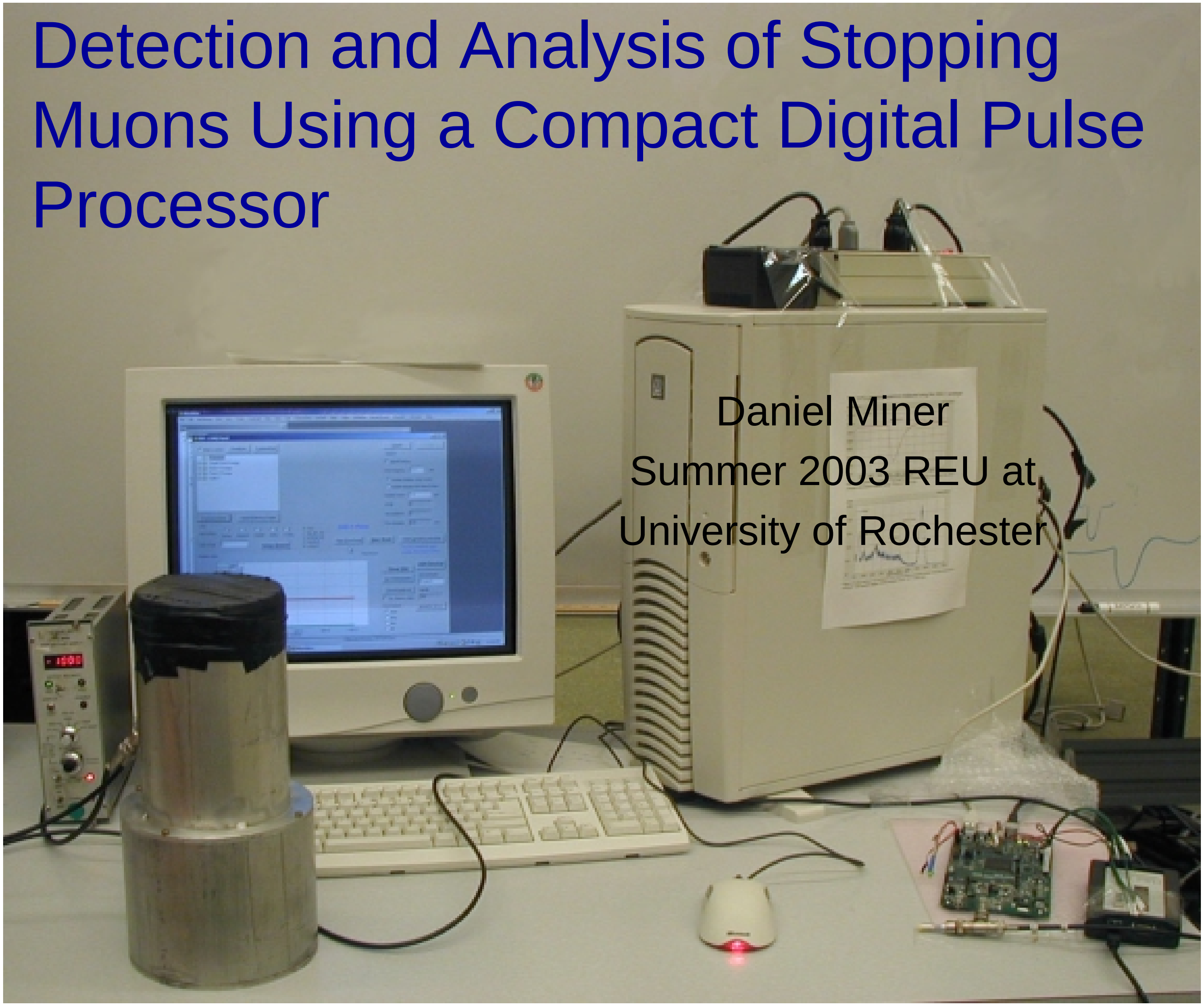
Detection and Analysis of Stopping Muons Using a Compact Digital Pulse Processor



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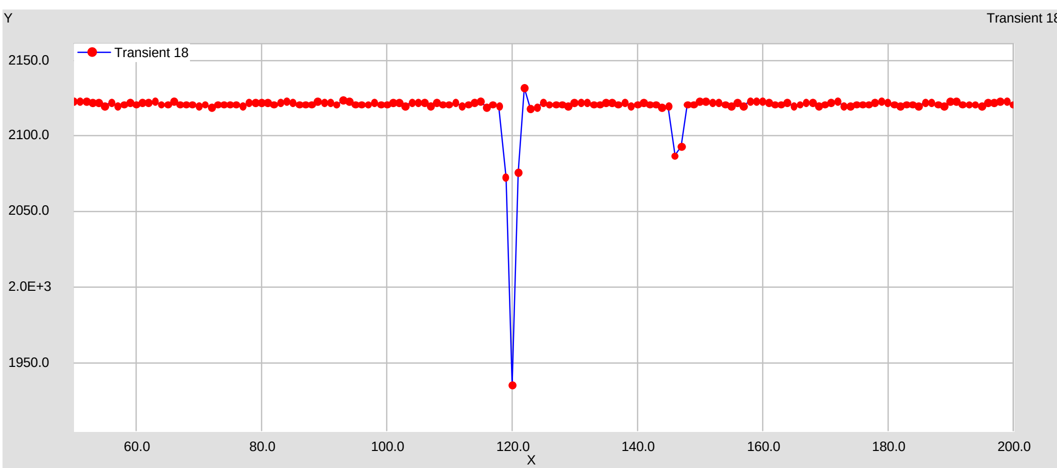
What Does Waveform Digitizing Do?

- Turns an analog signal into a set of discrete-valued samples taken at regular time intervals
- Must be digitized frequently enough to capture waveform features
- Discrete-valued samples are mathematically easy to work with

Why Digital Pulse Processing?

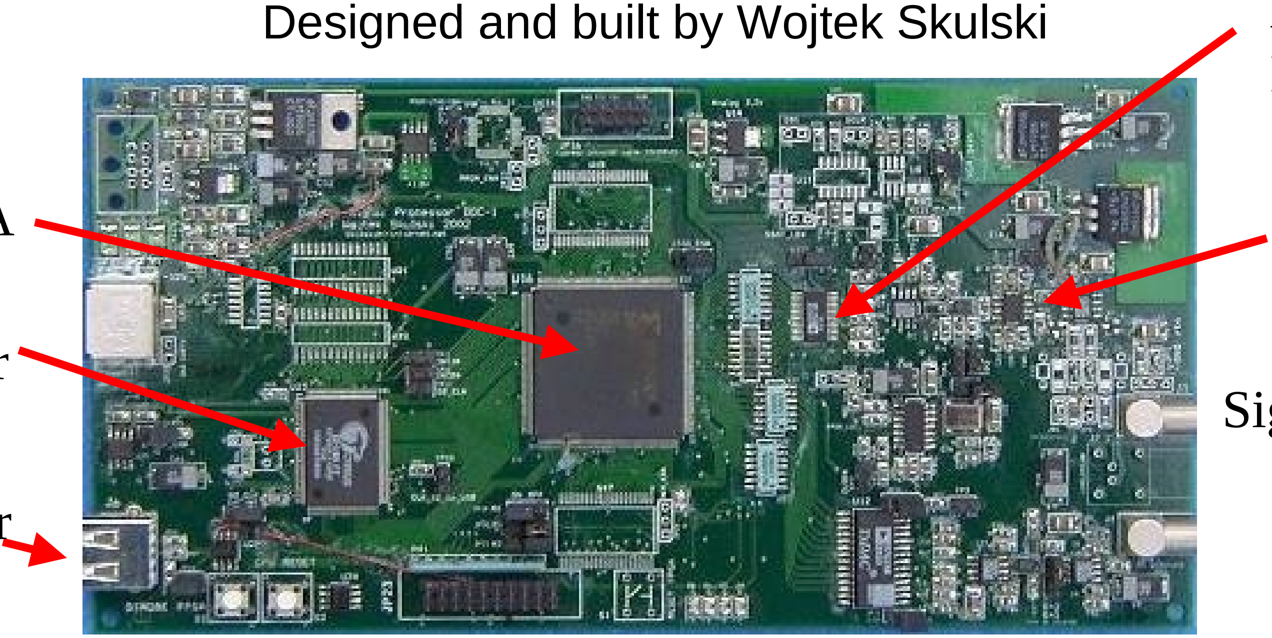
- Easily interfaced with a computer for analysis
- Can store data and process later
- One can extract more features of the signal using less bulky equipment than with analog methods



The blue line represents the analog signal, and the red dots represent the digital samples.

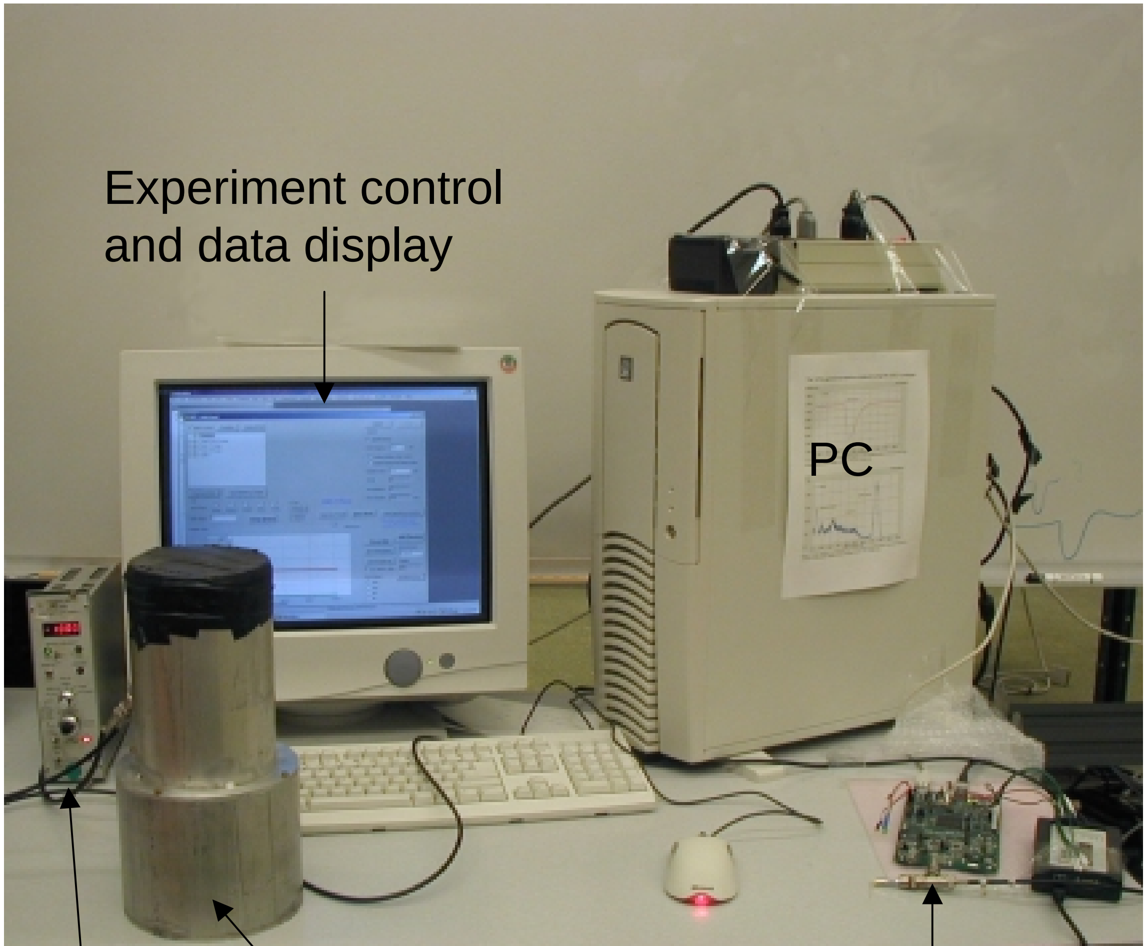
The DDC-1 Digital Pulse Processor

Designed and built by Wojtek Skulski



- 12 bit ADC (Analog to Digital Converter) – converts an analog voltage to a discrete value between 0 and 4095
- Run at 48 MHz
- Uses a looping buffer of 1024 samples

How Can We Demonstrate the Advantages of Digital Signal processing?



HV PS   Detector assembly   DDC-1 digitizer board

- A great deal of information can be extracted from the observation of muons
- With analog techniques, a comparable experiment would require several equipment crates
- All the information can be obtained with the simple digital setup shown

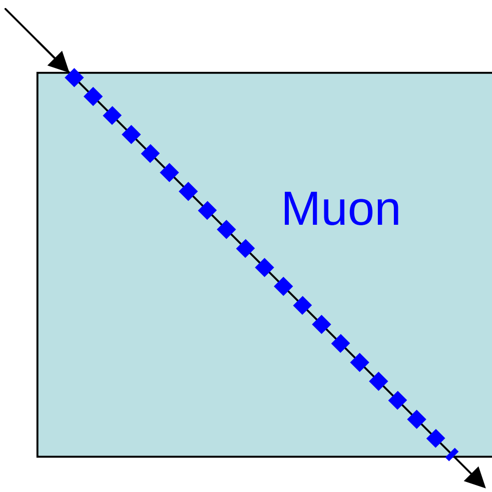
What are Muons?

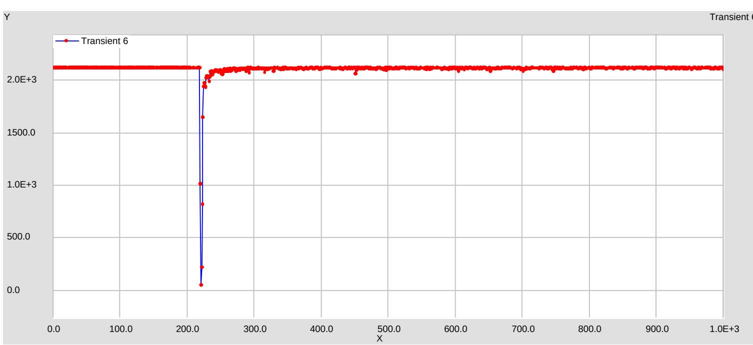
- Similar to electrons, except with much higher mass (about 200x electron mass)
- Created in the upper atmosphere by cosmic rays interactions
- Mean lifetime at rest of 2.2 microseconds
- Decay into an electron and two neutrinos
- Can be stopped by solid objects or dense liquids

Stopping Muons in a Scintillator

Non-stopping muons

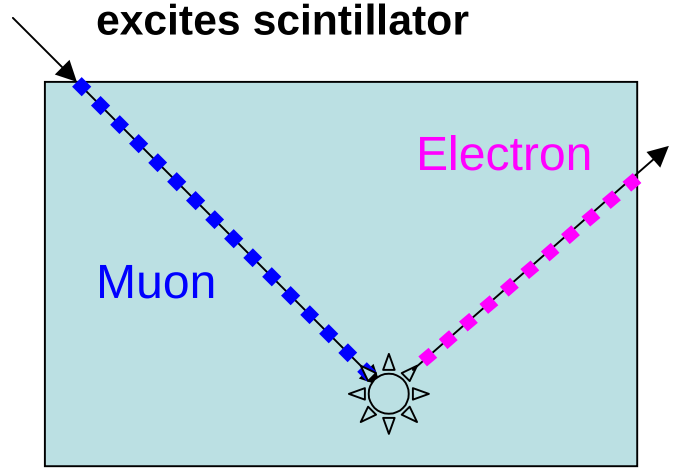
Muon excites scintillator molecules, causing photon emission along path

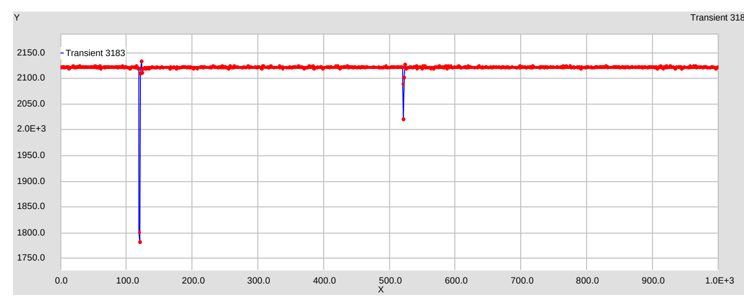




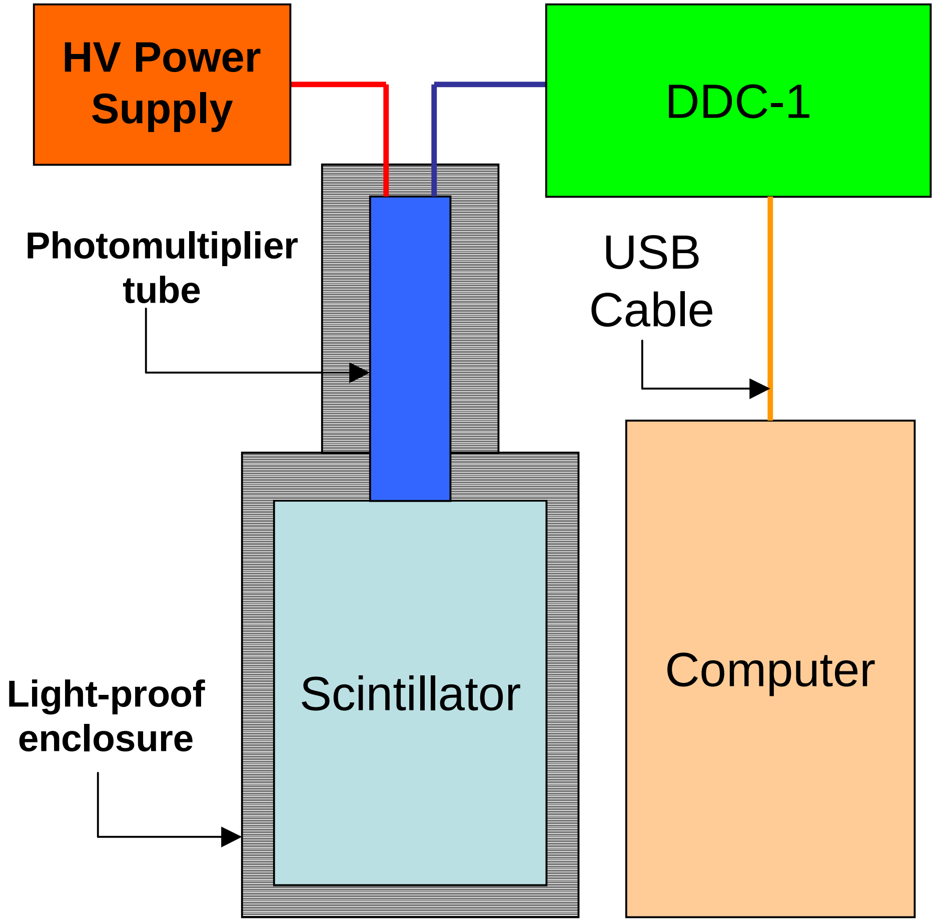
Stopping muons

Muon excites for some distance in scintillator, stops, then decays, emitting electron which excites scintillator





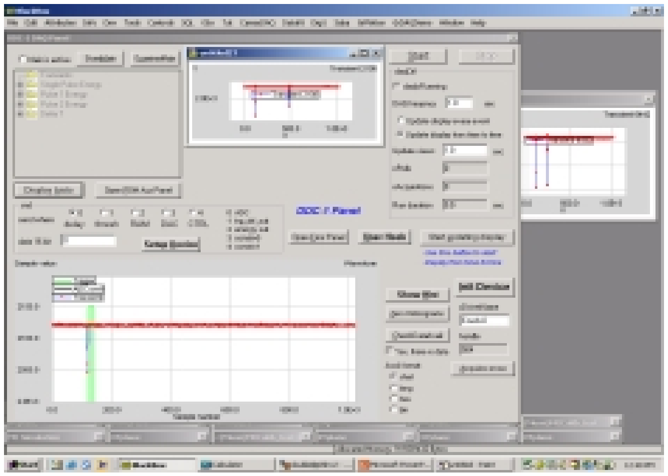
The Experimental Setup



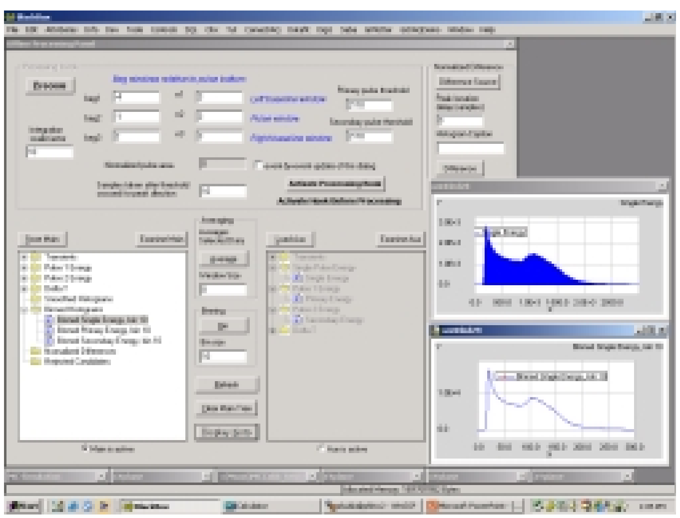
- Scintillator: Bicron BC-400 plastic, 6” X 5” cylinder
- Photomultiplier tube: Hamamatsu R1847-13, 2 inch
- HV: Tennelec TC 952, -1000 V
- Run for approximately 5 and a half days

DAQ and Offline Processing

MuonDAQ by Daniel Miner and Wojtek Skulski



MuonProcess by Daniel Miner



- Recorded Data:

  -Double pulse transients

  -Single pulse energy

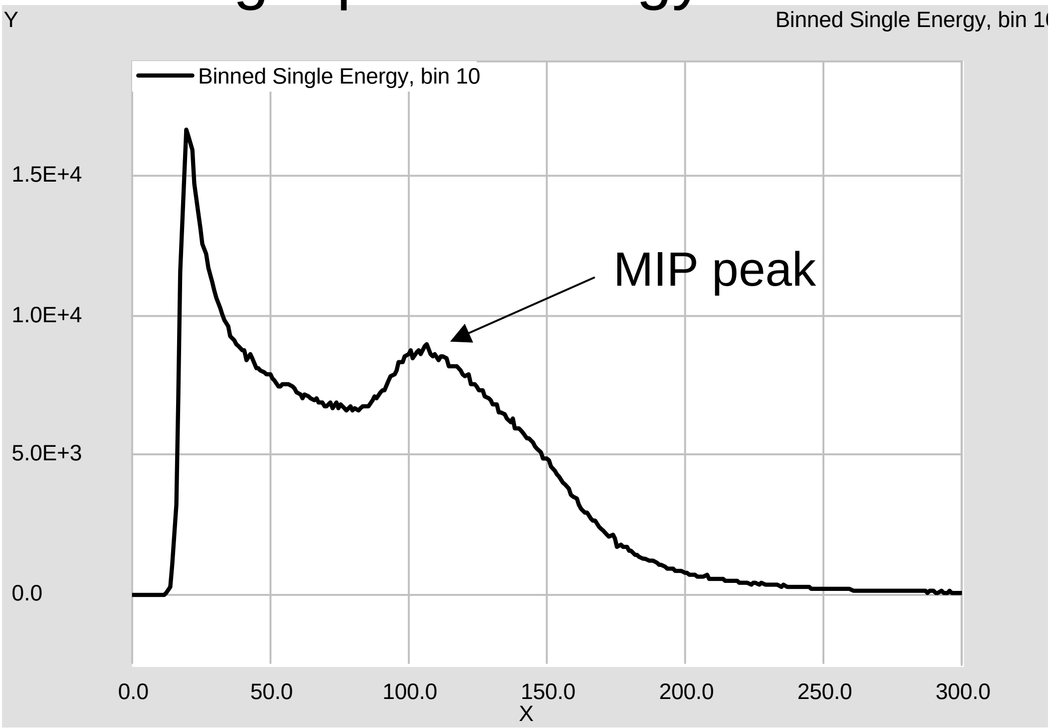
  -Primary double pulse energy

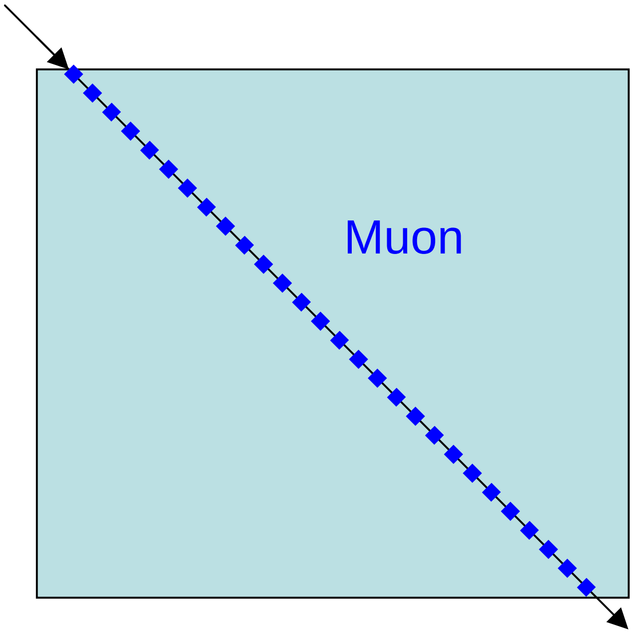
  -Secondary double pulse energy

  -Delay between primary and secondary pulse for double pulses
- Re-processes double pulses with more stringent criteria
- Smooths plots with moving average filter
- Plots normalized difference between two signals or histograms
- Integrates area under pulse with variable scaling factor

Single Pulse Energy Distribution

Raw single pulse energy distribution





Shape is result of :

•MIP peak (to be explained later)

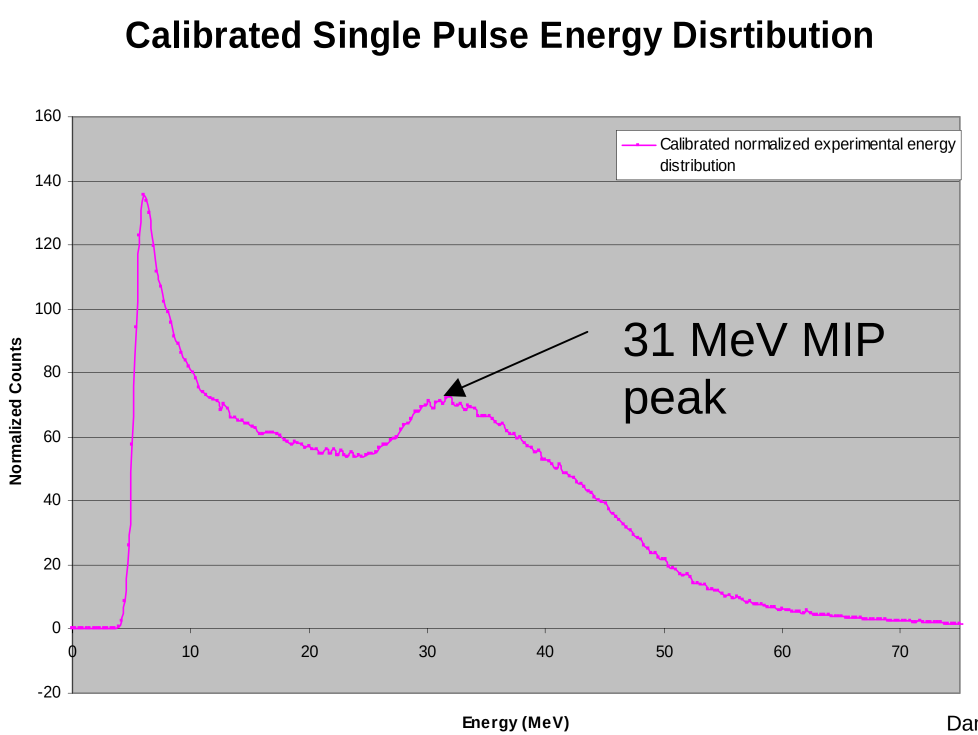
•Geometry of scintillator

•Background noise distribution

•Energy resolution of scintillator

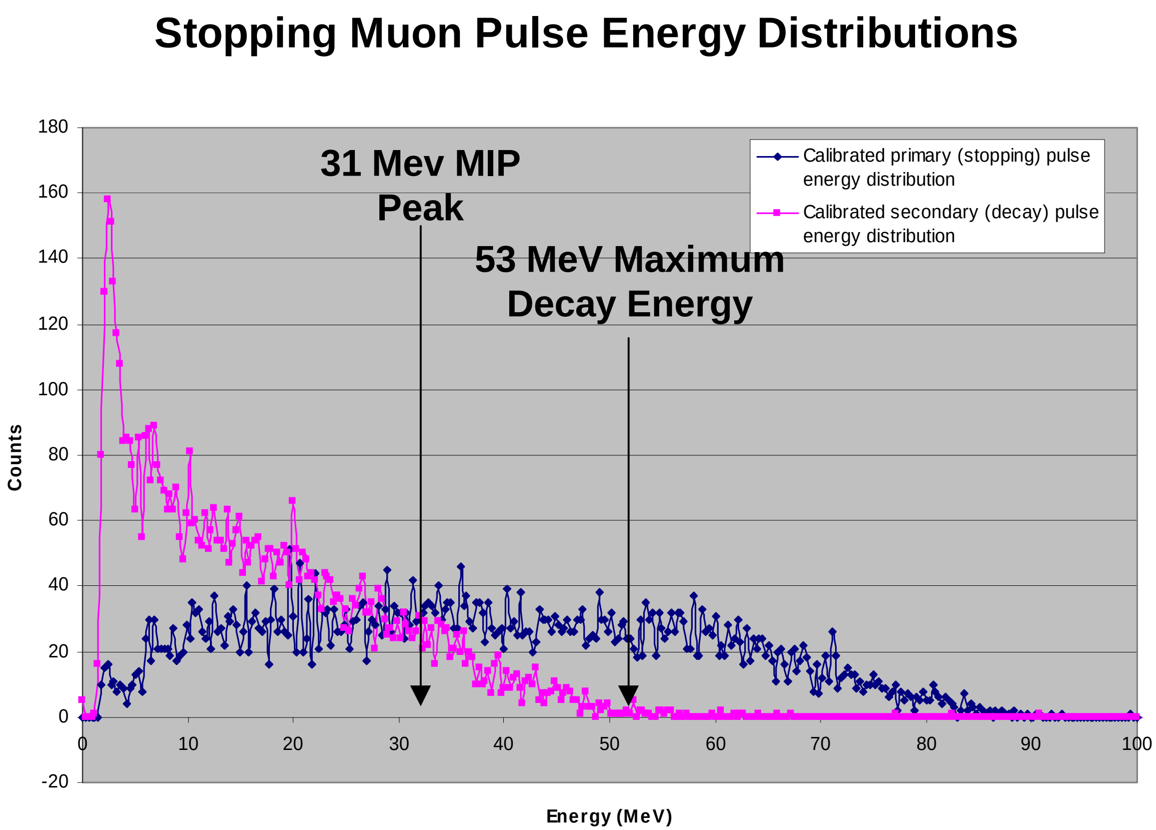
Energy Calibration

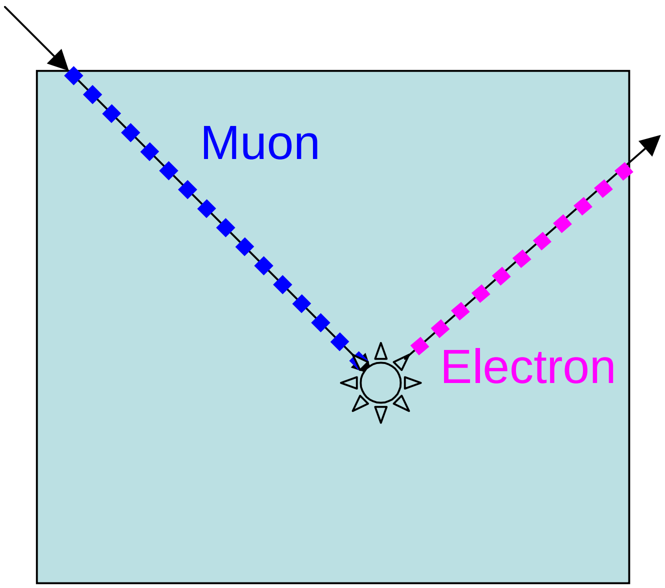
- Cosmic muons that don't stop can be approximated as MIP's – Minimum Ionizing Particles
- MIP energy loss through the plastic scintillator is 2.3 MeV / cm
- MIP energy distribution is path length distribution multiplied by MIP energy loss
- MIP peak is a good calibration point



Monte Carlo simulation software was written (by Daniel Miner and Wojtek Skulski) and used to determine the energy loss distribution and the energy of the MIP peak.

Calibrated Stopping Muon Energy Distribution

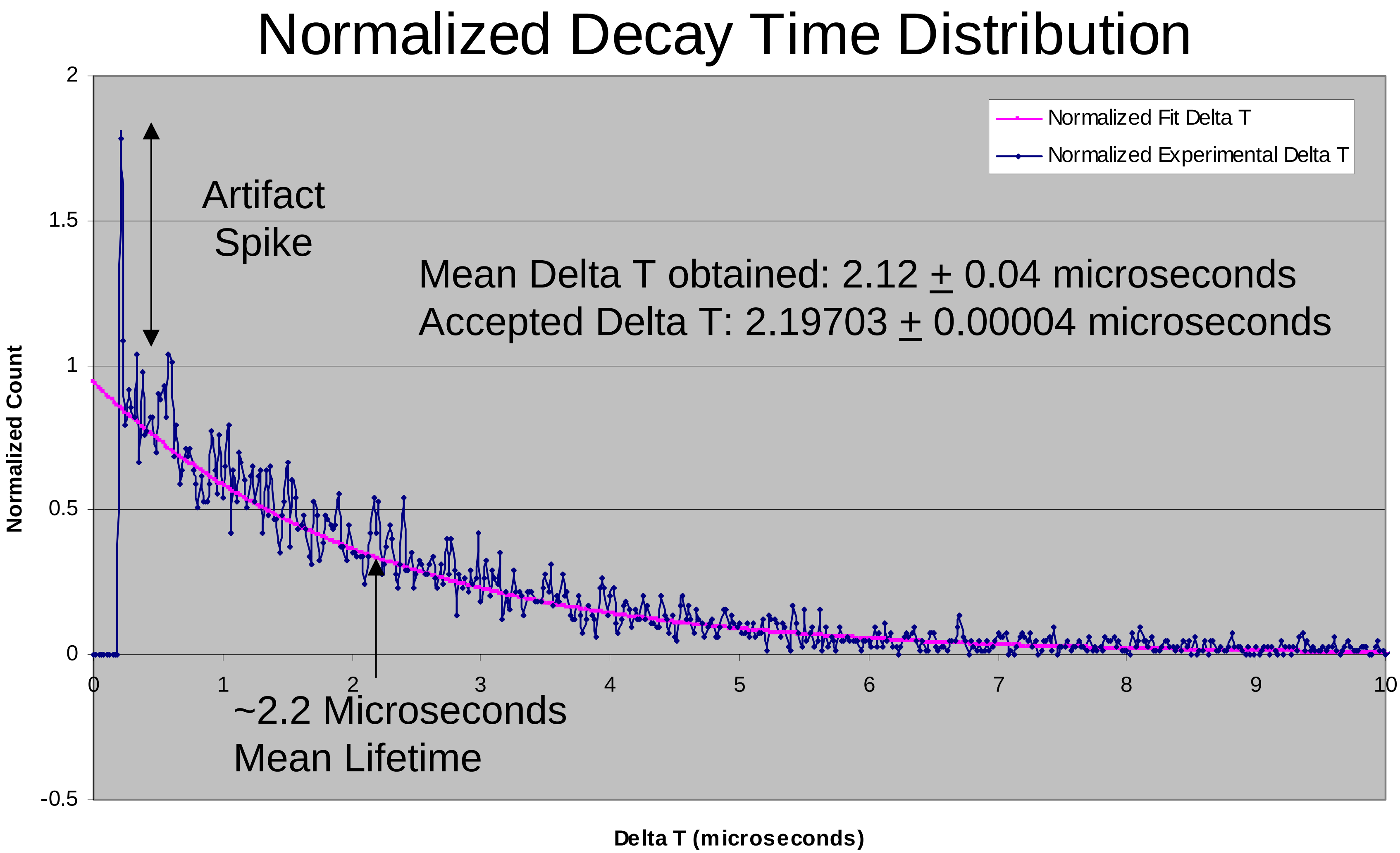




The electron decay endpoint at 53 MeV may be clearly observed.

The primary distribution is the result of the energy loss distribution for particles at the endpoint of the Bethe-Bloch equation range. The secondary distribution is the electron energy spectrum of beta decay from muons.

Decay Time Distribution



Conclusions

- Cosmic muons were observed and positively identified by their decay time
- Energy distributions were obtained for both MIP muons, stopping muons, and decay electrons
- The experiment, assembled essentially from scratch, performed beyond expectations
- The digital technology used has proved its capability and versatility

Developments by Daniel Miner

- Co-developed data acquisition (DAQ) software
- Developed pulse detection and sorting algorithms
- Co-developed data object management system
- Developed offline data processing software
- Co-developed Monte Carlo simulation system
- Constructed experimental setup
- Oversaw and performed data collection and calibration

Acknowledgements

- Wojtek Skulski
- Frank Wolfs
- Jan Toke
- Erik Bjorn Johnson