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PION DISSOCIATION IN THE NUCLEAR COULOMB FIELD†

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Abstract: A forward spectrometer detecting both charged particles and photons has been used at Fermilab to study the excitation of pions in the Coulomb field of heavy nuclei. The results have been analyzed to yield a new value for $\Gamma(\rho^- \to \pi^-\gamma)$ and an upper limit to $\Gamma(A_2^- \to \pi^-\gamma)$.

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The radiative decays of mesons ($a \to b + \gamma$) can be measured directly only if a sufficiently pure sample of "parent mesons" can be prepared. If, in addition, the decay $a \to b + \pi^0$ is also allowed, then it becomes very difficult to distinguish between a pure radiative decay and the emission of two photons forming a π^0. For these reasons it has thus far not been possible to measure the decays $\rho^- \to \pi^- + \gamma$ and $K^{*-} \to K^- + \gamma$ directly. These processes have been probed using the inverse reaction to determine the radiative branching ratios. A heavy nucleus (charge Z) is commonly employed as a source of photons. The reaction

$$b + Z \to a + Z,$$

mediated by one-photon exchange was first proposed by Primakoff[1] as a way to measure the width of the decay $a \to b + \gamma$. Further theoretical investigations,[2] including calculations of nuclear absorption effects[3] and of other competing exchanges,[4] have stimulated experiments to determine the $\rho \to \pi\gamma$ and $K^* \to K\gamma$ partial widths.[4,5,6] At the low energies at which these experiments were performed the competing ω-exchange made the extraction of the radiative widths somewhat model dependent. Both exchange reactions lead to coherent production off complex nuclei; the same J^P content of both exchanges also leads to identical predictions for the angular decay distributions of the vector mesons. Nevertheless, the difference in the Z-dependence and in the t-distributions [$d\sigma/dt \sim (t-t_{min})/t^2$ for one-photon exchange and $d\sigma/dt \sim t$ for ω-exchange at small t] enables one to separate the two contributions. The only difficulty lies in the fact that ω-exchange is comparable to γ-exchange at low energies and

and important interference between the two coherent exchanges must be unravelled to ascertain the partial widths.

At high energies, ω-exchange, which falls off approximately as the inverse of the laboratory momentum ($1/P_L$), becomes only a small correction to photon exchange, whose integrated cross section increases logarithmically with incident energy. We have therefore undertaken a program to measure the Coulomb-dissociation (one-photon exchange) of charged pions and kaons at energies of 150 and 250 GeV. The first run with substantial data took place during June and July of 1978; we present here the preliminary analysis of ρ^- and A_2^- production, based on a partial sample of data taken at only one energy (150 GeV).

The experimental setup, shown in Figure 1, is a forward spectrometer which can detect charged particles, neutral "Vee" decays, and photons. The incident beam is defined by two sets of MWPC's and tagged by three Čerenkov counters (not shown). Two arrays of drift chambers, before and after a bending magnet 20 cm × 60 cm in aperture, measure the momenta and directions of forward-going charged hadrons. Any short-lived neutral hadrons (K_S^0 or Λ), decaying in a 6 m long vacuum pipe downstream of the target, are also detected and analyzed using the same set of drift chambers. A liquid-argon electromagnetic-shower detector of 25 radiation lengths thickness, subdivided into 1.3 cm wide horizontal and vertical strips, measures both position and energy of all photons passing through the magnet aperture.

Various veto counters around the target, the vacuum pipe, and magnet aperture enhance triggers for only those events where all secondary charged particles or photons enter the spectrometer aperture. Two sets of MWPC's, located both in front and behind the magnet, as well as pulse-height criteria for sundry counters, are used as part of the trigger and allow selection of events with a specified number of charged particles entering the spectrometer. Small-angle elastic scattering events and particles in the beam halo are suppressed by a vetoing matrix between the MWPC's defining the beam and the MWPC upstream of the analyzing magnet.

The argon shower detector, with associated scintillation counters in front, was also included in the trigger by demanding that at least 15 GeV in total neutral energy be deposited in the front 13 radiation lengths of the detector.

In order to measure coherent diffractive processes off complex nuclei, and the even narrower Coulomb dissociation peaks, it is crucial that the transverse momentum resolution of the experimental setup be as good as possible. Using only a preliminary calibration of the argon detector we have achieved an energy resolution of $\pm 20\%/\sqrt{E(\mathrm{GeV})}$ and a position resolution of ±1 mm for this analysis. A calibration run with 50 GeV electrons showed an inherent resolution of ±2% at this energy (after correcting for the gain variations of the individual amplifiers). The presently achieved transverse momentum resolution of the combined charged-neutral spectrometer is ±20 MeV/c, as determined from reconstructing kaons from their $\pi^-\pi^0$ decay in the vacuum pipe.

We have thus far analyzed only that fraction of the pion data in which there was one charged particle associated with two photons. Figure 2a shows the 2γ mass distribution of all such events using a lead target; Figures 2b and 2c show the energy distribution of all $\pi^-\pi^0$ events from carbon and from lead. The larger contamination from low-momentum $\pi^-\pi^0$ events in carbon is probably associated with the copious diffractive A_1^- production, in which one of the π^0's is lost in the detector (or possibly misses the detector entirely). In Figure 3a we show the mass distribution of all "elastically" produced $\pi^-\pi^0$ events. The curve is a fit to the data, using the integrated Coulomb-dissociation cross section and a p-wave Breit-Wigner for the ρ-meson line shape. Note that Coulomb production distorts the ρ-shape by enhancing contributions at low masses.

In Figure 4 we show the coherent differential cross section $d\sigma/dt'$ for ρ-production off copper and lead. We also display curves showing pure on-photon exchange contributions smeared for experimental resolution. There is evidence at larger t' for a process different from photon exchange; without a more detailed analysis we cannot tell whether this is due to incoherent background reactions or whether this is evidence for ω-exchange. Extrapolating available low-energy data[7] to our energies, we expect an ω-exchange contribution for copper given by the solid curve. We estimate that any interference between the two exchanges will affect our data by at most 15%.

Integrating the differential cross section out to various values of t', we have determined the width $\Gamma(\rho \to \pi^-\gamma)$, separately

from the lead and from the copper data. We obtain for copper $\Gamma = 48 \pm 12$ KeV and for lead $\Gamma = 50 \pm 12$ KeV. Thus, we obtain a result which is consistent with a previous measurement by Gobbi et al,[5] at 22 GeV, where the ω-exchange contribution to ρ^- production at small angles was more important. Averaging our two values, we quote a value of 49 ± 10 KeV from our preliminary analysis.

The error quoted on the final value expresses both the uncertainty in the normalizations and the effects due to possible interference terms from ω-exchange. In a more complete analysis, including results from aluminum and carbon, as well as data taken at 250 GeV, we expect to reduce the error to less than 10%.

We have also searched for coherent production of A_2^- mesons via their $\eta\pi^-$ decay mode. A_2^- production should occur via one-photon exchange because of the expected large $A_2 \to \pi\gamma$ width.[8] The three events observed suggest that the radiative width of the A_2^- is $\lesssim 60$ KeV.

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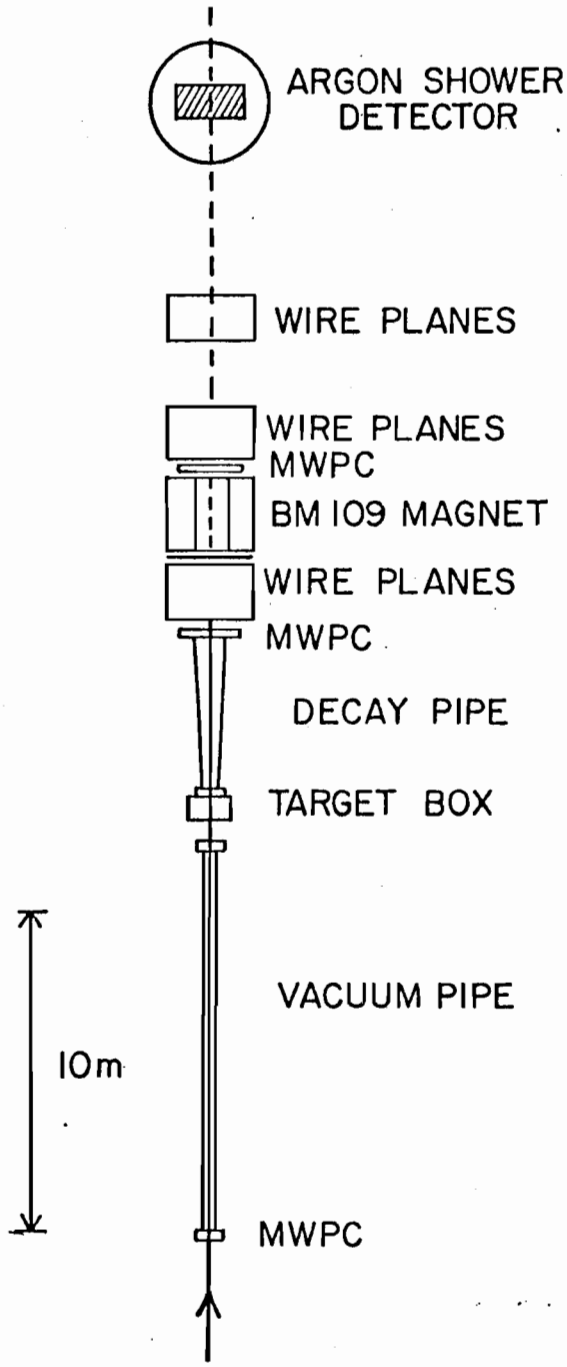
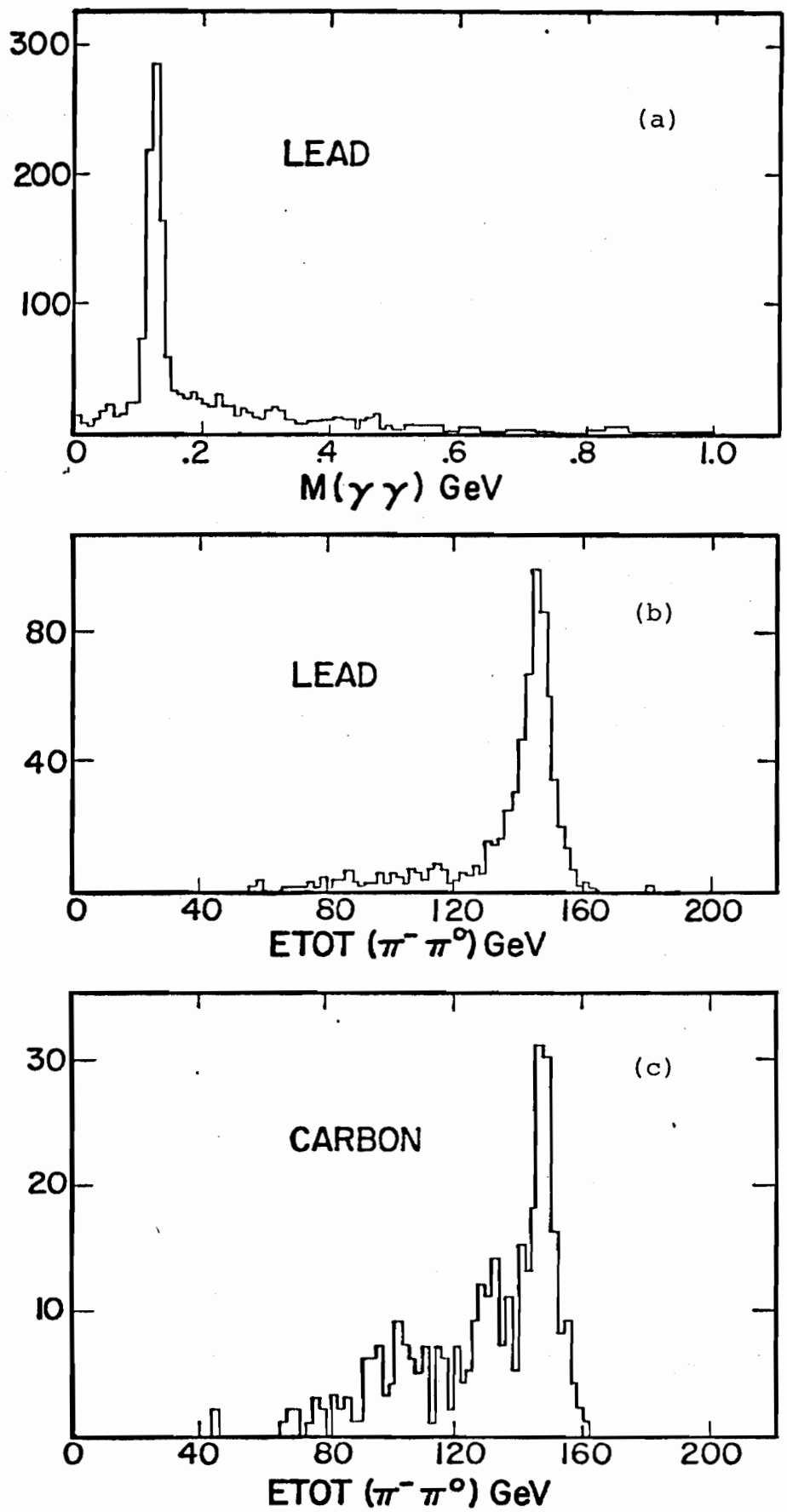
FIGURE CAPTIONS

1. Schematic of experimental arrangement.
2. Two-photon mass distribution for events containing a single charged track and two photons produced on a lead target (a). Total energy of $(\pi^-\pi^0)$ system for production on a lead target (b) and a carbon target (c).
3. The $(\pi^-\pi^0)$ mass distribution for production on a lead target. Only "elastic" events, i.e., events with $(\pi^-\pi^0)$ energy near 150 GeV, are displayed. The smooth curve is a fit of the Primakoff prediction to the data.
4. Distributions in t' for ρ^- production on lead and on copper targets. (Curves are described in the text.)



SCHEMATIC DIAGRAM OF APPARATUS

Figure 1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200
100
LEAD
(a)
0
.2
.4
.6
.8
1.0
M(γγ) GeV
80
40
LEAD
(b)
0
40
80
120
160
200
ETOT (π⁻π°) GeV
30
20
10
CARBON
(c)
0
40
80
120
160
200
ETOT (π⁻π°) GeV

Figure 2

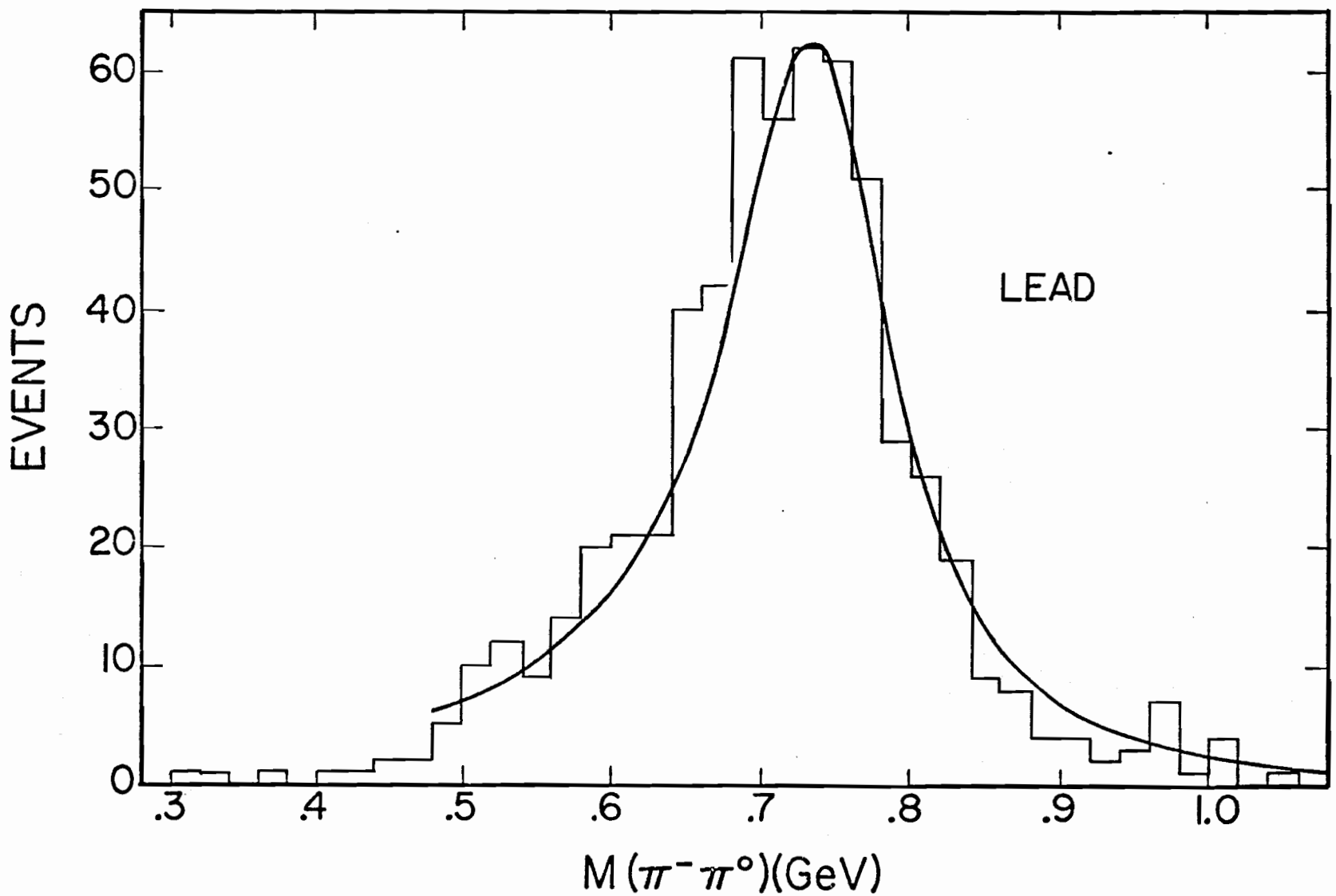
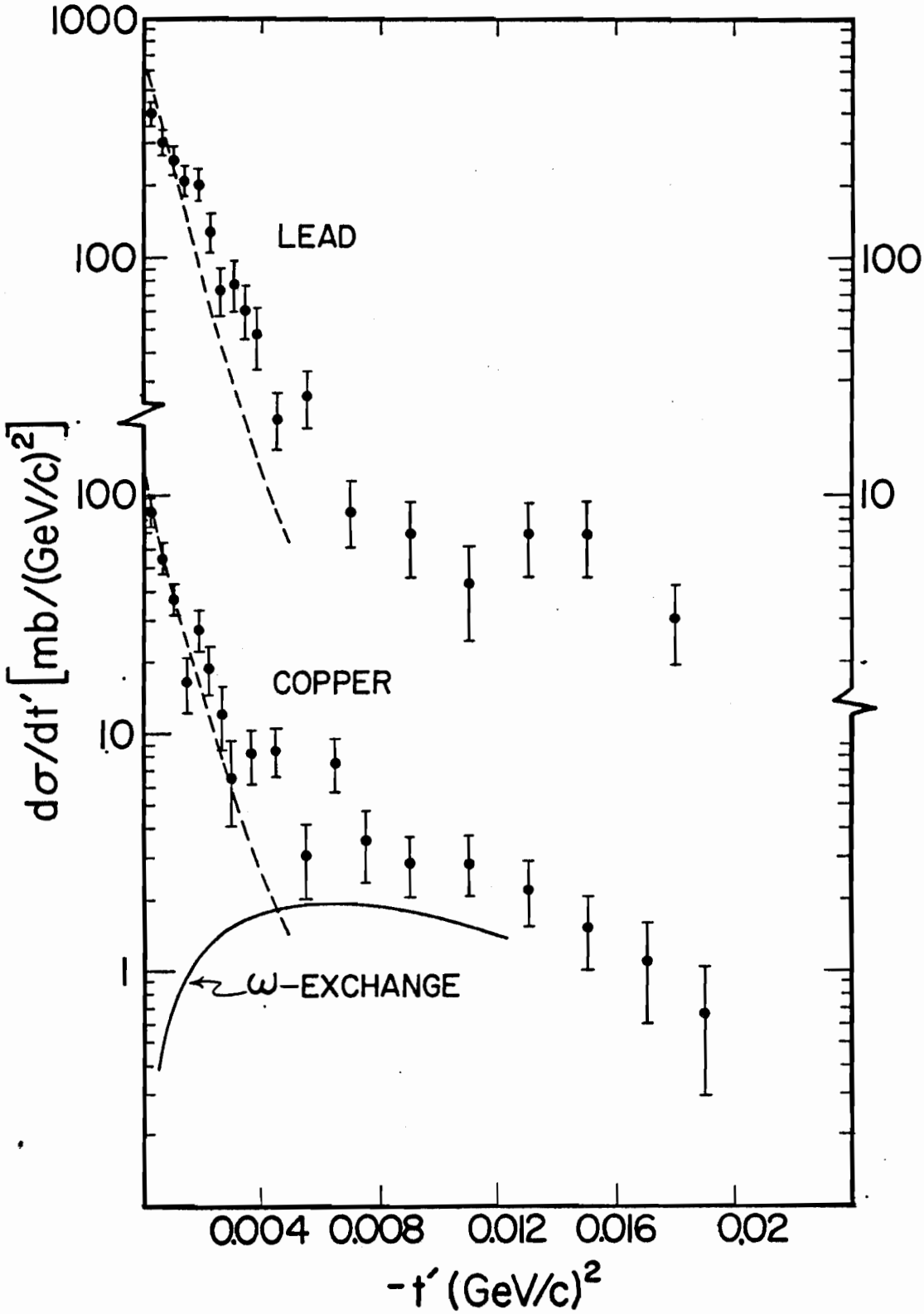


Figure 3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100
100
10
1
100
10
LEAD
COPPER
ω-EXCHANGE
dσ/dt' [mb/(GeV/c)²]
0.004
0.008
0.012
0.016
0.02
-t' (GeV/c)²

Figure 4