REPORT ON THE MUON WORKSHOP

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A Muon Workshop was held on September 23 and 24 to discuss plans for a new muon beam. One of the important new facilities planned to be constructed for the advent of 1-TeV protons is a new muon beam with energy up to 800 GeV and intensities up to several times 10^8 per pulse. The workshop program was divided into three parts: first, design of the new beam; second, theoretical expectations for new physics associated with high-energy muons; and third, new or improved experimental facilities for use with muon beams. There was also a general discussion in which various questions not fitting neatly into the above categories were covered.

Taken as a whole, the workshop was designed to answer the vague but important question of whether there would be a challenging and exciting experimental program of muon physics to pursue at the time we could reasonably expect the new beam and experimental facilities to appear. There was a general consensus that there would be such a program.

1. Design of the New Beam

Anthony Malensek of Fermilab presented the results of a muon-beam design study made by Fermilab and Argonne physicists. The design includes proton splitting and transport for 400- and 1000-GeV primary protons from the accelerator to a production target located between the existing Neutrino and Proton Laboratory facilities, almost 1 mile (1460 m) from the extraction point. The new production target will receive beam independently of all other experimental areas in the Laboratory and be coupled only through the overall number of accelerated protons. The muon beam itself is laid out to eliminate the penetration of nonbeam muons (halo) into other experimental areas. These two design principles alone will remove the most serious constraints on the present muon-physics program at Fermilab.

The muon-beam design is of the FODO type, with quadrupoles forming a channel to capture and hold charged particles, pions, and kaons as parent hadrons and muons as desired daughter particles. In some running configurations, the noninteracting portion of the primary proton beam is also transmitted. Quadrupoles and dipoles early in the transport capture the secondary hadrons from the production target and direct them into the FODO channel. Three-fourths of the way along the beam, the FODO is interrupted by a 30-ft beryllium metal absorber and bending magnet that combine to rid the beam of all hadrons and to select the desired band of muon momenta. At this point, the beam becomes a muon beam. Downstream, spoiler magnets and magnetized-iron pipe are used to sweep all off-momentum and wide-angle muons (halo) away from the beam itself. The final beam enters the new Muon Laboratory nearly 2 miles (3100 m) from the extraction point. The yields for three characteristic beam energies are shown in Table I. The halo quoted is for an area 200 in. × 200 in. centered on the beam at the Muon Laboratory. At the end of the muon beam line, there will be a new Muon Laboratory. For present discussion purposes, it is thought of as being about 200 ft long and 30 ft wide with the beam center line 10 ft below local ground level. It could accommodate two of the present muon experiments in tandem. Obviously, the evolution of thinking on the detector designs will have a strong impact on the actual building design and dimensions.

Table I. Estimated Muon Yields.

Central Parent Momentum (GeV/c)	800	600	305
Central Muon Momentum (GeV/c)	750	550	275
Mu±/Interacting Proton (Wang)	$(1.35 \pm 0.2)\ 10^{-5}$	$(7.86 \pm 0.9)\ 10^{-5}$	$(3.28 \pm 0.3)\ 10^{-4}$
$\Delta p/p$ (rms)	±9%	±11%	±13%
Halo/Beam	3%	3%	4%

The Fermilab Neutrino Department is continuing to work on the beam design. An interim report will be issued by December 1, 1977, and made available to persons interested in the details of the beam. Questions associated with the beam design should be referred to T. B. Kirk in the Neutrino Department.

2. Theoretical Expectations

Two theoretical physicists, J. D. Bjorken (SLAC), and J. D. Sullivan (University of Illinois), who have been active in this field, presented their expectations for the physics that could be investigated with the new facility.

Sullivan gave an outline of the physics associated with muon scattering in nuclear matter. Although many physicists are familiar with the general idea of photon vector dominance, VMD, (the real photon acting partly like a vector meson in nuclear matter) and the parton picture of deeply inelastic scattering of leptons (virtual photon absorption by pointlike nucleon constituents), the recent progress in connecting these very different physical notions with a smooth and continuous mathematical formalism is less familiar. Sullivan outlined the essentials of the theory that connects the one regime to the other. The experimental work to date has barely scratched the surface, particularly in exploring the so-called anti-shadowing region, which occurs when the Q^2 of the photon is moderate [1-2 $(GeV/c)^2$] but the energy is sufficiently high (hundreds of GeV) that the virtual photons are still in the diffractive regime. The entire transition can be mapped out by a scattering program. The increase in beam energy to 750 GeV or more will enable the scaling properties of the fully shadowed regime to be explored.

Bjorken talked on the fundamental parton physics that can be uncovered by measuring not only the muon inclusive scattering, but also the hadrons that emerge from collisions of virtual photons with partons in nuclear matter. He emphasized that the common view that "heavy-element target experiments study only messy nuclear physics " is wrong and that muon experiments with nuclear targets, particularly at very high energies and with moderate to high Q^2, uncover basic physics of considerable interest and importance. He also discussed the physics that can be learned by studying the systematics of recoil hadrons both in the forward direction and at large angles. This talk helped many to see a future for heavy-target physics that they had not previously considered. In addition to the physics of parton propagation in heavy nucleii, Bjorken outlined a number of other areas of physics that could benefit significantly from the proposed increase in muon energy.

Among these were:

i) Charm production by virtual photons

ii) EM-weak interference measurements

iii) Systematics of scaling violations in deeply inelastic scattering.

Although he did not mention it explicitly, the large increase in muon intensity and strong halo reduction will make some experiments possible which are impractical under present conditions.

3. Experimental Talks

The remainder of the workshop program was given over to talks by experimenters on various aspects of muon scattering, under present conditions and projected to the new facility. J. J. Aubert of the University of Annecy presented a stimulating and useful talk on the CERN European Muon Collaboration (EMC) program for muon scattering with the new 300-GeV beam at CERN. This program is modeled on the work of the CHIO Group (Experiment # 98) at Fermilab, but features an improved spectrometer with essentially 100% hadron acceptance in its final form, a large sophisticated multi-cell Cerenkov counter, and a beam of much better intensity and greatly reduced halo. They will be able to extend the CHIO scale-violation measurements on hydrogen and deuterium to the kinematic limits with precision and expand the recoil-hadron data to the target hemisphere. They also expect to make measurements on a polarized target at a later date.

Talks on existing lepton and neutrino data were given by K. W. Chen (Michigan State), L. Osborne (MIT), and J. Vander Velde (U. of Mich.). Chen showed inclusive muon-scattering data, while both Osborne and Vander Velde concentrated on properties of recoil hadrons. All presented comments and views on likely directions to pursue in a new set of muon experiments. W. A. Loomis (Harvard) and M. Strovink (UCB) presented ideas and methods for detecting and identifying final-state hadrons from hydrogen and deuterium targets in new types of spectrometers. P. J. Limon (Fermilab) discussed the EM-weak interference experiments using ep colliding rings and μp scattering. He concluded that both types of experiments are in principle able to be done, but that ep collisions are in a better position to succeed since they gain by a factor of about 20 in c. m. energy and benefit by growth with energy of the relative strength of the weak interaction.

The workshop was concluded with a general discussion led by T. B. Kirk (Fermilab) on the prospects for physics and the likely time scale for the new muon facility. An optimistic timetable might show initial experiments in mid-1981. To this end, the beam-design work will continue at Fermilab with a gradual transition to working engineering and architectural plans. At some point in the near future, Fermilab will issue a call for experimental proposals and letters of intent so that experiments and detectors can be designed and constructed on a time scale appropriate for keeping pace with the beam-line construction. All in all, the workshop generated a feeling of enthusiasm and challenge and reinforced the view that the proposed new beam will open up unique and exciting experiments which cannot be investigated as well by any other existing or planned facility.