERN Intersecting Storage Rings (ISR) with 63 GeV/c  $a$  beams and 31.5 GeV/c  $p$  beams. The luminosities achieved for  $aa$  interactions (at  $\sqrt{s} = 126$  GeV) were  $\sim 3 \times 10^{28}$  cm<sup>-2</sup> s<sup>-1</sup> and for  $ap$  interactions (at  $\sqrt{s} = 89$  GeV) they were  $\sim 50 \times 10^{28}$  cm<sup>-2</sup> s<sup>-1</sup>. Companion data for  $pp$  elastic scattering were collected at  $\sqrt{s} = 63$  GeV to provide a check of the apparatus and analysis.

The experimental apparatus (fig. 1) consisted of two sets of hodoscopes located symmetrically in each arm, downstream from the intersection region. Each of two small-angle hodoscopes (TB) comprised three components (fig. 1b). Two planes of scintillation counters (TB $\phi$ ) provided a trigger and off-line identification of the doubly charged  $\alpha$  particles through pulse-height analysis. The horizontal position of a particle impinging on the hodoscope was determined by arrays of "finger" counters (TBy), 25 mm wide, and the vertical position by two planes of drift tubes (TBx). Each drift tube [1] was a cylinder 10 mm in diameter and 300 mm in length, with 250  $\mu$ m aluminium walls and a 40  $\mu$ m diameter sense wire. The two planes, each of twelve tubes, were staggered vertically to resolve up/down ambiguities. This system was located 8.40 m from the intersection point and subtended the angular range  $3.5 < \theta < 16$  mrad. The lower limit corresponded to  $|t|$  values of 0.05 and 0.12 (GeV/c)<sup>2</sup> for  $a$  and  $p$  beams.

The hodoscopes  $H_3$  and  $H_4$  (fig. 1c) were roughly circular, covering the angular region  $25 < \theta < 130$  mrad. The fourfold coincidence ( $H_3 \cdot H_4$ )<sub>L</sub>  $\cdot$  ( $H_3 \cdot H_4$ )<sub>R</sub> served as a luminosity monitor, which had a monitor cross-section of 164, 68, and 24 mb ( $\pm 5\%$ ) for  $aa$ ,  $ap$ , and  $pp$ , when calibrated using the standard Van der Meer method [2]. The same hodoscopes were also used in the trigger logic to veto events with secondaries at large angles. The rejection factors of this veto were 10:1 for  $aa$  and 4:1 for  $ap$ , thus enhancing the fraction of elastic events in the collected data. (We have verified in special runs that  $< 1\%$  of elastic events were lost due to this requirement.)

Alpha particles were clearly resolved from singly charged particles by imposing cuts in the pulse-height distributions of both planes of a TB $\phi$  hodoscope. (Figure 1d shows one such distribution; in addition to the singly charged and doubly charged single-particle peaks, one also sees a small peak due to two singly charged particles.)

For the results presented in this letter, the requirement was made that the  $a$  was detected in the central element of the TBy hodoscope.

A candidate track in the drift tubes was defined using the following criteria: i) counts were required in an overlapping pair of tubes, one in each plane, and ii) the sum of the drift times had to correspond to the height of the cell determined by the overlap, i.e. the radius (5 mm) of a tube. Finally, elastic events were selected by requiring the collinearity of the left-arm track, the interaction diamond, and the right-arm track.

The analysis outlined above was complicated by  $\delta$ -ray production, which was manifested in one of two ways. Delta-rays could produce spurious hits in the tubes other than those of the trigger track (15% of  $a$  events). Alternatively, a  $\delta$ -ray could be detected in the same cell as the triggering particle, resulting in a drift-time sum inconsistent with criterion (ii) (30% of  $a$  events). Such events were excluded from the final sample and a correction factor was applied to the resulting  $d\sigma/dt$ . This correction factor was calculated by assuming that all events which passed the pulse-height cut and which had at least one pair of tracks collinear with the interaction diamond were elastic events. The value of the correction factor was found not to depend upon  $t$ .

The results for  $d\sigma/dt$  are presented in figs. 2a-2c for  $pp$ ,  $aa$ , and  $ap$  elastic scattering. In these figures the errors are statistical only. The major contributions to over-all scale errors are: i) uncertainty in the correction factor applied to the data (30%, 25%, and 10% for  $aa$ ,  $ap$ , and  $pp$ ); ii) uncertainty in the solid angle (10%), due mainly to the finite size of the source; and iii) uncertainty in the integrated luminosity (5%). The resolution in  $|t|$  was  $\pm 0.02$ ,  $\pm 0.02$ , and  $\pm 0.01$  (GeV/c)<sup>2</sup> for  $aa$ ,  $ap$ , and  $pp$ , and only slightly dependent on  $|t|$ . This resolution was determined largely by the finite horizontal size of the source and by the finite width of the TBy counters.

For the  $pp$  data at  $\sqrt{s} = 63$  GeV,  $d\sigma/dt$  (fig. 2a) exhibits a slope parameter  $b = 13.2 \pm 0.6$  (GeV/c)<sup>-2</sup> in the range  $0.02 < |t| < 0.07$  (GeV/c)<sup>2</sup>, reproducing the best ISR result [3] of  $b = 13.3 \pm 0.3$  (GeV/c)<sup>-2</sup> in

the same range. Using the optical theorem and the measured real part of the forward-scattering amplitude, we obtained a total cross-section  $\sigma_{\text{tot}}(pp) = 42.2 \pm 2.5$  mb, which reproduces the CERN–Pisa–Roma–Stony Brook result [4] of  $\sigma_{\text{tot}}(pp) = 43.04 \pm 0.3$  mb. (The errors given for  $\sigma_{\text{tot}}$  for all three interactions do not include scale errors.)

The  $aa$  elastic cross-section at  $\sqrt{s} = 126$  GeV (fig. 2b) shows a steep slope at low  $t$ :  $b = 100 \pm 10$   $(\text{GeV}/c)^{-2}$  for  $|t| < 0.1$   $(\text{GeV}/c)^2$ . A first minimum is observed at  $|t| = 0.09 \pm 0.01$   $(\text{GeV}/c)^2$  and a second at  $|t| = 0.38 \pm 0.02$   $(\text{GeV}/c)^2$ . Extrapolating this cross-section to  $|t| = 0$ , we obtained a total cross-section  $\sigma_{\text{tot}}(aa) = 500 \pm 150$  mb, assuming a negligible real part of the forward amplitude.

The  $ap$  elastic cross-section at  $\sqrt{s} = 89$  GeV (fig. 2c) has a slope  $b = 41 \pm 2$   $(\text{GeV}/c)^{-2}$  for  $|t| < 0.2$   $(\text{GeV}/c)^2$  and a minimum at  $|t| = 0.20 \pm 0.02$   $(\text{GeV}/c)^2$ . For this reaction the optical-theorem extrapolation gives  $\sigma_{\text{tot}}(ap) = 130 \pm 20$  mb, again assuming a negligible real part.

A summary of our results on all these reactions is presented in Table 1.

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## References

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Table 1

Summary of final results

	Alpha-alpha	Alpha-proton	Proton-proton
$\sqrt{s}$ (GeV)	126	89	63
$b$ (GeV/c) <sup>-2</sup>	100 ± 10	41 ± 2	13.2 ± 0.6
$\sigma_{\text{tot}}$ *) (mb)	500 ± 150	130 ± 20	42.2 ± 2.5
$ t _{\text{1st minimum}}$ (GeV/c) <sup>2</sup>	0.09 ± 0.01	0.2 ± 0.01	-
$ t _{\text{2nd minimum}}$ (GeV/c) <sup>2</sup>	0.38 ± 0.02	-	-

\*) Errors do not include scale errors.

Figure captions

Fig. 1: The experimental apparatus:

- a) Plan view of the intersection region.
- b) Exploded view of the TB hodoscopes.
- c) The  $H_3$  and  $H_4$  hodoscopes.
- d) Typical pulse-height distribution for one of the  $TB\phi$  counters.

Fig. 2: The measured cross-section  $d\sigma/dt$ . (Errors shown are statistical only.):

- a)  $pp$  at  $\sqrt{s} = 63$  GeV (over-all scale error: 15%).
- b)  $aa$  at  $\sqrt{s} = 126$  GeV (over-all scale error: 32%).
- c)  $ap$  at  $\sqrt{s} = 89$  GeV (over-all scale error: 27%).

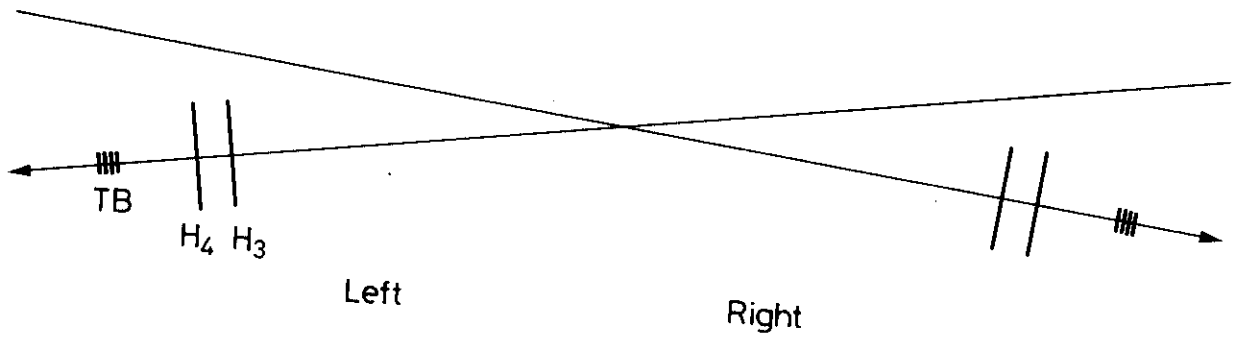


Fig. 1 a)

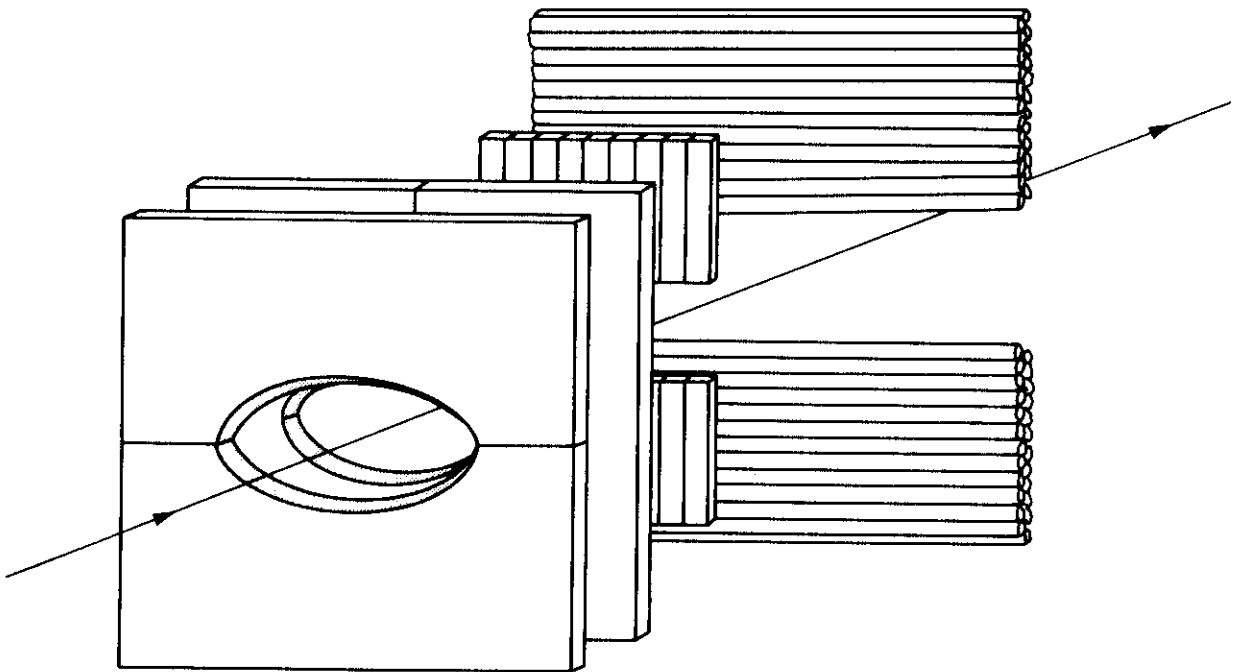


Fig. 1 b)

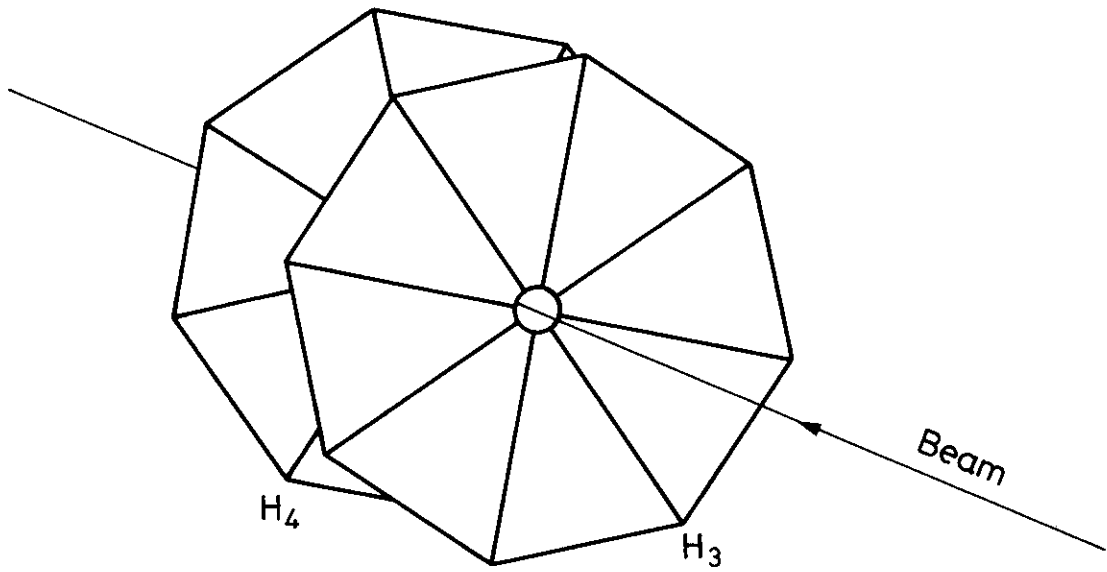


Fig. 1 c)

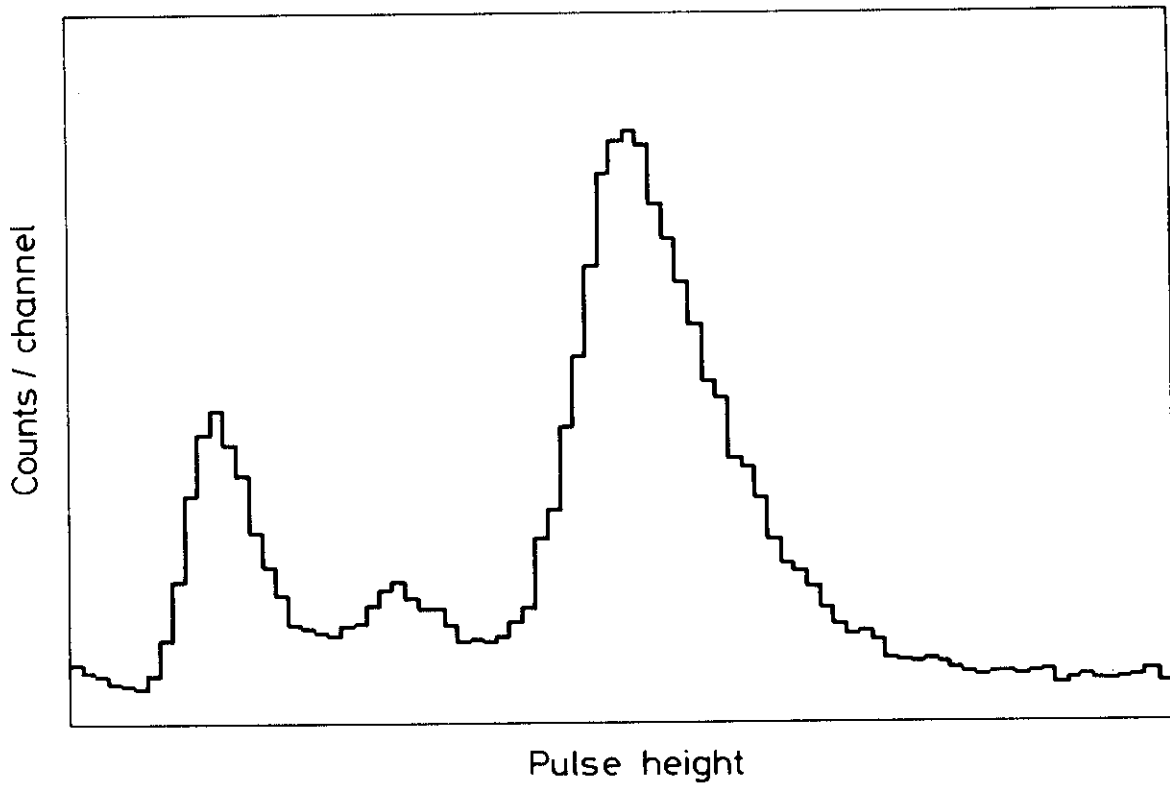


Fig. 1 d)



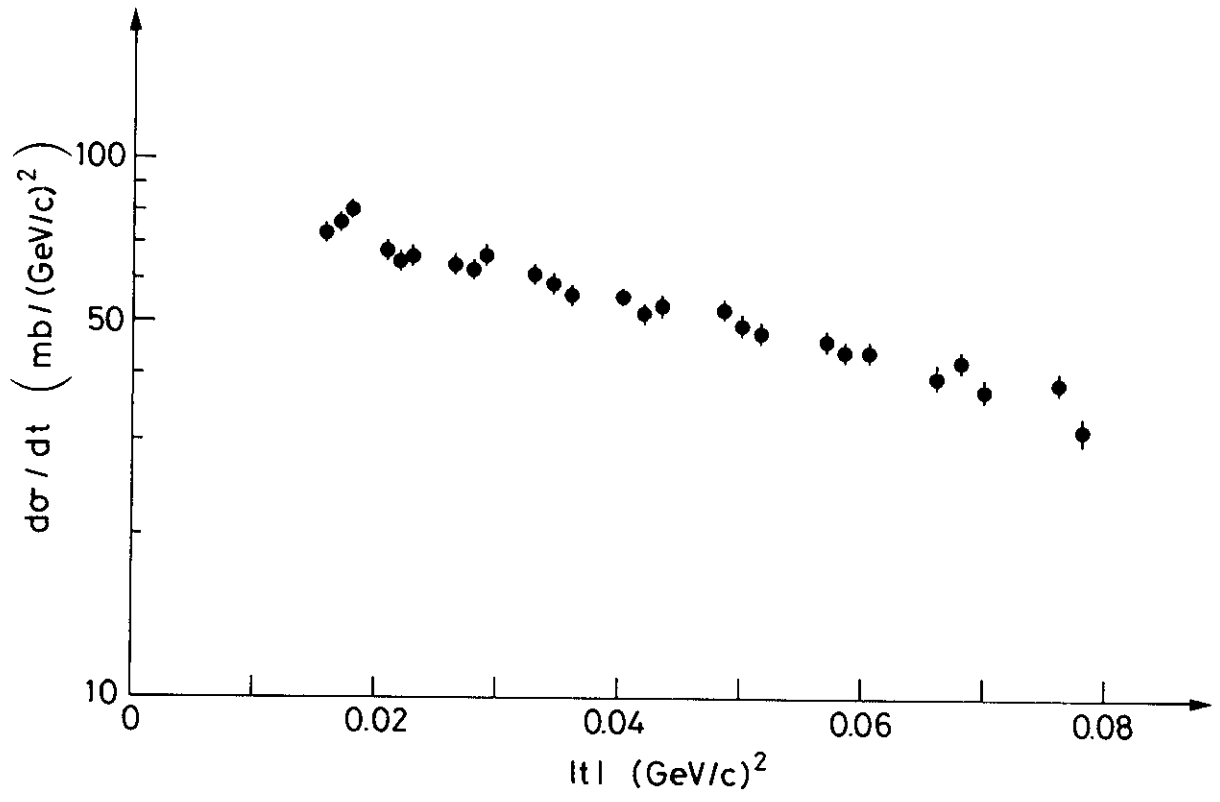


Fig. 2 a)

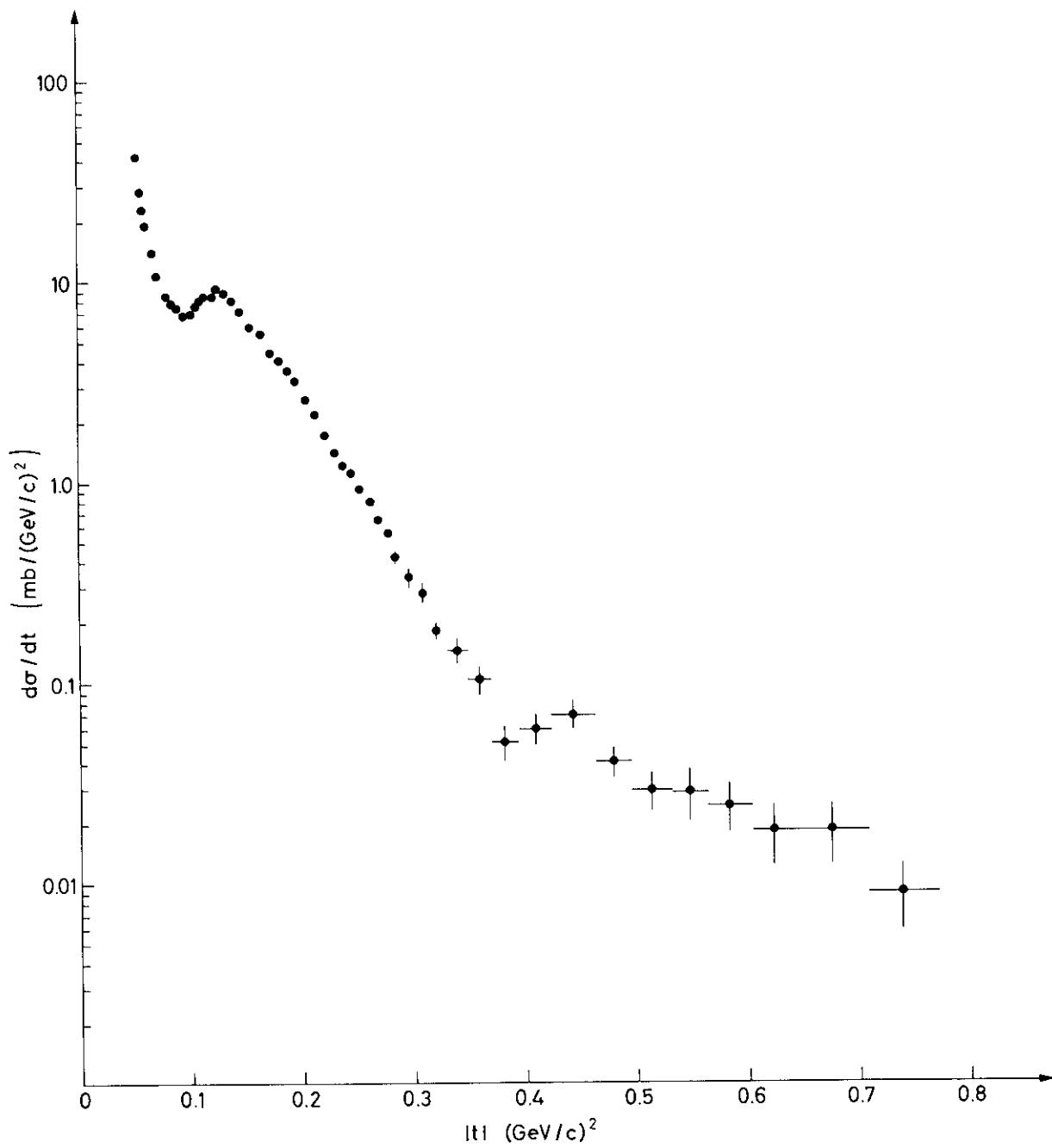


Fig. 2 b)

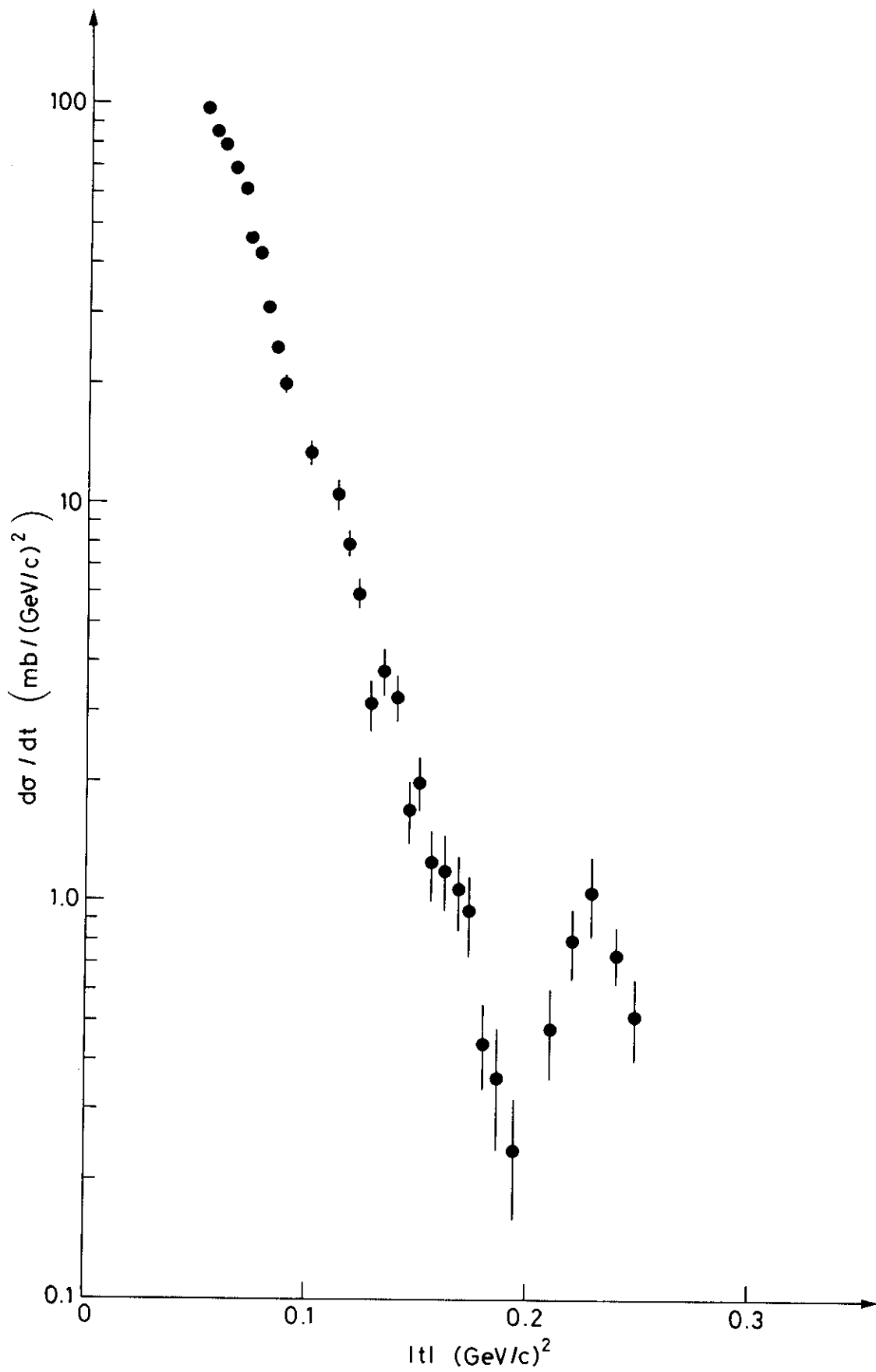


Fig. 2 c)