Using Digital Signal Processing in the Advanced Laboratory

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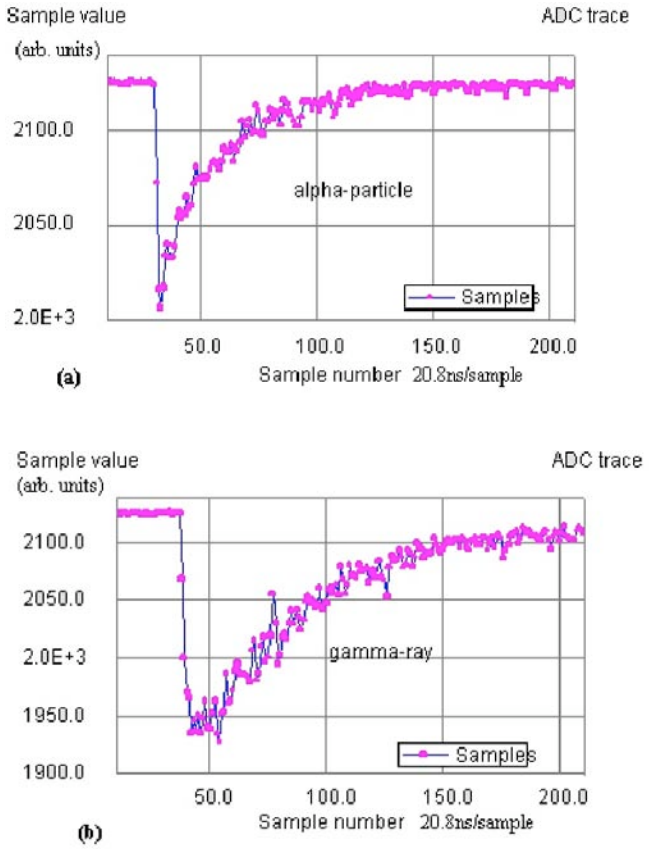
Outline.

- What is digital signal processing and how does it differ from traditional digitization of experimental signals?
- Why consider digital signal processing for the advanced laboratory?
- An example of the power of digital signal processing: comparing the "traditional" method of the muon lifetime experiment with an approach based on digital signal processing.
- Summary and outlook.

What is digital signal processing (DSP)?

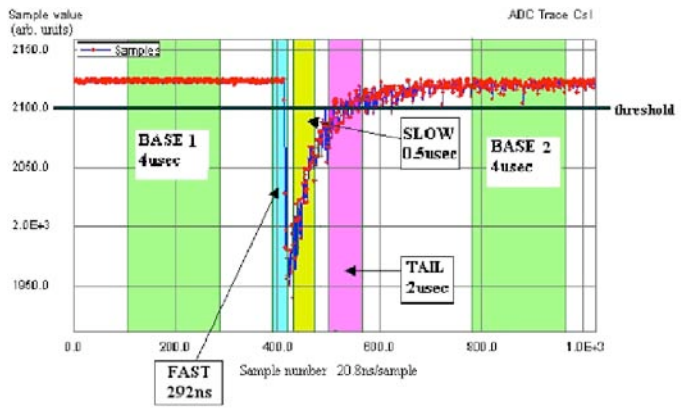
- Digital signal processing involves the capture of a detector signal (using a continuous running digitizer).
- The information contained in the pulse shapes is used to trigger the data acquisition system.
- A lot of information is contained in the signal shape (for example one can distinguish alpha particles from gamma rays in a CsI(Tl) detector).
- The pulse shape information can be written to a data file for off-line analysis (using a variety of tools).

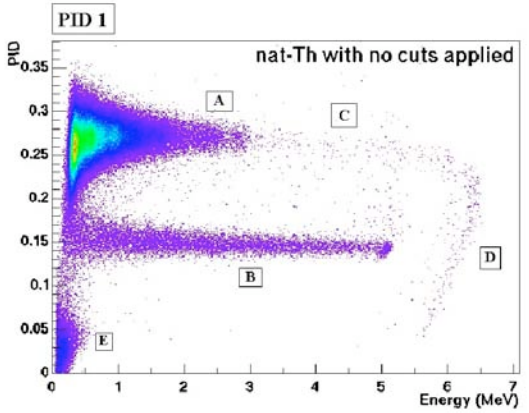


S. Zuberi, Senior Thesis, U of R

Why DSP in the advanced lab?

- DSP preserves the information provided by the equipment used and gives students access to sophisticated off-line data processing.
- DSP simplifies the hardware requirements for the advanced lab, since changes in signal processing only requires changes in on- and/or off-line data analysis tools.
- The level of student control can be adjusted based on educational goals of the lab/experiment.





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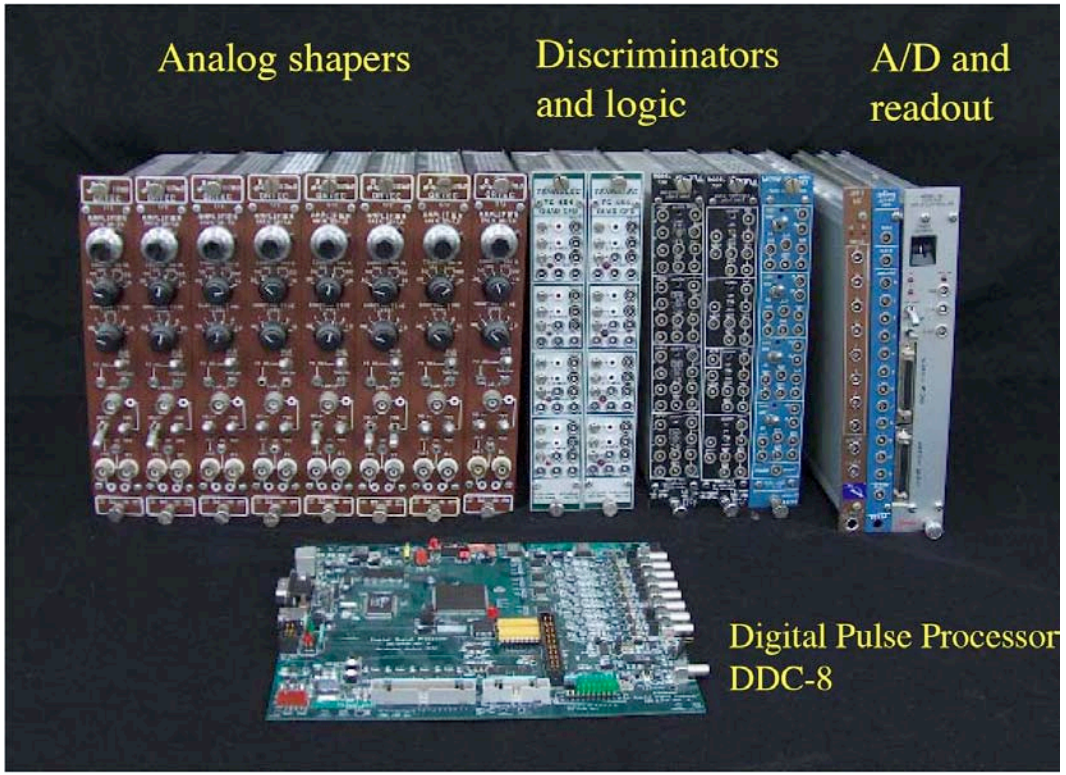
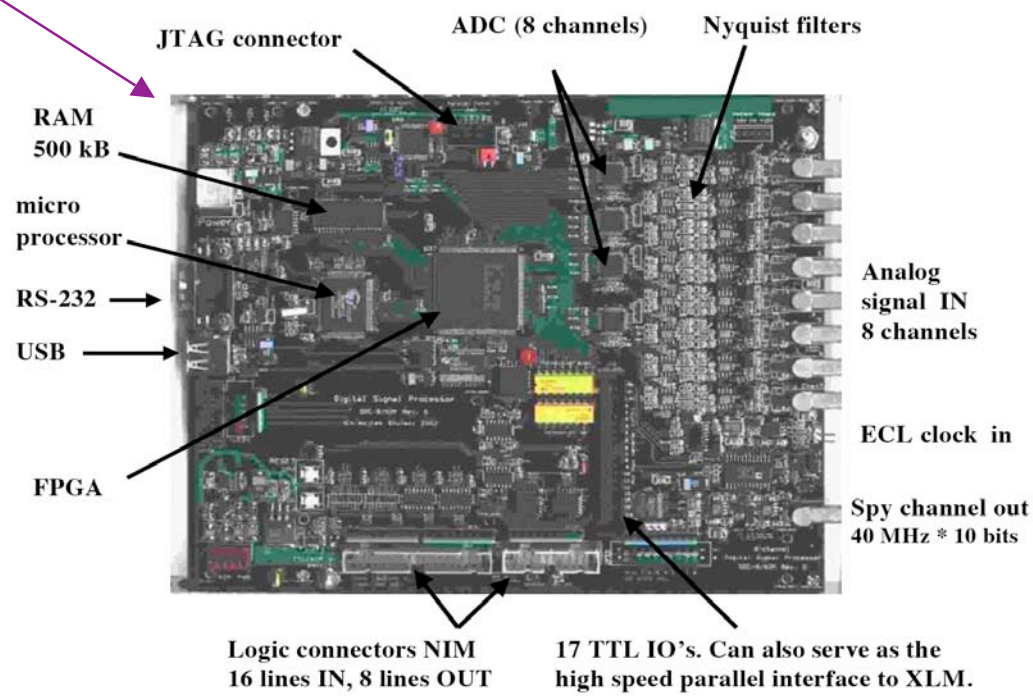
Digital signal processing: preserves information, increases flexibility, reduces cost.

- Traditional approach:
  - Hardware signal processing and trigger generation before digitization.
  - Information preserved:
    - Pulse height
    - Integrated charge
    - Time of arrival
  - Different detectors require different signal processing hardware.
- DSP approach:
  - Digitization first, followed by signal processing either in the processor, off-line, or both.
  - Information preserved is determined by the user (e.g. entire waveform, pulse height, time of arrival)



Options for digital signal processing.

- All our work to date has been carried out using DSPs developed by Wojtek Skulski.
- Commercial options for the advanced laboratory include the 100 MHz PCI-5112 from National Instruments.

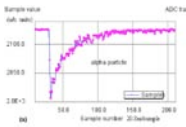


Note: the onboard processing capabilities are critical in this application.

Implementing DSP in the advanced laboratory.

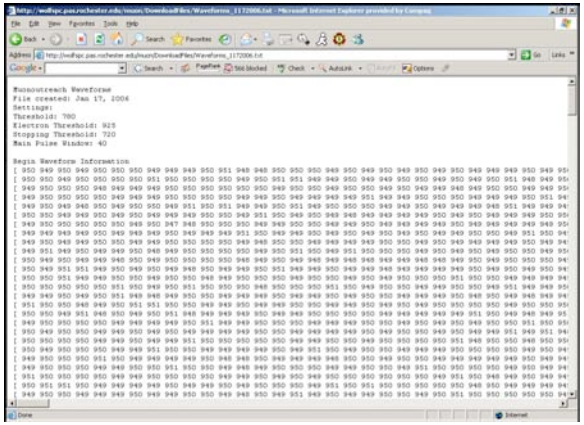
Experiment

DSP



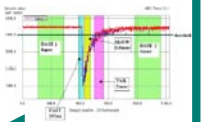
LabVIEW

Data file



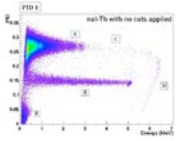
Laboratory

Off-line data analysis



ROOT, OBERON (free)
MatLAB, Mathematica,
LabVIEW ($$$$)

Physics Results



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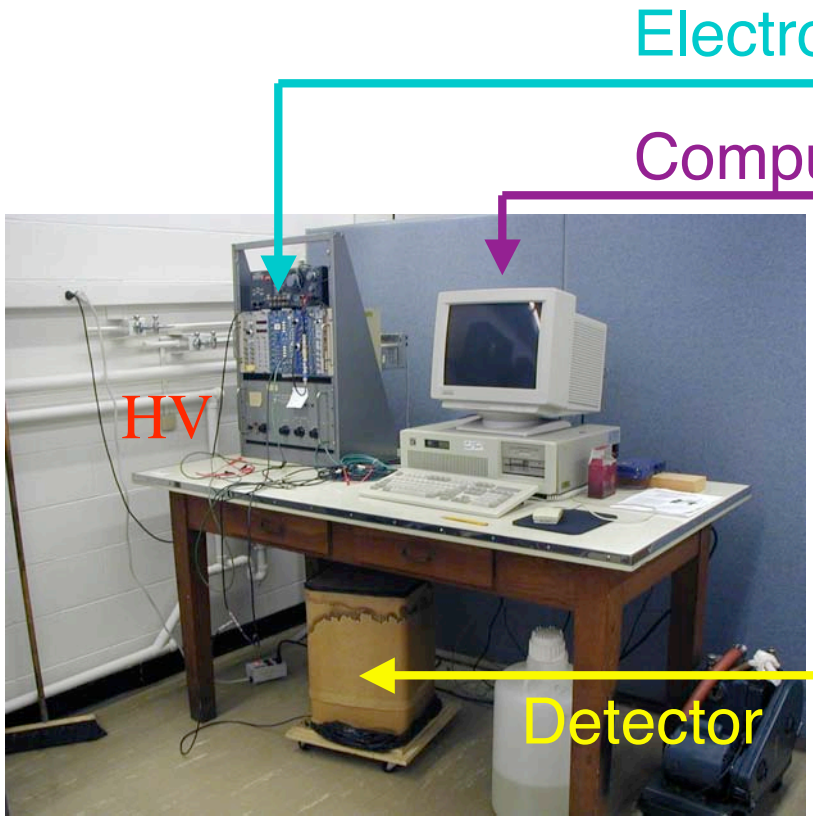
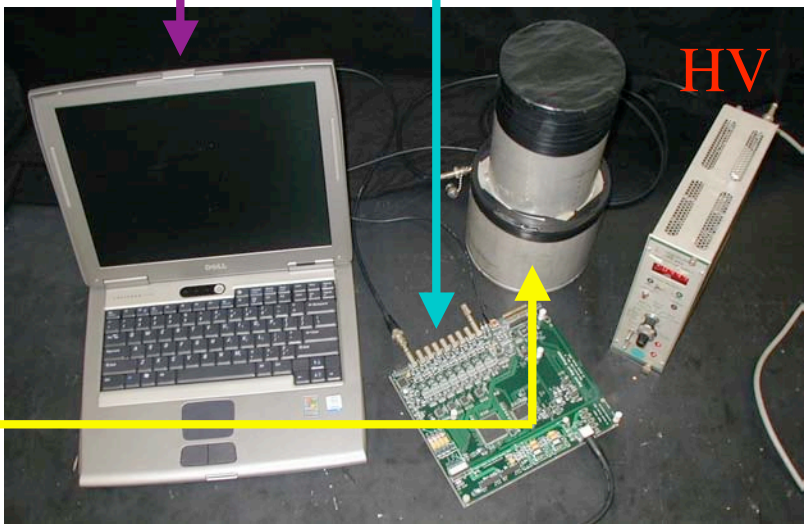
Concerns about digital signal processing.

- Is it a black box (signals in/physics out)?
  - Digital signal processing is very flexible and the level of control can be adjusted and matched to the skill level of the student and/or the focus of the experiment.
  - The analysis of the data carried out by the students can start with the digitized waveforms or at a higher level (pulse height, integrated charge, etc.)
- Why does it reduce cost? A DSP, such as the PCI-5112, costs $ 3,000, requires LabVIEW, and a Windows machine!
  - The cost reduction associated with DSP is a result of the reduced cost of signal processing and triggering hardware. A wide variety of signals can be processed with the same DSP system (although not at the same time).

An example of DSP: the muon lifetime. Traditional setup versus new setup.

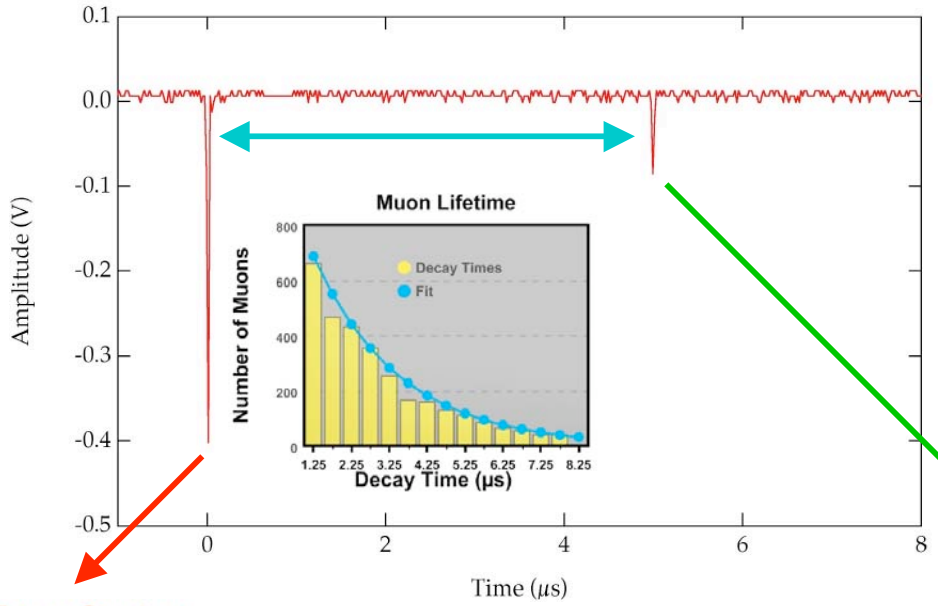


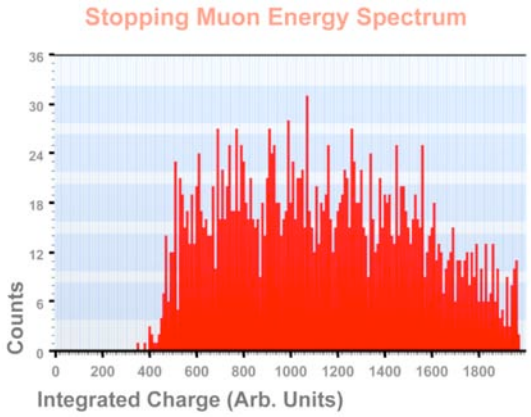
Current muon lifetime experiment in the advanced laboratory in Rochester.

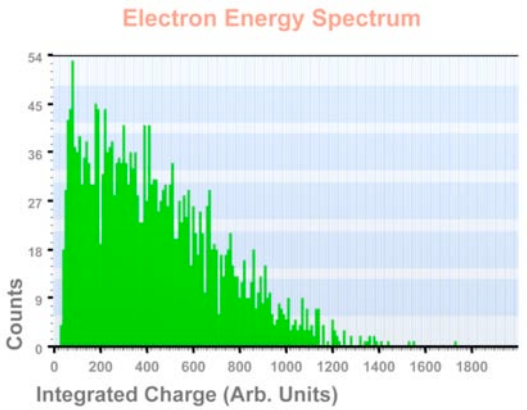


Muon lifetime experiment utilizing digital signal processing.

Measuring the muon lifetime using DSP. Waveform preserves energy information.







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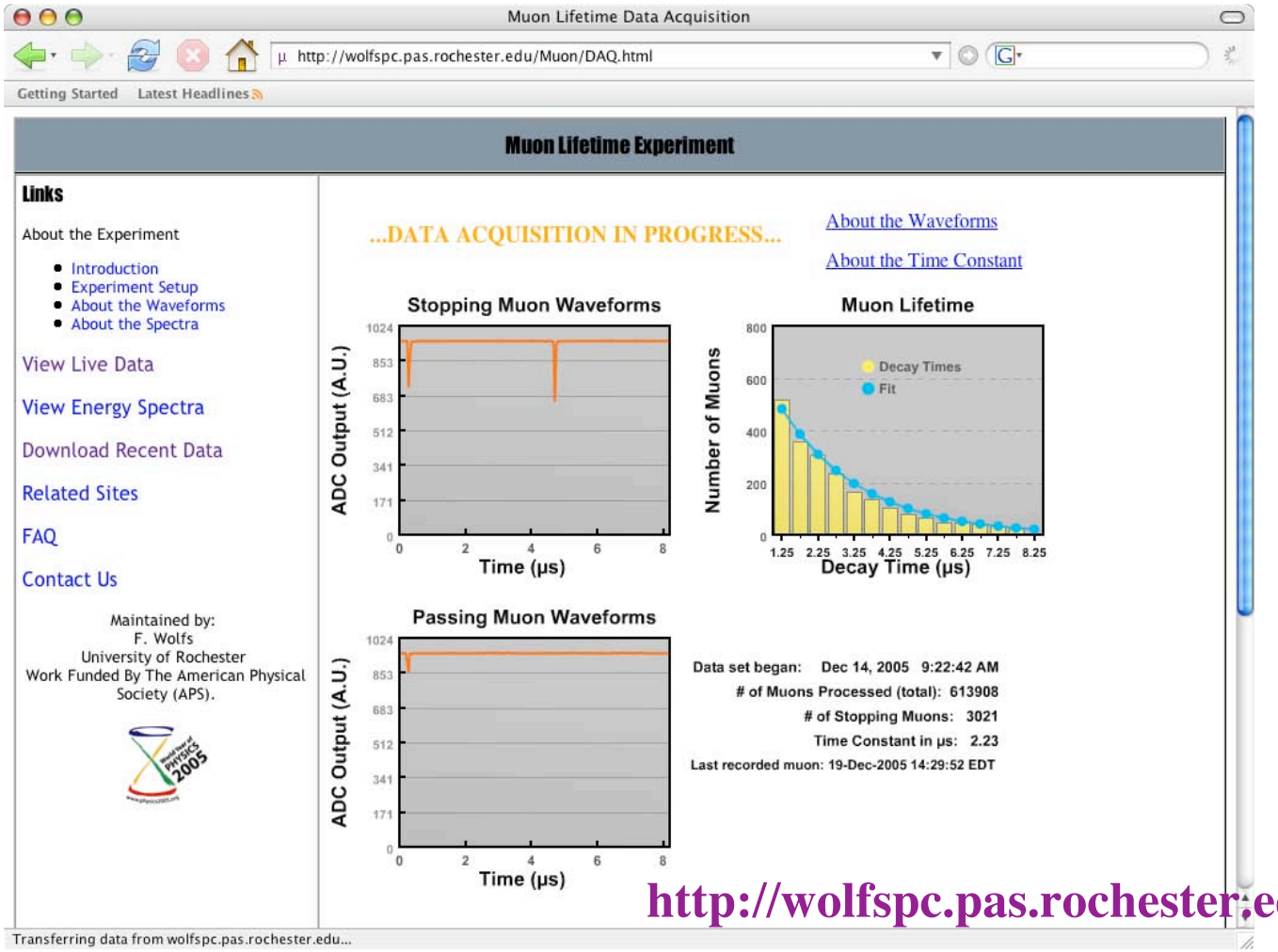
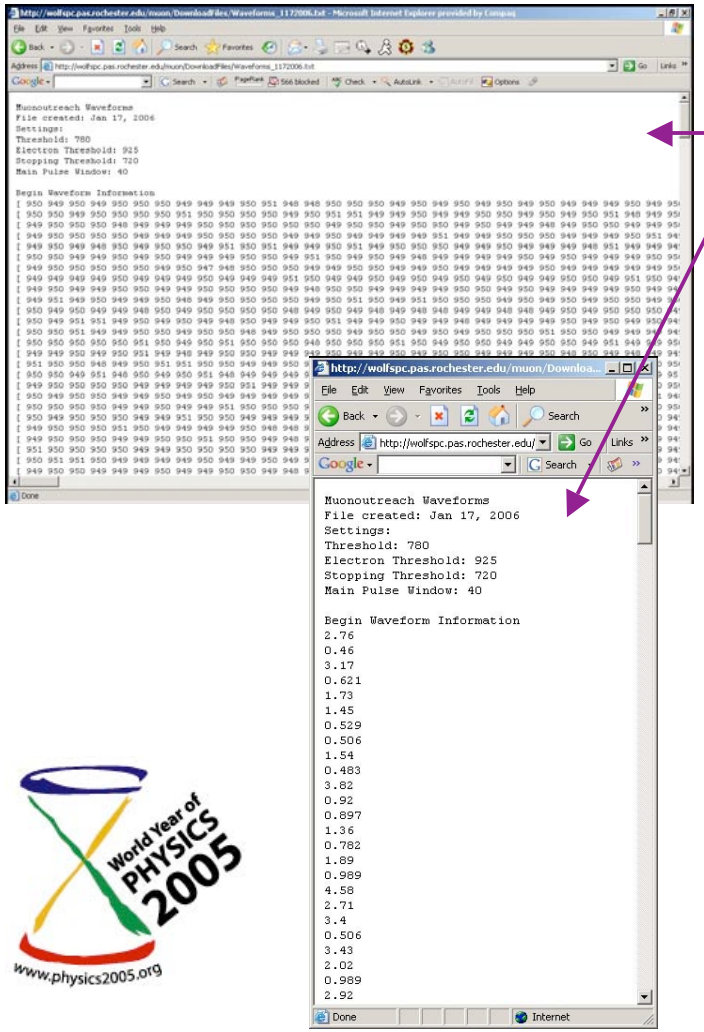
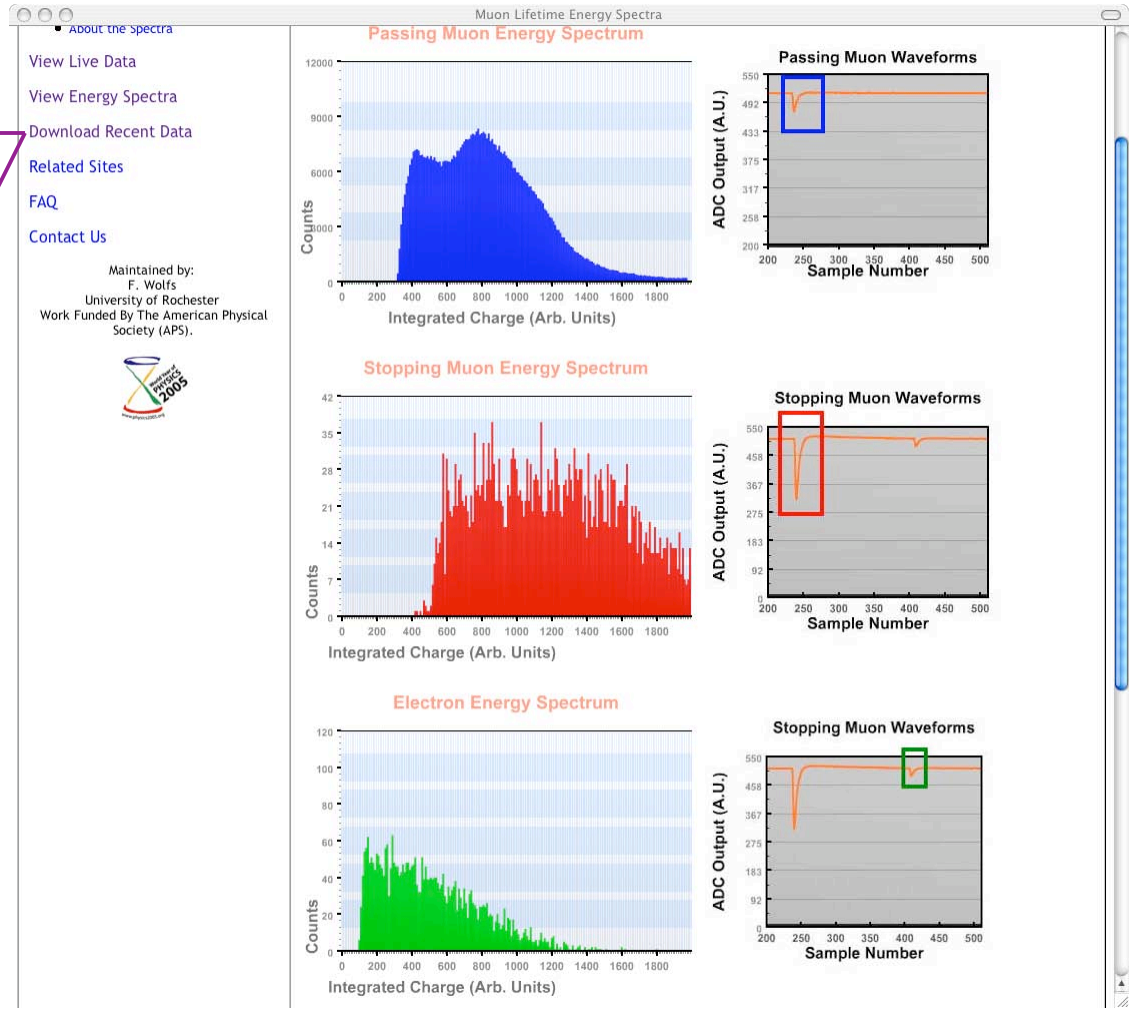
The muon lifetime on the WEB.
DSP makes it easy to interface to the WEB.



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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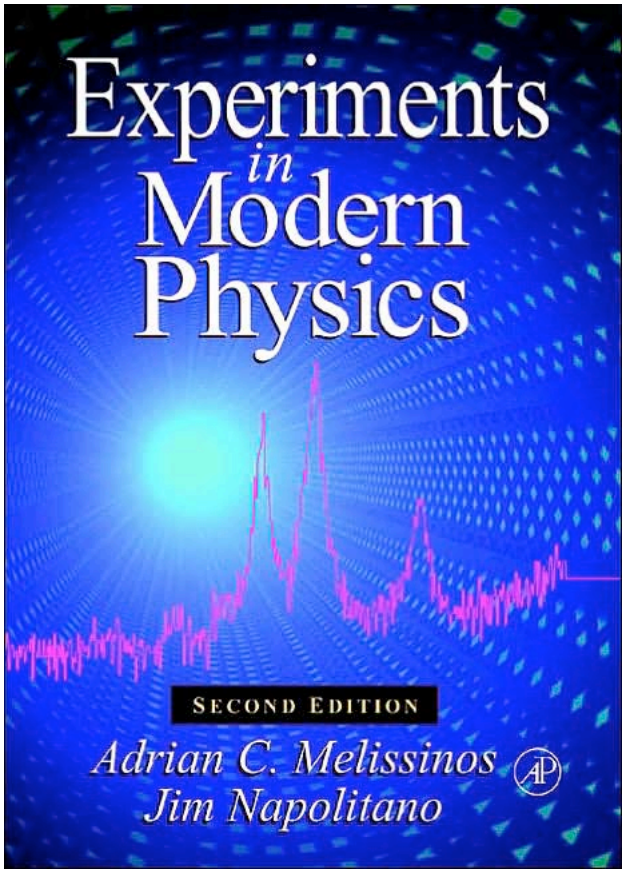
Summary.

- Digital signal processing in the advanced laboratory will modernize the upper-level experience of our undergraduates.
- One DSP can be used for many different applications; different applications in general require different DSP software but not hardware.
- The separation of data acquisition and data analysis mimics the mode of operation in modern research laboratories.
- The use of free software tools for data analysis provides the students with more flexibility to work on their analysis wherever and whenever is convenient.
- The standardization of DAQ hardware will reduce the cost (money and effort) to maintain the advanced laboratory.

Outlook.

- A collaboration between the University of Rochester (F. Wolfs) and Rensselaer Polytechnic Institute (J. Napolitano) have submitted a Phase-2 CCLI proposal to the NSF to introduce DSP in the advanced laboratory.
- The goal of this proposal is to introduce DSP in 4 classic experiment: NMR, magnetic moment of the muon, the Faraday effect, and the Mössbauer experiment.
- This project will ultimately lead to the third edition of *Experiments in Modern Physics*.



A special thanks to Prof. Adrian Melissinos.

- Much of my work on improving the undergraduate laboratories has been inspired by the work of Prof. Adrian Melissinos.
- His continued excitement about new developments in our laboratories continues to inspire me, ever since I moved to Rochester.
- When I bought his book as an undergraduate student (a long time ago) I could have never imagined that one day I would work with him.