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MUON EXPERIMENTS

M. Goitein
Lawrence Radiation Laboratory

and

J. Tenenbaum
Stanford Linear Accelerator Center

Comparison of the Proposals

Four experimental proposals have been submitted. Of these two are similar and effectively a collaboration. In this section we will discuss the general emphasis and characteristics of the resulting three proposals. They are: Harvard-SLAC (No. 29, No. 5); Chicago-Pennsylvania (No. 33); Michigan State-Cornell (No. 26).

The identification of muons is similar in all three experiments. A muon is a particle which emerges after many radiation lengths of iron. The spectrometry is quite similar to other types of experiments in two cases (Nos. 29 and 33). Wire chambers and large aperture magnets are used. The other experiment uses a solid iron spectrometer which is unique to muon work.

The Harvard-SLAC experiment is outlined in Fig. 1. The major emphasis is on

1. Inelastic form factors
2. Final states - especially ρ^0's
3. Muon anomalies (tridents, etc.),

in roughly that order. For the form factors one covers the range $0.2 < -q^2 < 20$ $(GeV/c)^2$, $20 < \nu < 90$ GeV. To achieve these low q^2 and high ν values, scattered muon angles down to 10 mrad are accepted. The result is a complex triggering arrangement which demands that the muon scatter through more than 7 mrad and lose more than 20 GeV.

The Chicago-Pennsylvania experiment is outlined in Fig. 2. The major emphasis is on the detection of hadronic final states for high q^2 events. The muon is detected in the angular range $1^o < \theta < 4^o$ with $5 < q^2 < 13$ $(GeV/c)^2$. The counting rate is enhanced by using a beam of 10^7 μ/pulse and employing wire chambers with 100 nsec time resolution. These proportional mode chambers form spaced half-cylinders downstream of a segmented hydrogen target. Both target and chambers are within a large volume ($2 \times 3 \times 4$ m^3) magnet. The magnet causes low-energy knock-ons to execute cyclotron oscillations and keeps the instantaneous rate at $<$ 10 MHz. Because of the emphasis on final-state hadrons, π^0 detection is also required. The energy resolution

(~ 200 MeV) is not sufficient to provide kinematic fits. Therefore the magnet also contains γ-converting material followed by additional proportional chambers. The performance of these chambers is currently being studied at Cornell in an electro-production experiment. The large magnet would be the major new piece of equipment and is estimated by the experimenters to cost $1.7 M.

The Michigan State-Cornell experiment is outlined in Fig. 3. The main emphasis of this proposal is an early check of scale invariance. Such a check can be done with limited precision and limited attention to the hadronic final states. To simplify the experiment, a high-Z target consisting of a 100-g/cm^2 lead-plate spark chamber is used. Portions of the chamber are interspersed with proportional chambers. This approach requires an understanding of the A dependence of the cross section. The proposal gives several arguments that this is possible. The remaining portion of the apparatus is unique to muons. A magnetized-iron spectrometer provides momentum resolution of ±7%. The muon trajectory is determined at 4 points within 12 m of iron. Data are taken at muon energies of 50, 100, and 150 GeV. The scale of various portions of the apparatus (pion filter, beam magnets, target length, spectrometer length, apparatus spacing) are all scaled with the muon energy. This method keeps the systematic errors constant. Finally, the overall technique relies on the relatively slow E' dependence of the cross section.

Details of Muon Beam Requirements

Proposal	Intensity (muons/1-sec pulse)	Energy Range (GeV)	Momentum bite % Δp/p fwhm	Spot Diameter (cm)
5	10^6	80 - 120	10%	10
26	10^6	50 - 150	few % (?)	~10
29	10^6	100	5%	10
33	$10^7 - 5 \times 10^7$	100 - 200	5%	~10

On the question of beam intensity we note that all experiments could make use of proportional chambers and the high (10^7/pulse) beam rate. Only the authors of # 33 say they intend to do so at this time. Proponents of No 26 and 29 say they will use them if the technology looks propitious. We feel that the separation of W_1 and W_2 as well as the probable desire to tie onto SLAC measurements will lead to requirements of a lower-energy beam (perhaps with a modest loss in intensity). Thus the beam transport should be capable of going down to 15 GeV. Pursuit of the deep-inelastic cross section to higher energies, albeit with poorer apparatus resolution, may well lead to calls for beams up to 300 GeV.

The spot sizes and momentum bites proposed are not critical experimental quantities except insofar as they reflect a sober judgment of the parameters necessary for adequate intensities.

Under the general beam requirements the following categories arise:

1. Momentum measurement on muon beam

All proposals except No. 26 call for an event-by-event incident muon momentum measurement to a few tenths of a percent or so. This could really be done on the last transport bending magnet. One then looks to the designer to leave space for a chamber/ scintillator array both immediately fore and aft of the magnet and then two more spaces 10 m upstream and downstream. The detectors would require a space of about 1 m × 1 m × 1/2 m (along beam).

2. Pion filter accessibility

The pion filter (variously Be and steel in the proposals) should be accessible so that the depth of absorber can be altered (Proposal 26 would require this to be done frequently).

3. Veto counter

An upstream veto to reject halo muons must be placed at least 5 ft upstream of the target. Its size should be that of the projection along the beam direction of the sensitive detectors of the apparatus. Typically this will be some 3 m × 3 m. Room for such a detector must be left.

4. Beam height - 8 ft recommended

Apparatus extends below beam height as follows:

Proposal #	Distance (m)
5	2.1
26	~1
29	1.5
33	2.75

The magnet of No. 33 is large and might constitute an exceptional case for which excavation is appropriate. However, the extension of these experiments to better resolution will require more magnets and, if solid angle is not to be sacrificed, large gaps and hence lower magnets. We believe a beam height of 8 ft (2.5 m) is appropriate for a muon beam since the experiments are characterized by large solid-angle devices standing well back from the target.

5. Long spill--compatibility with short spill

We mention, for completeness, the need to resolve the question of the relationship to the short-spill bubble-chamber neutrino and rf-separated beams.

6. Pion contamination

This can be a vexing problem, but none of the proposals mention it. All of them assume a "pion filter" shortly before the last bending magnet of about 20 mean free paths, to give a π/μ ratio $< 10^{-6}$. At 100 GeV, this will scatter through 1 mrad.

7. Muon halo

All proposals mention the problem of muon halo, and none discuss how to avoid it. The presence of the halo is one limitation on useable beam intensities.

Details of Apparatus Requirements

1. Real estate

Proposal	Distance from target to end of the apparatus (m)	Half width of the apparatus (m)
5	15	1 1/2 (?)
26	30	1
29	35	2 1/2 (?)
33	27	3 3/4

These areas do not include the beam analysis discussed above. Typically, a 25-m run is required for that section.

The typical experiment consists of a target surrounded by counters and shower counters/chambers followed by a spectrometer magnet with wire chambers in front and behind and betwixt--followed by a range device to identify muons. We take these separately:

2. Target

Proposal	Type of target	Volume of liquid H_2
5	75 cm hydrogen	13 liters
26	high Z, 200 g/cm^2	
29	200 cm hydrogen and D_2 also, perhaps, high Z as No. 26	40 liters
33	100 cm liquid H_2	20 liters

In Proposal 33 the target is within the spectrometer. In No.'s 5 and 29 one would need 1 1/2 m clear for surrounding detectors.

We note that these targets represent safety hazards and their handling will impose constraints on their environment.

The high Z targets will weigh approximately one ton and will require appropriate handling facilities.

3. Spectrometer

Proposal (#)	Field Volume (H × W × Gap) (M^3)	$\int H \cdot dl$ (kG·m)	Weight (tons)	Power (kW)	Source
5	1 × 2 × 2	20	?	?	NAL
26	1.5 × 2 × 6	50	160	20	user
29	0.76 × 1.52 × 2.08	30	200*	750	user
33	2 × 3 × 6	120	1780	6000	NAL

*Subsections ≤ 50 tons

The outside dimensions of these spectrometers are covered under real estate above. Clearly these vast dipoles place requirements on crane availability and floor loading (see also next section).

4. Muon range

With the exception of Proposal 26 (whose range requirement is satisfied by penetration through the solid spectrometer), all proposals include a "wall" to filter out hadrons and low-energy muons. The lower limit on the size of the wall is determined by the requirement that it be many interaction lengths thick. The upper bound is largely determined by expense. One generally wants as much absorbed as possible to range out low-energy muons which lead to undesirable triggers.

Proposal	Thickness	Weight (tons)
5	1.5 m iron	70
29	4800 g/cm^2 concrete	250
33	5 m iron	400

Conclusions

The three proposals presented place emphasis on different portions of what may be learned from muon experiments. They encompass the full range of what is likely to be desirable and feasible at NAL over the next several years.

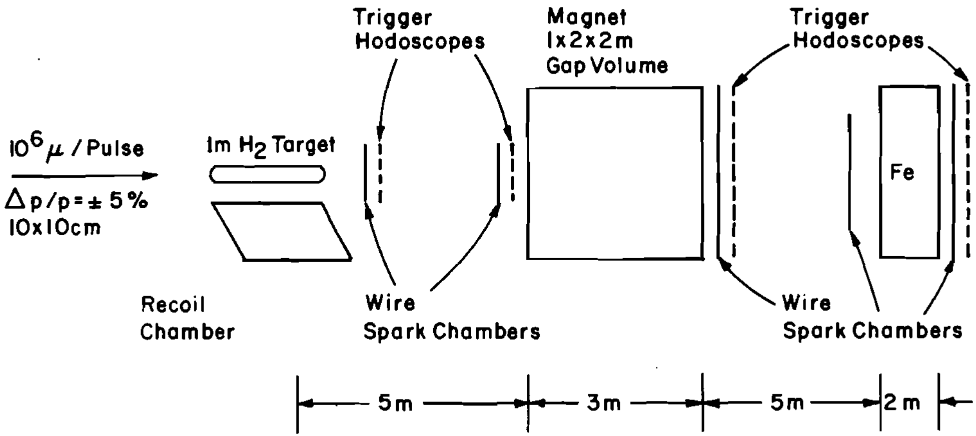

Fig. 1. Harvard-SLAC Proposals 5 and 29.

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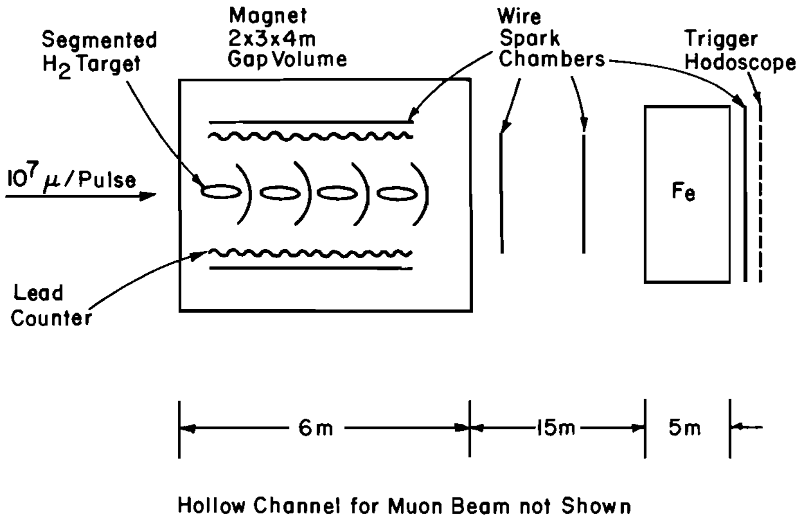

Fig. 2. Chicago-Pennsylvania Proposal 33.

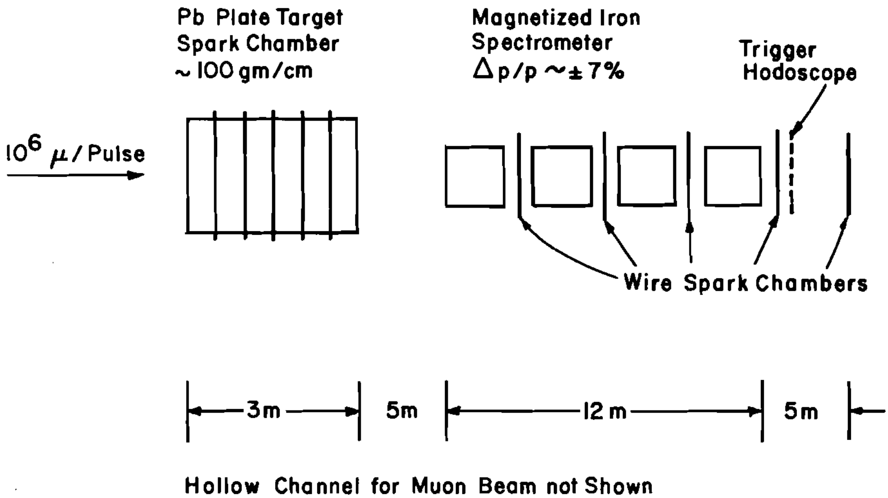

Fig. 3. Michigan State-Cornell Proposal 26.