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Muon Interactions at 490 GeV *

The E665 Collaboration

presented by

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MUON INTERACTIONS AT 490 GeV

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ABSTRACT.

E665 is a new, high-energy muon scattering experiment at Fermilab. Data were taken with a 490 GeV muon beam incident on deuterium, hydrogen, and xenon targets during the 1987-88 fixed target run. These data are being analyzed with various physics objectives in mind, and a number of preliminary results have been obtained. This paper presents four of these results, specifically the small x_{Bj} ratio of xenon and deuterium cross sections, inclusive hadron distributions, two jet signals, and exclusive ρ^0 production.

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INTRODUCTION.

E665 is a muon scattering experiment at Fermilab[1] designed to investigate a wide variety of fixed target physics using the highest energy muon beam in the world: the mean muon energy during the 1987-88 run was 486 GeV, with an energy spread of roughly 60 GeV. Data were collected with liquid deuterium, hydrogen, and pressurized gaseous xenon targets, each approximately 1.1 meters long.

The apparatus was designed to detect hadrons and photons in addition to the scattered muon. The target was installed in a streamer chamber inside a superconducting magnet to allow detection of charged hadrons in the negative x_F region, for a subset of the events. Forward charged tracks, deflected in a second superconducting dipole magnet, were detected in a series of multiwire proportional and drift chambers. A time-of-flight counter, two threshold Cerenkov counters, and a RICH detector were installed to provide $\pi/K/p$ separation up to 100 GeV. A gas sampling electromagnetic calorimeter detected photons and electrons. Muons were detected in four scintillator and eight wire chamber planes placed behind a steel hadron absorber. A detailed description of the apparatus can be found in reference 2. The results presented here are based on the forward tracking and calorimeter data only.

Two triggers were used for collecting data. The large angle trigger (LAT) demanded a scattered muon signal in large scintillator counters behind the hadron absorber, and no signal in a veto region centered on the beam. It was designed to collect the maximum number of high W events. The small angle trigger (SAT) projected dynamically a subset of the beam to the back of the apparatus, and demanded no signal in a small veto spot in the small scintillator hodoscopes behind the absorber. It was designed to collect data at very small x_{Bj}.

The unique characteristic of E665 with respect to other lepton scattering experiments is the wide kinematic range it covers. The Q^2 range extends from 0.01 to 100 (GeV/c)^2, and the useful ν range from 20 to 500 GeV. As a result, deep inelastic data exist for x_{Bj} well below 10^{-2}, and W ranges from 4 GeV up to 32 GeV.

RATIO OF CROSS SECTIONS.

Structure functions are empirical distributions related to the differential cross section for inelastic scattering.

$$\frac{d^2\sigma^{DIS}}{dx dQ^2} = \frac{4\pi\alpha^2}{xQ^2}\left[1 - y + \frac{y^2}{2(R(x,Q^2)+1)}\right] F_2(x,Q^2)$$

These functions are the starting point for theoretical models such as the Quark Parton Model (QPM) with QCD.

Before the QPM, the Vector Dominance Model (VDM) predicted that at low Q^2 and low x_{Bj}, the photon interaction rate in nuclei would not scale as fast as the number of nucleons, A. This phenomenon was called "shadowing," and was observed in experiment. The naive VDM predicted that shadowing should weaken as Q^2 or x_{Bj} were increased; other models (such as Generalized VDM) predict a weak Q^2 dependence.

E665 is analyzing data taken on xenon and deuterium targets at very low x_{Bj}, and over a large range of Q^2. The particular quantity of interest is the ratio of the deep inelastic cross sections for xenon and deuterium[3]. To the extent that $R(x,Q^2)$ $(= \sigma_L/\sigma_T)$ is the same for xenon and deuterium, this ratio equals the ratio of the F_2 structure functions.

One of the most formidable analysis problems encountered when comparing xenon and deuterium data is the fact that the radiative corrections are much larger for xenon than for deuterium. In particular, there is a large contribution in the xenon data coming from coherent scattering off the xenon nucleus.

E665 studies these effects in three independent ways. First, the radiative processes have been calculated and implemented in Monte Carlo programs. Second, by varying kinematic cuts, a stable behavior of the ratio σ^{Xe}/σ^{D2} can be found. Finally, the coherent and quasi-elastic contributions can be identified using the electromagnetic calorimeter, and removed on an event-by-event basis. All three methods give consistent results.

A preliminary result for $\sigma^{Xe}(x)/\sigma^{D2}(x)$ is shown in figure 1. (The errors shown are statistical only; the net systematic error is estimated to be 5%.) The radiative corrections have been made using Monte Carlo calculations. The evidence for shadowing over the range of x_{Bj} from 10^{-3} to 10^{-1} is clear. For comparison, recent data from CERN experiment NA28 taken on calcium are shown. The figure also shows the Q^2 dependence of the effect, for $x_{Bj} < 0.025$ and $x_{Bj} > 0.025$. The dependence on Q^2 is weak.

HADRON DISTRIBUTIONS.

The simplest inclusive hadron distribution is $(1/N_\mu)dN_{had}/dZ$, where $Z = E_{had}/\nu$. After correcting for geometric acceptance and pattern recognition efficiency, good agreement is obtained with distributions from EMC ($E_{beam} = 280\ GeV$) and CHIO ($E_{beam} = 147\ GeV$). Similarly, a plot of $(1/N_\mu)dN_{had}/dP_t^2$ (P_t is the momentum component of a hadron perpendicular to the virtual photon direction) also agrees well with EMC data, when W is limited to the range 10 to 20 GeV.

The quark struck by the virtual photon should emerge from the target nucleon nearly parallel to the virtual photon direction. Deviations of the hadron distributions from axial symmetry about the virtual photon direction are interesting. For example, the azimuthal angle ϕ about the photon axis measured with respect to the lepton scattering plane can be defined. Intrinsic k_t and higher order QCD corrections are expected to give an asymmetry of the hadron distribution as a function of ϕ; this asymmetry was observed by the EMC. E665 observes a ϕ asymmetry also, as illustrated in figure 2. (Only statistical errors are shown.)

Another general feature of inclusive distributions worth investigating is the energy flow in the photon-nucleon center-of-mass frame. Anticipating the emergence of planar events, one defines a "hadronic event plane" which is allowed to rotate about the virtual photon direction. Its orientation is set by the requirement that the quantity $\Sigma P_{t,out}^2$ is minimized, where $P_{t,out}$ is the component of P_t perpendicular to the plane. After this plane has been found, the variation of $\Sigma P_{t,out}^2$ and $\Sigma P_{t,in}^2$ with W can be studied. It is found that $\Sigma P_{t,out}^2$ does not change with W, but the tail to the $\Sigma P_{t,in}^2$ distribution grows significantly as W increases, particularly for $W > 20$ GeV. Using the LUND Monte Carlo program to simulate deep inelastic events with so-called "hard" QCD processes (which includes hard gluon Bremsstrahlung from the struck quark, and photon-gluon fusion), good agreement with the data is found. If the hard QCD processes are turned off in the simulation, then poor agreement is found.

Motivated by the comparison of the data with LUND, a parameter is defined which measures the spread of P_t in the hadronic plane: $\Pi = (4/\sqrt{N_{trk}})\Sigma[|P_t| - P_t^c]$, where $P_t^c = 0.32$ GeV/c. For a minimum value of $\Pi_{min} = 3$, the distribution of energy flow in the event plane shows a two-lobed structure clearly, which apparently is a signal for *two* forward partons. This interpretation is supported by studies with the LUND Monte Carlo.

The two-lobed structure obtained by the cut on Π justifies empirically an event filter designed to select events with a two-jet structure. An algorithm finds for each event a pair of axes meant to define the directions of two partons. This algorithm includes photons detected in the calorimeter in addition to forward charged tracks. Cuts are made on the minimum angle between the two axes, the minimum energy of each "jet," and the ratio of the energies of the two jets. A plot of the energy flow shows a two-lobed structure again. LUND Monte Carlo events with hard QCD processes match the data well when normalized to the number of incident muons, whereas LUND without hard QCD falls far below. This is shown in figure 3.

Taking the LUND model as a guide, one finds that most of the two-jet events are due to the photon-gluon fusion process, and very little due to hard gluon Bremsstrahlung. In principle these measurements are sensitive to the gluon distribution, and indeed different parametrizations of gluon distributions used in the Monte Carlo give significantly different fractions of events passing the event filter[4].

EXCLUSIVE ρ^0s.

The Vector Dominance Model describes the process $\mu A \rightarrow \mu\gamma^* A \rightarrow \mu V A$ well, where V represents a neutral vector meson, such as the ρ^0, ϕ, or ω. It predicts a differential cross section exponential in t (the momentum transfer to the target), analagous to elastic hadronic interactions. An extention of the model, called "s-channel helicity conservation" (SCHC), links the helicity of the vector meson to that of the virtual photon. This model is well verified for small momentum transfers $Q^2 \leq 1$ (GeV/c)^2.

The EMC showed that the predictions of VDM break down at large $Q^2 \sim 6 - 12$ (GeV/c)^2. The photon is said to have lost its soft, hadronic qualities, and that its interactions with the target have become pointlike. This result stimulated theoretical calculations based on perturbative QCD which model the pomeron as a gluon ladder, for example.

E665 data taken with the small angle and the large angle triggers cover a range of Q^2 which joins the VDM regime to the perturbative QCD regime. Only the scattered muon and the decay products from the vector meson are observed. Since the process is exclusive, a clear signal can be obtained by demanding that the observed tracks take up the entire energy ν lost by the scattered muon. In the case of the ρ^0, events with two opposite-sign hadrons are selected for which $Z_{sum} = (P^+ + P^-)/\nu$ is close to one. Plotting the invariant mass of the two pions, a clear ρ^0 resonant peak, containing roughly 2000 events, is found. (A clean ϕ peak is observed, also.)

A preliminary analysis of the ρ^0 helicity as a function of Q^2 has been performed. The polar distribution of the decay pions in the ρ^0 center-of-mass frame was plotted for three ranges of Q^2 (see figure 4). After correcting for acceptance, these distributions show a clear transition from a $\sin^2\theta$ distribution (indicating a transverse polarization of the ρ^0), to a $\cos^2\theta$ distribution (indicating a longitudinal polarization). Fitting each distribution to the function $W(\cos\theta; A, r) = A(1 - r + (3r - 1)\cos^2\theta)$ yields values for r which increase with Q^2. (The parameter r has value 0 for transversely polarized ρ^0s, and value 1 for longitudinal ρ^0s.) Although more work is needed to reduce systematic errors, it is clear that the statistical precision is good.

By calculating the outgoing ρ^0 momentum from the pion momenta, the momentum transfer t to the target may be calculated. Binning in Q^2 as for the helicity, the exponential slope parameter from the uncorrected distributions decreases as Q^2 is increased.

CONCLUSION.

E665 is exploring structure functions and hadronization physics in ranges of x_{Bj} and W^2 inaccessible to other lepton scattering experiments. Preliminary results on shadowing in the xenon cross section, on the azimuthal asymmetry of inclusive hadron distributions, on two-jet signals at high W, and on exclusive ρ^0 production have been presented.

References.

1. The E665 Collaboration consists of eighty physicists from thirteen institutions, including Argonne, UC San Diego, INP Cracow, Fermilab, Freiburg, Harvard, UI Chicago, Maryland, MIT, MPI Munich, Washington, Wuppertal, and Yale.

2. E665 Collaboration, "A Spectrometer for Muon Scattering at the Tevatron," Fermilab Pub-89/200-E (to be published in NIM)

3. This result was presented in more detail at a meeting of the APS: Stephen R. Magill, "Xe/D_2 Cross-section Ratio at Low x_{Bj} from Muon Scattering at 490 GeV/c," Proceedings from the DPF Conference in Houston, 1990

4. Douglas G. Michael, "A Study of Transverse Momentum and Jets Using Forward Hadrons and Photons in Deep Inelastic Muon Scattering at 490 GeV/c," Ph.D. Thesis, Harvard University, April, 1990

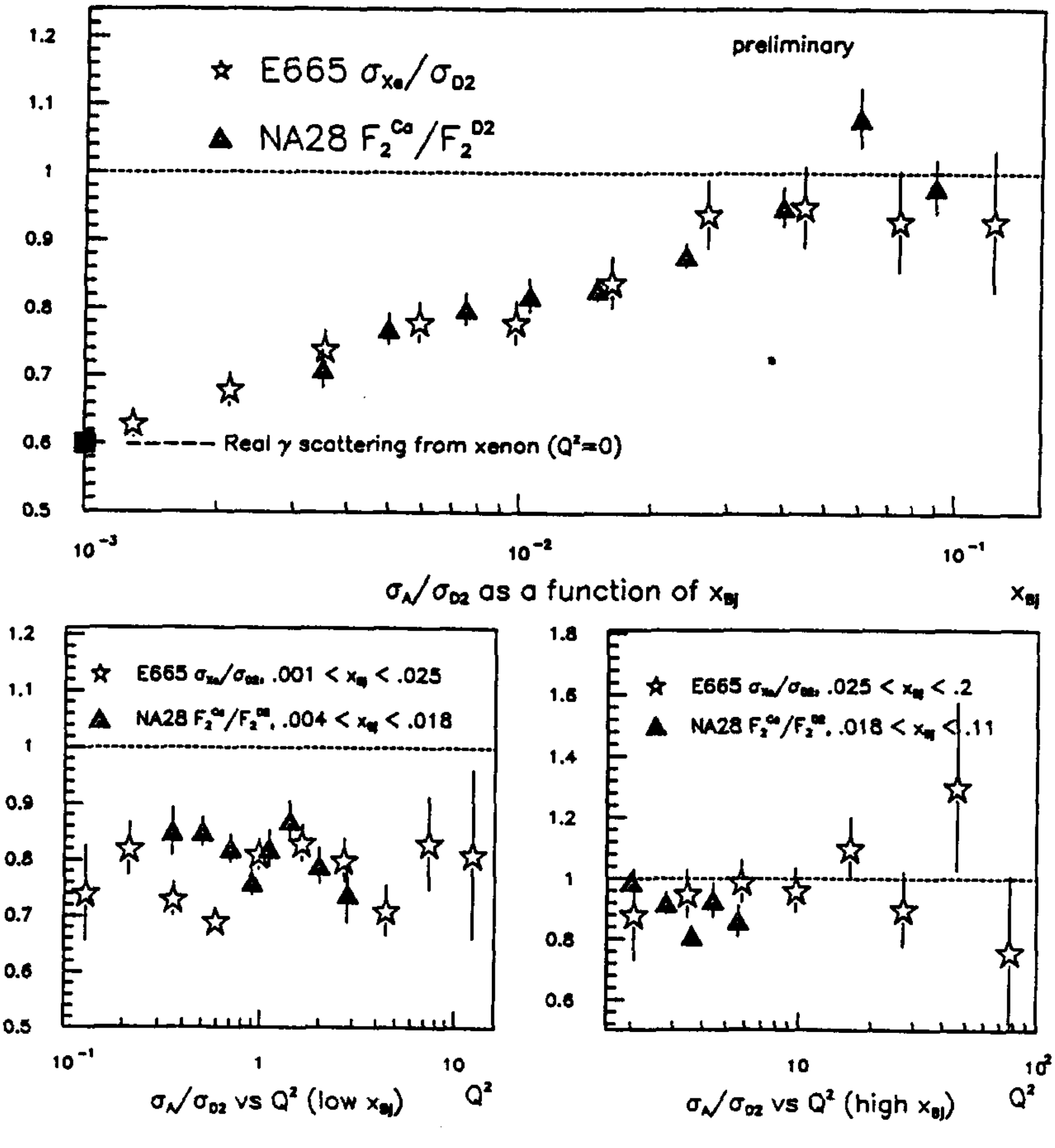

figure 1. Ratio of Cross Sections

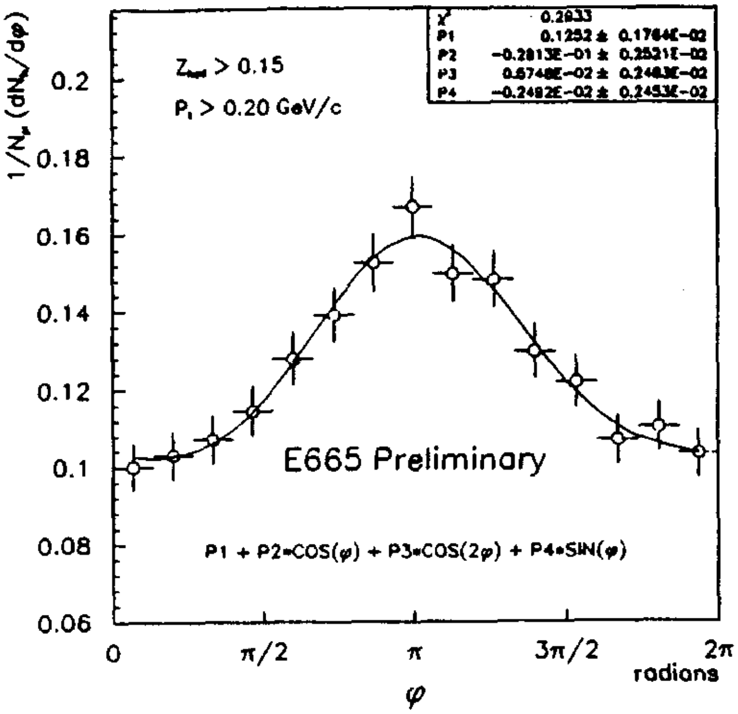

Figure 2. Azimuthal asymmetry

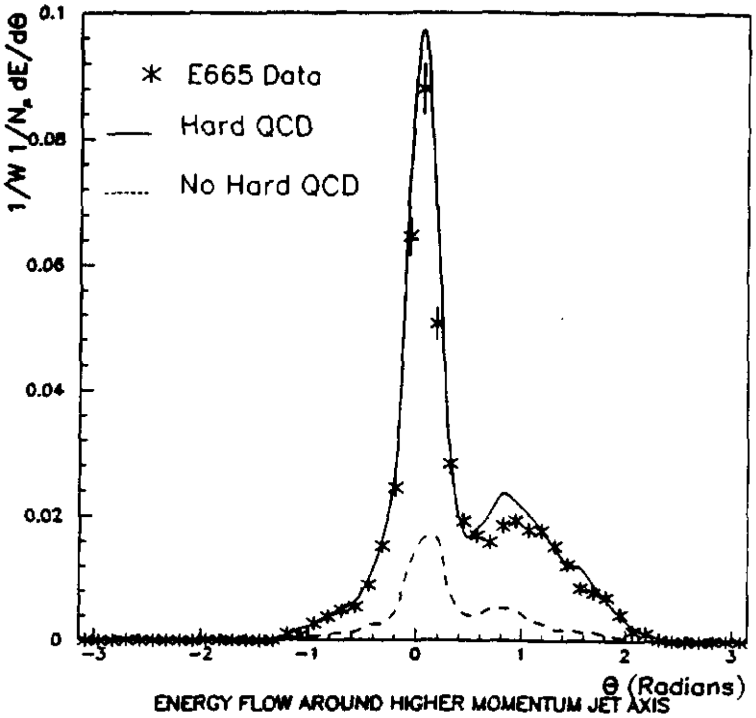

Figure 3. Two-jet energy flow

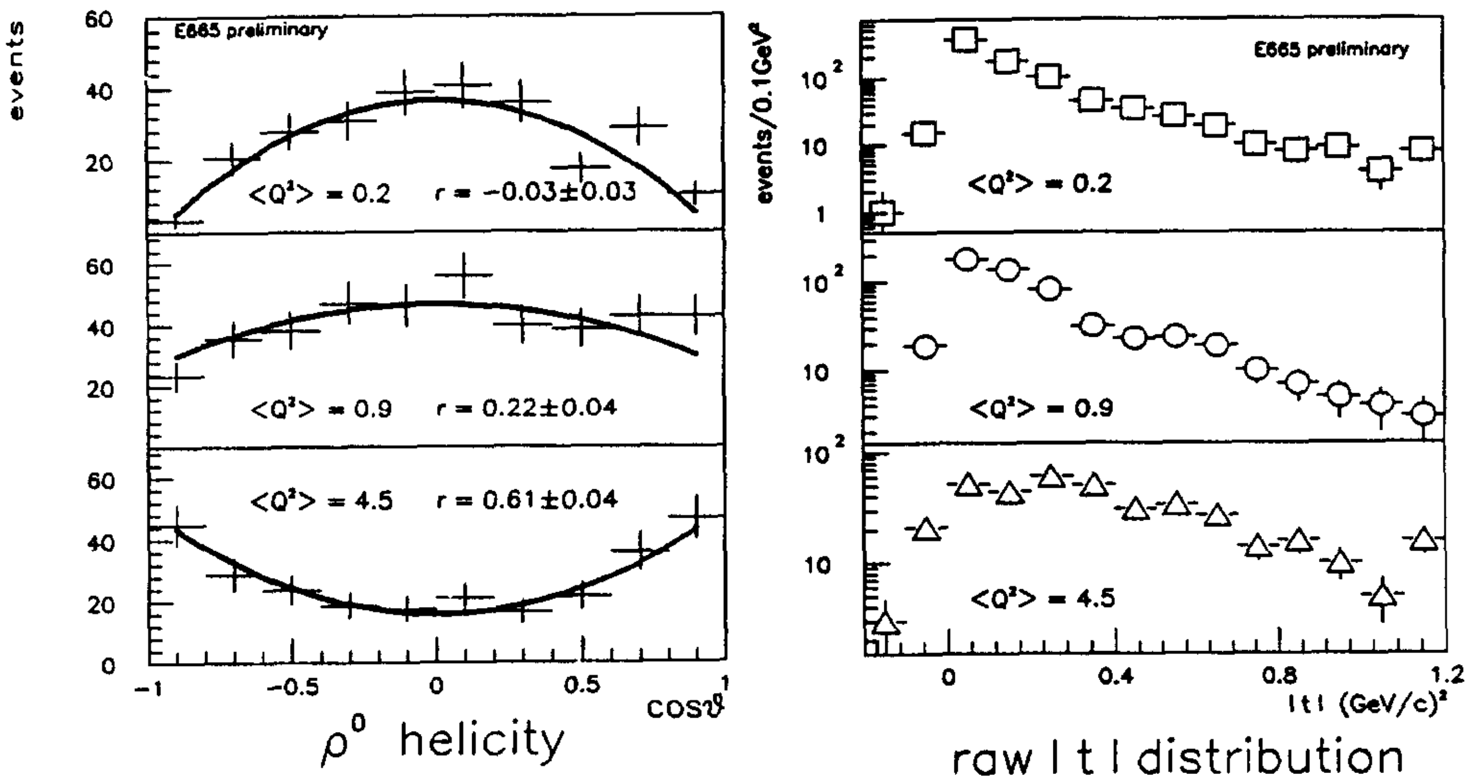

Figure 4. Exclusive ρ^0s