INELASTIC MUON SCATTERING USING A VERTEX SPECTROMETER

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ABSTRACT

Inelastic muon scattering at 100 GeV can be measured quite efficiently using a vertex spectrometer. A closed iron magnet with aperture 1.3 m × 1.3 m × 4 m long is used with liquid hydrogen target and wire chambers operated in the magnetic field. Muon scattering angles in the range 15 mrad < θ_μ < 140 mrad are covered over the full 2π polar angle. Rates are 2 per second using a muon beam of 10^7 μ's per one-second-long burst, easily obtained at NAL. The range of q^2 and ν greatly extends that covered in the SLAC electron experiments. Here we measure over the range $1(\text{GeV})^2 < q^2 < 60\ (\text{GeV})^2$ and $10\ \text{GeV} < \nu < 80\ \text{GeV}$. The shower particles can be studied in considerable detail. The spectrometer is particularly useful in measuring the forward-going particles carrying high momentum. Thus, the ρ and other bosons expected from the diffractive scattering due to vector dominance ought to be easily identified.

The cost of the magnet is estimated to be less than $500,000. Other equipment including the wire chambers and readout are estimated not to exceed $300,000.

I. INTRODUCTION

The recent inelastic electron scattering experiments at SLAC have shown an unusually interesting behavior for large values of the inelasticity, which makes a more detailed study of what is going on highly desirable. In these experiments, only the electron is observed and the cross sections for the process in which the electron loses an energy ν and transfers a momentum q is measured. The cross section shows the usual q^{-4} dependence which is characteristic of the electromagnetic interaction between two point-like particles. However, the further steep q^2 behavior due to the form factor of the proton, evident when the elastic channel only is observed, does not appear when the collision is sufficiently inelastic, since the cross section observed is the sum over many possible channels.

A similar behavior is expected with muons except that at 100-GeV energies at NAL, the range of ν and q^2 can be greatly extended. It is a matter of considerable importance to find out to what extent the lack of any form factor for the total process continues to hold for large values of q^2.

Moreover, very little is known about the nature of the channels which are opened by such highly inelastic collisions. A study of these should throw some light on the mechanism involved in the process.

In general, it will be difficult to observe the hadronic shower in complete detail. This is because the shower will contain a certain number of neutral particles, difficult to detect without interfering with the measurement of the charged particles. It will also be difficult to identify which particles are present, whether π's or K's, protons or antiprotons, etc. Furthermore, in a wire plane array certain angles of emission are unfavorable for precise measurement. Nevertheless, such gross information as how many particles are in the shower and what their momentum distribution and their charge distribution is could be most informative at this stage. In particular, if some characteristic of the shower can be identified, call it Γ, it will be of interest to study $d^3\sigma/d\nu dq^2 d\Gamma$ over the available range of ν and q^2.

In this report we explore what can be done with a single vertex spectrometer by measuring not only the inelastic muon scattering but also the hadronic shower in considerable, if not complete, detail. Such information should be capable of deciding quite decisively about the merits of several models that have been proposed and should provide important insights into the mechanisms of such processes.

Related inelastic muon scattering experiments have already been discussed in summer study reports. The experiments proposed by Perl (B. 2-68-47) emphasize measurements at low q^2 and simple channels in the shower. Our motivation is the same as that expressed by Hand for an experiment proposed in SS-48 but can cover a greater range of the parameters ν and q^2 and is capable of showing the hadronic shower in greater detail. Moreover, the event rate will be considerably higher than in Hand's experiment.

II. KINEMATICS

We study the reaction $\mu + p \rightarrow \mu + M$ as shown in Fig. 1. The incoming μ has an energy $E \sim 100$ GeV, and after scattering by the proton through an angle θ_μ, emerges with energy E'. The hadronic shower has a total mass M and emerges with an angle θ_M. For the muon, it is a good approximation to take its momentum $|p| \approx E$ since $M_\mu << E_\mu$. Also, since the differential cross section varies as θ^{-4} most of the observable scatters will have $\theta << 1$. With these simplifications we write the squared momentum transfer,

$$q^2 = EE' \theta_\mu^2. \tag{1}$$

The inelasticity

$$\nu = E - E'. \tag{2}$$

The hadronic mass is given by

$$M^2 = m^2 + 2m\nu - q^2, \tag{3}$$

where m is the proton mass. Finally, the angle of emission of m is

$$\theta_M = \frac{E'}{\sqrt{\nu^2 + q^2}}\,\theta_\mu. \tag{4}$$

In order to orient the study, we have given in Table 1 the two-body kinematics for M = 5 GeV and for M = 10 GeV. Here it is worth noting that if the mass M = 10 GeV, it comes away with a total momentum of from 50-80 GeV/c at an angle in the lab $10° < \theta_M < 2.5°$. Thus, a very large momentum is carried in the forward direction by the shower, and the question is what is it that takes away so much momentum? The situation is the same but less dramatic for M = 5 GeV. The momentum carried away tends to be less and the angle of emission, always less than 10°, is still a small angle. This dictates the use of wire planes disposed at right angles to the beam direction. Maximum possible mass for 100-GeV muons is 13.73 GeV which is the total c.m. energy.

Note also that the values of q^2 range up to 80 $(\mathrm{GeV/c})^2$ since the acceptance of the spectrometer extends to θ_μ = 140 mrad. This compares with the range of q^2 in the SLAC electron experiment.

$$0.5 < q^2 < 2\text{-}3\ (\mathrm{GeV/c})^2.$$

In the SLAC experiment the scaling parameters

$$\frac{m\nu}{q^2} < 2.5.$$

Here this quantity approaches 70.

Rates

We obtain an estimate of the rates from the following formula given by Bjorken from an analysis of the SLAC experiments and applicable in the range

$$0.5 < q^2 < 2\text{-}3\ \mathrm{GeV}^2$$

and

$$1.5 < \frac{m\nu}{q^2} < 2.5$$

$$\frac{d^2\sigma}{dq^2 d^2\nu} = \frac{4\pi\alpha^2}{q^4} \frac{E'}{E} W_2(q^2,\nu)\left[1 + \frac{\nu^2}{EE'}\left(\frac{\sigma_T}{\sigma_T+\sigma_S}\right)\right]. \tag{5}$$

The value of $\sigma_T/\sigma_T+\sigma_S$ is not known but the truth is supposed to be between $\sigma_S = 0$ and $\sigma_T = 0$. For rough calculation purposes we neglect the second term in the bracket since in any case it will be smaller than one. Then write

$$\frac{d^2\sigma}{dq^2 d\nu} = \frac{4\pi\alpha^2}{q^4} \frac{E'}{E} W_2(q^2,\nu)$$

and take the value νW_2 in the range 1/3 to 1/2, in accordance with the analysis that has been given.

We take $W_2 = 1/3\nu$ and transform to spatial coordinates

$$\frac{d^2\sigma}{d\Omega d\nu} = \frac{4\alpha^2}{3E^2} \frac{1}{\theta^4} \frac{1}{\nu} .$$

Thus, since our acceptance will extend over the full 2π of polar angle, we can calculate a total cross section over the range of θ and ν which is practical

$$2\pi \int \frac{d^2\sigma}{d\Omega d\nu} \sin\theta d\theta\, d\nu = \frac{4\pi\alpha^2}{3E^2} \log\frac{\nu_{max}}{\nu_{min}}\left(\frac{1}{\theta^2_{min}} - \frac{1}{\theta^2_{max}}\right).$$

Then

$$\sigma = 1.05\times10^{-35}\left(\frac{1}{\theta^2_{min}} - \frac{1}{\theta^2_{max}}\right) cm^2,$$

where we have taken $\log \nu_{max}/\nu_{min} = 1.25$. For the rates we take $10^7\mu$/pulse and a 1-meter hydrogen target.

$$R = 7\times 6\times 10^{23}\times 10^7\times 1.05\times 10^{-35}\left(\frac{1}{\theta^2_{min}} - \frac{1}{\theta^2_{max}}\right)$$

$$= 4.4\times10^{-4}\left(\frac{1}{\theta^2_{min}} - \frac{1}{\theta^2_{max}}\right).$$

For $\theta_{min} = 10$ mrad, $\theta_{max} = 140$ mrad. This gives $R = 4.2/10^7\mu$'s (4200 events/hour). The number of events near the upper end of the range for q^2 is 1/200 of the number near the lower end of the range--e.g., about 21/hour.

III. SPECTROMETER DESIGN

We propose to use wire plane spark chambers equipped with a non-magnetic readout. The readout has been described by Nunamaker and Neumann in Nuclear Instruments and Methods and is being further developed at the University of Chicago for large wire plane arrays. It is described in more detail in the Appendix. The non-magnetic readout allows operation of the wire plane in a strong magnetic field in any orientations. It is a low-voltage, low-current device with high multi-track efficiency. The operation is similar to the Charpak chamber except that the discharge is carried to the Geiger region to provide enough signal (10 volts) to operate with a field effect transistor.

With such wire planes, a closed-type iron magnet can be used with the attendant economies in fabrication and the advantage of a highly uniform field. Having a uniform magnetic field within the spectrometer simplifies the reconstruction of the particle trajectories and the calculation of the momenta.

For reasons of economy and simplicity we chose a magnet of modest size for the spectrometer. This may be classed as a "window-frame" type with square aperture 1.3 m × 1.3 m × 4 m long. Wire planes of 1 m × 1 m useful area can be accommodated with an allowance of 15 cm on all sides for the frame and connections.

The magnet is open at both ends so that the whole array of wire planes together with the liquid hydrogen target can be assembled in its own frame outside the magnet and then slid into place within the magnet gap. The design of the magnet is similar to the standard deflection magnets in common use (such as BM105 at Argonne).

Here we scaled the design down from a recent design by Leith for a special magnet for SLAC. The Leith magnet is of the "window-frame" type with an aperture 2 m high, 3 m wide, and 1.5 m deep. It produces a 20-kG field, weighs 600 tons, and required 7 megawatts of power. Its cost is estimated at $766,000. Using the same current density and the same number of ampere-turns per meter of gap--and as much area of iron in the yoke as in the gap, we obtain the following numbers:

Magnet frame	147 tons × $500/ton = $74,000
Coils	78 tons × $4000/ton = $312,000
Miscellaneous	Plumbing, electrical = $50,000
	Total cost of magnet = $436,000

The power requirement for 20 kG due to more efficient use of iron is 2.3 MW. Figure 5 shows a sketch of the magnet.

Wire Planes

The wire planes are assembled in sets (modules) of four--two vertical and two horizontal as shown in Fig. 6. Following our current construction, the high voltage plane is 0.005-in. Al foil. The gas seal is 0.00075-in. mylar. The horizontal planes are tilted with respect to each other by about 0.1 radian to remove ambiguity in locating the position of more than one track in space. Wires are 0.004-in. Al and spaced 1 mm apart. The readout currently costs $1 per wire. Thus, each plane costs $1000 for readout alone. Construction of the planes plus mounting and connections are estimated to run $500 per plane. The spectrometer will use 25 such modules at a total cost of $150,000. Additional scintillation counters, Charpak planes, etc., may cost an additional $100,000. It is assumed that the on-line computer needed for the readout ($100,000) will be available. A calculation of the multiple scattering in the wire planes gives, for each module of 4 planes, 1.06×10^{-3} radiation lengths. Thus, 25 modules will give 0.026 radiation lengths, appreciably less than in 1 meter of liquid hydrogen--0.12 radiation lengths.

Beams

The muon beam designed by J. Christensen (SS-96) is capable of providing 2×10^8 μ's per 10^{13} protons. This beam has a purity $\pi/\mu \approx 10^{-6}$, diameter of 4 in. and a divergence of 1 mrad. There is a great advantage in reducing the diameter of the beam. This can be done at the collimator with a loss of intensity by a factor of 4. We suppose that the proton flux actually available will not be 10^{13} but about 2×10^{12} on a 1-second long spill and so arrive at a muon beam of 10^7/sec. This is at the upper limit of what can be managed simply using Charpak chambers and simple scintillation counters in the beam to keep track of each beam particle.

IV. MUON SCATTERING EXPERIMENT DESIGN

The arrangement for measuring the muon inelastic scattering is shown in Fig. 7. The incoming muon momentum and direction are measured by a 4-meter deflection magnet and the counter assemblies $C_1C_2C_3C_4$. The deflection magnet need only have a 10 cm × 10 cm aperture to accommodate the 5 cm diameter muon beam. Each counter assembly consists of a small 2 in. × 2 in. scintillation counter surrounded by an anticoincidence counter. Behind each 2 in. × 2 in. counter is a set of Charpak-type proportional wire chambers capable of handling 10^7 particles per second and capable of locating the track position to within 0.5 mm. With 5-meter spacing between C_1 and C_2 and between C_3 and C_4, angles should be measurable to within 0.1 mrad. A 100-GeV muon will be deflected by 24 mrad in the 4-meter magnet so that the momentum will be measured to 0.6%.

The spectrometer proper has a 1-meter liquid hydrogen target (0.12 radiation lengths) in the upstream end. The 25 wire-chamber modules total 0.026 radiation lengths. Assuming a 100-GeV muon in and 50-GeV muon out, $<\theta^2>^{1/2} \approx 0.1$ mrad. This sets a limit on the accuracy of the angular measurement of the muon which emerges at angles from 10 to 140 mrad in this experiment.

Momentum Measurement

Measurement of the momentum of the emergent muon may be made by measuring the curvature of the 3 meters of path in the magnet beyond the hydrogen target. This is a measurement of the sagitta and can be made with an accuracy of 2.2 GeV/c for a 50-GeV muon. A better measurement can be made using the field-free path of the muon downstream of the magnet, using wire planes at C_5 and C_6, provided the vertex of the scattering can be determined to within the 0.5 mm measuring error. In this case, the two angles, the scattering angle projected on the horizontal plane θ_x, and the magnetic deflection angle χ can be unscrambled and the accuracy of the momentum measurement increased by a factor of 4. It should not be difficult to locate the vertex to the required accuracy since several particles should be seen emerging from the vertex. These considerations show some of the compromises that were made in the choice of the magnet dimensions. To improve the accuracy in the momentum measurement by a factor of 4 by the sagitta method would require doubling the measurement length, in this case by increasing the length of the magnet by 3 meters. However, this would reduce the aperture unless the height and width of the magnet were increased in proportion.

According to (3) the uncertainty in the missing mass is

$$\Delta m = \sqrt{\left(\frac{m}{M} \Delta\nu\right)^2 + \left(\frac{\Delta q^2}{2M}\right)^2} \quad . \tag{4}$$

In general, the error contributed by q^2 is small so that

$$\Delta M \approx \frac{m}{M} \Delta\nu .$$

It would be useful to keep the $\Delta M < 0.1$ GeV since this tests the presence or absence of a pion in the shower. We meet this with $\Delta\nu = 1$ GeV and $M = 10$ GeV, but this is just at the edge of our present design. To satisfy this test we should either go to a larger magnet or improve the accuracy of the wire-chamber measurement. There is a good prospect that this could be done by operating the wire chambers at liquid air temperatures and scaling wire diameters and spacings down by a factor of 4. This has been tried by Rubbia at Cern who obtained in this way an improvement in resolution by a factor of 4.

In view of this, the present size of magnet could have extended usefulness when higher precision appears needed. At the present stage, the added accuracy might have limited usefulness because of the difficulty in accounting for every particle in the shower, in any case.

Trigger

Triggering is done with the help of scintillators at C_6, C_7, C_9, and C_{10}. C_6 has a hole for the beam which is twice the expected beam size at this position. It covers an area of 2.7 m × 2.7 m with a 16-cm hole for the beam. The same is true of C_9 which is 3.3 m × 3.3 m with a hole twice the beam diameter expected at this position. Counters C_7 and C_{10} are antibeam counters so that the trigger is

$$(C_1C_2C_3C_4)\ (C_6\overline{C_7}C_9\overline{C_{10}}).$$

A muon filter, 2 meters of iron behind C_6, is supposed to absorb any hadronic component of the beam. Muons lose 2.3 GeV in this filter and scatter about 2.5 mrad.

Wire planes at C_5, C_6, C_8, and C_9 are used to track the scattered muons beyond the spectrometer and through the filter.

If there is appreciable halo around the beam this may not be a stringent enough trigger. C_3 and C_4 could be arranged as a hodoscope array to accept particles with angular dispersion $\leq$ 1 mrad. A further trigger requirement would be provided in the spectrometer magnet just downstream of the hydrogen target which would require the presence of 1 or 2 shower particles to enable the trigger.

The arrangement would then trigger on muons scattered through angles 10 mrad $< \theta_\mu <$ 140 mrad. The efficiency of triggers at 10 mrad will be less than 100%, and it may be necessary to raise the minimum angle to 15 mrad or so if the halo effect proves to be objectionable. It should be noted that the wire plane system is capable of triggering as fast as 500 times a second. This permits a loose trigger since a simple check of the track location on planes at C_5 and C_6 can tell whether the angle of the scattered muon was large enough to merit a complete retrace of its trajectory.

Shower Detection

With the wire plane set perpendicular to the beam direction, the spectrometer measures efficiently particles emitted in the forward cone. The accuracy of momentum measurement falls rapidly when the angle of emission exceeds 45°. It is usually possible to detect the particle but the length of its trajectory is in the range 0.5 to 1.0 meters, not sufficient to make a good momentum measurement.

At quite low momentum, $\approx$ 2.25 GeV/c, the radius of curvature is less than 0.50 meters and on 90° emission, the track may be followed through more than 360° as seen in Fig. 8. Other sample trajectories in the momentum range of 0.5 and 1.0 GeV/c are sketched in Figs. 9 and 10 to show the extent to which these might be measurable.

Assume that the module spacing is 12 cm in judging the number of points on the trajectory that would be measurable.

In the high-energy collisions considered here, however, most of the momentum of the shower is carried forward, generally at angles less than 10°. For example, for a muon scattering at 50 mrad and producing a shower of mass 10 GeV, the mass carries a momentum of 58 GeV/c at an angle of 2° in the lab. For the more frequent collisions at lower q^2, the angle of the shower is even smaller. Thus, most of the momentum will be in a direction in which the spectrometer is capable of measuring it quite accurately--in general, to better than 1%.

It will be of considerable interest to determine how many particles are involved in carrying the bulk of the momentum of the shower.

For measuring the low momentum particles at large angles, it will be better to arrange the same wire planes along the target parallel to the beam. In this case, the momentum may be measured to better than 3% for momenta around 1 BeV/c. Note that the width of the wire planes is 1 meter, just the same as the hydrogen target.

π^o Detection

For π^o detection lead radiators could be placed between the wire planes and these in turn used to observe the development of electron showers from the γ rays of π^o decay. In order to keep the same muon trigger and measurement, the lead would be placed in the lower half of the aperture, the upper half being kept clear for the muon to traverse without excessive multiple scattering.

Neutron Detection

In a similar way neutron emission could be detected by placing brass plates in front of the lower half of the wire planes and then looking for a nucleonic shower. This technique would be useful to obtain the number of neutrons, but the energy measurement would be necessarily crude.

Arrangement of the Wire Planes

Of course the more planes the better for the purpose of reconstructing the shower. However, the planes are costly, and we prefer to dispose the 25 modules which would be made for this purpose in a non-uniform way. We ask that each forward trajectory be measured at 10 or more somewhat uniformly spaced positions within the magnet. We place one set of planes at the exit end of the magnet, and then, since this distance to the center of the hydrogen target is 3.5 meters, we place the second plane $1/10 \times 350 = 35$ cm upstream of the first. The distance to the center of the hydrogen is now 315 cm, so we place the third set of planes $1/10 \times 315 = 31.5$ cm further upstream--and so on, until a spacing of 12 cm is reached after which the modules are uniformly spaced 12 cm apart. In this way, 25 modules (100 planes) suffice to fill the magnet aperture.

Track Reconstruction

While wire chambers have been used quite successfully in the reconstruction of simple events involving one or two particles for using a spectrometer, it is clear that the problem becomes increasingly more difficult as the multiplicity of the event increases. In the present design we have specified a minimum of ten pairs of measurements per track. This is more than is needed if there are just two or three tracks to be measured. As the number of tracks to be analyzed in any given event increases, the amount of computer time required and the possibilities for ambiguity would increase as some power of the multiplicity. We haven't examined this question adequately, although this is experience of an analogous kind of analysis in the HPD type of handling of bubble-chamber photographs. We do not know at this point what the best way will be to handle the multiparticle problem with wire planes. However, it will help a good deal to know that inside the magnet the field is highly uniform and that the trajectory follows a simple mathematical curve, the helix, with relatively few parameters to characterize it. Moreover, the events are all triggered events, and it will rarely happen that there is more than one interaction in the array. Thus, all tracks have to originate at the vertex (except V events from K or Λ decay), and every collection of connected points would have to fit a helix passing through the vertex.

If events of interest turn out to be those of very high multiplicity, then the vertex detector of choice would turn more strongly to the streamer chamber, which provides a much higher information content per event at much lower cost than wire planes. The optimum streamer-chamber vertex spectrometer appears to require a much larger magnet and represents a much larger commitment than the system described here.

Our view is that the measurement of $d^2\sigma/d\nu dq^2$ for the muon, at the rates and over the range of parameters E, ν, and q^2 is possible with this system, already justifies an \$800,000 effort. The number of wire planes required could be greatly reduced if this were the only purpose. However, there is considerable interest in measuring the partial cross sections.

$$\frac{d^3\sigma}{d\nu dq^2 d\Gamma},$$

where Γ is some clearly identified characteristic of the shower. Thus Γ could be a high momentum $\pi^+\pi^-$ pair such as would be expected from the diffractive production of ρ due to vector dominance in the reaction. Other relatively simple topologies might be identified and selected by running the data tapes through a computer capable of presenting a visual display of the reconstructed track positions. A learning process is involved here which only adds some interest to the problem and will force some thinking about the number and kind of channels that should be looked for.

V. CONCLUSIONS

1. A vertex spectrometer with wire planes is very well adapted to a study of $d^2\sigma/d\nu dq^2$ for inelastic muon scattering over a wide range of the parameters E, ν, and q^2.

2. Great possibilities are offered to measure the partial mass sections $d^3\sigma/d\nu dq^2 d\Gamma$, where Γ is a simple channel or a collection of simple channels. One could look for high momenta σ's or other vector bosons. The event rate is high enough to give appreciable statistics for a number of well-selected groups Γ.

3. The wire plane array is flexible and allows easy insertion of auxiliary devices such as lead radiators for π^0 detection or converters to permit neutron emission to be detected.

4. Both signs of μ are available and both directions of longitudinal polarization. It will be of interest to study what asymmetries are produced by these.

5. Statistical information about the shower will be of interest; multiplicities, charge distributions, momentum distributions $p_{\parallel}$ and $p_{\perp}$ are all accessible.

6. Different arrangements of the wire planes (e.g., parallel to the beam at the target) will permit the measurement of low momentum particles emitted at large angles. Identification of slow protons should be possible by using dE/dx to produce a measurable momentum change.

7. Production of strange particles could be judged from the presence of V's in the spectrometer.

APPENDIX: THE NON-MAGNETIC WIRE-CHAMBER READOUT

Specifications for the readout assembly being developed at the University of Chicago are given in Figs. 11 and 12. The circuit can be understood from the simple sketch given in Fig. 13. If a discharge occurs on the wire, current flows from the HV plane and charges the condenser C to about 10 volts, but not more than 20, since at 20 volts the bias is overcome and the diode limiter takes the current.

Sufficient charge to operate a buffer register is held by the condenser for 0.1 sec or more. The readout operates in parallel groups of 32 wires. When the gate opens those 32 wires are read out into a buffer register, and the binary information (1 for charged, 0 for no charge) then transferred to the appropriate address in a large memory store by the computer. It takes about 1 μsec to read out 32 wires in this way. A scanner then shifts the gate signal to the next set of 32 wires and the process is repeated. In this way 32,000 wires can be read out in 1 msec--100,000 wires in 3 msec. The system is ready to go again in 3 msec--by which time the discharge is cleared. Thus 300 events per second can be handled. If a greater rate is needed and the wires can be ready in less than a msec, parallel scanners can be used. Cost of the readout is about $1.25 per wire.

The development of large-scale integrated circuits has progressed to the point that makes possible an appreciable reduction in cost. We are aware of a development at Fairchild which is producing semiconductor active memories for the Illac IV computer at the University of Illinois. Each silicon chip 0.110 in. × 0.140 in. is made with 256 bi-polar devices complete with all circuitry for addressing, reading-in, or reading-out. Current cost is $0.07 per bit. There is a good possibility that something similar could be devised for wire-chamber readouts, which would greatly decrease the cost of the readout and make more practical arrays of greater resolution and higher information content.

Table 1. Kinematics for the Process $\mu + p \to \mu + M$.

θ_{cm} deg.	p_μ GeV	θ_μ deg.	p_M GeV	θ_M deg.	q^2 GeV^2	ν GeV	$m\nu/\gamma^2$	θ_μ mrad
M = 10 GeV								
0								
10	46.8	0.69	53.2	0.60	0.67	53.2	74.6	11.9
20	45.7	1.38	54.3	1.16	2.65	54.3	19.2	24.1
30	44.0	2.10	56.0	1.65	5.90	56.0	8.9	36.6
40	41.6	2.85	58.4	2.03	10.29	58.3	5.3	49.7
50	38.8	3.65	61.3	2.31	15.72	61.2	3.65	63.7
60	35.4	4.52	64.7	2.47	22.00	64.6	2.75	78.8
70	31.7	5.48	68.5	2.53	28.98	68.3	2.21	95.6
80	27.8	6.56	72.5	2.51	36.40	72.23	1.86	114.5
90	23.7	7.81	76.6	2.41	44.07	76.30	1.62	136.4
100	19.6	9.30	80.7	2.25	51.74	80.38	1.46	160.6
110	15.7	11.14	84.7	2.05	59.22	84.33	1.34	194.4
120	12.0	13.48	88.4	1.81	66.26	88.04	1.25	235.3
M = 5 GeV								
0	87.1	0	12.9	0		12.86		
10	86.5	0.69	13.6	4.37	1.24	13.52	10.3	11.9
20	84.5	1.38	15.6	7.49	4.90	15.47	2.96	24.1
30	81.3	2.10	19.0	9.04	11.71	18.67	1.50	36.6
40	77.0	2.85	23.4	9.41	19.03	23.00	1.11	49.7
50	71.7	3.65	28.9	9.09	29.05	28.35	0.92	63.7
60	65.5	4.52	35.1	8.44	40.68	34.54	0.80	78.8
70	58.6	5.48	42.0	7.65	53.56	41.39	0.73	95.6
80	51.3	6.56	49.4	6.82	67.30	48.69	0.68	114.5
90	43.8	7.82	56.9	6.00	81.47	56.22	0.65	136.4
100	36.2	9.31	64.5	5.22	96.69	63.75	0.63	160.7
110	28.9	11.14	71.8	4.47	109.50	71.05	0.61	194.5
120	22.1	13.49	78.7	3.76	122.56	77.90	0.60	235.5

Note: In Fig. 2 we give a plot of q^2 vs ν, in Fig. 3, a plot of θ_M vs θ_μ, and in Fig. 4 a plot of $\nu M/q^2$ vs θ_μ in mrad.

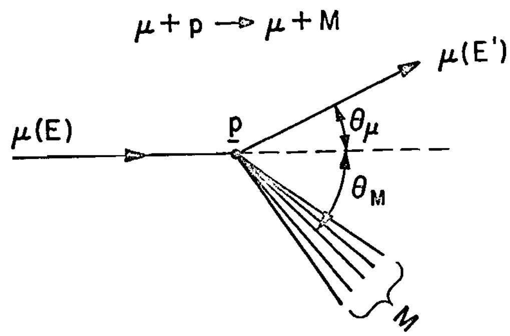


Fig. 1. Quantities used in describing inelastic muon scattering.

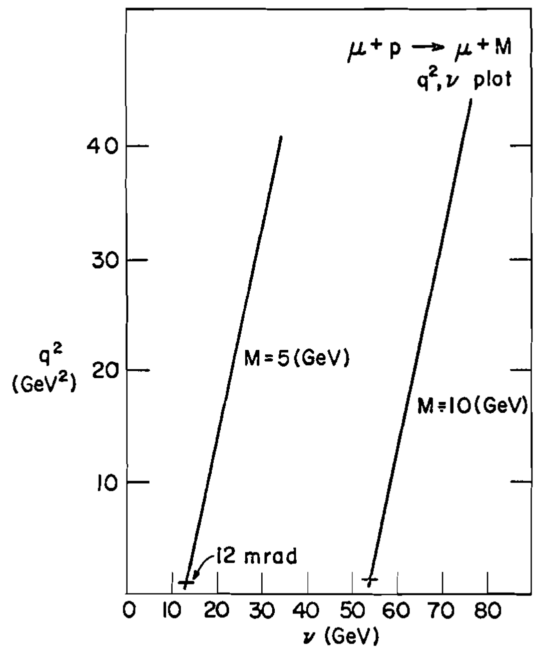


Fig. 2. Inelastic muon kinematics: q^2 vs ν.

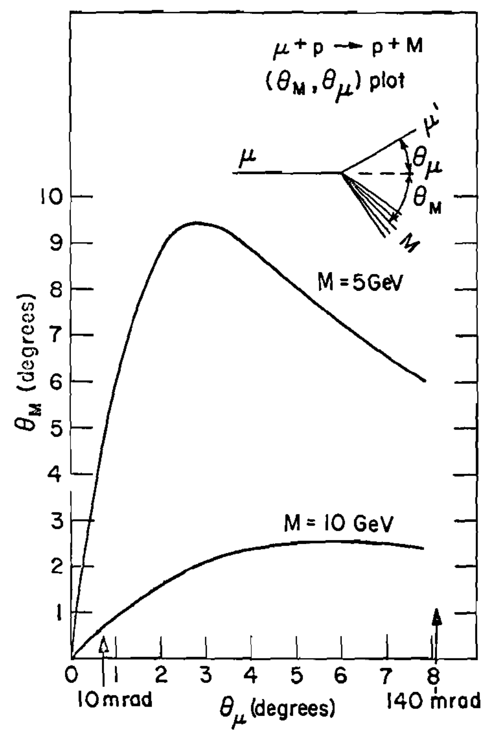


Fig. 3. Inelastic muon kinematics: θ_M vs θ_μ.

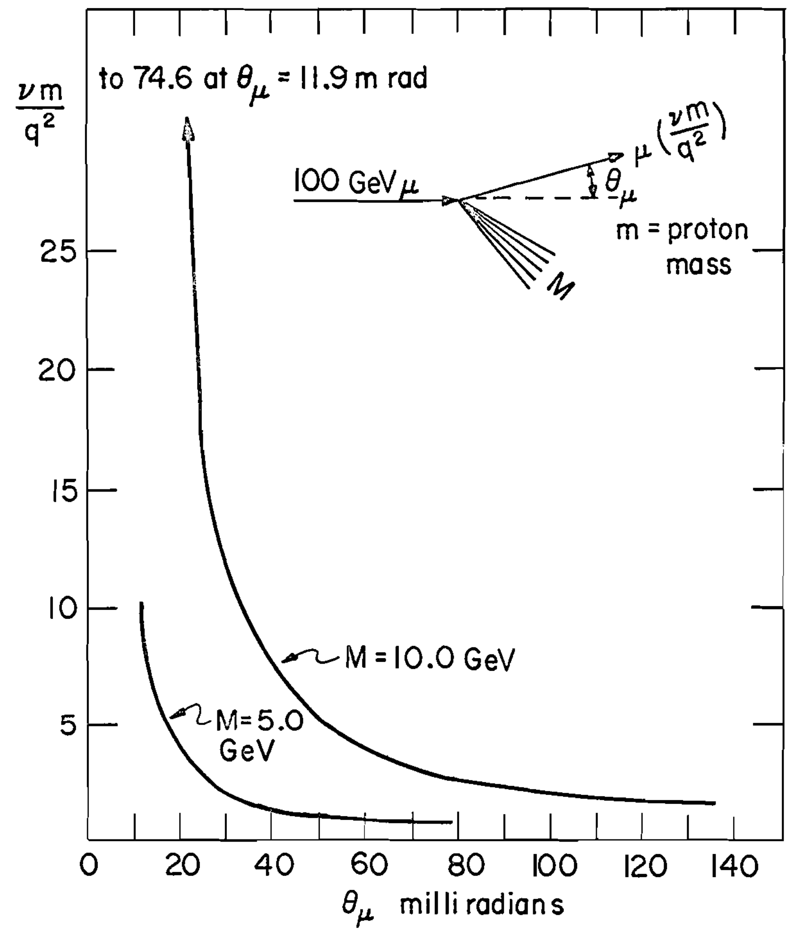


Fig. 4. Inelastic muon kinematics: ν_M/q^2 vs θ_μ.

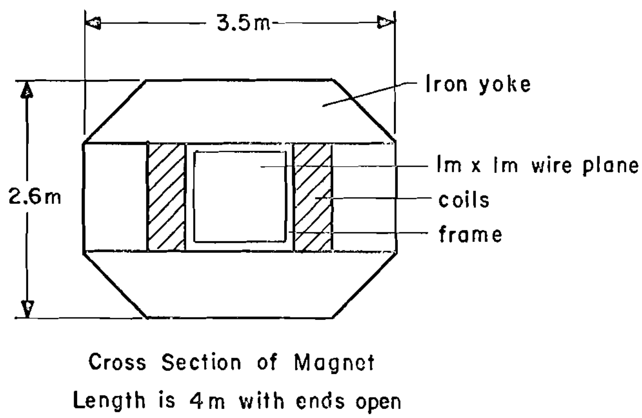


Fig. 5. Sketch of proposed magnet.

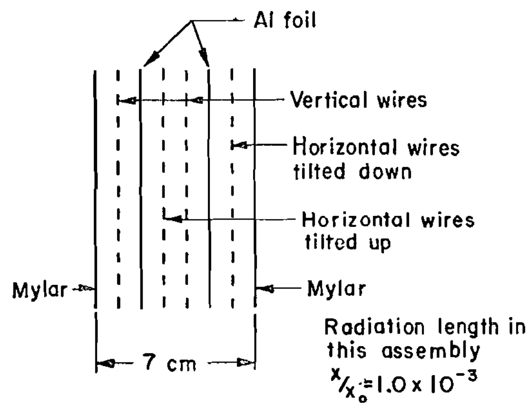
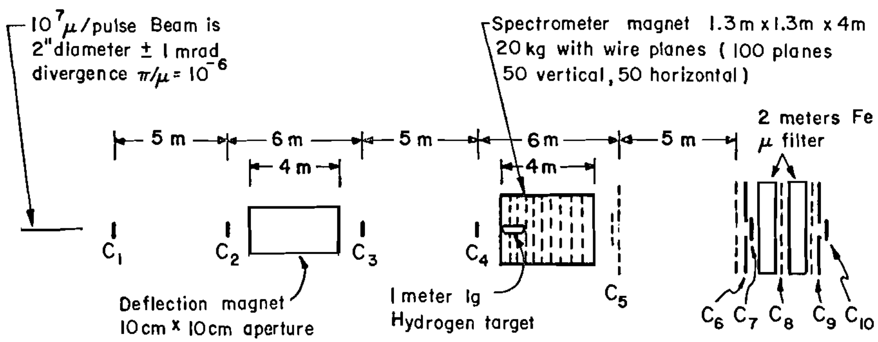


Fig. 6. Construction of a wire-plane module containing four digitizing planes.

Muon Inelastic Scattering Experiment



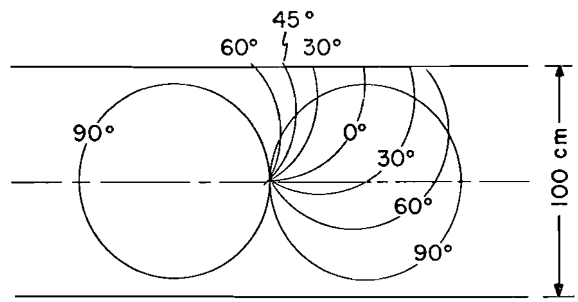
Trigger is $(C_1 C_2 C_3 C_4)(C_6 \bar{C}_7 C_9 \bar{C}_{10})$

C_3 and C_4 are hodoscopes
to define incoming angle
to ± 1 mrad

$C_1 C_2 C_3 C_4$ are equiped with Charpak planes
for precise angular measurement.

C_5 C_6 have wire planes made insensitive in the region of the beam.
C_5 has a Charpak plane for beam measurement.

Fig. 7. Layout of inelastic muon scattering experiment.

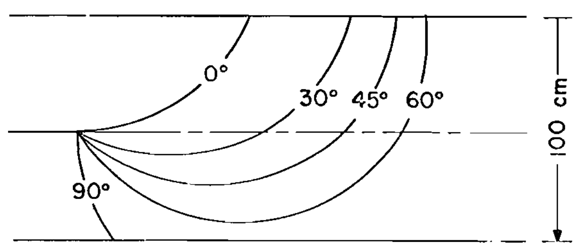


Some trajectories for

p = 0.25 GeV/c R = 0.416 meters

Dip angle = 0°

Fig. 8. Some magnet trajectories of 0.25 GeV/c particles.



Some trajectories for

p = 0.5 GeV/c R = 0.833 meters

Dip angle = 0°

Fig. 9. Some magnet trajectories for 1.0 GeV/c particles.

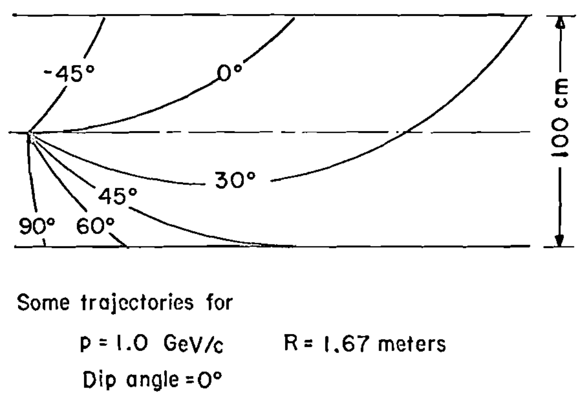
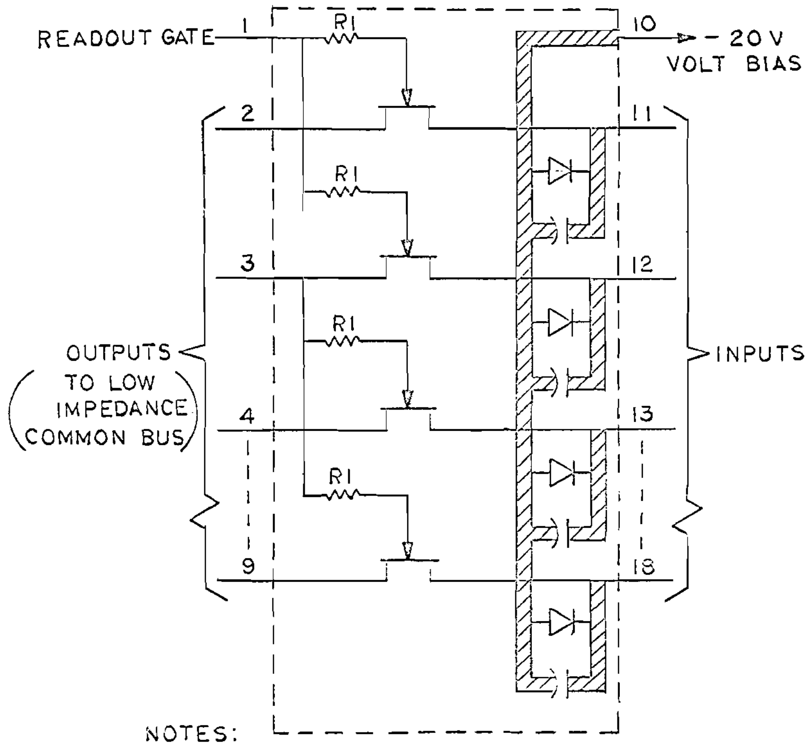


Fig. 10. Some magnet trajectories for 0.5 GeV/c particles.



NOTES:

1. CAPACITOR 1000 pf ± 20%
   WVDC 25 VOLTS
2. DIODE: 1N914
   LEAKAGE AT 10V < 50 n AMP
3. N CHANNEL JUNCTION FIELD EFFECT TRANSISTOR — SUCH AS FAIRCHILD 2N5163
   IDSS (MIN) = 5 ma
   BVGSS = 35 VOLT
   IGSS (25°C) = 10 n AMP
   VP (OFF) = 8 VOLTS
4. GATE RESISTOR "R1": 3K ± 20%, 0.1 W
5. PACKAGE, 10 PIN - NON-MAGNETIC FLAT-PACK PREFERRED (PLASTIC PACK O.K.)
6. 8 CIRCUITS PER PACKAGE.
7. (hatched) LOW INDUCTANCE WIRING.

Fig. 11. Readout package for 8 wires.

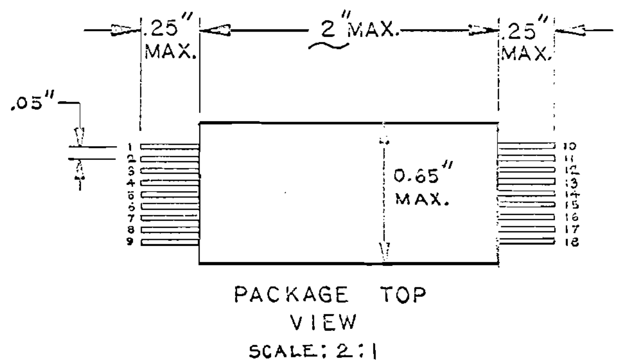


Fig. 12. Dimensions of 8-wire readout package.

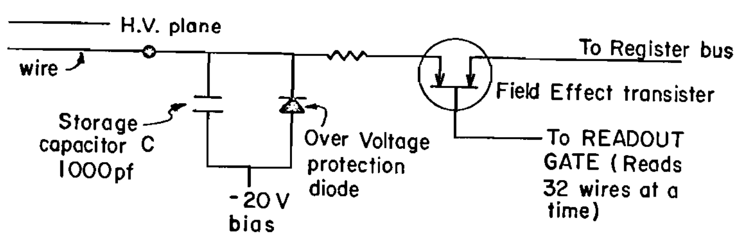


Fig. 13. Circuit diagram of individual wire readout.