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PRODUCTION OF LARGE TRANSVERSE MOMENTUM GAMMA RAYS IN pp COLLISIONS FROM 50 TO 400 GeV

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ABSTRACT

We have measured the single photon inclusive cross section $d^2\sigma_\gamma/dk\,d\Omega$ for the reaction $p + p \rightarrow \gamma +$ anything at incident proton energies from 50 to 400 GeV for a fixed laboratory angle of 100 mrad. The experiment was performed in the NAL Internal Target Area, using a scintillation telescope and a lead-glass total-absorption counter. The invariant π^0 cross sections derived from the measurements show a deviation from simple exponential behavior in p_t for incident proton energies greater than 50 GeV and p_t greater than about 1 GeV/c. We present preliminary results on the energy dependence of this effect.

The behavior of cross sections for processes occurring with large transverse momentum is currently of considerable interest. In particular, measurements of inclusive pion production at the CERN ISR[1-3] have exhibited at large p_t a strong enhancement over the simple exponential falloff found at small p_t (< 1 GeV/c). We have studied the process $p + p \rightarrow \gamma +$ anything in the range of p_t from about 0.2 to 3 GeV/c for incident proton energies from 50 to 400 GeV. Using the method of Sternheimer[4] and assuming all the observed photons come from π^0 decay, the invariant π^0 cross sections can be derived from these measurements.

The experiment was carried out in the C0 straight section of the NAL main ring, using the circulating proton beam incident on a thin internal target. Thus data could be taken over the range of proton energies available during the accelerator cycle. Figure 1 shows the layout of the apparatus in the internal target area and a schematic of the detection system. The target was either a hydrogen gas jet[5,6] or 7 μ carbon fibers on a rotating wheel. For the data presented here, the apparatus was set at a laboratory angle of 100 mrad with respect to the beam direction. Permanent magnets were used to sweep away low momentum charged particles. A lead collimator restricted the apparatus to detecting only one of the two photons from π^0 decay for transverse momenta well in excess of those measured.

The detection system consisted of a veto counter (#1), a removable lead converter (1.1 radiation lengths), two coincidence counters (#2 and

#3), a lead-glass shower counter (#4, 14.1 radiation lengths), and two more scintillation counters (#5 and #6) plus lead absorber for identifying energetic muons and charged hadrons. Photons were selected by a $\overline{1} \cdot 2 \cdot 3 \cdot 4$ trigger, and "muons" by a $1 \cdot 2 \cdot 3 \cdot 5 \cdot 6$ trigger. The solid angle for photons accepted by the system was 9.5 μsr, defined by the converter which was 54 feet from the target.

Data were collected using a CAMAC system of scalers, ADC's, and latches linked to a PDP-11 computer. When a trigger occurred, the computer recorded on magnetic tape the pulse heights in all counters, the main ring magnetic field (giving the incident proton momentum for the event), plus certain scaler information. In addition to normal photon runs, data were taken with the lead converter removed and also with the "muon" trigger. The converter-out data rate was found to be about 1.5% of the converter-in rate at all transverse momenta measured, consistent with photon conversion in the counters and wrappings. For runs with the "muon" trigger, the pulse height distribution in the lead-glass counter #4 showed a clean peak, the position of which could be determined to better than ± 2%. These runs then served to monitor the lead-glass counter energy calibration,[7] which had been derived from measurements using electrons of 1.8 to 5 GeV/c in a momentum-analyzed charged beam at the Argonne ZGS.

For the preliminary analysis presented here, the photon events were binned in 25 GeV intervals of incident proton energy. A cut was made on the pulse height in counter #2 to select events with greater than minimum-ionizing pulse height, corresponding to pair production in the lead converter. Fewer than 2% of the events failed this cut. The events were then histogrammed as a function of pulse height in the lead-glass counter, expressed as photon energy or transverse momentum using the calibration described above. Checks for possible backgrounds showed them to be negligible, so no subtraction was necessary. A single calibration constant was used, as the photomultiplier tube and base for the lead-glass counter had been tested with a light pulser and found to be linear up to a response equivalent to 280 GeV photon energy.

Examples of these photon energy spectra from the hydrogen jet are shown in Fig. 2 for 50, 100, and 375 GeV incident proton energy. On this semilogarithmic scale, the 50 GeV spectrum appears as a straight line, while the higher energies show significant curvature. The deviation becomes significant above about $p_t = 1$ GeV/c. A least-squares fit to a function of the form[2, 3]

$$\frac{d^2\sigma_\gamma}{dk\,d\Omega} = A\,e^{-B\,p_t + C\,p_t^2} \tag{1}$$

was made for all energies, from both hydrogen and carbon targets, with A, B, and C being free parameters. Good fits were obtained in all cases, and the results for the shape parameters B and C are plotted in Fig. 3. The error bars are only statistical and do not include overall systematic errors, such as in the calibration of the lead-glass counter. The dashed line is included only to guide the eye. It can be seen that there is good agreement between hydrogen and carbon measurements. The B (slope) parameter values appear essentially constant with energy, while C is approximately zero at 50 GeV, increases sharply between 50 and 100 GeV, then increases relatively slowly with energy at higher energies.

The invariant π^o cross sections can be derived from the inclusive photon spectra if one assumes all the gamma rays came from π^o decay. In that case, as shown by Sternheimer,[4]

$$E \frac{d^3\sigma_\pi}{dp^3} \propto \frac{\partial}{\partial k}\left(\frac{d^2\sigma_\gamma}{dk\, d\Omega}\right) . \tag{2}$$

Since the fits described above are a good representation of the data, it is convenient to substitute Eq. (1) in Eq. (2), yielding

$$E \frac{d^3\sigma_\pi}{dp^3} \propto (B - 2C\, p_t)\left(\frac{d^2\sigma_\gamma}{dk\, d\Omega}\right) . \tag{3}$$

A measured photon spectrum and corresponding fit parameters can then be substituted in Eq. (3) to yield the invariant π^o spectrum. The distributions so derived were fitted to Eq. (1), yielding a new set of B and C parameters. Within errors, these parameters for π^o spectra were the same as for the original photon spectra.

The fact that the B parameter is approximately constant with energy is a well-known feature of particle production and is true up to the highest cosmic ray energies. The new result reported here is the very strong energy dependence of the C parameter in the region of 100 GeV incident proton energy. This result could be due to

a) dynamic or kinematic effects

b) the onset of inelastic channels

c) production of some new heavy state (or states) decaying into pions of large p_t.

At this time we have no reason to prefer any particular explanation.

It should be emphasized that at a fixed laboratory angle, the angle in the center of mass at which photons are detected increases as the incident proton energy increases. Furthermore, at lower energies our spectra reach a larger fraction of the kinematic limit on p_t. At this time we are making measurements at different laboratory angles to see if this affects the results.

In conclusion, we confirm the result from the ISR on inclusive single pion production, that the distributions at high incident proton energy and large p_t deviate markedly from a simple exponential in p_t. Our values of the C parameter (which is a measure of this deviation) for π^o spectra at 300 to 400 GeV are in reasonable agreement with those found at the ISR[2] for charged pions at similar CM energy. In addition, we present preliminary results on the energy dependence of this effect showing rapid change of the C parameter between 50 and 100 GeV. This energy dependence is being studied further.

The authors wish to thank E. Malamud, D. Jovanovic, and the Internal Target laboratory staff for their enthusiastic assistance in making this experiment possible. We are indebted to the members of the USSR-USA collaboration for providing the opportunity to use the hydrogen-jet target, especially V. Bartenev, A. Kuznetsov, B. Morozov, V. Nikitin, Y. Pilipenko, V. Popov, and L. Zolin. We would like to acknowledge the dedicated effort of the synchrotron operating staff in providing us with accelerated beam. We are grateful for the assistance of our technicians, D. Burandt, R. Olsen, and J. Hanks.

REFERENCES AND FOOTNOTES

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[1] R. L. Cool et al., (CERN-Columbia-Rockefeller collaboration), paper presented at the XVI International Conference on High Energy Physics, Chicago and Batavia, September 1972.

[2] M. Banner et al., (Saclay-Strasbourg collaboration), Phys. Letters 41B, 547 (1972); Phys. Letters 44B, 537 (1973).

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[4] R. M. Sternheimer, Phys. Rev. 99, 277 (1955).

[5] Development and operation of the hydrogen jet target supported by the State Committee for Utilization of Atomic Energy of the USSR, Moscow.

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[7] At the present time we quote a ± 10% uncertainty on the energy calibration of the lead-glass counter.

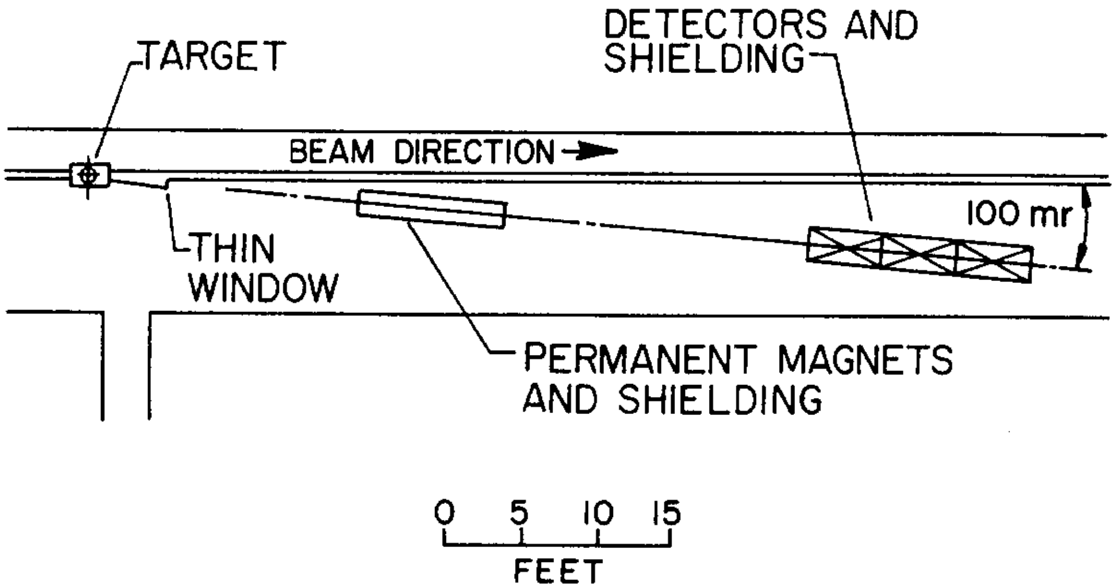
FIGURE CAPTIONS

Fig. 1 Layout of the experiment in the Internal Target Area, and schematic of the detection apparatus.

Fig. 2 Single-photon inclusive cross sections as a function of transverse momentum for protons incident on hydrogen at 50, 100, and 375 GeV.

Fig. 3 Fit parameters B and C as a function of incident proton energy for photon distributions from hydrogen and carbon. Hydrogen points are identified by circles and carbon points by squares. The error bars shown do not include systematic effects.

INTERNAL TARGET AREA



DETECTOR SYSTEM

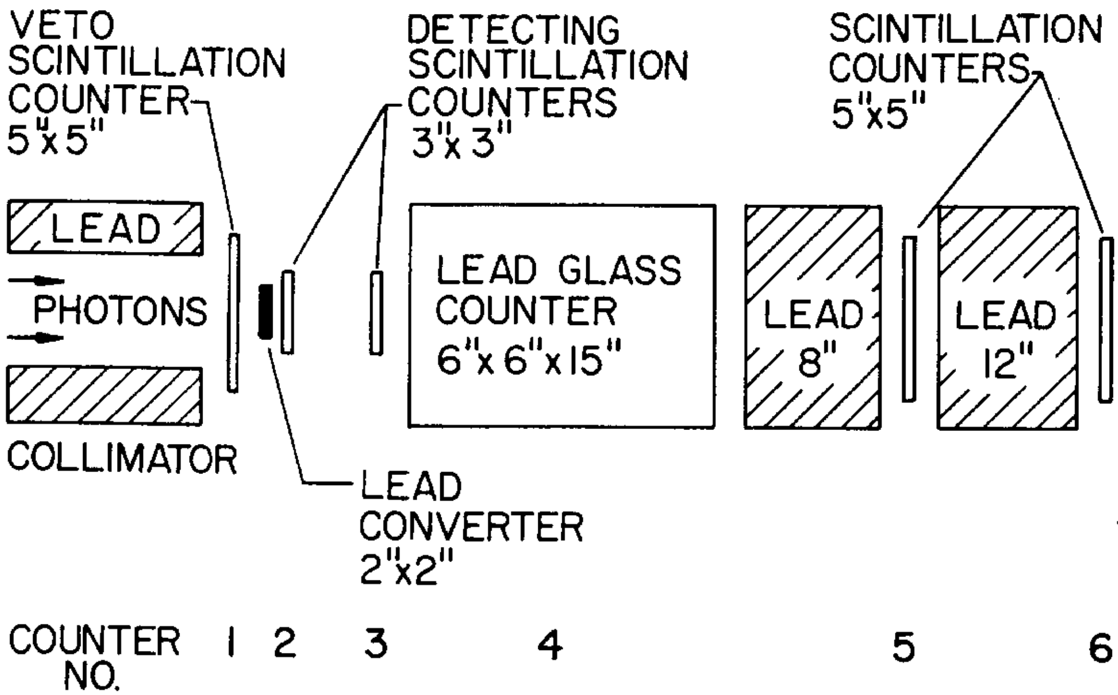
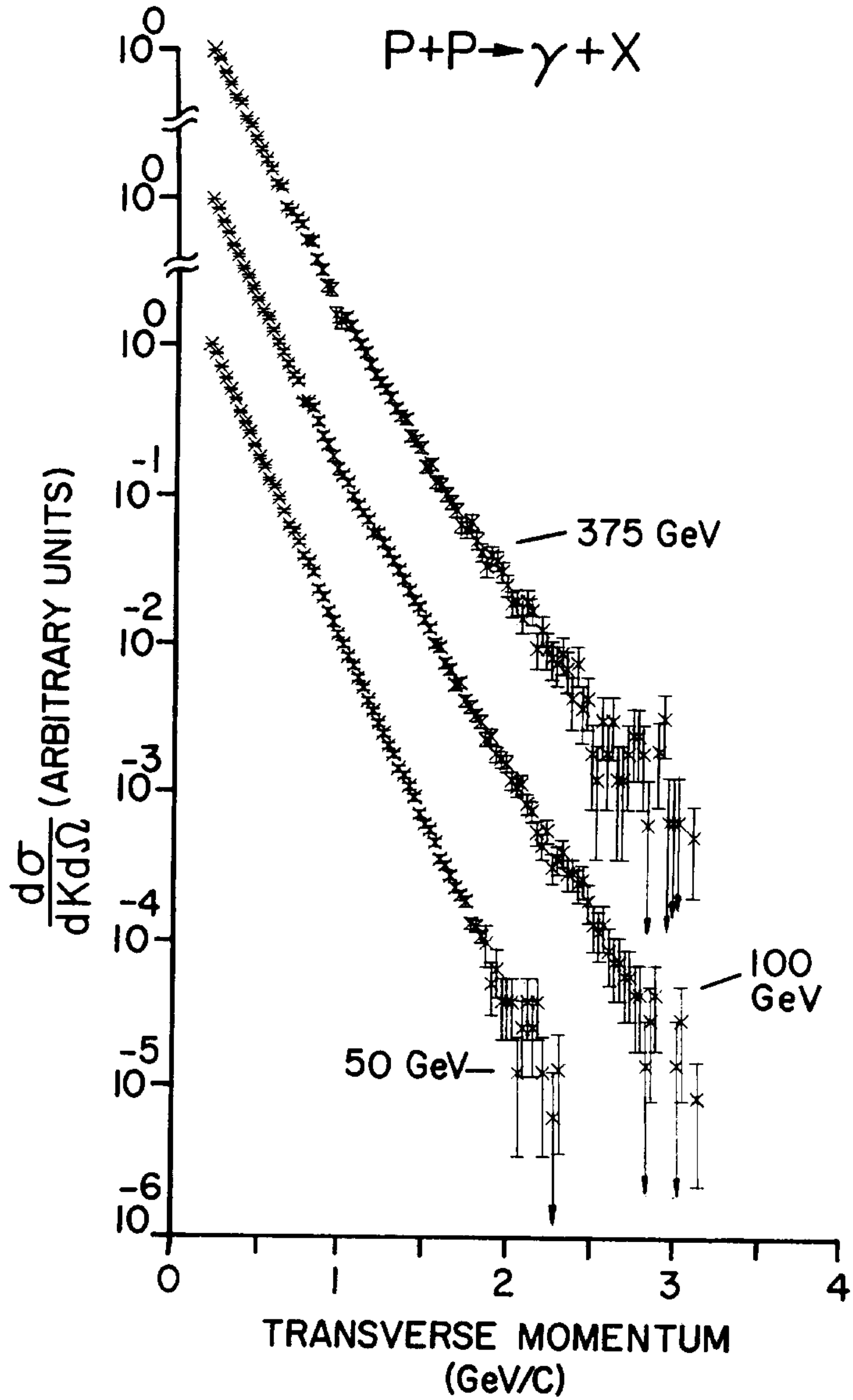


Fig. 1



P+P→γ+X
375 GeV
100 GeV
50 GeV
10^0
10^0
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
dσ/dKdΩ (ARBITRARY UNITS)
0
1
2
3
4
TRANSVERSE MOMENTUM (GeV/C)

Fig. 2

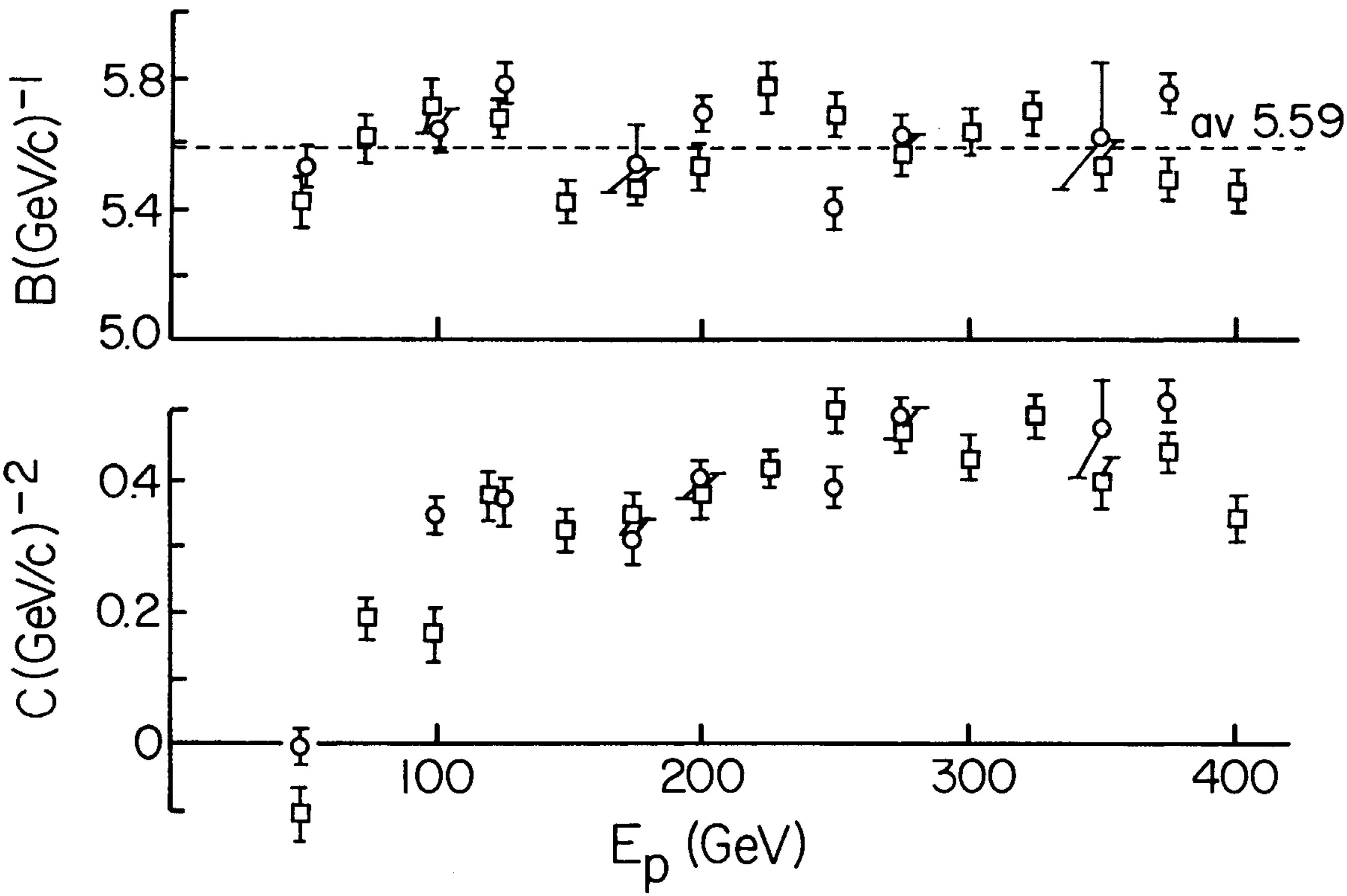


Fig. 3