DOE/ER/40033--T1

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TECHNICAL PROGRESS REPORT

Experimental Studies of Elementary-Particle Interactions at High Energies

November 1, 1981

Technical Report No.
DOE/ER/40033-15)

The Rockefeller University
New York, N.Y. 10021

DISCLAIMER

TECHNICAL PROGRESS REPORT

I. INTRODUCTION:

During 1981, the research program in experimental high energy physics at The Rockefeller University has made substantial contributions to the understanding of both strong and weak interactions. The new results have been reported at several international conferences and most are now published or have been distributed as technical reports. A list of the published work is attached as Appendix A.

The principal Laboratories which have been utilized in this work are the 500 GeV accelerator at Fermilab and the Intersecting Storage Rings facility at CERN. The latter is a facility unique in the world which provides the highest available energies for proton-proton collisions.

The results of the individual experimental projects obtained during 1981 are described in some detail below. Section II discusses the experiment at the CERN ISR; Section III discusses the research projects at Fermilab; Section IV discusses progress on two new research projects initiated in 1981.

II. RESEARCH PROGRAM AT THE CERN ISR:

Routine data-taking of the CERN-Columbia-Oxford-Rockefeller experiment R-108 at the CERN ISR was completed on July 16, 1979. A modification of the apparatus used in experiment R-108 which extends the region of photon and electron detection to the entire azimuth, complementing the full azimuth charged particle detection already available, was proposed on February 28, 1979 and approved on March 23, 1979. This new configuration (R-110) provides a factor of ~ 4 increase in acceptance for the detection of e^+e^- pairs. The new shower counters are made of conventional lead and scintillator. The experiment was installed in the ISR in 1980. An enormous amount of support was provided by CERN in order to get the experiment installed in such a short time. After some

months of routine operation, mechanical supports of the superconducting magnet coil failed. Repairs required about six months. The repaired apparatus is now in routine operation. Beside p-p data, a small amount of data on $\bar{p}$-p interactions has been obtained.

From the data of R-108, new results of considerable current interest have been obtained and published[1,2]. These results are directly related to the question of the internal (quark) structure of hadrons. The high energy of the ISR, combined with its high luminosity, makes it possible to study the rare interactions with very large momentum transfer (Q). These interactions are expected to be dominated by q-q and $\bar{q}$-q collisions and therefore capable of revealing information about internal quarks and the quantum of their interaction, the gluon.

Direct γ-rays - Recently there has been considerable interest in the so-called QCD Compton effect; i.e., the constituent reaction quark + gluon → quark + γ-ray. QCD predicts that this process should dominate as a source of single γ-rays at large Q. If QCD is correct, the only in principle unknown is the gluon distribution in the proton. The beauty of this reaction from the experimental point of view is that the γ-ray, unlike a quark or gluon, emerges from the proton without fragmentation.

Single γ-rays and $\pi^0 \to \gamma\gamma$ cannot be resolved in this experiment. However, the statistical division of a given sample into the fraction of single γ-rays and $\pi^0 \to \gamma\gamma$ is accomplished by measuring the average conversion probability for the sample in a one-radiation-length-thick converter.

Figures 1a and 1b show that the single γ-rays are, for the most part, unaccompanied by charged particles. This new result[1] strongly suggests that the QCD Compton effect dominates, as expected, since other competing processes would be accompanied by charged particles from a fragmentation process.

In addition, for the QCD Compton effect in p-p collisions, the quark involved should be eight times more often positively charged than negatively charged. This large ratio ($R=N_+/N_-$) should be reflected in the charge of the leading particle of the fragmentation of the jet on the side opposite the observed γ-ray. The new result of Figure 2 shows that this ratio is large, and increasing with p_T, as is consistent with the QCD Compton process.

Thus we believe that our new evidence strongly supports QCD. In addition, the process provides a tool for studying the gluon distribution in the proton. Our new work at the SPS with $\bar{p}$-p and p-p will be directed toward this objective.

Observation of Triple Jet Structures - QCD predicts, qualitatively, that in a fraction of the high p_T two jet events which we observe, there should be an additional third jet. This third jet would result from radiating an additional gluon which subsequently fragments into pions. Indeed, the observation of this QCD radiative effect in e^+e^- collisions at PETRA gave very strong support to QCD. Observation of this effect in p-p collisions is much more difficult experimentally. Recently, however, we have been able for the first time to give clear evidence that this radiative process also occurs in p-p collisions[2]. As is qualitatively expected, the third jet appears in a larger fraction of p-p events than in e^+e^- collisions. Further experimental and theoretical analysis will be required before quantitative agreement can be firmly established.

Production of high $p_T\pi^0$-mesons in p-α and α-α collisions -

The inclusive cross section for the production of high p_T π^0-mesons in α-p and α-α collisions has been measured[3]. This measurement was made possible by the successful storage of high intensity α-particle beams in the ISR. The results may also be compared to our earlier measurement for p-p collisions.

It is of considerable interest to compare the ratio of production of p-α to p-p and of α-α to p-p. If, as is usually supposed, the production of high p_T π^0-mesons arises dominantly from quark-quark or quark-gluon collisions, then the cross sections ratios should be 4 and 16, respectively. As seen in Figs. 3 and 4, the p-α to p-p ratio approaches 4 at high p_T. Surprisingly, the α-α to p-p ratio is well above 16 at all measured p_T's, and at the highest is $\sim$ 40. There is not any clear interpretation of this unexpectedly large ratio. It could imply the onset of new, coherent effects which have been suggested could take place for collisions of very heavy ions (e.g., Uranium). However, the small size of the α-particle nucleus argues against this conclusion. Secondary scattering might also account for such an effect, but the fact that the p-α to p-p ratio does not rise above 4 does not appear consistent with this view. A number of theoretical groups are in process of calculations seeking to understand quantitatively this new result.

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1) - A.L.S. Angelis et al., Phys. Lett. 98B, 115 (1981).

2) - A.L.S. Angelis et al., Phys. Lett 105B, 233 (1981).

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III. RESEARCH PROGRAM AT FNAL:

A. Hadron Dissociation - The analysis of Fermilab Experiment #396, designed to measure the elastic and diffractive dissociation cross sections of $\pi^{\pm}$, $K^{\pm}$ and $p^{\pm}$ on p for $0.03 < |t| < 0.1$ $(GeV/c)^2$, has been completed. An extensive study was performed of the proper parametrizations and calibrations of the various parts of the apparatus, the drift chambers, recoil counters, multiplicity counters and lead-glass blocks. After completing this tedious work we turned to extracting the slope dependence of the elastic cross sections. During the past year, great interest developed in the slope of the $\pi^- p \to \pi^- p$ cross section in our t range because measurements below and above this range indicated a sharp break in the slope. Such a break would violate unitarity [see S.M. Roy, Phys. Lett. 43, 19 (1979)]. Our data[1] show no sign of a break (see Fig. 5), and we can indeed fit all existing data with a slope that is a gentle function of t consistent with unitarity. Thus, perhaps unfortunately, the elastic data present no urgent theoretical challenge but our results do fill important gaps and extend the measurements to higher energies.

Besides their intrinsic interest, the elastic events provide an important tool for checking the quality of our data since their behavior in our apparatus can be easily understood. Previously measured slopes of $pp \to pp$ elastic cross sections are in excellent agreement with our results.

The diffraction cross sections for various incident hadrons[2] seem to satisfy simple factorization rules indicated by Mueller-Regge theory. All the hadronic cross sections go as $1/M_X^2$, where M_X^2 is the missing mass squared, pointing to the Triple-Pomeron dynamic contribution independent of particle type. While these results were anticipated, they had not previously been experimentally verified.

New results, somewhat unanticipated, were obtained on the multiplicity of the hadronic final state[3]. We have found, among other results, that the multiplicity of the diffractive system exhibits KNO scaling[4], and that the shape of the multiplicity distribution is consistent with quark fragmentation models. Hence, it is possible that in the near future diffraction dissociation may be understood within the same framework of quarks and partons that increasingly explain other strong interaction processes.

B. Photon Dissociation - The apparatus TREAD (The Recoil Energy and Angle Detector) for experiment E-612 has now been completed on time and on budget. It was installed in the tagged-photon beam at FERMILAB early in 1981, and a successful test run with beam was carried out in the spring of 1981.

TREAD provides a new and unique detector for the detailed study of low t elastic and diffraction scattering by photons and hadrons. The construction of this device and the results of detailed operational testing have been described in a paper submitted to Nuclear Instruments and Methods[5]. Further applications of the principles of this device are under discussion.

The data obtained during the test run has been analyzed and some preliminary results of general interest were submitted to the 1981 Lepton-Photon Conference in Bonn[6]. The cross section is shown in Fig. 6.

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1) - R.L. Cool et al., Rockefeller University Report No. RU81/A-2 (accepted for publication by Phys. Rev. D)

2) - R.L. Cool et al., Phys. Rev. Lett. 47, 701 (1981).

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4) - Z. Koba, H.B. Nielsen and P. Oelsen, Nucl. Phys. B40, 317 (1972).

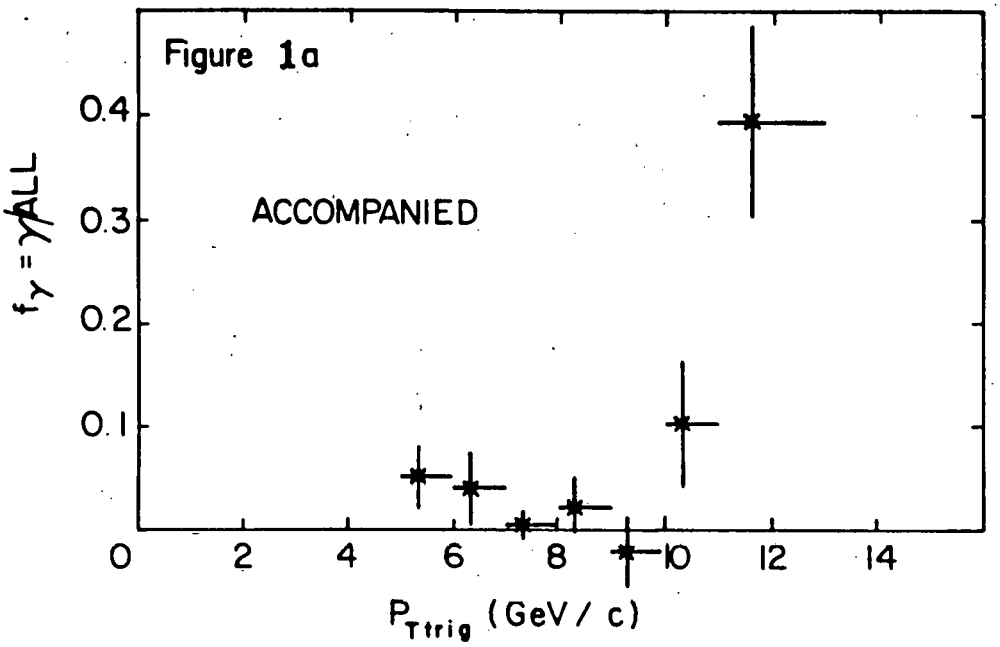
5) - T.J. Chapin et al., Rockefeller University Report No. RU81/A-9 (accepted for publication - Nuclear Instruments & Methods).

6) - T.J. Chapin et al., Rockefeller University Report No. RU81/A-10 [DOE/ER/40033-10] (contributed to the 1981 Intl. Sym. on Lepton and Photon Interactions at High Energies, Bonn, Germany, August 1981).

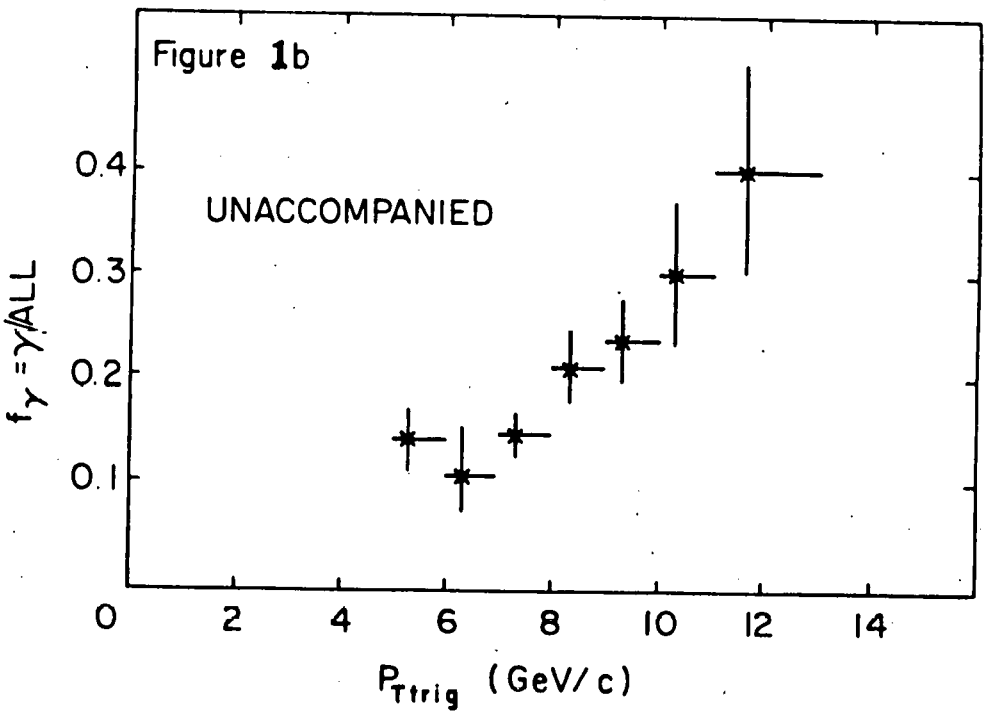
IV. NEW EXPERIMENTAL INITIATIVES:

A. Last year we proposed to build a new wide-aperture, high-resolution beta spectrometer to measure the tritium beta decay spectrum. The goal of the work is to search for a non-zero mass of the electron neutrino with a resolution more than one order of magnitude greater than that heretofore achieved. The experiment should be able to observe masses down to $\approx$ 4 eV with a resolution of $\approx$ 2 eV. Detailed design and testing of design concepts are in progress. Further discussion of the motivation for this work, together with details of the design progress and budget, is to be found in our new contract Proposal.

B. $\bar{p}$-p and p-p Interactions at the CERN SPS - Our proposal, presented to CERN in 1980, was approved in 1981 and designated UA-6. Conceptual design has been completed and detailed design and testing of components is now in progress. The detailed proposal to CERN and the expected time and financial schedules are to be found in our new contract Proposal.



The fraction of events attributed to direct-photon production as a function of $p_{T\,trig}$, for those events where the trigger was accompanied by a particle in the trigger hemisphere.



The same for those events where the trigger was not accompanied by a particle in the trigger hemisphere.

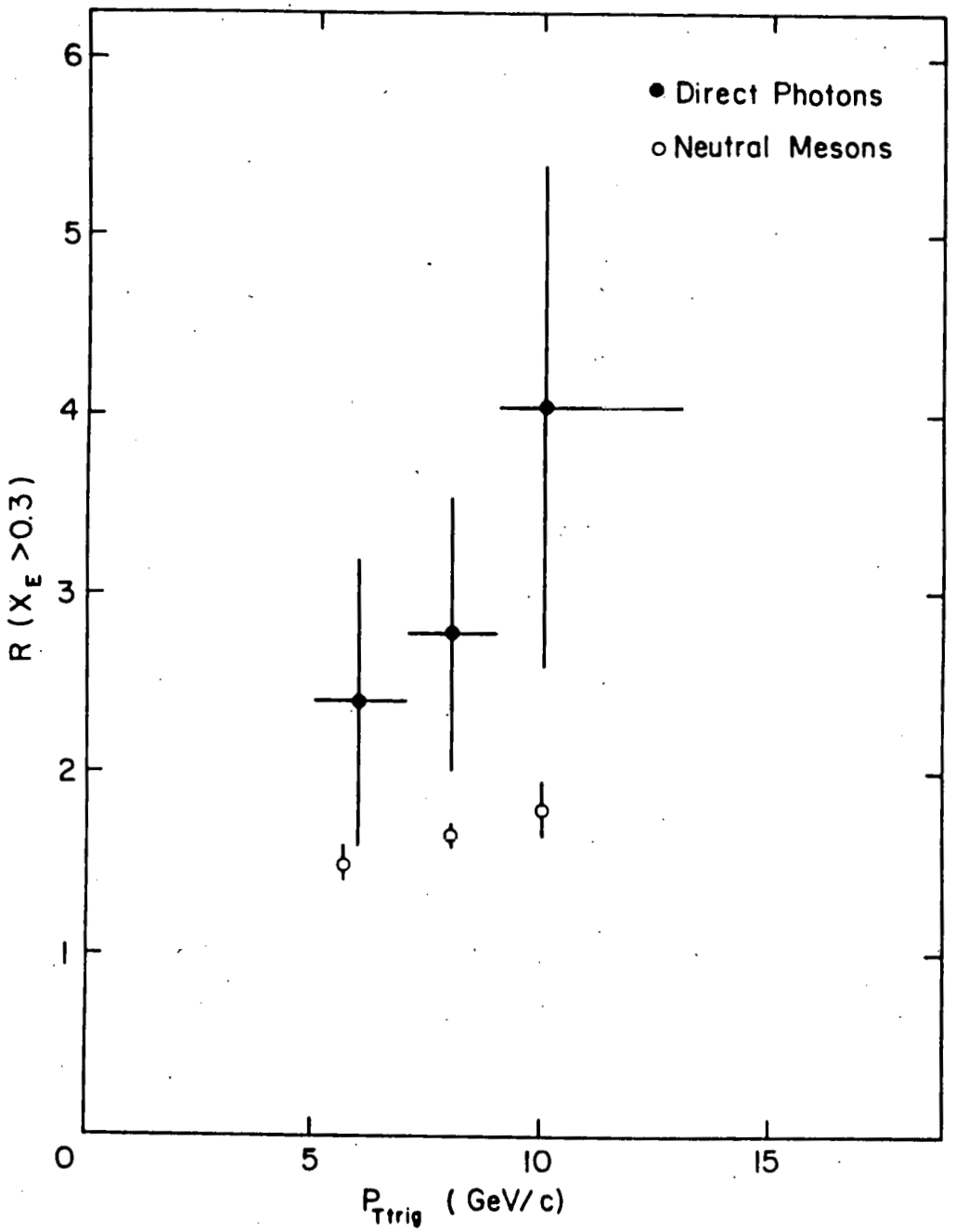


Fig. 2

The charge ratio R for $x_E > 0.3$ plotted as a function of $p_{T\,trig}$ for direct photons and neutral mesons. In addition to the errors shown, there is an over-all systematic uncertainty of ±20%.

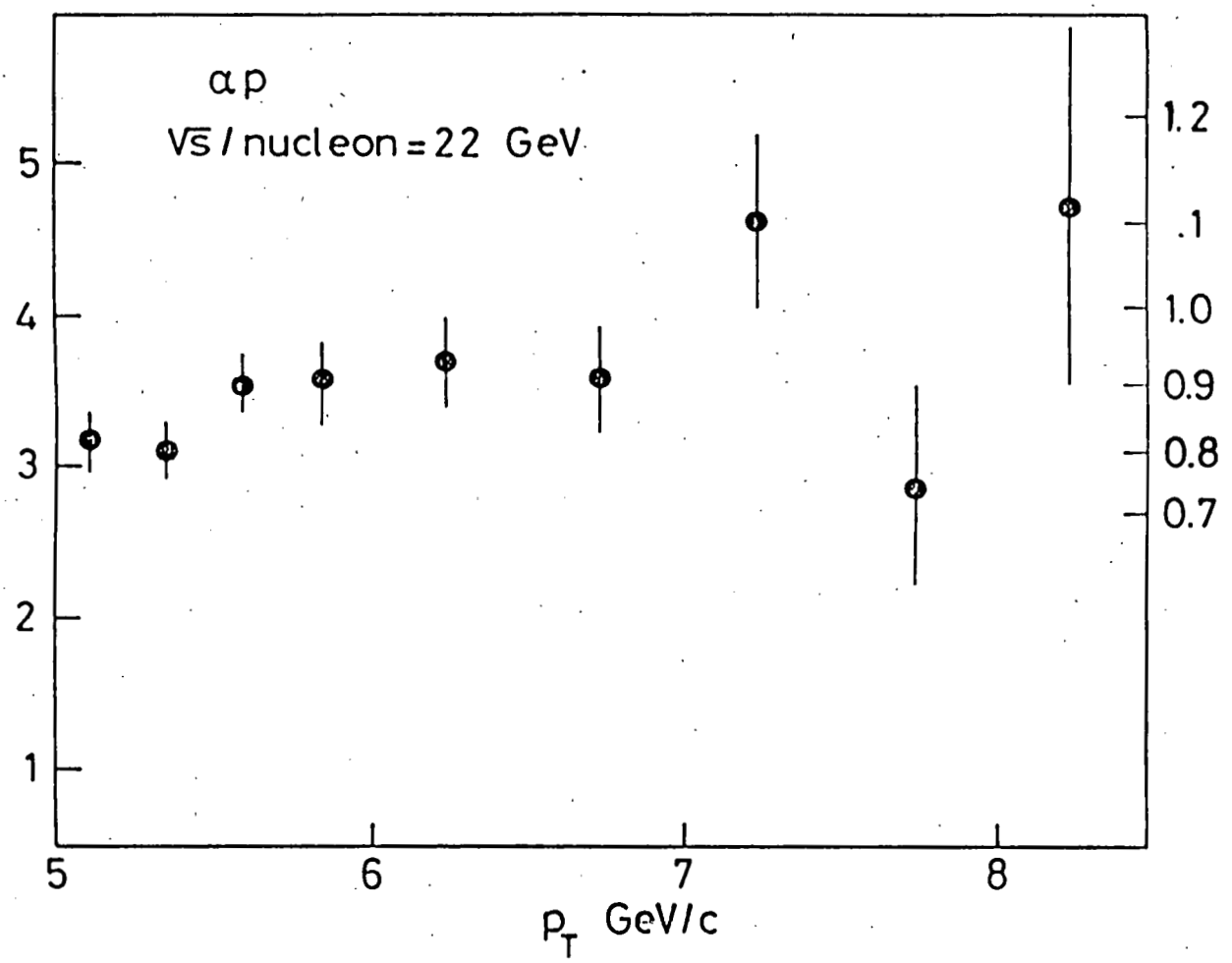


FIGURE 3

The ratio as a function of the transverse momentum p_T of the inclusive cross section for the production of π^0-mesons near 90^0 c.m. in α-p collisions to that in p-p collisions at $\sqrt{s}$ per nucleon equal to 22 GeV. The ratio R is shown on the left hand ordinate; the values of $\alpha = \ell n(R)/\ell n(A_1 \cdot A_2)$, where A_1 and A_2 are the atomic numbers of the beam particles, are shown on the right hand ordinate.

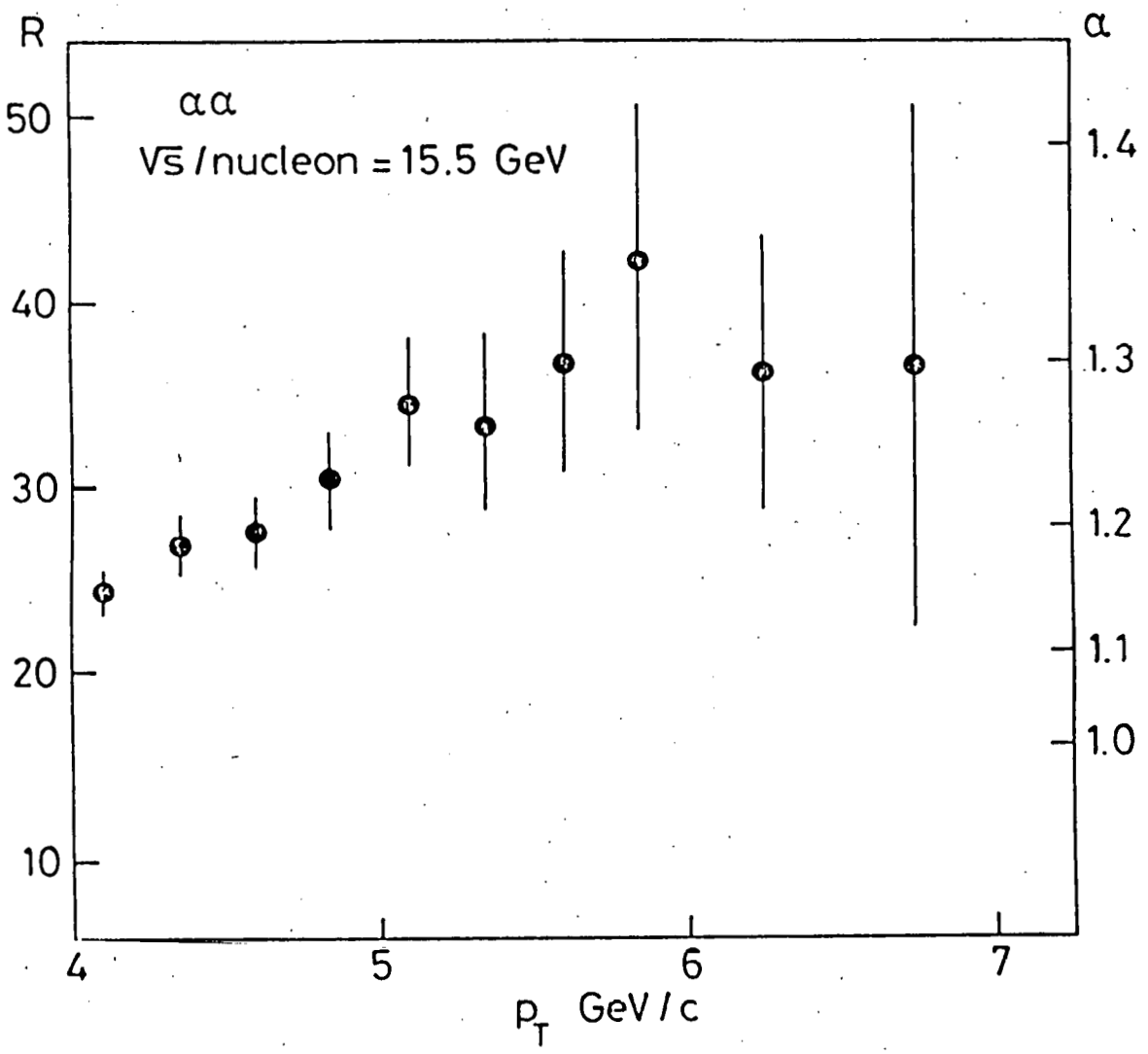


FIGURE 4

The ratio as a function of the transverse momentum p_T of the inclusive cross section for the production of π^0-mesons near 90° c.m. in α-α collisions to that in p-p collisions at $\sqrt{s}$ per nucleon equal to 15.5 GeV. The ratio R is shown on the left hand ordinate; the values of $\alpha = \ell n(R)/\ell n(A_1 \cdot A_2)$, where A_1 and A_2 are the atomic numbers of the beam particles, are shown on the right hand ordinate.

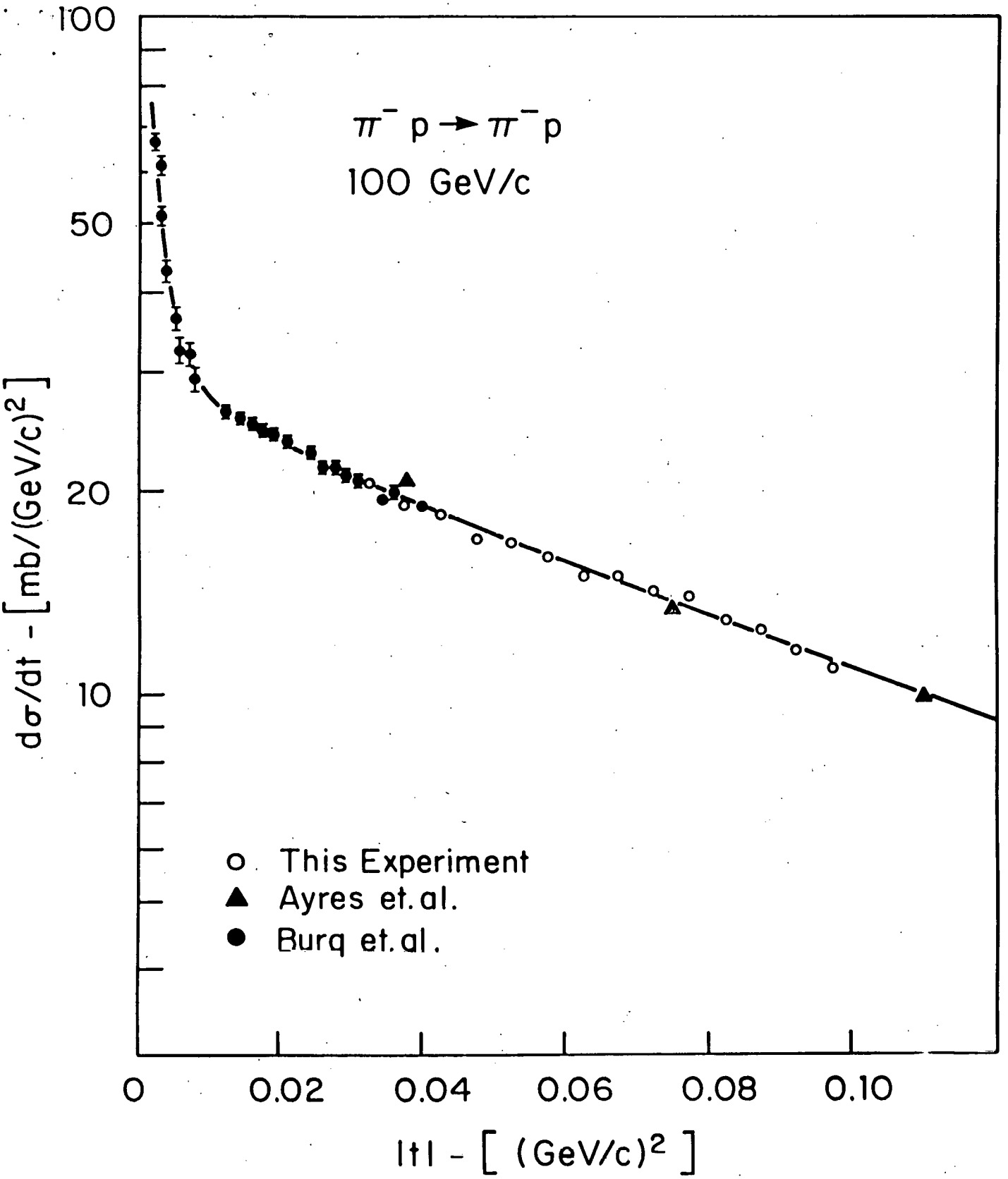


FIG. 5 - Elastic differential cross section $d\sigma/dt$ versus t for $\pi^- p$ at 100 GeV/c. The line represents a fit to the data which includes both the Coulomb and nuclear interactions.

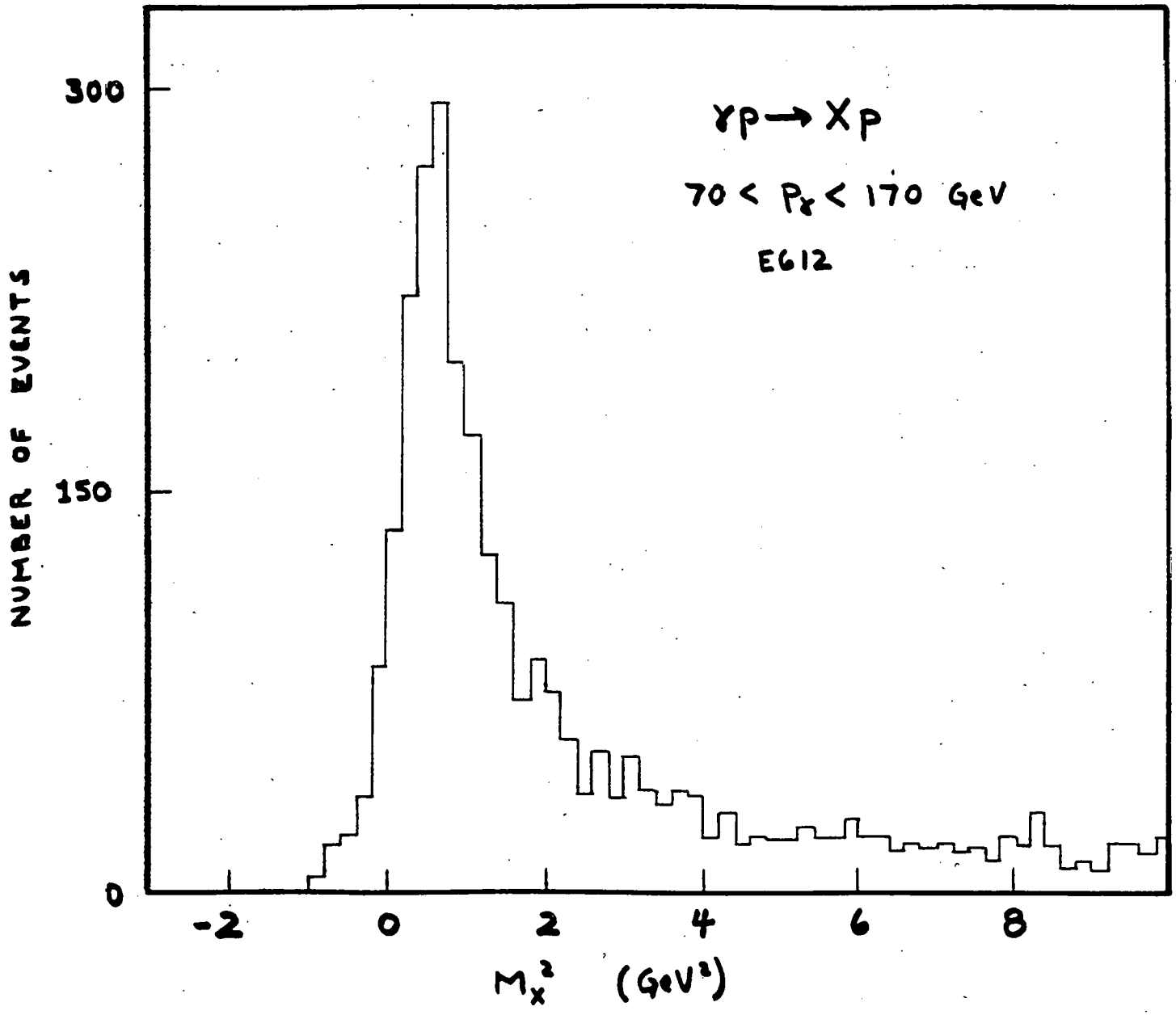

300
150
0
NUMBER OF EVENTS
γp → Xp
70 < P_γ < 170 GeV
E612
-2
0
2
4
6
8
M_X^2 (GeV^2)

FIGURE 6

APPENDIX A

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