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FNAL-E665 Tevatron Muon Scattering

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High energy deep-inelastic muon scattering experiments fall into two major categories, 1) the open geometry spectrometers such as EMC, NMC and E665, 2) closed geometry experiments such as BFP and BCDMS in which iron toroids are used to reconstruct the scattered muon. The first class of experiments generally have lower statistics but gain in systematic errors due to decreased multiple scattering and good knowledge of magnetic fields and detector alignment. The closed geometry experiments have excellent statistical power but are limited in resolution and calibration by the difficulties of tracking through dense material and in determining the magnetic field within a solid piece of iron.

Structure Functions

E665 belongs to the first class of experiments, with high precision but lower statistics; the areas in which we contribute to structure function measurements are control of systematic errors and exploration of kinematic regions inaccessible to previous experiments. Considerable effort has been devoted to extending the trigger acceptance to very low muon angles; allowing our x_{bj} acceptance to extend down to values of 10^{-4} and below. This is an order of magnitude lower than any previous fixed target experiment.

Jets and Fragmentation

The Tevatron muon beam has also extended the center of mass energy accessible in fixed target muon scattering into regions previously only studied at e^+e^- colliders. For a 500

GeV muon beam the kinematic limit on $W \approx E_{CM}$ is 32 GeV. The full E665 data sample has more than 100,000 events with $Q^2 > 4$ GeV^2/c^2 and $W > 20$ GeV. For comparison, the Mark II at PEP logged 60,000 events at $W = 29$ GeV.

Because E665 is an open geometry detector, with full acceptance in the forward region, we can study fragmentation and jets in the same kinematic regime as the PEP/PETRA experiments. However, multi-jet production in muon scattering differs from the e^+e^- case in two respects: 1) there are additional diagrams, such as initial state gluon radiation and photon-gluon fusion and 2) the scales Q^2 and W^2 are independent. The jet rates and kinematics at high W can thus be used to study the gluon content of the proton and to measure the Q^2 dependence of higher order QCD processes. We are sensitive over the kinematic region $0.1 \leq Q^2 \leq 100$ GeV^2/c^2 in which many QCD processes make the transition from non-perturbative to perturbative behavior. This experiment is thus complementary to the HERA experiments in the high Q^2 regime.

The Future

E665 ran in 1987 (0.5 pb^{-1} on H_2, D_2 and Xe), 1990 (0.5 pb^{-1} on each of H_2, D_2, C, Ca and Pb) and 1991 (4 pb^{-1} on each of H_2 and D_2). Analysis of the 1987 data is essentially complete. Fourteen students have already written Ph.D. dissertations on the 1987 data and the last three 1987 students will graduate this December. We have published four papers from the 1987 run [1-4] and and six more are in preparation. The experiment was enhanced significantly between 1987 and 1990 as follows:

- We installed a moving target stand which exchanged targets every spill. This eliminated most sources of target dependent systematic error in cross section ratios.

- The small angle trigger was upgraded to accept 70% of the beam; in 1987 the acceptance was 10-15%.

- 72 layers of high precision drift chambers were added directly after the target. This improved the momentum and angle resolution of the forward spectrometer by a factor of two. The new chambers also extend the acceptance of the spectrometer into the backwards region in the center of mass frame. Figure 1 shows an event

from the 1990 run, three of the eight reconstructed hadrons appear only in the new chambers.

- The 1990-91 data sample is 8-10 times larger than the 1987 sample for large angle triggers and around 50 times larger in the very low angle regions.

We have run a preliminary reconstruction pass on 20% of the 1990 data and are now preparing to run the full production. The 1990 heavy target data will be reconstructed by the end of 1992 and the full 1991 sample will be reconstructed by June of 1993. Eleven students will write their dissertations on the 1990-91 data, one is already complete. Topics being studied include Bose-Einstein correlations, jet and leading particle charges, structure functions, A dependence of fragmentation, and jet kinematics. Two examples of the impact of the 1990/91 data are given below.

Structure Function Ratios at low x

We have measured the ratios of cross sections for Xe/D2 and n/p over the range $Q^2 > 0.01$ GeV^2/c^2 and $10^{-5} \leq x \leq 1$ [1,2]. Evidence for the saturation of nuclear shadowing in the low x, Q^2 region is found (Figure 2). The ratio of neutron to proton structure functions is found to be consistent with unity in the very low x region [5]. Both of these results show a smooth transition to the real photon cross sections as $Q^2 \rightarrow 0$.

When the 1990 and 91 data are included, the statistical and systematic errors on the n/p F_2 ratios will be reduced from 5-10% to 1-2%. For example, the projected statistical error on the Gottfried sum for the range $0.001 < x, Q^2 > 1$ GeV^2/c^2 is 0.02-0.03, comparable to the existing NMC measurements.

Higher order QCD processes

Multi-jet events from higher order QCD processes (gluon bremsstrahlung and photon-gluon fusion) have been observed [4] in events with center-of-mass energies above 20 GeV (Figure 3). We are now studying the dependence of the jet kinematics on $\alpha_s(Q^2)$ and the gluon distribution function $G(x, Q^2)$. Note that multi-jet cross sections at a given Q^2 are directly proportional to terms of order α_s while structure function measurements are sensitive to α_s only through the $\log Q^2$ slopes. First results from a study of the Q^2 dependence of jet p_T will presented at the November DPF meeting.

The jet rates recently published in PRL were determined from 12,000 events. The 1991 data has 100,000 events with center of mass energies above 20 GeV and improved acceptance.

Multi-jet event statistics above Q^2 of 25 GeV^2/c^2 are currently quite small. With the full statistics, the data will extend from below 1 to above 100 GeV^2/c^2.

What we need in the future

We are currently concentrating our efforts on data analysis. We have not submitted a proposal to run again in 1995. This does not mean that E665 is over. We have several years of full time data analysis ahead of us and most of that effort will go on at FNAL. To complete this work we will still need computing and office space for twenty people for at least the next three years. Our 1987 run has been very productive, a minimal investment will make the 1990/91 runs even more so.

References

[1] M.R. Adams *et al.*, Distribution of Charged Hadrons Observed in Deep-Inelastic Muon-Deuterium Scattering at 490 GeV, Phys. Lett **B**272, 163 (1991).

[2] M.R. Adams *et al.*, Shadowing in the muon-xenon inelastic scattering cross section at 490 GeV, Phys. Lett. **B**287, 375 (1992).

[3] M.R. Adams *et al.*, Saturation of Shadowing at Very Low x_{bj}, Phys. Rev. Lett. 68, 3266 (1992).

[4] M.R. Adams *et al.*, First Measurement of Jet Production Rates in Deep-inelastic Lepton-Proton Scattering, Phys. Rev. Lett. 69, 1026 (1992)

[5] Talk presented by V. Papavassiliou at the 26th International Conference on HEP, Dallas, August 1992.

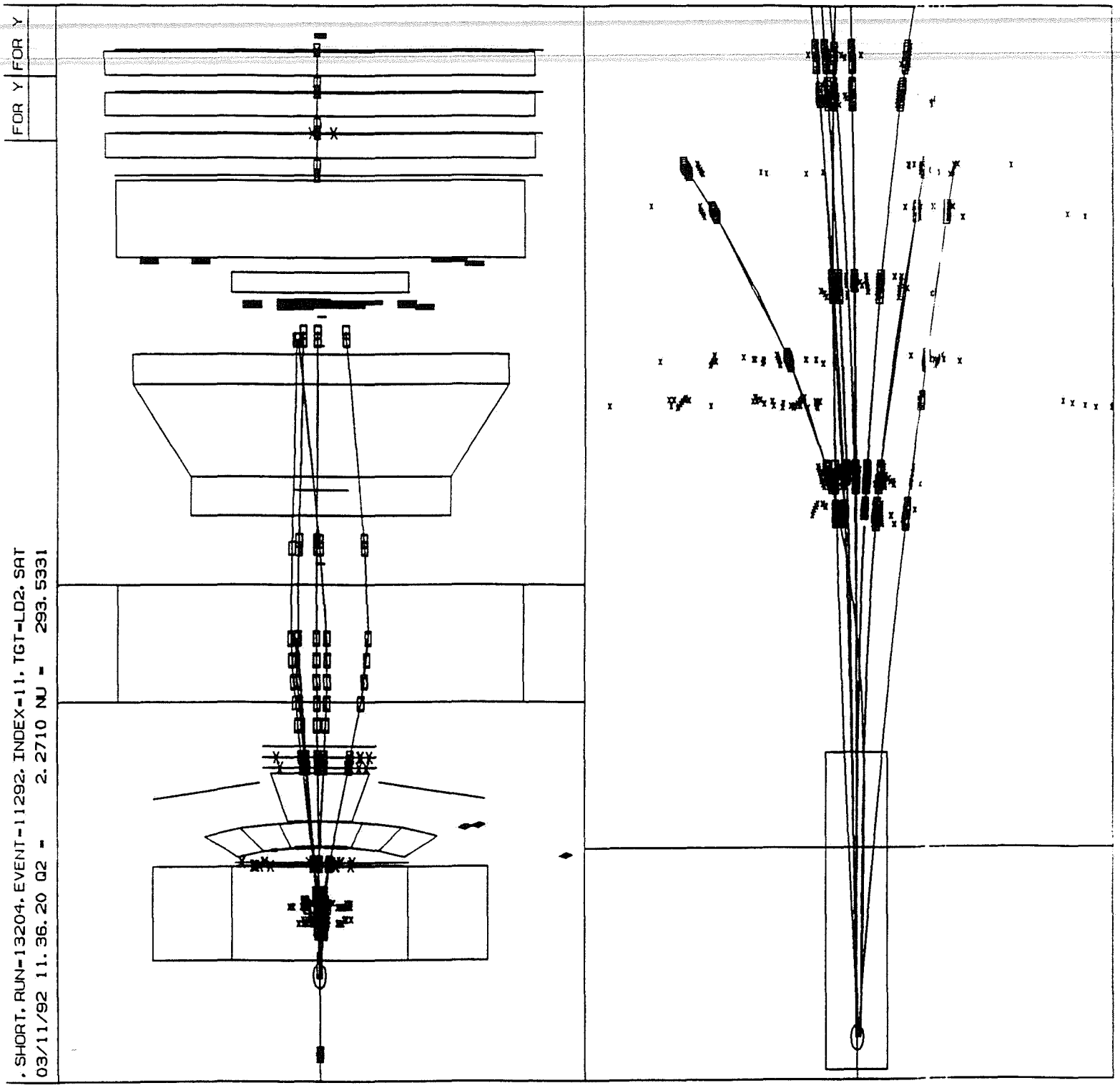


Figure 1: 1990 event with $Q^2 = 2.3$ GeV^2/c^2 and a center of mass energy of 23.4 GeV. The top frame shows the full spectrometer viewed from above. The bottom frame is a blowup of the vertex region.

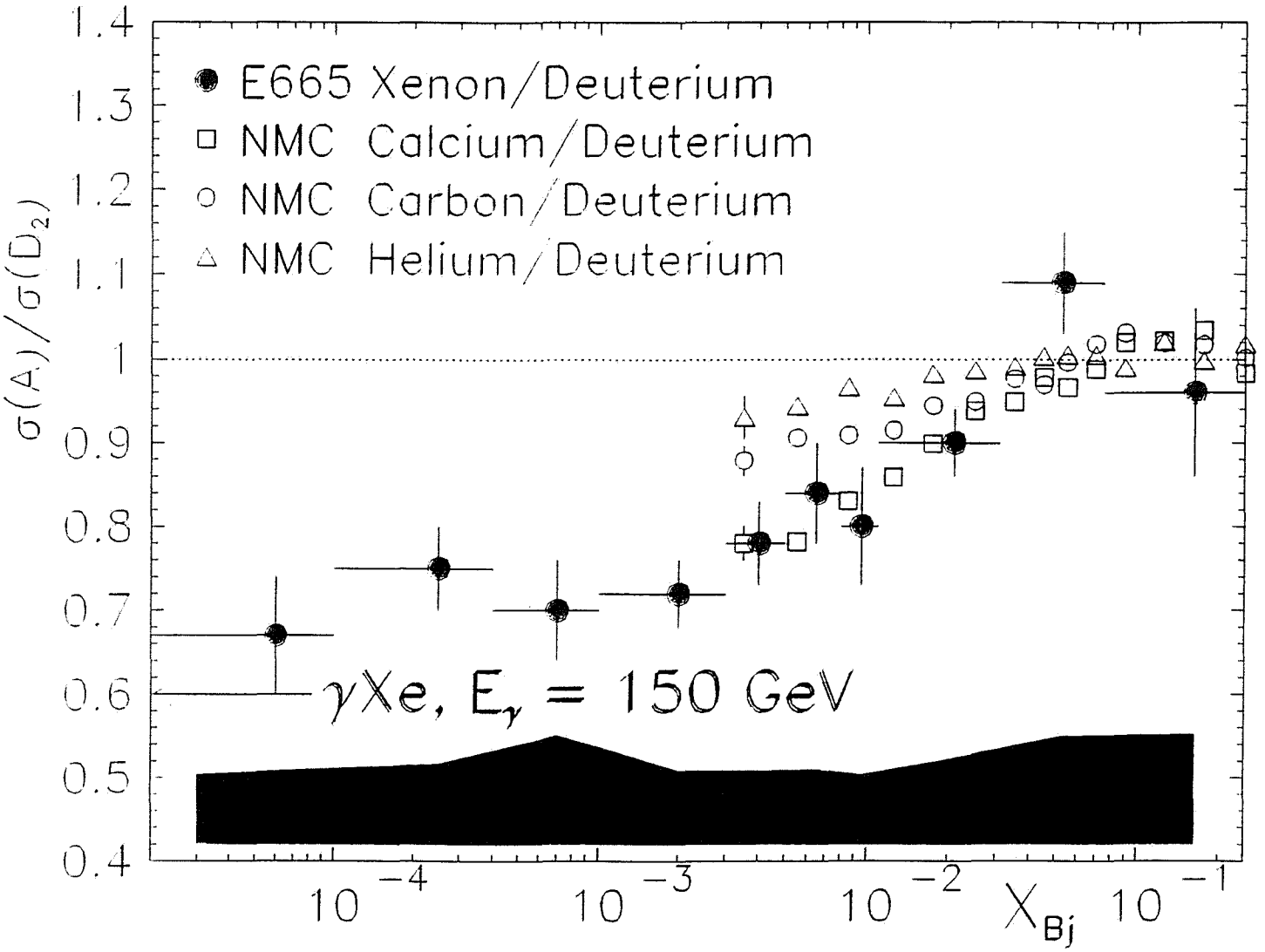
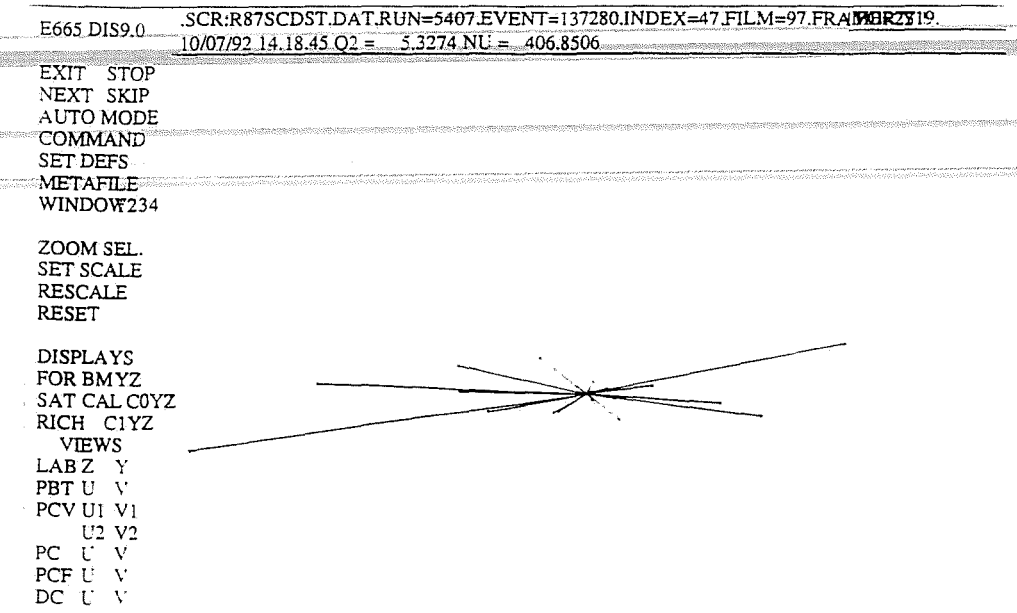


Figure 2: Saturation of Shadowing from reference [1].



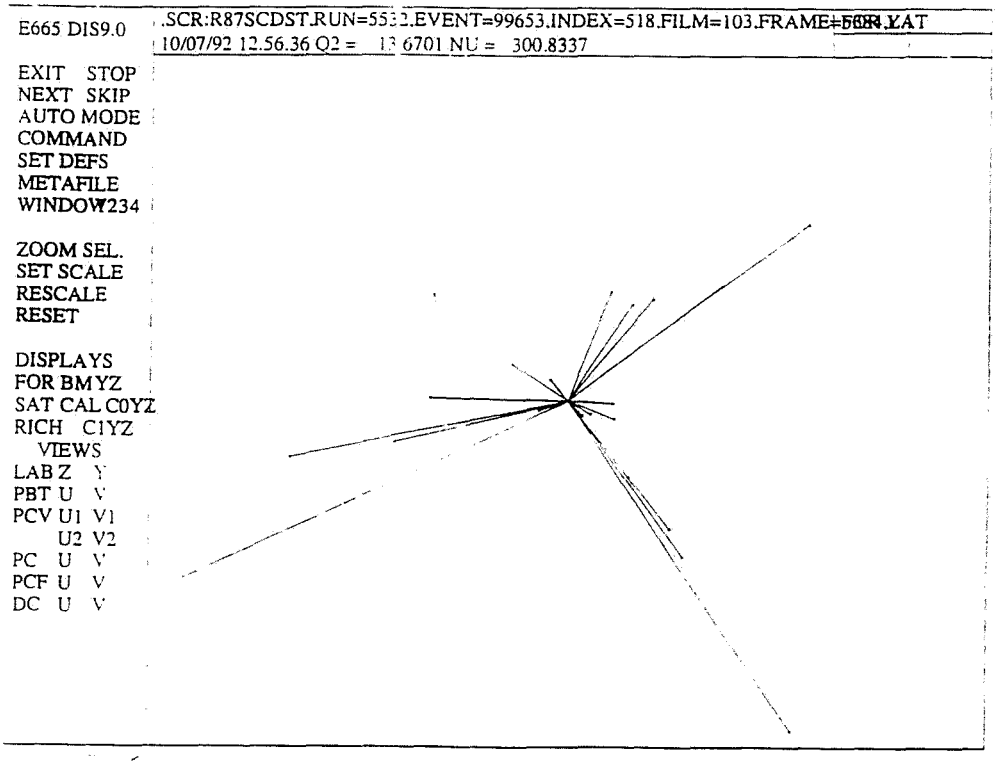


Figure 3: 2 and 3-jet events in the center-of-mass frame. The information in the backward region is from a photographic streamer chamber which provided information for some events in the 1987 run. Only the forward tracks are used in the jet analysis.