A SURVEY OF PHYSICS WITH MUON BEAMS

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This is a brief summary of a very rich field; it is written solely because a more detailed summary is not available to form a backdrop to the muon beam recommendations.

The physics with muon beams can be roughly divided into three classes, the interest in each one of which is increasing with time and will increase further if the energy of the accelerator is increased to 1000 GeV (an English, or real, billion eV).

I list them here in order of decreasing demand on beam quality and increasing demand on intensity:

1. A study of deep inelastic scattering of muons from hydrogen and deuterium with emphasis on accurate measurement of the proton and neutron structure functions $W_1(q^2, x)$ and $W_2(q^2, x)$ and a study of the final states in a geometry approaching $4\pi$. The range of $q^2$ covered might be limited. This is exemplified by Experiment 98.

2. A specific study of scaling; in this study we assume that scaling breaks down for a collection of protons and neutrons. Experiment 26 is an example of this.

3. Various studies in weak interactions; heavy lepton searches, W searches, QED studies by $\mu$, tridents or otherwise.

I will start with experiments of type 2.

Experiment 26 is in operation at low muon intensity $5 \times 10^4$/pulse. A scaling test consists of plotting the structure function as a function of $q^2$ at constant $x = 2Mv/q^2$. Experiment 26 estimates that present data will enable them to stretch this test about a factor of 2 beyond the test already performed by an MIT-SLAC group.

As the machine intensity and energy increase, it becomes desirable to extend this type of experiment, with high accuracy, over the whole accessible range of $q^2, v$. If we express the cross section in the form

$$
\frac{q^2 v}{dq} \frac{d^2 \sigma}{dv} = v W_2 \frac{4\pi a^2}{q^2} \left( 1 - \frac{2Mv}{s} \right) \left[ 1 - \frac{M^2 q^2}{s(s-2Mv)} \right] \left[ 1 + \frac{2M^2 (v^2 + q^2)}{s^2 - 2Mv s - M^2 q^2} \right]
$$

$$
\rightarrow v W_2 \frac{4\pi a^2}{q^2} \quad \text{for} \quad \frac{2Mv}{s} < 1 \quad \frac{q^2}{s} < 4,
$$

we can see that if we keep bins of constant $dq^2/q^2$ and $dv/v$, the count rate varies only slowly with $v$ and incident c.m. energy $s$ and inversely as $q^2$ (until we reach the kinematic limits $\nu s/2M, q^2 < s$).
At 500-GeV muon energy, \( \nu \) can reach 500 GeV, and \( q^2 \) can reach 1000 (GeV/c)^2. Thus to extend data up to this momentum transfer will need an increase of intensity of perhaps 1000/20 or about 50.

When muon intensities are raised this much (to \( 5 \times 10^7 \) pulse), it will be necessary to be very careful about beam halo; \( 10^6 \) muons/pulse in the halo begin to choke the trigger electronics and correspond to a reasonable upper limit.

No muon beam has yet been built with such a small halo, but we have confidence that a variety of methods are available to keep the halo down including careful matching of the energy acceptances of the front and back end, and magnetic collimators or spoilers to throw out halo muons.

As we consider experiments at this high momentum transfer, we anticipate failures of scaling due to weak interactions. If present conjectures of Weinberg are correct, we might expect the cross section to be reduced by a factor of the form

\[
\frac{4}{1 + \frac{q^2}{(40 \text{ GeV})^2}}^2.
\]

This gives a factor \( 1/4 \) in cross section at \( q^2 = 1500 \) and an easily observable factor already at \( q^2 = 200 \).

The studies of weak interactions, particle searches, and QED have already been mentioned somewhat in the above discussion; we envisage here specific experiments to look for specific objects. Proposal 203 by Strovink and others, to look for heavy leptons, is already before NAL.

This field clearly expands as energy and intensity increases; weak interaction cross sections rise with energy and muon targets can be long. We anticipate, therefore, that many more proposals will come in this area.

If QED again becomes a topic of lively concern, an exciting method of studying QED (as emphasized so often by Tannenbaum) is to measure muon tridents.

It is possible that experiments such as this can be operated behind Experiments 26 and 98 simultaneously with these experiments. This is highly attractive, but we must beware of illusory compatibility. Accordingly it may be attractive to make other muon beams especially tailored to these experiments such as a beam suggested by Strovink in this summer study.

The scaling tests of Experiment 26 and its descendents, will give an initial indication of where Experiment 98 and its descendents should direct their attention. While it is obviously desirable to work at the same high \( q^2 \) values as discussed above for the solid target experiments, the desires for studying hydrogen, and examining final states, may enforce further limitations; it is for most experiments necessary to measure the incident energy, the apparatus is larger so that halo is more serious, and the reduction in target density reduces the counting rate.

Nonetheless, if Weinberg's conjectures are correct, the possibility of failures of scaling at \( q^2 = 200 \) (GeV/c)^2 is raised, and an examination of final states in this region becomes particularly exciting.

Also needing higher intensity is the use of a polarized proton target, in conjunction with the longitudinally polarized muons. This study of the spin dependence of the cross section is

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analogous to a comparison of neutrino and antineutrino cross sections, but with all the precision of incident and final particle measurements.

### Beam Intensities

It is perhaps useful to summarize, as best we can, some beams that have been proposed.

It is worth noting that muon beam calculations agree with experiment to about a factor of 2, at BNL and at the existing NAL $\mu$ beams. Electron beam calculations agree with experiment at Serpukhov to an accuracy unknown to the present writer. The electron beam numbers are intended as a very rough guide only.

<table>
<thead>
<tr>
<th>Beam Description</th>
<th>$\mu/p$ Ratio</th>
<th>Intensity for $10^{13}$</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAL beam, August, 1973</td>
<td>$10^{-7}$ (calculation)</td>
<td>$10^6$/pulse</td>
<td>Intensities at 1/2 the incident proton energy</td>
</tr>
<tr>
<td>Existing NAL beam and triplet</td>
<td>$3 \times 10^{-7}$</td>
<td>$3 \times 10^6$/pulse</td>
<td></td>
</tr>
<tr>
<td>FODO channel into existing beam line (Skuja)</td>
<td>$1.2 \times 10^{-5}$</td>
<td>$1.2 \times 10^8$/pulse</td>
<td>Halo large without magnetic collimators</td>
</tr>
<tr>
<td>CERN design (Brianti : Brasse)</td>
<td>$3 \times 10^{-5}$</td>
<td>$3 \times 10^8$/pulse</td>
<td>Cost proportional to intensity. Both may be reduced.</td>
</tr>
<tr>
<td>Design of smaller FODO channel (Mo)</td>
<td>$10^{-5}$</td>
<td>$10^8$/pulse</td>
<td>Halo smaller, but halo rejection not studied</td>
</tr>
<tr>
<td>Large aperture quadrupole beam (Rand)</td>
<td>$2 \times 10^{-6}$</td>
<td>$2 \times 10^7$/pulse</td>
<td>Cheaper than FODO</td>
</tr>
<tr>
<td>Toroidal iron magnet beam (Strovink)</td>
<td>$1.5 \times 10^{-5}$</td>
<td>$1.5 \times 10^8$/pulse</td>
<td>Lower quality; small and hopefully cheap</td>
</tr>
<tr>
<td>Electron beam (Guiragossian)</td>
<td>$\approx 10^{-5}$</td>
<td>$10^8$/pulse</td>
<td>$\pi/e &lt; 10^{-8}$ intensity rises at low energy</td>
</tr>
<tr>
<td>ordinary magnets</td>
<td>$\approx 10^{-4}$</td>
<td>$10^9$/pulse</td>
<td></td>
</tr>
<tr>
<td>superconducting magnet</td>
<td>$\approx 10^{-4}$</td>
<td>$10^9$/pulse</td>
<td></td>
</tr>
</tbody>
</table>

The competition of the CERN beam is obvious. CERN is committed (conversation with W. Jentschke and F. Brianti, May 1973) to a 100-GeV electron/tagged photon beam in the West area into the omegatron by 1977; plans for both a high quality electron beam and a high quality muon beam are actively encouraged for the North area with completion dates of 1978; CERN has an enviable record of completing plans on schedule, and the dates tend to mean dates for complete, reliable operation.