The History of the Measurement of the Muon Lifetime.

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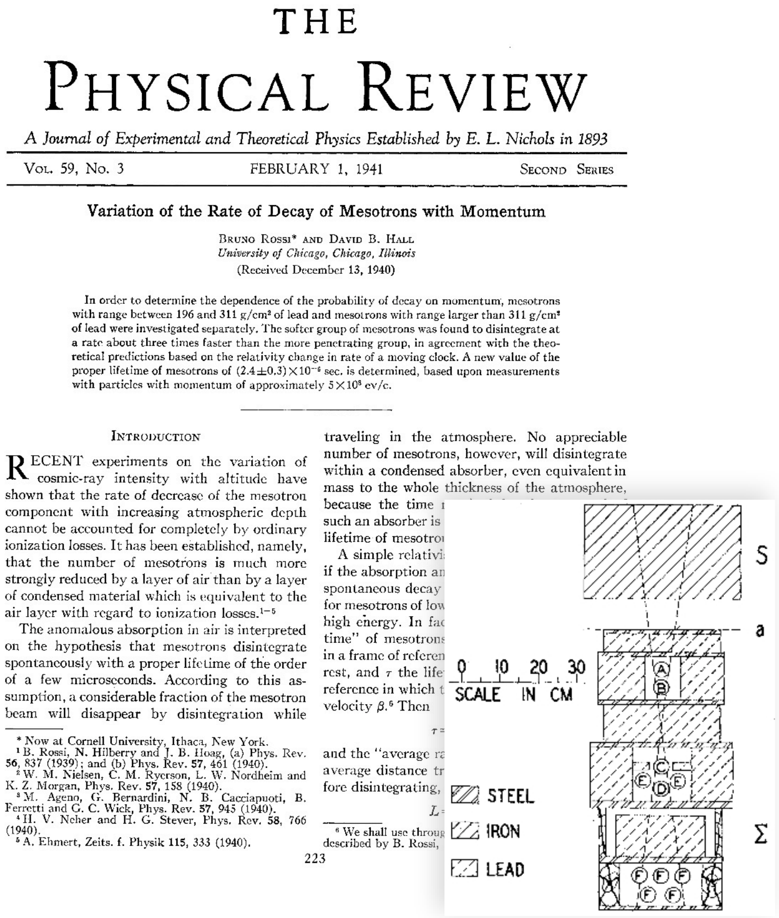
Introduction.

- Measurements of the lifetime of the muon, coupled with measurements of the muon flux as function of altitude, confirmed the predictions of the theory of relativity.
- The connection between the muon lifetime and the theory of relativity makes the muon lifetime experiment an exciting experiment for the advanced laboratory.
- The techniques used to determine the lifetime of the muon have changed over time and will be discussed in this talk.
- The muon lifetime experiment can be improved significantly by using digital signal processing techniques.
- These improvements not only enhance the advanced laboratory experiment, but also allow us to share the data in real time with the general public.

Obtaining the muon lifetime by studying the anomalous absorption of muons in air.

- The original muon lifetime was measured by Rossi and Hall by comparing the muon absorption of air and dense absorbers (with equivalent stopping powers).
- The previously observed anomalous stopping of muons in air was assumed to be due to the decay of muons.
- Based on carefully measured muon rates at different altitudes, with and without absorbers, Rossi and Hall obtained a lifetime of 2.4 ± 0.3 μs.



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PHYSICAL REVIEW
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Variation of the Rate of Decay of Mesotrons with Momentum

Bruno Rossi* and David B. Hall
University of Chicago, Chicago, Illinois
(Received December 13, 1940)

In order to determine the dependence of the probability of decay on momentum, mesotrons with range between 196 and 311 g/cm² of lead and mesotrons with range larger than 311 g/cm² of lead were investigated separately. The softer group of mesotrons was found to disintegrate at a rate about three times faster than the more penetrating group, in agreement with the theoretical predictions based on the relativity change in rate of a moving clock. A new value of the proper lifetime of mesotrons of $(2.4\pm0.3)\times10^{-6}$ sec. is determined, based upon measurements with particles with momentum of approximately 5×10^{8} ev/c.

INTRODUCTION

RECENT experiments on the variation of cosmic-ray intensity with altitude have shown that the rate of decrease of the mesotron component with increasing atmospheric depth cannot be accounted for completely by ordinary ionization losses. It has been established, namely, that the number of mesotrons is much more strongly reduced by a layer of air than by a layer of condensed material which is equivalent to the air layer with regard to ionization losses.[1–5]

The anomalous absorption in air is interpreted on the hypothesis that mesotrons disintegrate spontaneously with a proper lifetime of the order of a few microseconds. According to this assumption, a considerable fraction of the mesotron beam will disappear by disintegration while traveling in the atmosphere. No appreciable number of mesotrons, however, will disintegrate within a condensed absorber, even equivalent in mass to the whole thickness of the atmosphere,
because the time
such an absorber is
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A simple relativi
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* Now at Cornell University, Ithaca, New York.

[1] B. Rossi, N. Hilberry and J. B. Hoag, (a) Phys. Rev. **56**, 837 (1939); and (b) Phys. Rev. **57**, 461 (1940).

[2] W. M. Nielsen, C. M. Ryerson, L. W. Nordheim and K. Z. Morgan, Phys. Rev. **57**, 158 (1940).

[3] M. Ageno, G. Bernardini, N. B. Cacciapuoti, B. Ferretti and G. C. Wick, Phys. Rev. **57**, 945 (1940).

[4] H. V. Neher and H. G. Stever, Phys. Rev. **58**, 766 (1940).

[5] A. Ehmert, Zeits. f. Physik **115**, 333 (1940).

[6] We shall use throug
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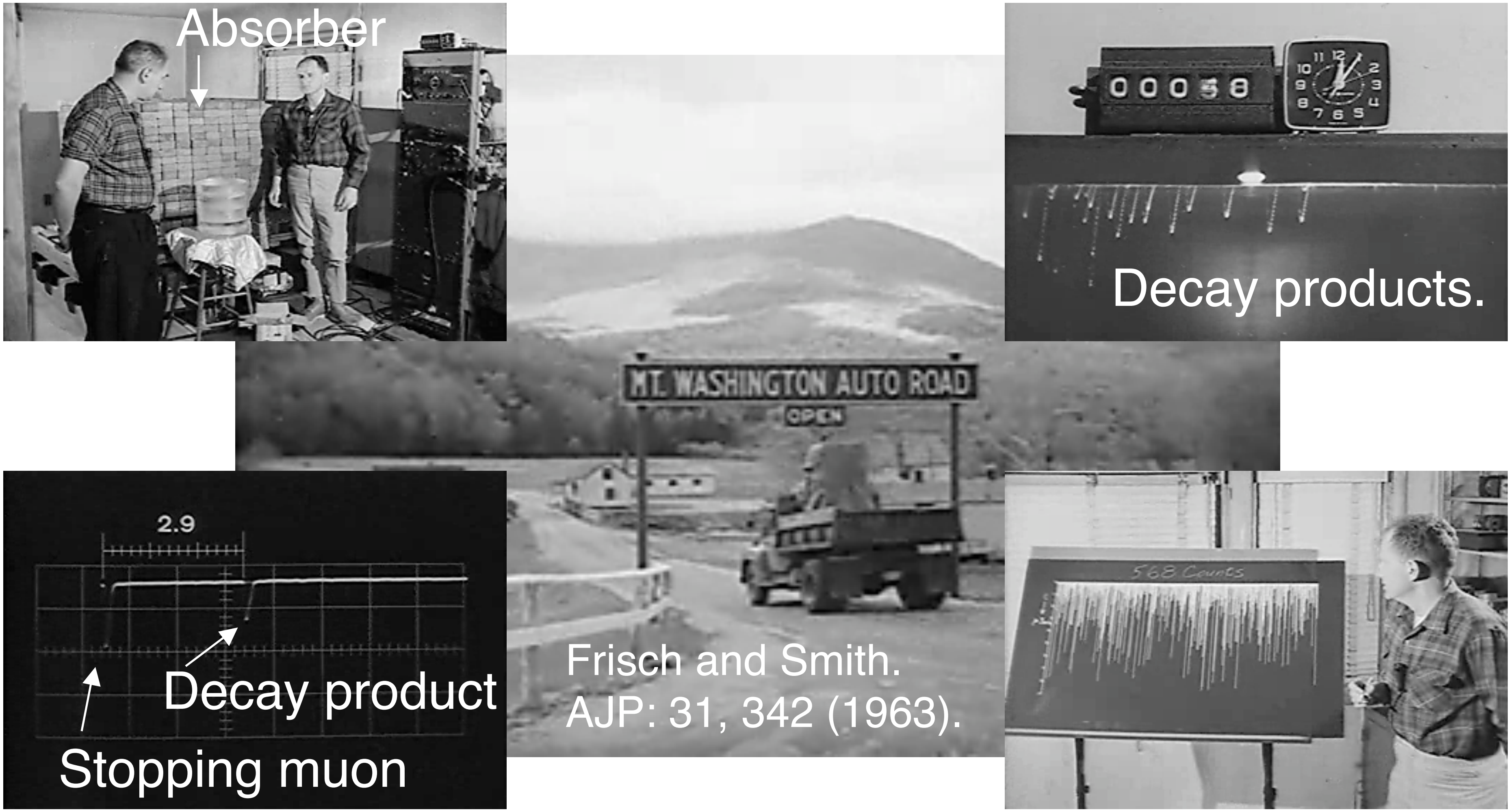
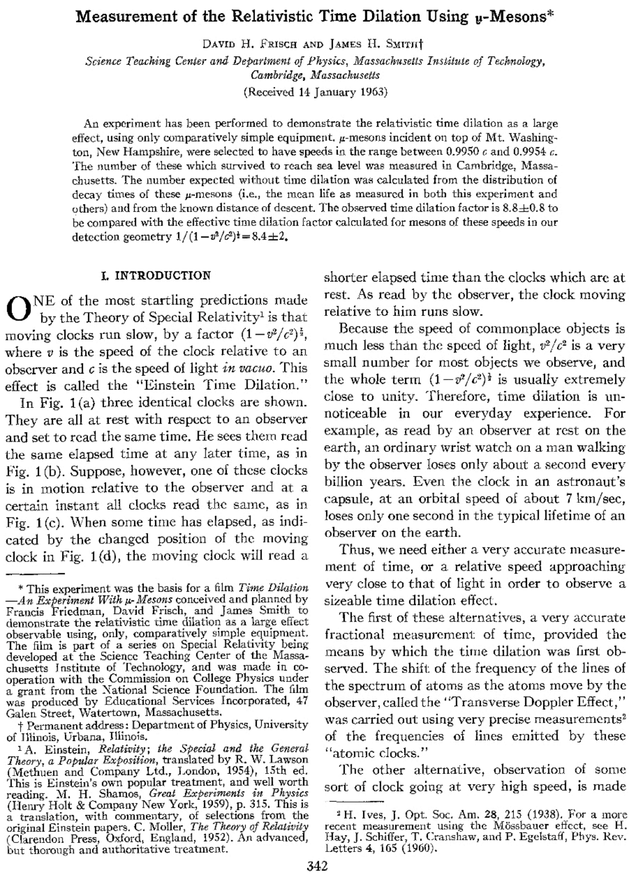
Direct measurement of the muon lifetime. Scenes from the 1962 movie “Time Dilation”.



Frisch and Smith.
AJP: 31, 342 (1963).

Direct measurement of the muon lifetime. Result: $2.2 \pm 0.2\ \mu$s.



Measurement of the Relativistic Time Dilation Using μ-Mesons*

David H. Frisch and James H. Smith†
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(Received 14 January 1963)

An experiment has been performed to demonstrate the relativistic time dilation as a large effect, using only comparatively simple equipment. μ-mesons incident on top of Mt. Washington, New Hampshire, were selected to have speeds in the range between $0.9950\ c$ and $0.9954\ c$. The number of these which survived to reach sea level was measured in Cambridge, Massachusetts. The number expected without time dilation was calculated from the distribution of decay times of these μ-mesons (i.e., the mean life as measured in both this experiment and others) and from the known distance of descent. The observed time dilation factor is 8.8 ± 0.8 to be compared with the effective time dilation factor calculated for mesons of these speeds in our detection geometry $1/(1-v^2/c^2)^{\frac{1}{2}} = 8.4 \pm 2$.

I. INTRODUCTION

ONE of the most startling predictions made by the Theory of Special Relativity[1] is that moving clocks run slow, by a factor $(1-v^2/c^2)^{\frac{1}{2}}$, where v is the speed of the clock relative to an observer and c is the speed of light *in vacuo*. This effect is called the "Einstein Time Dilation."

In Fig. 1(a) three identical clocks are shown. They are all at rest with respect to an observer and set to read the same time. He sees them read the same elapsed time at any later time, as in Fig. 1(b). Suppose, however, one of these clocks is in motion relative to the observer and at a certain instant all clocks read the same, as in Fig. 1(c). When some time has elapsed, as indicated by the changed position of the moving clock in Fig. 1(d), the moving clock will read a shorter elapsed time than the clocks which are at rest. As read by the observer, the clock moving relative to him runs slow.

Because the speed of commonplace objects is much less than the speed of light, v^2/c^2 is a very small number for most objects we observe, and the whole term $(1-v^2/c^2)^{\frac{1}{2}}$ is usually extremely close to unity. Therefore, time dilation is unnoticeable in our everyday experience. For example, as read by an observer at rest on the earth, an ordinary wrist watch on a man walking by the observer loses only about a second every billion years. Even the clock in an astronaut's capsule, at an orbital speed of about 7 km/sec, loses only one second in the typical lifetime of an observer on the earth.

Thus, we need either a very accurate measurement of time, or a relative speed approaching very close to that of light in order to observe a sizeable time dilation effect.

The first of these alternatives, a very accurate fractional measurement of time, provided the means by which the time dilation was first observed. The shift of the frequency of the lines of the spectrum of atoms as the atoms move by the observer, called the "Transverse Doppler Effect," was carried out using very precise measurements[2] of the frequencies of lines emitted by these "atomic clocks."

The other alternative, observation of some sort of clock going at very high speed, is made

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* This experiment was the basis for a film *Time Dilation—An Experiment With μ-Mesons* conceived and planned by Francis Friedman, David Frisch, and James Smith to demonstrate the relativistic time dilation as a large effect observable using, only, comparatively simple equipment. The film is part of a series on Special Relativity being developed at the Science Teaching Center of the Massachusetts Institute of Technology, and was made in cooperation with the Commission on College Physics under a grant from the National Science Foundation. The film was produced by Educational Services Incorporated, 47 Galen Street, Watertown, Massachusetts.

† Permanent address: Department of Physics, University of Illinois, Urbana, Illinois.

[1] A. Einstein, *Relativity; the Special and the General Theory, a Popular Exposition*, translated by R. W. Lawson (Methuen and Company Ltd., London, 1954), 15th ed. This is Einstein's own popular treatment, and well worth reading. M. H. Shamos, *Great Experiments in Physics* (Henry Holt & Company New York, 1959), p. 315. This is a translation, with commentary, of selections from the original Einstein papers. C. Moller, *The Theory of Relativity* (Clarendon Press, Oxford, England, 1952). An advanced, but thorough and authoritative treatment.

[2] H. Ives, J. Opt. Soc. Am. **28**, 215 (1938). For a more recent measurement using the Mössbauer effect, see H. Hay, J. Schiffer, T. Cranshaw, and P. Egelstaff, Phys. Rev. Letters **4**, 165 (1960).

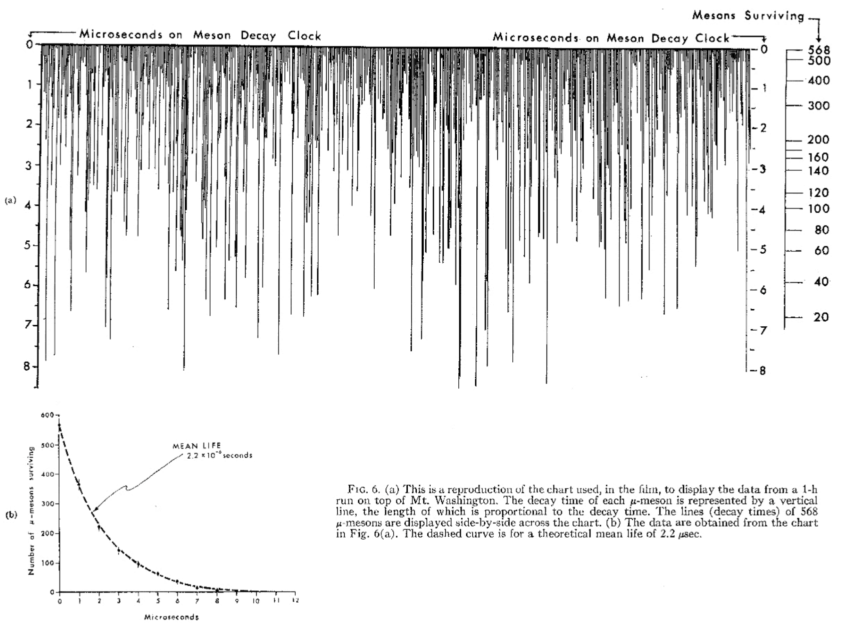
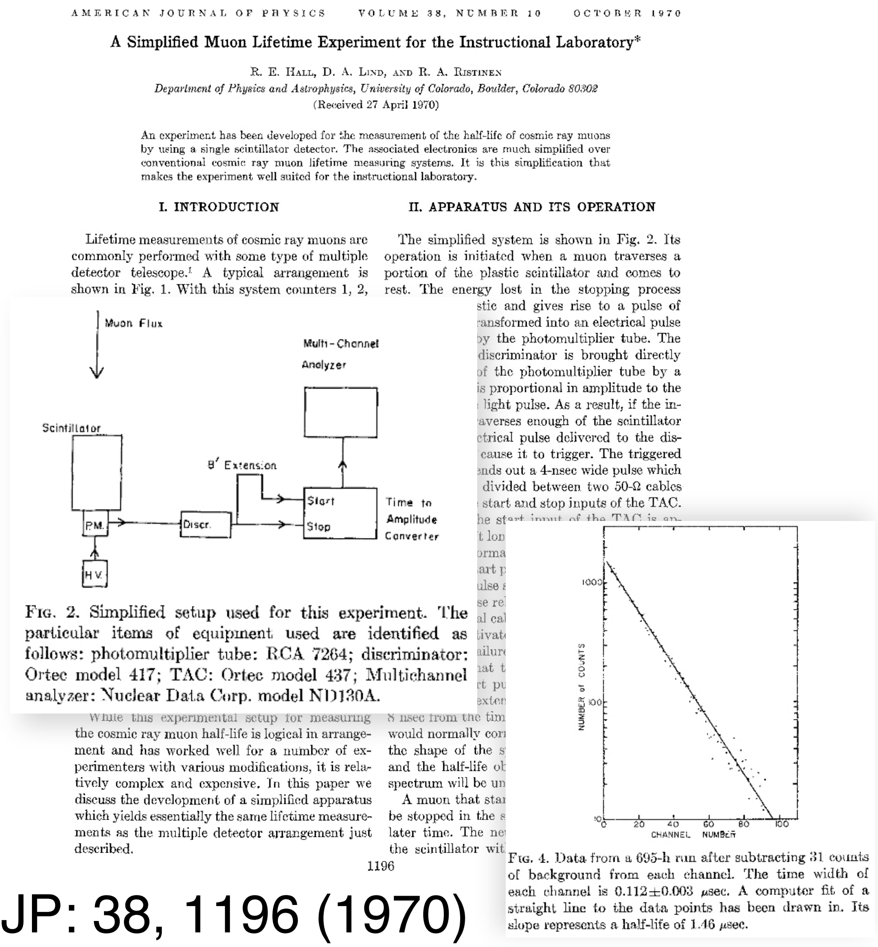


Fig. 6. (a) This is a reproduction of the chart used, in the film, to display the data from a 1-h run on top of Mt. Washington. The decay time of each μ-meson is represented by a vertical line, the length of which is proportional to the decay time. The lines (decay times) of 568 μ-mesons are displayed side-by-side across the chart. (b) The data are obtained from the chart in Fig. 6(a). The dashed curve is for a theoretical mean life of $2.2\ \mu$sec.

AJP: 31, 342 (1963)

Muon-decay experiments in the advanced laboratory.

- The processing of photographs to determine the lifetime of the muon was rather cumbersome.
- The development of TACs or TDCs made it possible to collect data over extended periods of time, but sacrificed the detailed information about the pulse shapes contained in the photographs.
- Despite these draw backs, the TAC/TDC-based measurement technique currently dominates the approach used in the advanced laboratory.



AMERICAN JOURNAL OF PHYSICS VOLUME 38, NUMBER 10 OCTOBER 1970

A Simplified Muon Lifetime Experiment for the Instructional Laboratory*

R. E. Hall, D. A. Lind, and R. A. Ristinen

Department of Physics and Astrophysics, University of Colorado, Boulder, Colorado 80302

(Received 27 April 1970)

An experiment has been developed for the measurement of the half-life of cosmic ray muons by using a single scintillator detector. The associated electronics are much simplified over conventional cosmic ray muon lifetime measuring systems. It is this simplification that makes the experiment well suited for the instructional laboratory.

I. INTRODUCTION

Lifetime measurements of cosmic ray muons are commonly performed with some type of multiple detector telescope.[1] A typical arrangement is shown in Fig. 1. With this system counters 1, 2,

Fig. 2. Simplified setup used for this experiment. The particular items of equipment used are identified as follows: photomultiplier tube: RCA 7264; discriminator: Ortec model 417; TAC: Ortec model 437; Multichannel analyzer: Nuclear Data Corp. model ND130A.

While this experimental setup for measuring the cosmic ray muon half-life is logical in arrangement and has worked well for a number of experimenters with various modifications, it is relatively complex and expensive. In this paper we discuss the development of a simplified apparatus which yields essentially the same lifetime measurements as the multiple detector arrangement just described.

II. APPARATUS AND ITS OPERATION

The simplified system is shown in Fig. 2. Its operation is initiated when a muon traverses a portion of the plastic scintillator and comes to rest. The energy lost in the stopping process
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ansformed into an electrical pulse
by the photomultiplier tube. The
discriminator is brought directly
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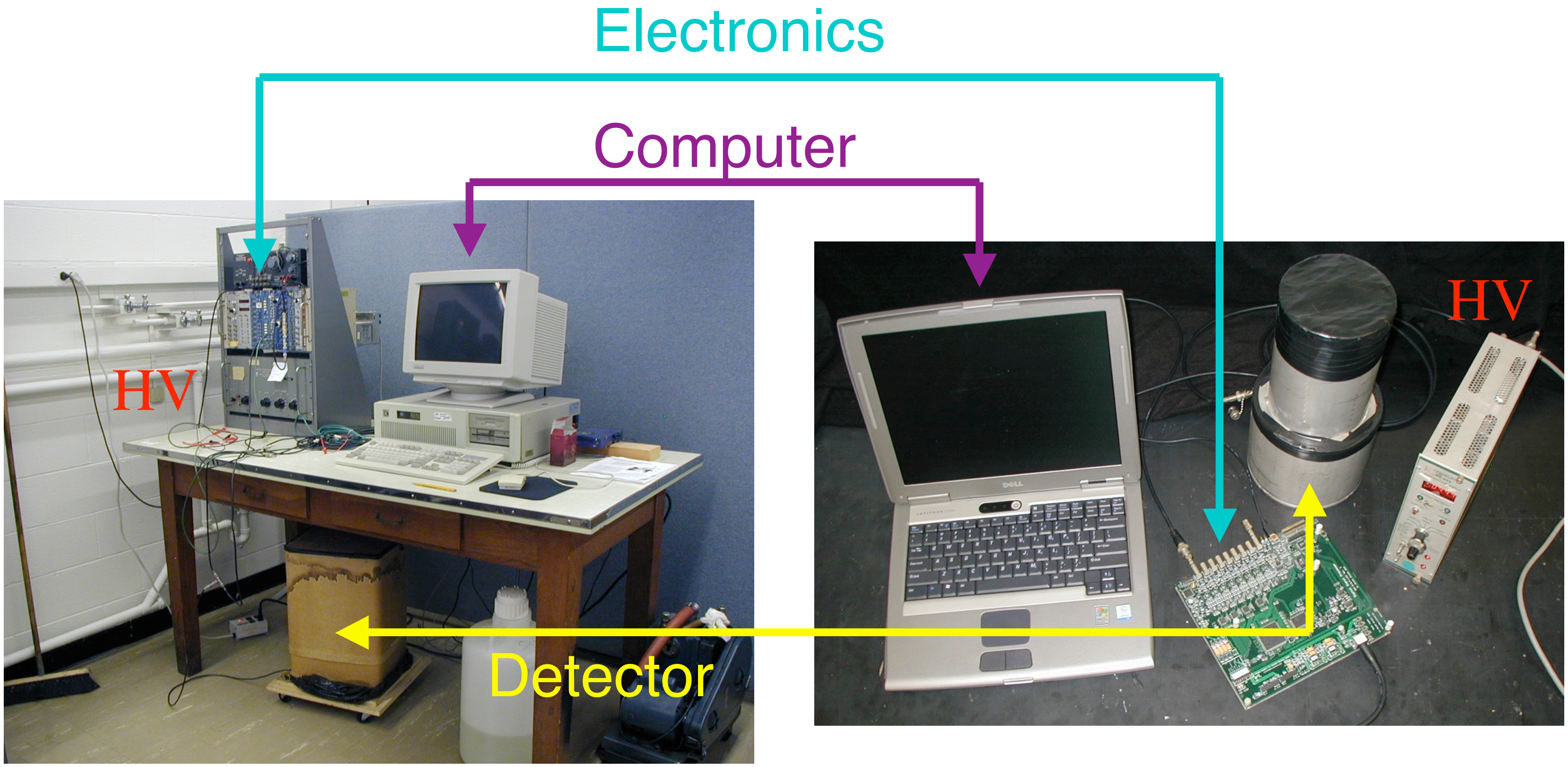
Fig. 4. Data from a 695-h run after subtracting 31 counts of background from each channel. The time width of each channel is 0.112±0.003 μsec. A computer fit of a straight line to the data points has been drawn in. Its slope represents a half-life of 1.46 μsec.

AJP: 38, 1196 (1970)

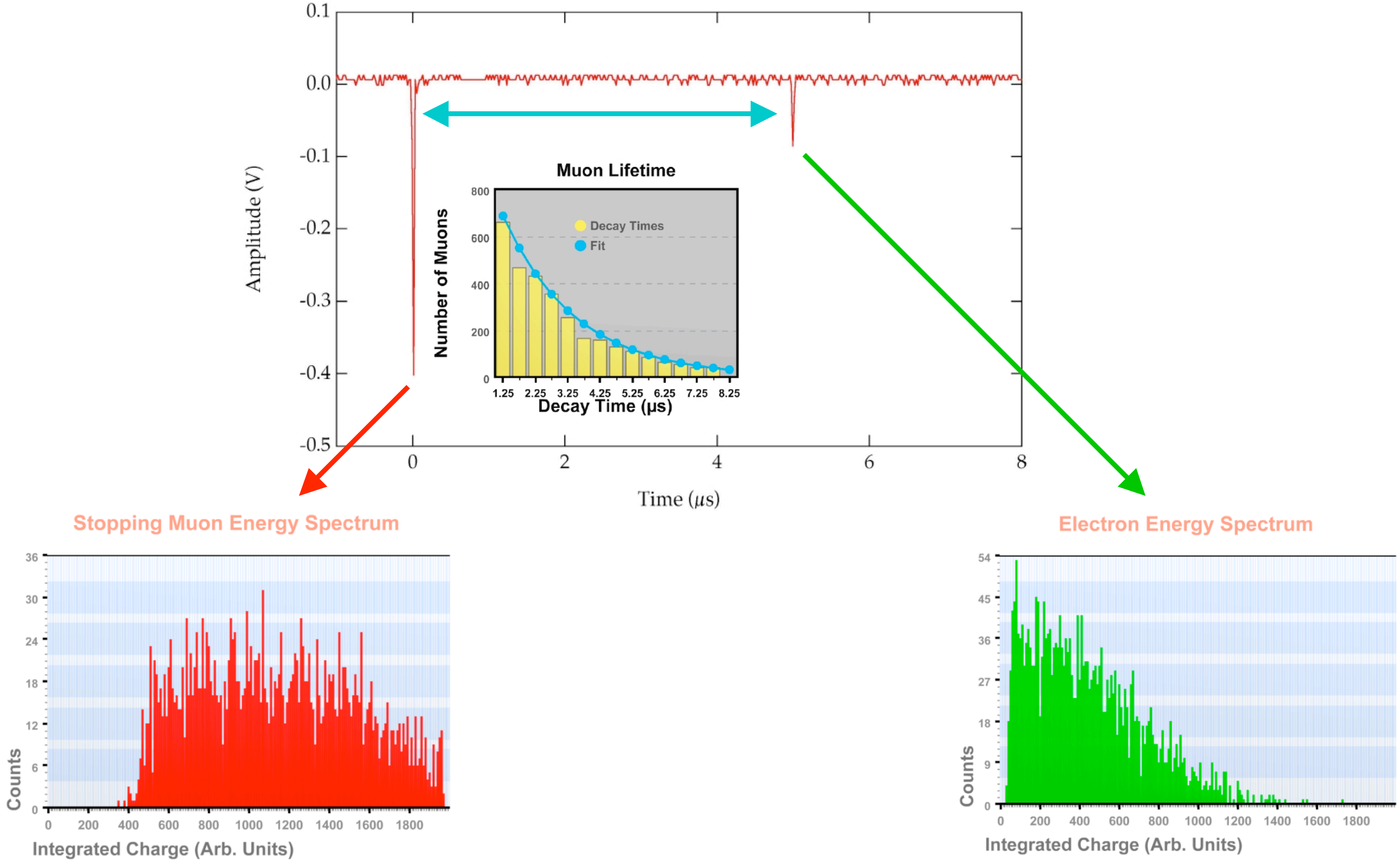
The future generation: utilizing digital-signal processing (DSP) in the advanced laboratory.



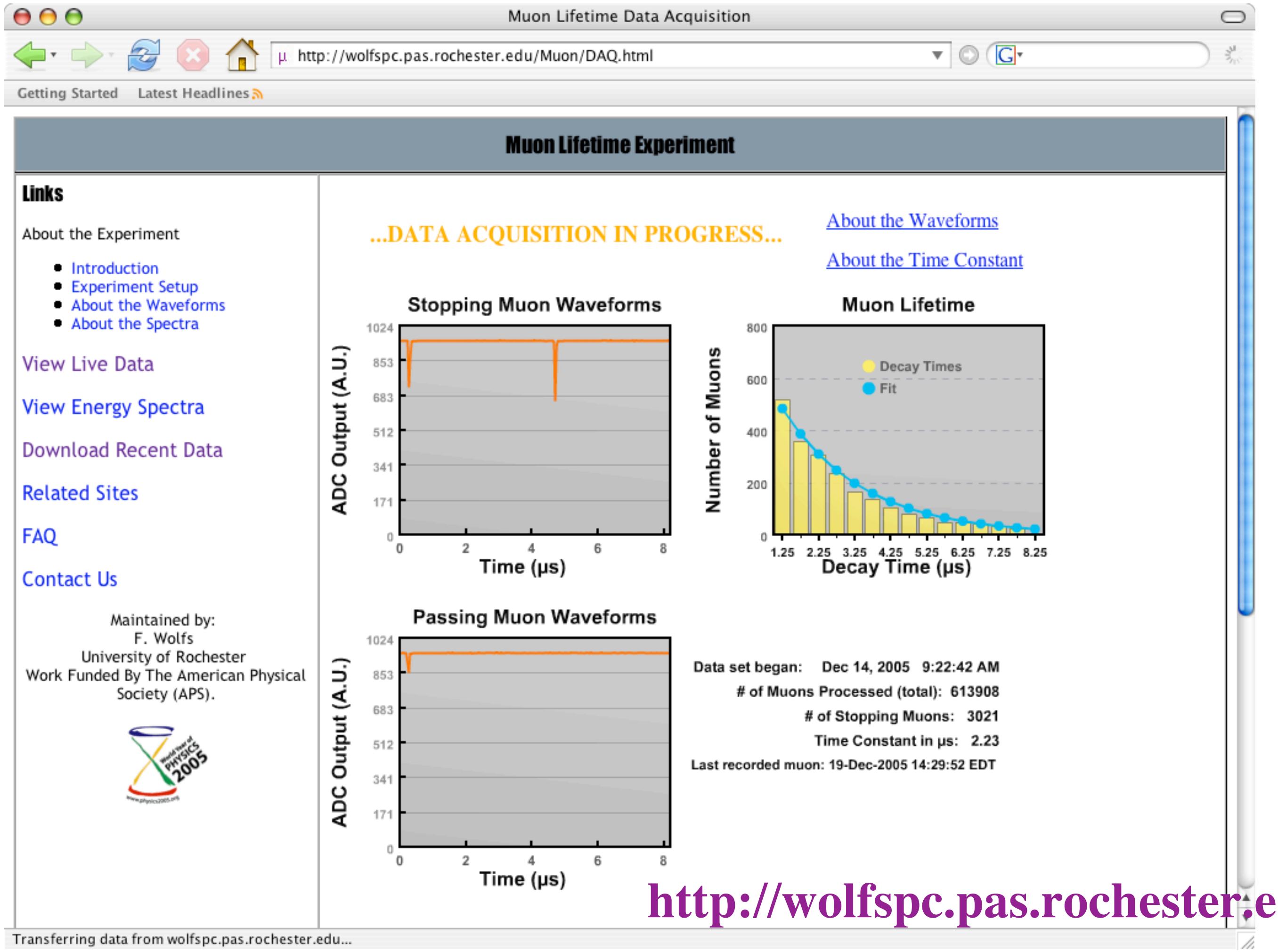
Current muon lifetime experiment in the advanced laboratory in Rochester.

Muon lifetime experiment utilizing digital signal processing.

Measuring the muon lifetime using DSP.
The waveform preserves energy information.



The muon lifetime on the WEB.
DSP makes it easy to interface to the WEB.



Muon Lifetime Experiment

Links

About the Experiment

- Introduction
- Experiment Setup
- About the Waveforms
- About the Spectra

View Live Data

View Energy Spectra

Download Recent Data

Related Sites

FAQ

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...DATA ACQUISITION IN PROGRESS...

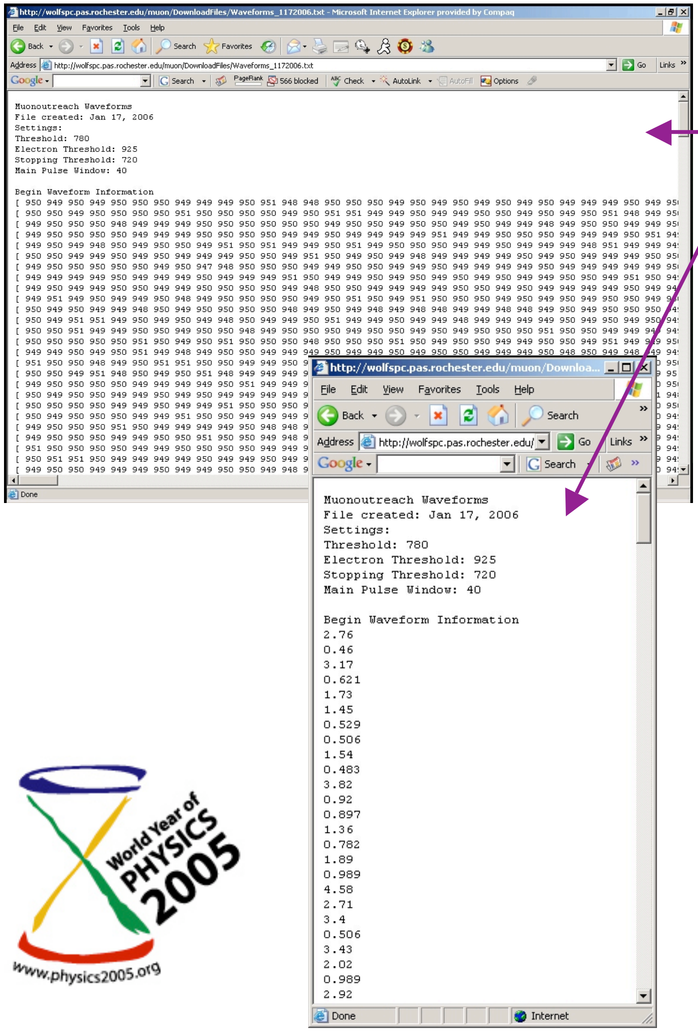
About the Waveforms

About the Time Constant

Data set began: Dec 14, 2005 9:22:42 AM
# of Muons Processed (total): 613908
# of Stopping Muons: 3021
Time Constant in µs: 2.23
Last recorded muon: 19-Dec-2005 14:29:52 EDT

http://wolfspc.pas.rochester.edu/muon/

The muon lifetime on the WEB.
View data in real time or do your own analysis.



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Muonoutreach Waveforms
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Stopping Threshold: 720
Main Pulse Window: 40

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Muonoutreach Waveforms
File created: Jan 17, 2006
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Begin Waveform Information
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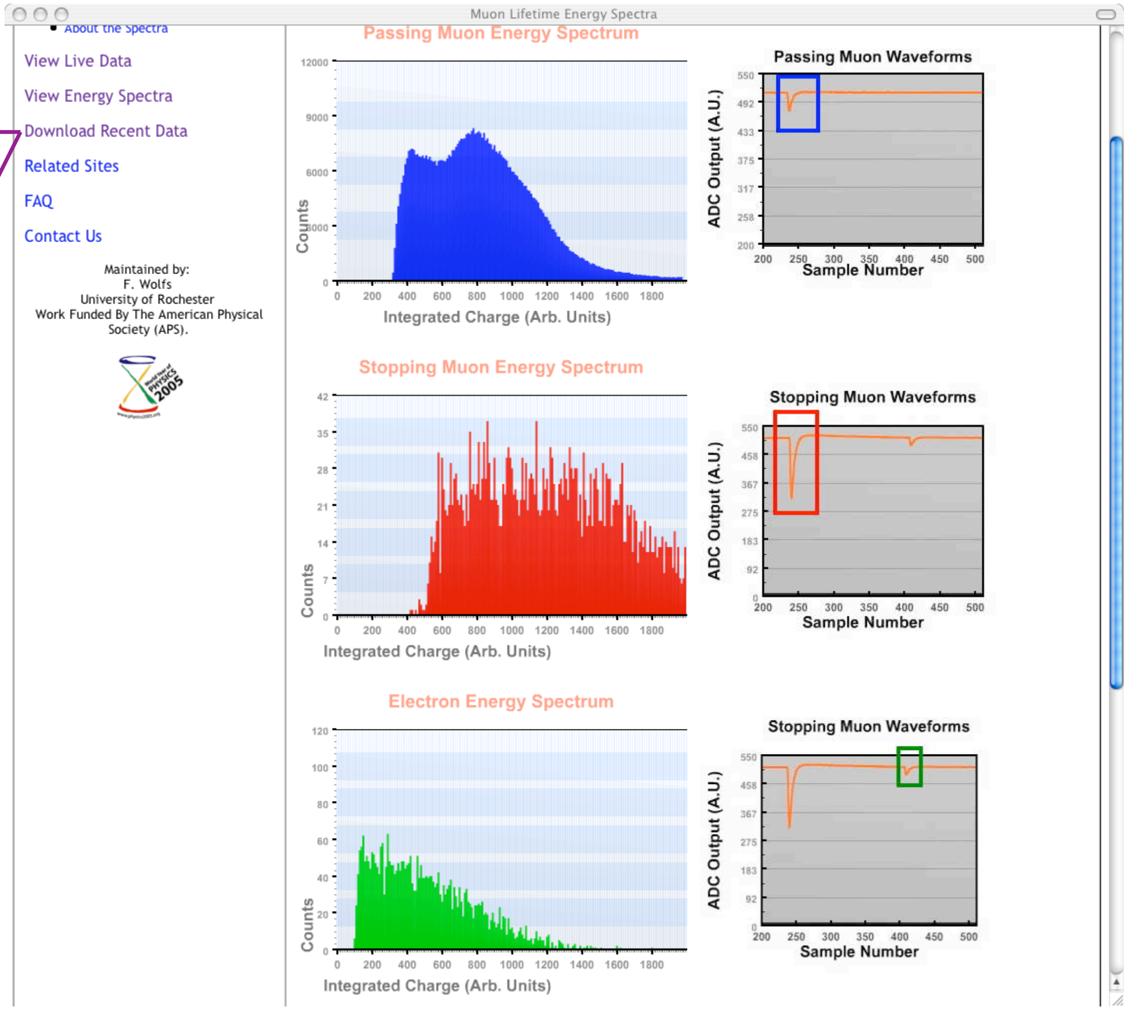

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Summary.

- The first direct measurements of the muon lifetime used photographs to capture the waveforms produced by the stopped muons.
- The current generation of muon experiments used in the advanced laboratory only preserve the time correlation between the stopping and the decay pulse.
- The future generation of muon experiments use DSP to capture the full information contained in the waveform of a stopping muon.
- The DSP information is accessible to everyone, everywhere.