276
3-28-69

739 SLAC-92

ANALYSIS OF MUON HYDROGEN BUBBLE CHAMBER EXPERIMENTS

MASTER

M. Perl

SLAC REPORT NO. 92

December 1968

AEC Contract AT(04-3)-515

STANFORD LINEAR ACCELERATOR CENTER
Stanford University • Stanford, California

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SLAC-92
UC-34, Physics
(EXPI)

ANALYSIS OF MUON HYDROGEN
BUBBLE CHAMBER EXPERIMENTS

by

Martin L. Perl

December 1968

Technical Report
Prepared Under
Contract AT(04-3)-515
for the USAEC
San Francisco Operations Office

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:
A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.
As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

Printed in USA. Available from CFSTI, National Bureau of Standards, U. S. Department of Commerce, Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TABLE OF CONTENTS

	<u>Page</u>
I. Introduction	1
II. Muon Beam Properties at SLAC	2
III. Event Rate for Inelastic Reactions at SLAC	3
IV. Other Incident Momenta.	5
V. Very Large Hydrogen Chambers	6
VI. Triggering the Chamber	7
References	8

I. INTRODUCTION

The first purpose of this report is to present the basic data for the consideration of muon exposures in liquid hydrogen bubble chambers at the Stanford Linear Accelerator Center. The object of the exposures would be to study muon + proton inelastic reactions. A second purpose is to show the improvement in the data rate if a very large hydrogen bubble chamber is used. First, the relevant properties of the SLAC muon beam are discussed. Then the inelastic event rate to be expected in a SLAC bubble chamber is given. Finally, the event rate is given for a very large hydrogen bubble chamber such as the Argonne National Laboratory 12-foot chamber or the 25-foot chamber proposed by Brookhaven National Laboratory.

All of this report is based on our current knowledge and experience obtained from the muon spark chamber experiment now being conducted at SLAC. Therefore, one should keep in mind that it is possible that more ingenious or more persistent experimenters may make major improvements in the situation as described here. This is not the place to present the detailed physics arguments for carrying out the muon exposures in a bubble chamber. The general argument is simply that at present there is very little known about muon + proton (or electron + proton) inelastic interactions, compared to pion + proton or kaon + proton--or even photon + proton--inelastic interactions. Some aspects of the electron inelastic interaction are now being studied with great care by spectrometer and counter experiments. Spark chamber muon experiments here at SLAC will add yet more information. But there will still be large areas of ignorance, which can be most fruitfully explored by the bubble chamber technique, with its capability of complete analysis of events. The basic limitation

is the small number of events which will be obtained in the bubble chamber. No conclusion is drawn in this note as to whether the complete analysis of events compensates for the small number of events.

II. MUON BEAM PROPERTIES AT SLAC

The present muon beam at SLAC at 10 GeV/c can yield about 500 muons per pulse in a 30-cm^2 area with a 17-GeV/c electron beam of 20-mA peak current. For 2-pulse-per-second operation, one can go to 40-mA peak current. This yields about 30 muons per cm^2 per pulse. The momentum resolution is $\pm 1.5\%$. Further details of the beam are given in Ref. 1, and we only note that the intensity falls off a factor of 2 at 4 or 12 GeV/c compared to 10 GeV/c. Also, the momentum resolution can be improved to $\pm 0.8\%$ with an intensity loss of 50%.

There are two ways of using the muon beam in a chamber, as a dispersed beam or as a "pencil" beam. As will be seen in Sect. III below, we need as much flux as possible, and a pencil beam might provide more flux. To consider the pencil beam in more detail we need to estimate its maximum diameter, d . Suppose the minimum scattering angle of the muon which we need to observe is θ_m (rad). Allowing a maximum 100-cm path length, $d \text{ (cm)} = 100 \theta_m$. If we take $\theta_m = 0.02$ rad, we may lose some useful events, whereas $\theta_m = 0.01$ is certainly safe. We use $\theta_m = 0.015$ or $d = 1.5$ cm. Now $d = 1.5$ cm means that recoil protons which must completely cross the pencil beam (at 45°) must have a momentum greater than 170 MeV/c. In a 1.5-cm-diameter pencil beam we can obtain about 50 muons per pulse. A substantial increase in the diameter, to say 3 cm, would seem to lead to too great a loss of forward particles and of

slow recoil protons. For a particular experiment this point might be reconsidered and one might use a 3-cm diameter pencil beam with 200 muons per pulse.

Now a dispersed beam might have anywhere from 20 to 80 muons per pulse,² depending on the chamber width. For the SLAC 40-inch chamber I have used 40 muons per pulse. Thus, a dispersed beam has as much flux as the 1.5-cm diameter pencil beam.

III. EVENT RATE FOR INELASTIC REACTIONS AT SLAC

We shall calculate the event rate for 10-GeV/c muons and for a 0.5-meter interaction length in the chamber. The differential inelastic cross section can be written:

$$\frac{d^2\sigma}{dq^2 dp_2} = \frac{\alpha}{2\pi q^2} \left(\frac{p_2 |\vec{q}|}{E_2 p_1^2} \right) \left[1 - \frac{2m_\mu^2}{q^2} + \frac{2E_1 E_2 - q^2/2}{|\vec{q}|^2} \right] \left[\sigma_T(q^2, q_0) + \epsilon \sigma_L(q^2, q_0) \right]$$

$$\epsilon = \left(\frac{2E_1 E_2 - q^2/2}{|\vec{q}|^2} \right) \left(1 - \frac{2m_\mu^2}{q^2} + \frac{2E_1 E_2 - q^2/2}{|\vec{q}|^2} \right)$$

where, $\vec{p}_1$, E_1 is the the initial muon momentum, energy

$\vec{p}_2$, E_2 is the final muon momentum, energy

$\vec{q}$, q_0 is the virtual photon momentum, energy

$$\vec{q} = \vec{p}_1 - \vec{p}_2$$

$$q_0 = E_1 - E_2$$

$$q^2 = |q_0^2 - |\vec{q}|^2|$$

m_μ = muon mass

$$\sigma_T(q^2, q_0) \xrightarrow[q^2 \rightarrow 0]{} \sigma_{\text{real photons}}(q_0)$$

$$\sigma(q^2, q_0) \xrightarrow[q^2 \rightarrow 0]{} 0$$

We use our current spark chamber measurements of σ_T and σ_L and some electron measurements to get the event rate given in Table 1. The number of events in each interval are per 1,000,000 exposures, with 20 muon-meters of track length per picture. Table 1 uses q_0 intervals (note that q_0 is the laboratory energy of the virtual photon) and q^2 intervals. We use the rough approximations:

$$\text{For } q^2 \leq 0.4 \text{ (GeV/c)}^2, (\sigma_T + \epsilon\sigma_L) = 100 \mu\text{b}$$

$$\text{For } q^2 > 0.4 \text{ (GeV/c)}^2, (\sigma_T + \epsilon\sigma_L) = 300 \left(\frac{1}{1 + q^2/M_\rho^2} \right)^2 \mu\text{b}$$

Table 1

NUMBER OF EVENTS, 10 GeV/c INCIDENT MUONS

(40 Muons per Exposure
0.5 M Interaction Length Per Muon
1,000,000 Exposures)

$\begin{matrix} q^2 \\ (\text{GeV/c})^2 \\ q_0 \\ \text{GeV} \end{matrix}$	$\begin{matrix} 0.05 \\ \text{to} \\ 0.10 \end{matrix}$	$\begin{matrix} 0.1 \\ \text{to} \\ 0.2 \end{matrix}$	$\begin{matrix} 0.2 \\ \text{to} \\ 0.4 \end{matrix}$	$\begin{matrix} 0.4 \\ \text{to} \\ 0.6 \end{matrix}$	$\begin{matrix} 0.6 \\ \text{to} \\ 0.8 \end{matrix}$	$\begin{matrix} 0.8 \\ \text{to} \\ 1.0 \end{matrix}$	Above 1.0	Total all q^2
1 to 2	9	8	8	3	1.2	0.6	0.3	30
2 to 4	7	7	7	3	1.4	0.8	0.3	27
4 to 6	3	3	3	1.6	0.8	0.4	0.15	12
6 to 8	2	2	2	1.0	0.6	0.3	0.10	8
8 to 10	1.2	1.3	1.4	0.7	0.4	0.2	0.05	5
Total all q_0	22	21	21	9	4	2	0.9	

We find the total number of events for $q_0 > 1$ GeV and $q^2 > 0.05$ (GeV/c)² is about 82 in 10⁶ pictures.

We can make a rough estimate from real photon bubble chamber exposures³ as to the kind of events we will find. This is given below.

<u>Reaction Products</u>	<u>Percent of all Events</u>
$\mu + \text{All strange particle events}$	3 to 6
$\mu + Y + K$	0.5 to 1
$\mu + Y + K + \pi$	1
$\mu + p + \pi^+ + \pi^-$	20
$\mu + p + \pi + \pi^-$ (ρ^0 only)	15
$\mu + p + \omega^0$	1 to 2
$\mu + p + \pi^+ + \pi^+ + \pi^- + \pi^-$	4 to 5
$\mu + N^* + \pi$	≈ 2
$\mu + (p \text{ or } n) + \pi$	≈ 2

Thus, except for the $p + \pi^+ + \pi^-$ channel, we can only expect a few events or one event per channel in 10⁶ exposures. Clearly then 10⁷ to 10⁸ exposures is the number which must be considered.

IV. OTHER INCIDENT MOMENTA

It is easy to derive a crude equation for use at other momenta, neglecting the muon mass and taking $2E_1 E_2 \gg q^2/2$

$$\frac{d^2 \sigma}{dp^2 dp_2} = \left(\frac{\alpha}{\pi q^2} \right) \left(\frac{p_2}{p_1 q_0} \right) \Sigma$$

where $\Sigma = \alpha_T + \epsilon \alpha_L$

For a q_0 range from $q_0 \text{ min} = r_1 p_1$ to $q_0 \text{ max} = r_2 p_1$ with $0 < r_1 \leq r_2 \leq 1$

$$\frac{d\sigma}{dq^2} = \frac{\alpha}{\pi q^2} \int_{r_1 p_1}^{r_2 p_1} \frac{(p_1 - q_0) \bar{\Sigma}}{p_1 q_0} dq_0$$

$$\frac{d\sigma}{dq^2} = \frac{\alpha \bar{\Sigma}}{\pi q^2} \left[-(r_2 - r_1) + \ln \frac{r_2}{r_1} \right]$$

and $\bar{\Sigma}$ is almost independent of P_1 for estimation purposes.

Thus, in any q^2 interval the total number of events is independent of P_1 . For most experiments we take $r_2 = 1$, $r_1 = 0.1$ because $q_0 < 0.1 P_1$ events are not of interest relative to the entire q_0 range. Then

$$\frac{d\sigma}{dq^2} \approx \frac{1.4 \alpha}{\pi q^2}$$

where we can use for $\bar{\Sigma}$ the approximations used before for $(\sigma_T + \epsilon \sigma_L)$. For $q^2 \leq 0.4 \text{ (GeV/c)}^2$ we get $\sigma(0.05 \leq q^2 \leq 0.4) = 0.7 \mu b$ independent of energy.

We do not get a substantial increase of events as the energy increases, unless we use very low q_0 events.

V. VERY LARGE HYDROGEN CHAMBERS

The only way to increase the event rate is to increase the number of muons or to use a longer chamber. Both of these conditions are met by the Argonne 12-foot hydrogen chamber now being built, or by the 25-foot chamber proposed by BNL.

Because these chambers are wider we might allow 60 muons per pulse. Then using 200 inches interaction length as an average between the 12-foot and 25-foot chambers:

$$\text{Events per } 10^6 \text{ exposures} = 1200$$

This is a much better rate per exposure. However, the events per second are not so different. At SLAC the 40-inch chamber can go twice per second. The large chambers may go, say, every 2.5 seconds. The large chamber event rate per second is then three times the small chamber rate. The relative event rate per exposure of the large chambers versus the small chambers is 15.

VI. TRIGGERING THE CHAMBER

It is evident that a great saving in film can be made by triggering the chamber lights and camera on inelastic muon interactions. It is possible to insert a counter hodoscope in the muon beam before and after the chamber to trigger on muons which have deflected in the chamber by at least 10 or 15 mrad. False events will come from elastic scattering and interactions in the entrance and exit windows. The hodoscope design depends on the particular chamber and muon beam and will not be discussed here.

ACKNOWLEDGMENT

The author wishes to thank the Aspen Center for Physics for its hospitality during the time this report was written.

REFERENCES

1. Cox, J., Martin F. Perl, T. H. Tan, W. T. Toner, and T. F. Zipf, "A High Energy, Small Phase-Space Volume Muon Beam", SLAC-PUB-434, HEPL-565, June 1968. (to be published in Nuclear Instruments and Methods).
2. Fry, W., private communication on the CERN, Oxford, Padua, Wisconsin, muon experiment in the Cern 1 meter, heavy liquid, bubble chamber.
3. Lohrman, E., "Proceedings of the 1967 International Symposium on Electron and Photon Interactions at High Energies", Stanford, 1967, K. Stranch, ibid.