Instrumentation for µSR

or

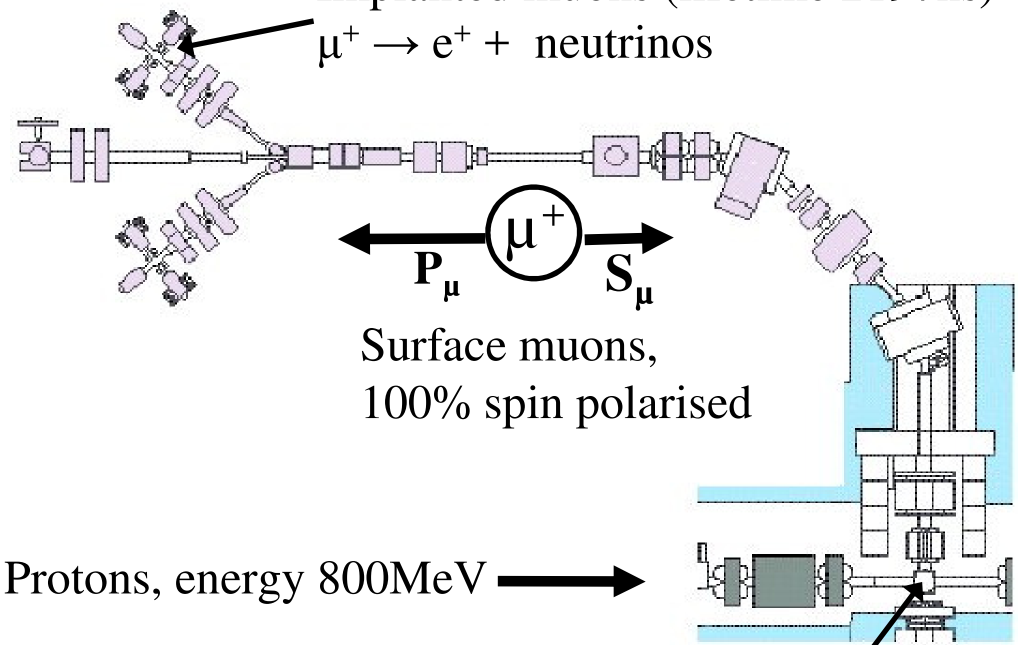
Building a Spectrometer!

Outline

- Experiment Overview
- The Detector Chain
- Making an Instrument

Overview...

Getting the Muons



Muons implanted as a pulse, FWHM 80ns

Not symmetric because of pion decay

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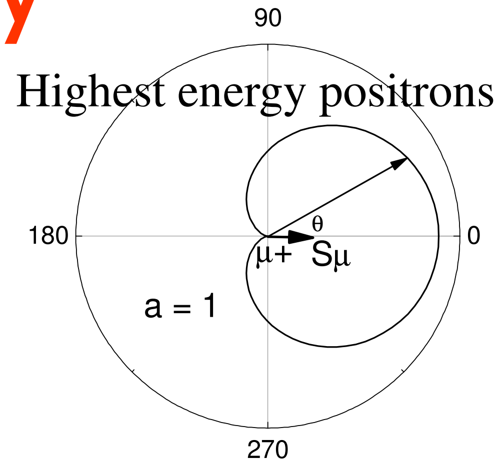
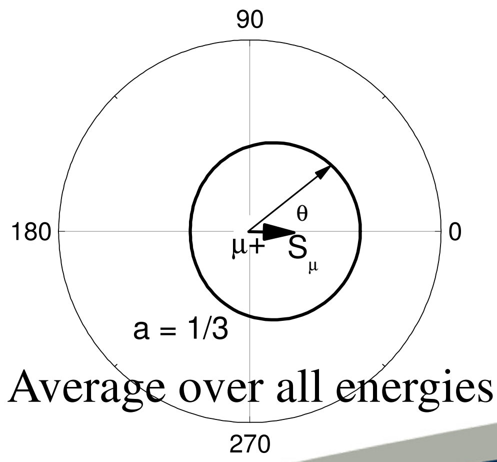
Muon Decay

- μSR depends on **detecting positrons** from **implanted muons**
- Need **time of decay and direction** for time differential measurements
- Positron emitted **preferentially along S_μ** (what if there's a field?)
- Positron **energies and asymmetry can be tuned** by degrader



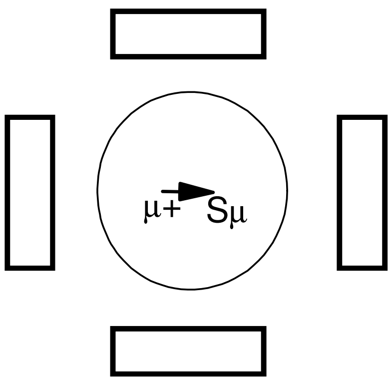
$W(\theta) = 1 + a.\cos(\theta)$



Experiment Geometries

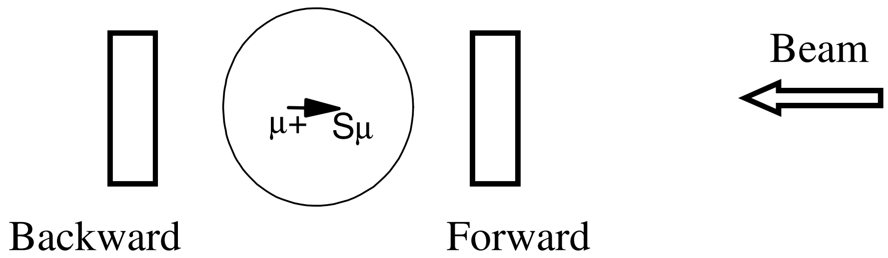
Decide on experiment, then position detectors to maximise asymmetry, count rate, etc

Transverse



Field out of screen

Longitudinal



Field parallel to beam

Have enough detectors

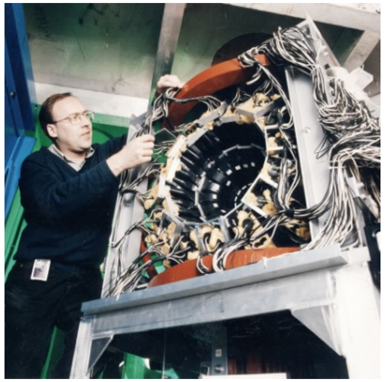
- ***Cope with rates at a Pulsed source:***
  1000s muons stopped / pulse,
  Very high instantaneous counting rates at short times,
  Require several counts / detector / pulse,
  Detector responds at limited speed,
  Segment detectors to avoid deadtime (see Pabi's talk)
  Typically 32 detectors for ~20-30Mev/hr
- ***What about a Continuous source – PSI/TRIUMF?***
- ***Cover a large solid angle:***
  Efficient counting, but
  Need to allow for beam/cryostat entry!
  Typically 2π coverage

Other considerations

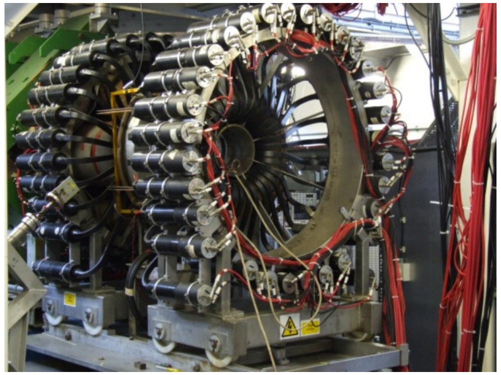
- ***Magnetic field coils***
  Resistive or superconducting …
  Coils are required for the **main field**, **calibration field** and **compensation for the Earth's field**.

- ***Mounting for Sample Environment***
  Leave space to accommodate experiment kit

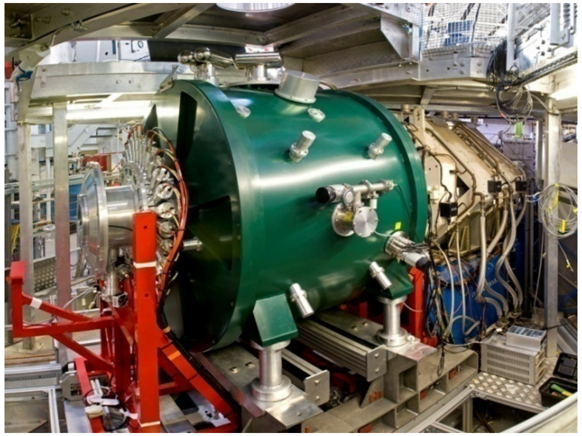
Real Spectrometers



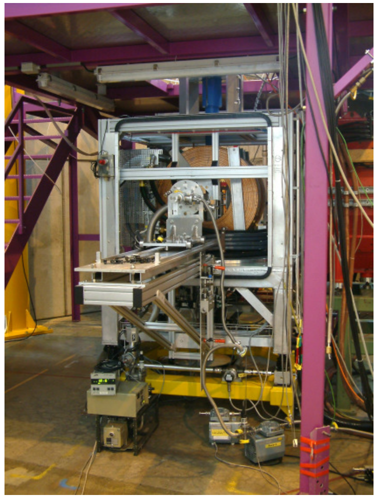
ARGUS (RIKEN-RAL)



MuSR (ISIS)

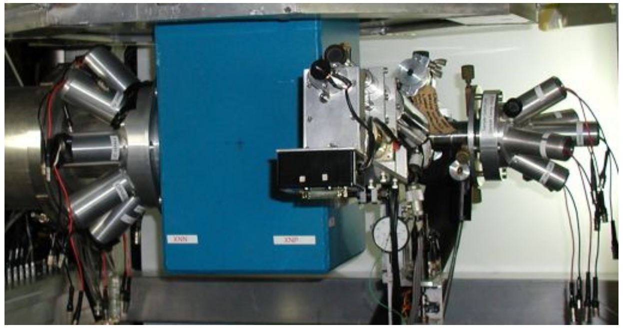


HiFi (ISIS)



GPD (PSI)

Chronus (RIKEN-RAL)

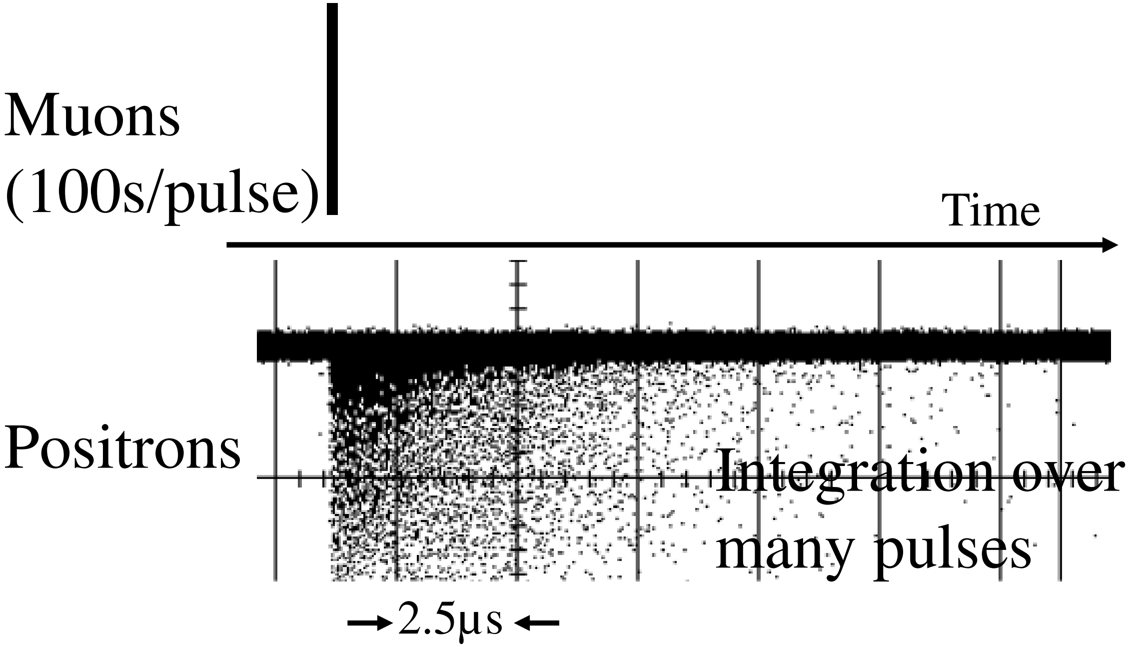


High-Time(TRIUMF)

Detector Chain...

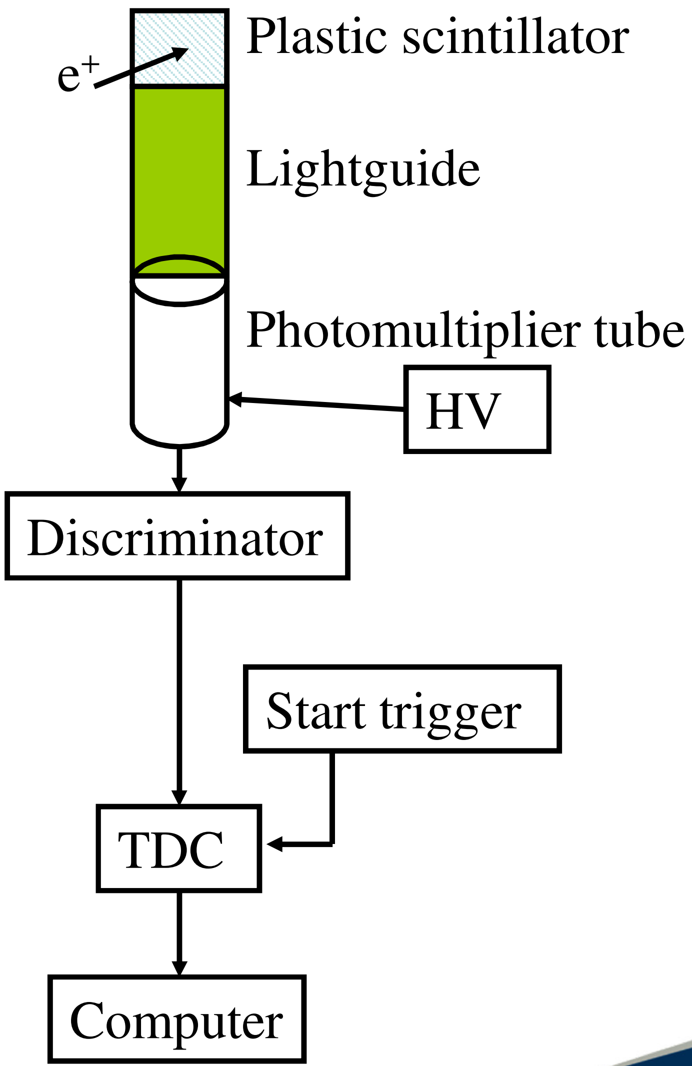
Positron Detection

If NO time evolution of muon polarisation positron count rate is: $N(t) = N_0 \exp(-t/\tau_\mu) + B_g$



Usually, there is a time evolution of the muon polarisation.
Studying this is where the physics lies.

The Detector Chain



Particles to Light

↓

Transmission

↓

Light to electrons

↓

Reject Noise, Logic Output

↓

Measuring time

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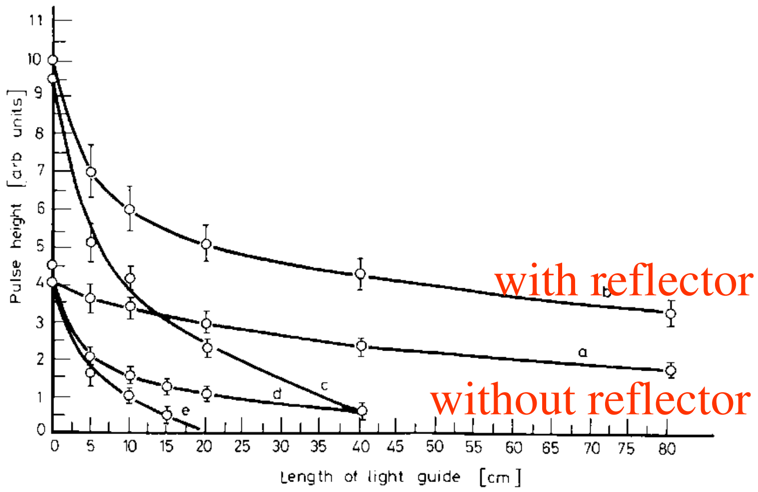
Scintillators: *Particles to Light*

- Energetic particles cause luminescence
- High efficiency
- Ensure sufficient track length (5-10mm thickness usual)
- Fast response (ns) and rapid recovery
- Spectral range can be selected (matched to PMT)
- Plastic typically used for μSR (but many others, e.g. liquid, gases)

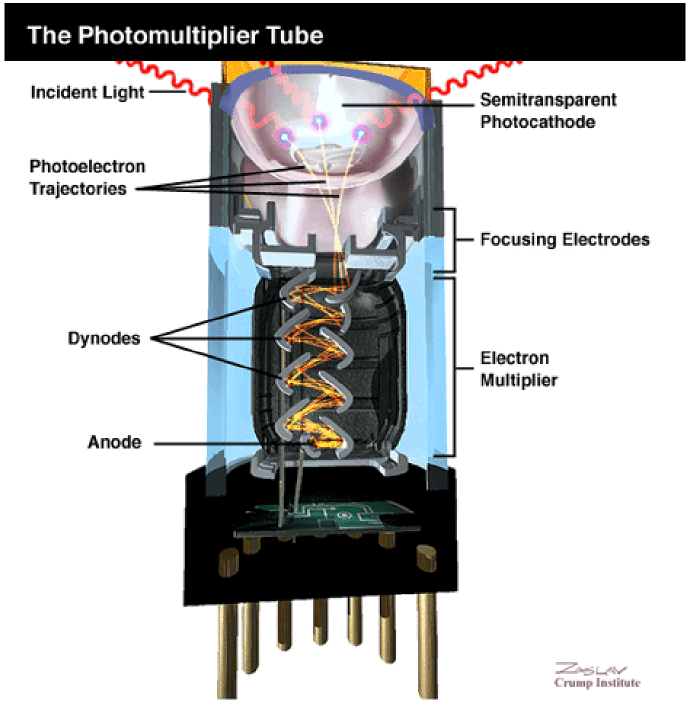
Lightguides: *Transmission*

- Made from plastic (e.g. perspex)
- Conducting light by internal reflection
- External reflector incl. transmission
- Constant area (light incompressible!)
- Adiabatic (gradual change in shape)



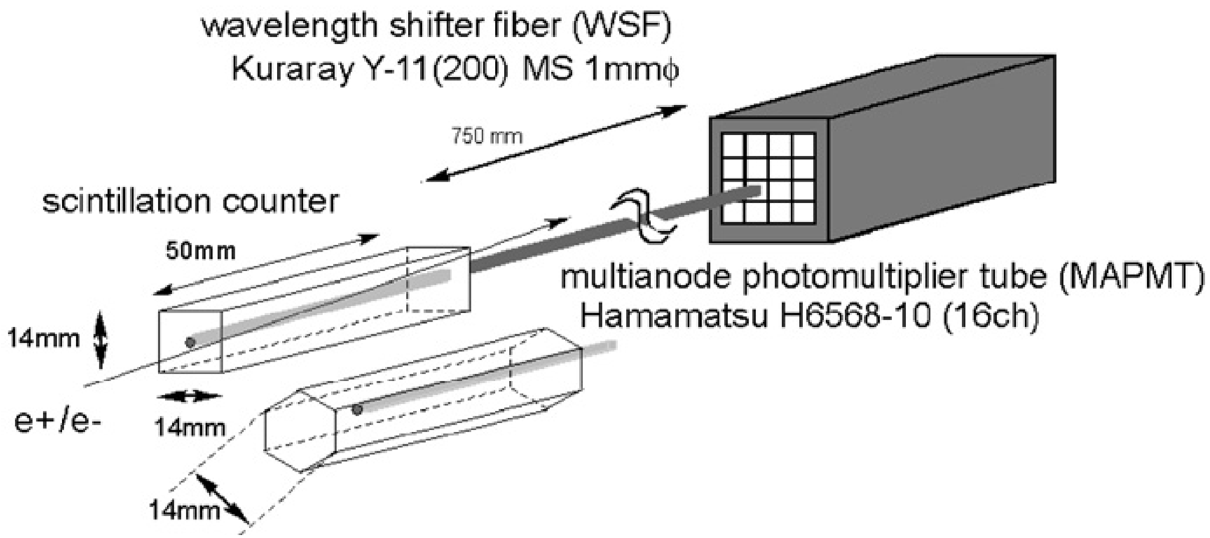
Photomultipliers: *Light to e^-*

- Quantum efficiency and Peak response must be selected
- Field sensitive – place in low field using a lightguide
  - Set gain by adjusting HV



Chronus: *High Segmentation*

Forming the detector chain for a
High Density detector array …



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Solid-state Photomultipliers?

Si Photomultipliers now popular at Continuous sources …\
Why aren't we using them at ISIS at the moment?

At a 'continuous' source …
counting one muon at a time

- Very high timing resolution
- Deadtime not important

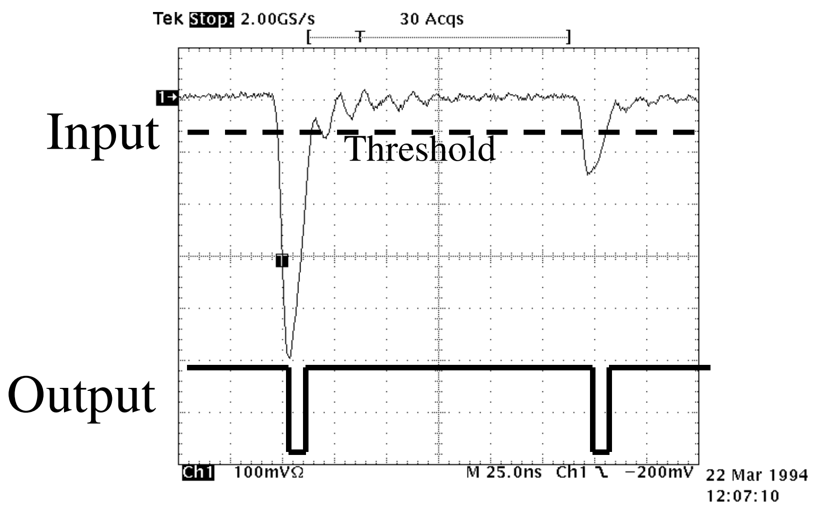
At a 'pulsed' source …
counting 100s muons at a time

- Modest timing resolution
- **Very high data rates, Deadtime huge issue**

Properties of SiPMs well-suited to continuous muon sources,
R&D on-going to understand their behaviour at high data rates

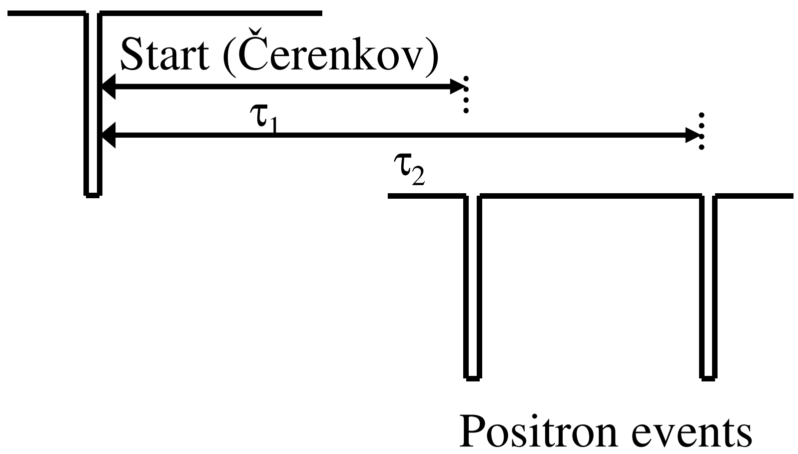
Discriminators:
Logic Output, Reject Noise

- Leading edge triggers as input voltage rises through preset threshold
  - Output is a (logic) pulse of preset width
  - Double pulse resolution important (why?)
- Setup Threshold (~75mV) and Pulse Width (5-10ns)



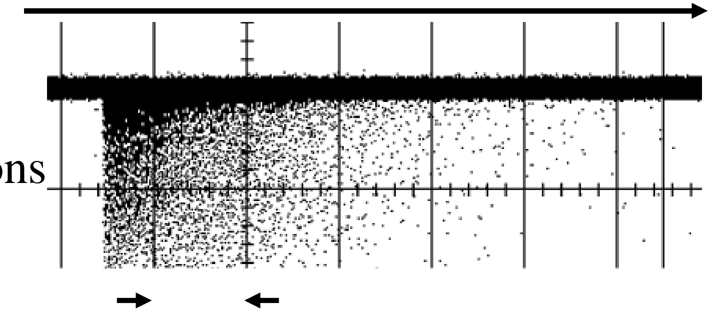
Time to Digital Convertor: *Measuring time*

- Multi-hit TDC
- Common start for all channels
- Measure time between start trigger and positron events
- Time bins determined by clock (typically 16ns bins at ISIS)
- TDCs buffer multiple hits following the muon pulse to avoid distortion



Setting things up...

PMT Voltages

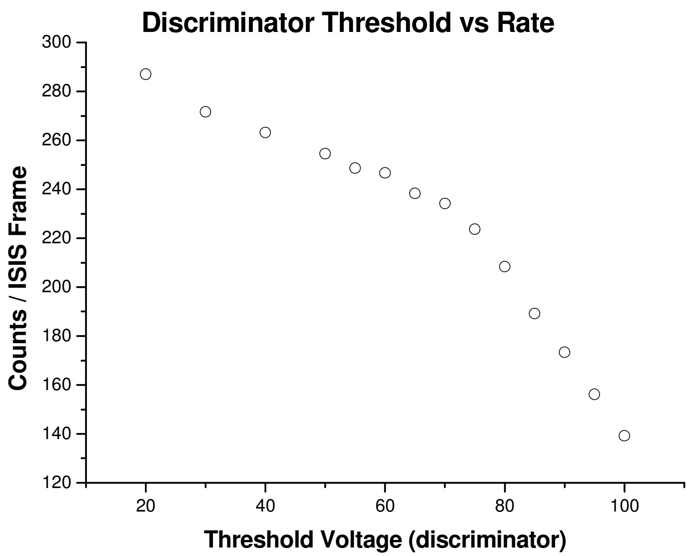


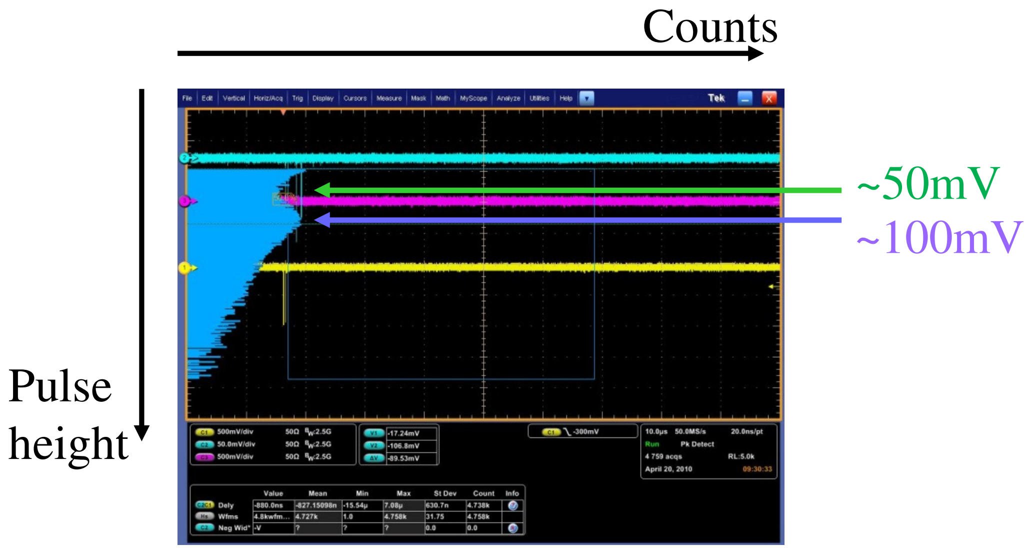
A histogram of pulse heights enables us to adjust the ***<u>HV</u>*** for:

- Uniform response between detectors (why?)
- Gain appropriate to intended discriminator threshold

Discriminators

We can also scan the ***discriminator threshold*** to check how things are setup





The result should be consistent with our histogram of pulse heights

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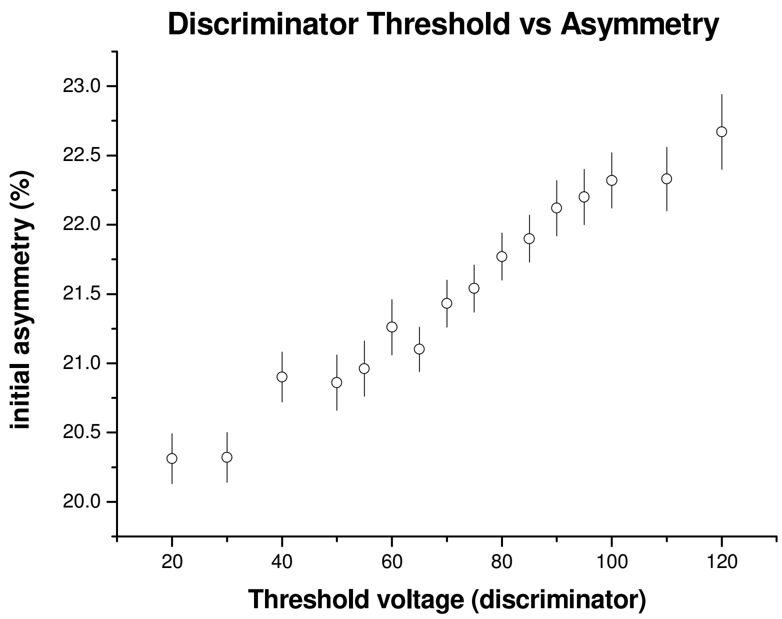
Is it worth the effort?

Yes, because we get cleaner signals and improved data



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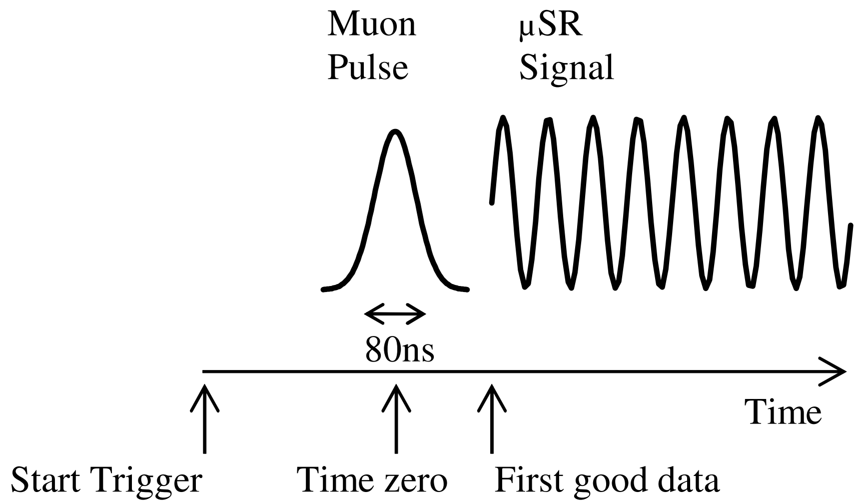
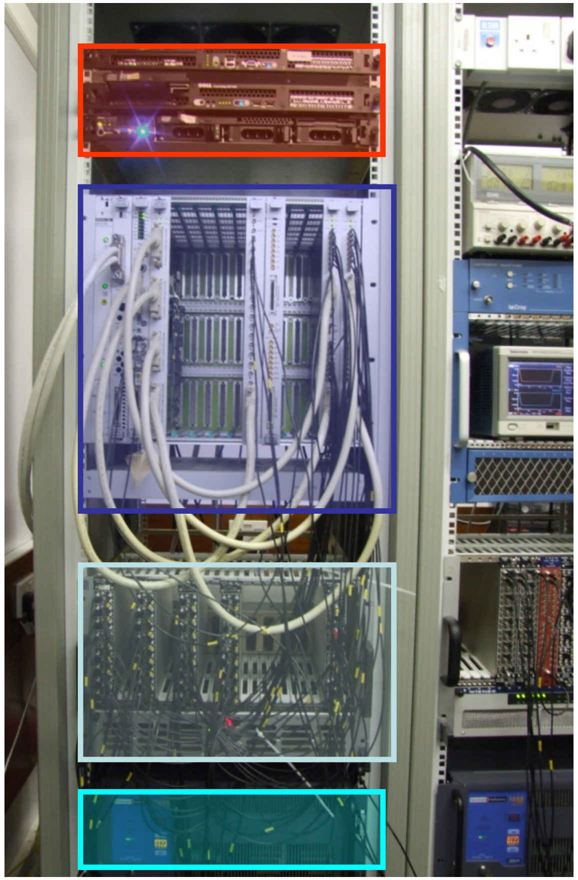
Time Zero and First Good Data



- Times are referenced to the centre of the muon pulse ('Time zero'). Fitting starts from the point where good clean data is available ('First good data')
- The values of 'Time zero' and 'First good data' vary according to spectrometer

Making an instrument...

Control electronics



Control and analysis PCs

DAE-II: TDCs and period card

Discriminators

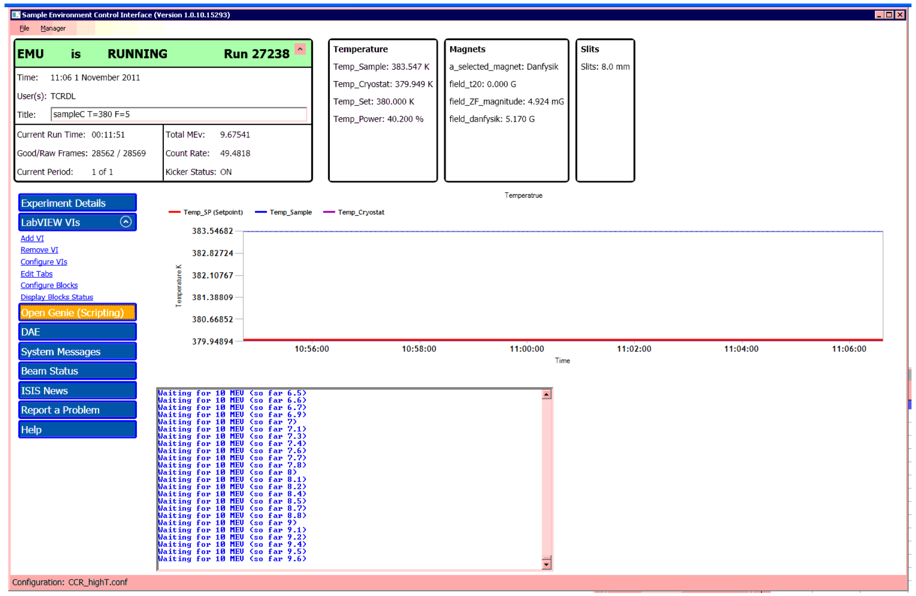
High voltage for PMTs

- Clean environment
- Air conditioned room (lots of heat!)
- Separate from people (lots of noise!)

Control Computer

Acquisition, control and storage

- Accumulate and manage data
- Experiment running in closed area – remote control essential!
  - LabView used to control kit
- Automated running desirable (!)
  - 'Nice' interface



If you'd like to know more …

- **Commissioning of the Rutherford Appleton Laboratory Pulsed Muon Facility**,
  G.H. Eaton *et al*,
  Nuclear Instruments and Methods A 269 (1988) 483-491
- **Uppset: A pulsed electrostatic kicker to improve the mSR frequency response in the ISIS pulsed muon beam,**
  A.I. Borden *et al*,
  Nuclear Instruments and Methods A 292 (1990) 21-29
- **Fast E-Field Switching of a Pulsed Surface Muon Beam: The commissioning of the European Muon Facility at ISIS**,
  G.H. Eaton *et al*,
  Nuclear Instruments and Methods A 342 (1004) 319-331
- **The RIKEN-RAL pulsed muon facility**,
  T. Matsuzaki *et al*,
  Nuclear Instruments and Methods A 465 (2001) 365-383
- **Development of a new multi channel μSR spectrometer**
  D. Tomono *et al*,
  Nuclear Instruments and Methods A 600 (2009) 44-46
- **Techniques for Nuclear and Particle Physics Experiments**,
  W.R. Leo, Springer-Verlag ISBN 3-540-17386-2
  (parts also on the web at http://books.google.com)