Science & Technology Facilities Council
ISIS Neutron and Muon Source

Instrumentation

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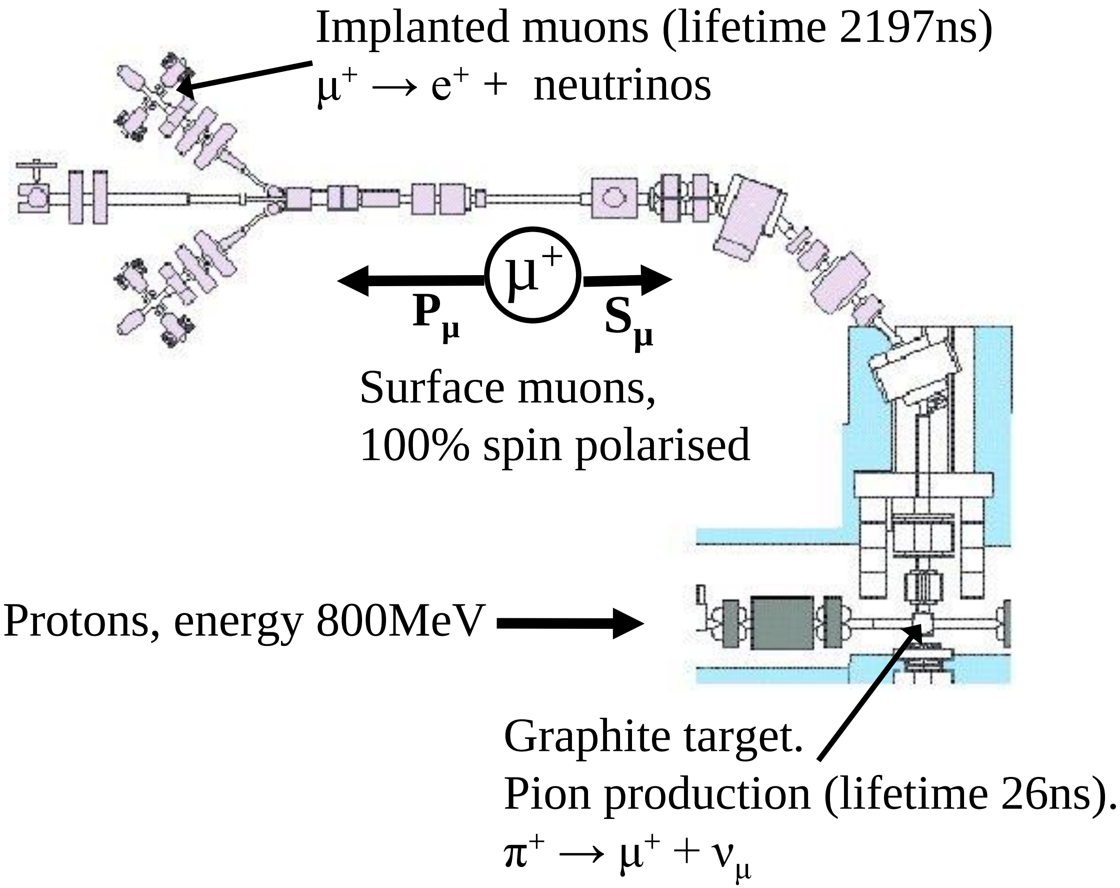
ISIS Muon Group

Muon Production – Brief Recap



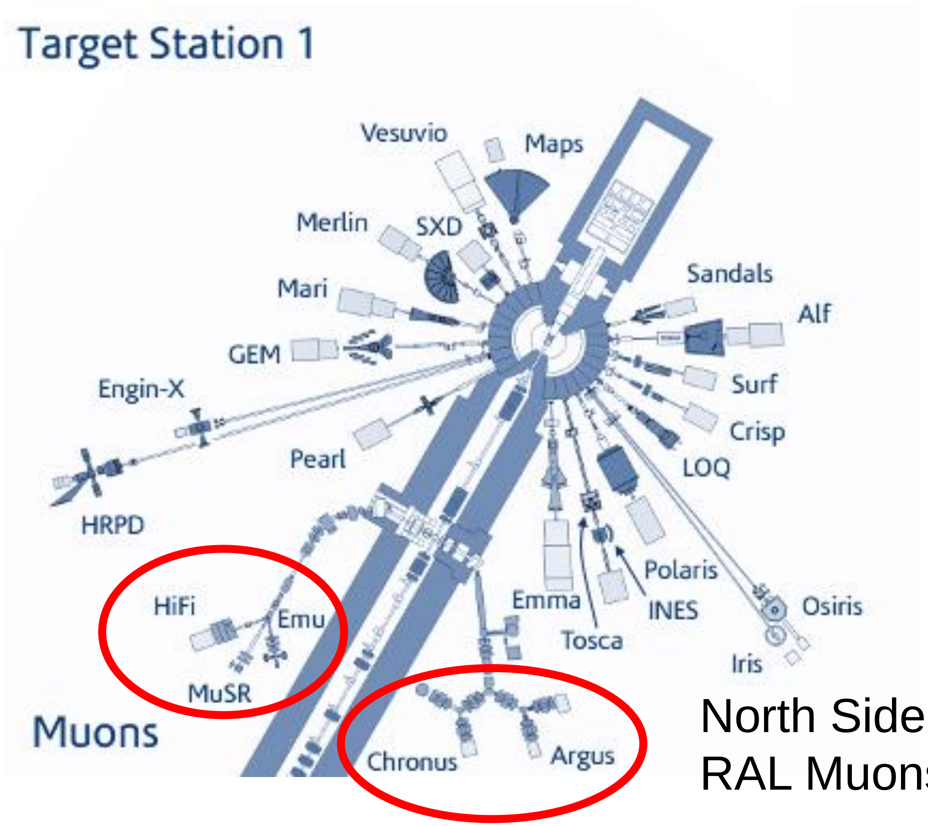
Muons implanted as a pulse, FWHM 80ns

Not symmetric because of pion decay

What do we get or have to deal with at a pulsed source?

- High Rates
  - 1000's muons implanted per pulse
- Large number of muon decays at short times
  - Multiple detectors
- Detector response time
- Low Background
- Can count to long times

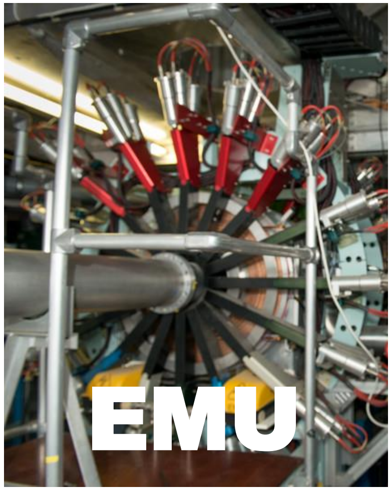
The ISIS Beamlines

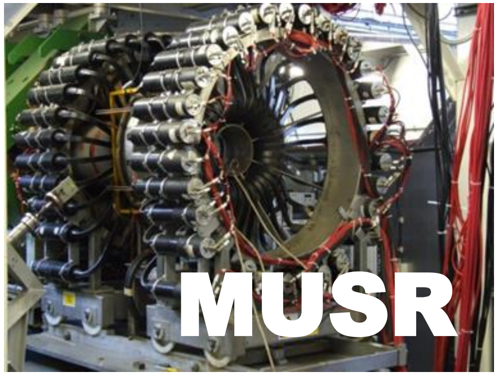


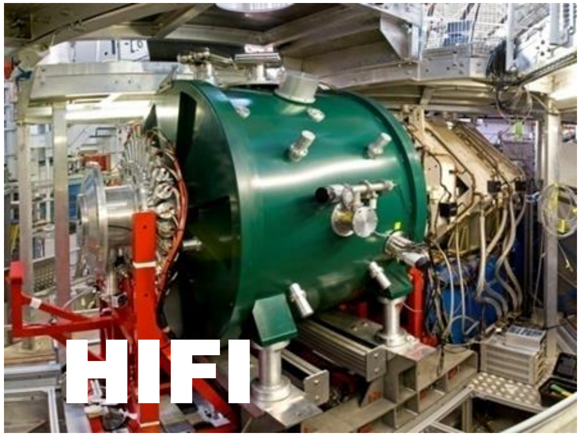
South Side, EC-Muons

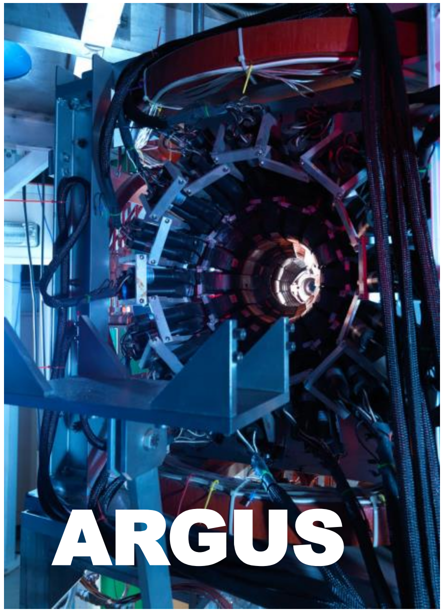
North Side, RIKEN-RAL Muons

The Instruments









Also have
RIKEN-RAL
Ports 1 and 3

So the question is, how do we get from the muons in your sample to you here at ISIS?

Explore this idea from cradle to grave
with emphasis on a pulsed source

The supply chain

Plastic scintillators

First, we need a way to detect positrons from muon decay

Scintillators :

- ✓ give off light when hit by a positron
- ✓ High efficiency
- ✓ Fast response (ns) and rapid recovery
- ✓ Spectral range can be selected (matched to PMT)

Be mindful of track length (5-10 mm)

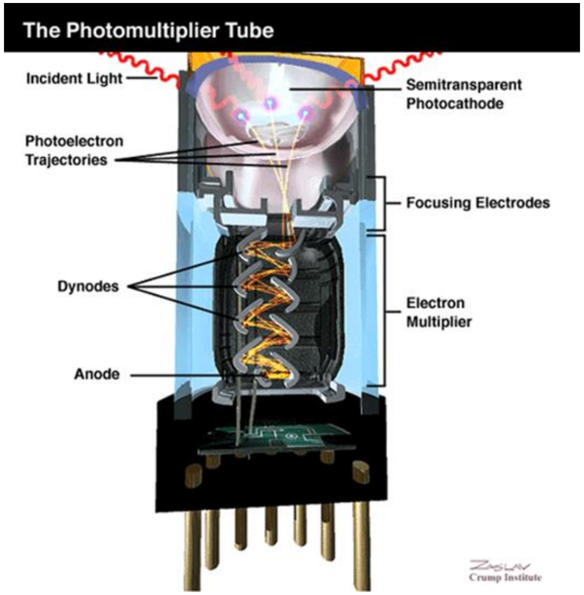
And…plastic typically used for µSR
(but many others, e.g. liquid, gases)

We wrap the scintillator material in a reflective coating to increase the intensity of the light

The supply chain

PMTs

Plastic scintillators



How do we then collect the light? We need to turn this into a signal.

Use photomultiplier tubes (PMTs) – convert pulse of light into a voltage

- Requires high voltage across PMT

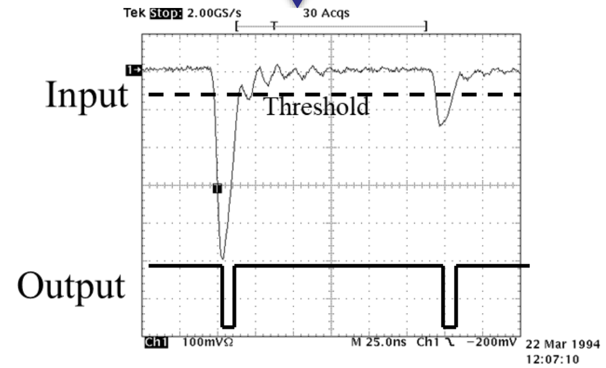
The supply chain

Plastic scintillators

PMTs

Discriminators

Discriminators to … discriminate noise against a muon decay (positron)



Leading edge triggers as input voltage rises through preset threshold

Output is a (logic) pulse of preset width

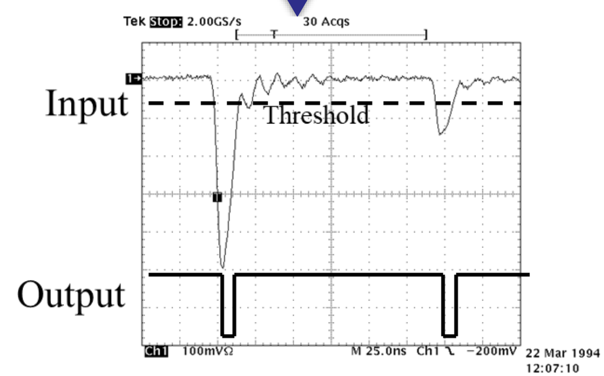
The supply chain

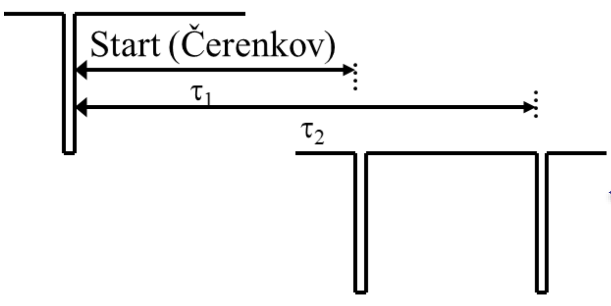
- Multi-hit TDC
- Common start for all channels
- Measure time between start trigger and positron events
- Time bins determined by clock (typically 16 ns bins at ISIS)
- TDCs buffer multiple hits following the muon pulse to avoid distortion

Plastic scintil

ITs

Discriminators





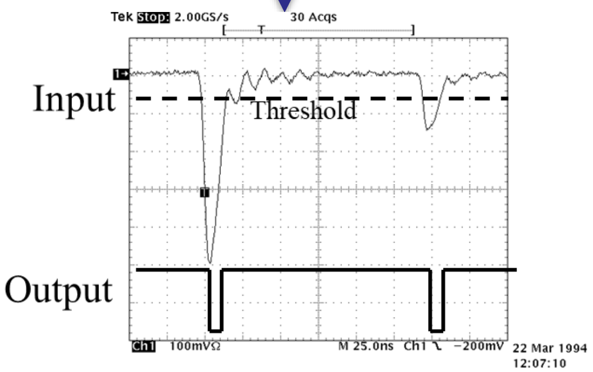
Time to Digital Converter

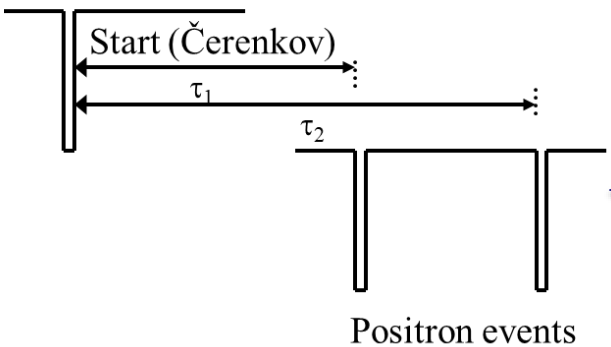
The supply chain

Plastic scintillators

PMTs

Discriminators





Time to Digital Converter

To you!

The DAQ in real life

Cables from Discriminators to TDC

TDCs in rack

Discriminators 16 channels per card

HV supply for PMTs

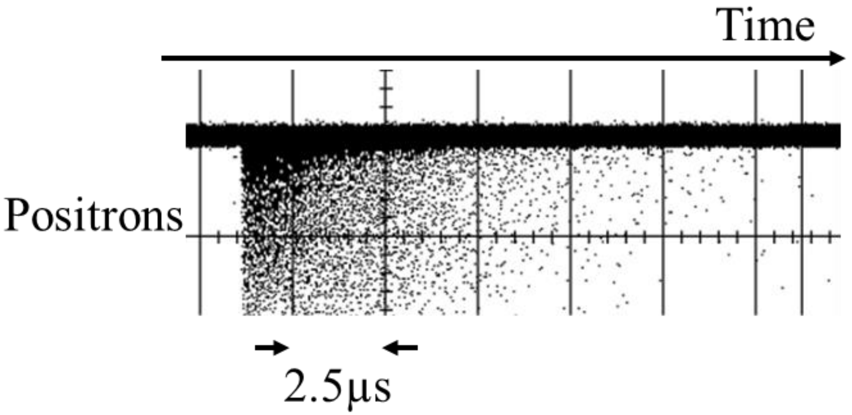
Cables from detectors

Inside a cupboard that is air conditioned and clean!

What do we need to consider?

1. How do we make the most of our high rates?

- 1000's muons implanted in sample per pulse
- Lots of muon decays at short times
- Dead time



Positrons emitted over a distribution of angles – think transverse vs longitudinal experiments

So we also want to maximise solid angle

And… positron energies and asymmetries can be tuned by degrader

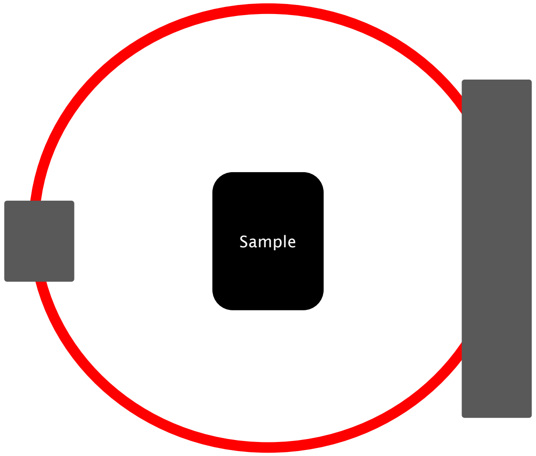
What do we need to consider?

1. How do we make the most of our high rates?

Solid angle coverage, where do you want detectors?

Small area vs. large area – typically 2π

Need to leave room for cryostats and beam entry!



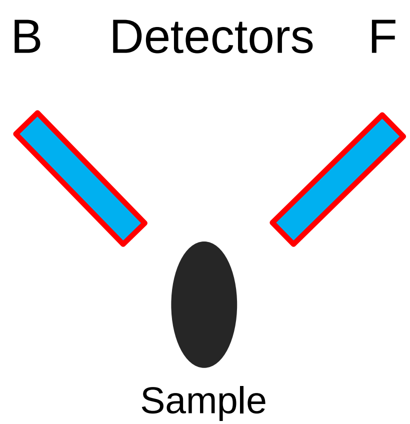
Overcome all of this using detector arrays i.e. lots of detectors covering a wide angle

ARGUS – 192 detectors

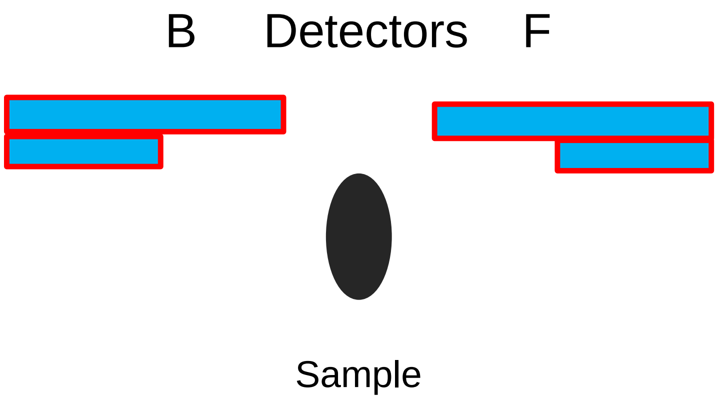
What do we need to consider?

1. How do we make the most of our high rates?

Also can consider detector array design…



Telescopic



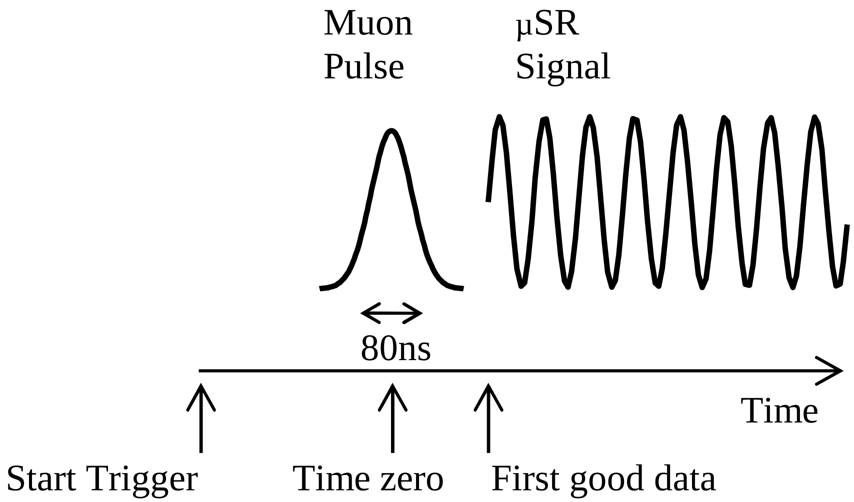
Cylindrical overlapping

Are there any advantages or disadvantages?

What do we need to consider?

2. Timing?

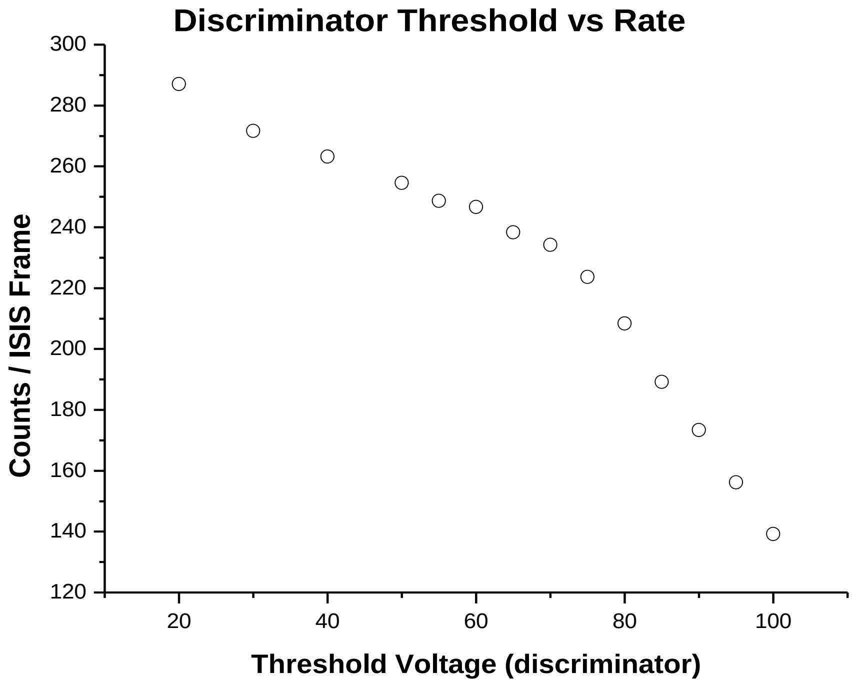
- Use a Cherenkov detector upstream to get Time zero (t_0)
- How do you know when your data starts?

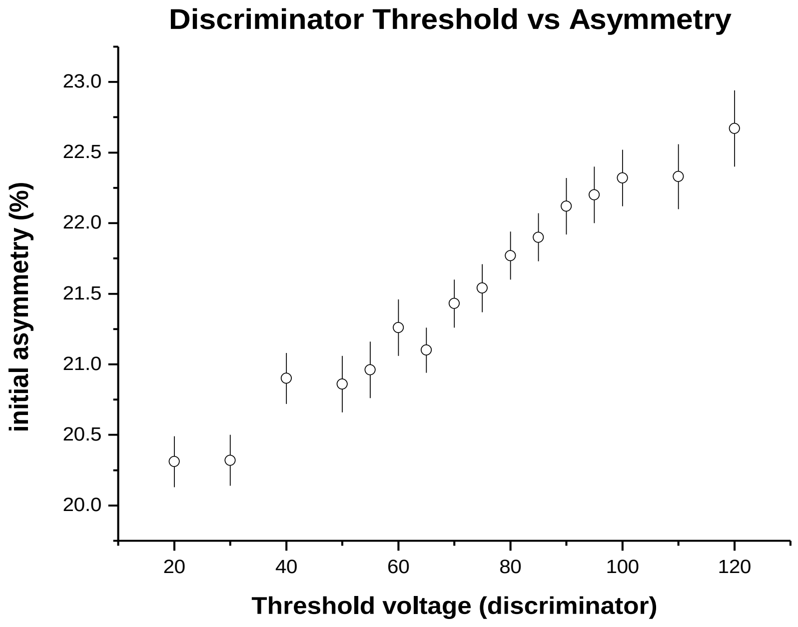


What do we need to consider?

3. How do we get the best data?

- Positron emission from all the muon decays over a wide angle
- Double counting
- Noise
- Making sure we use our discriminators to it's best!
- Same for our detector HV





Data from EMU

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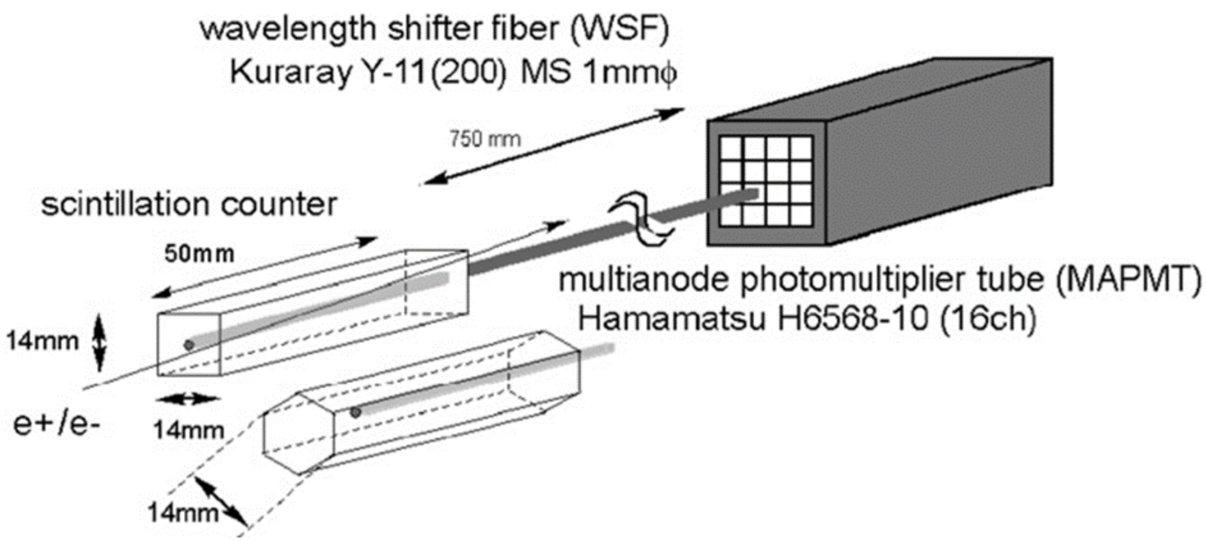
What do we need to consider?

Is all this effort worth it?

Yes, if you define
"data quality" = rate x A_0^2

Development

- Have lots of detectors!
- CHRONUS – 606 detectors
- Multianode PMTS
- Need to get light from scintillator all the way to the MAPMT



Development

Could we use Si or solid state photo multipliers?

At a continuous source

- Count 1 muon at a time
- Don’t have to worry about dead times

At a pulsed source

- Count 1000 muons per pulse
- Timing resolution an issue
- Dead is a very big issue!

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

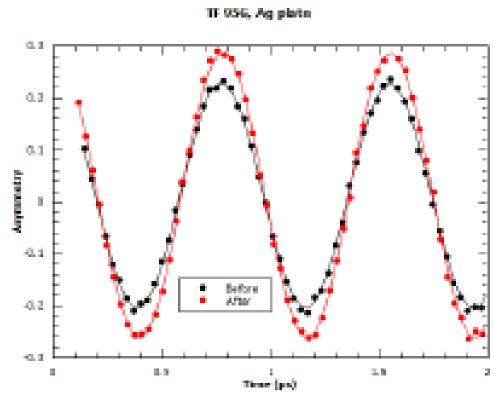
HIFI positron degraders

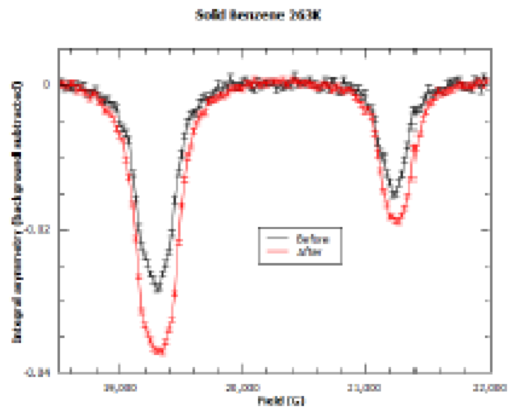
POSITRON DEGRADERS

Over the summer positron degraders were fitted to the HiFi detectors to improve the asymmetry and figure of merit.

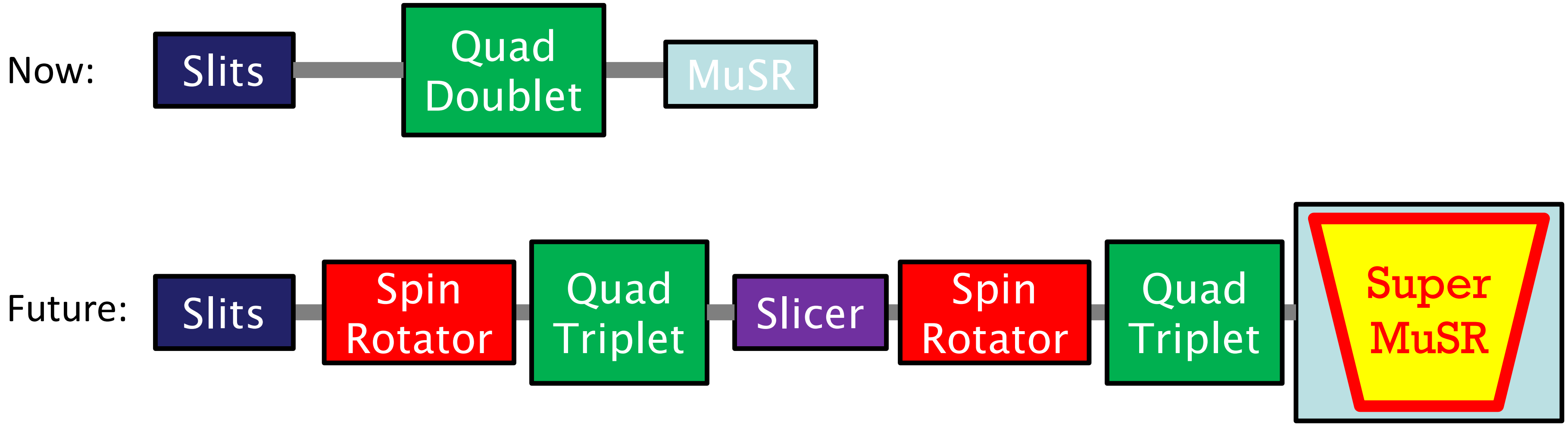
The asymmetry in low field has increased from about 22 to 29% (see top figure) with more modest improvement above 1.5T.

For most users this means an increase in beam slit width can be tolerated while keeping the rate the same yet improving data quality.



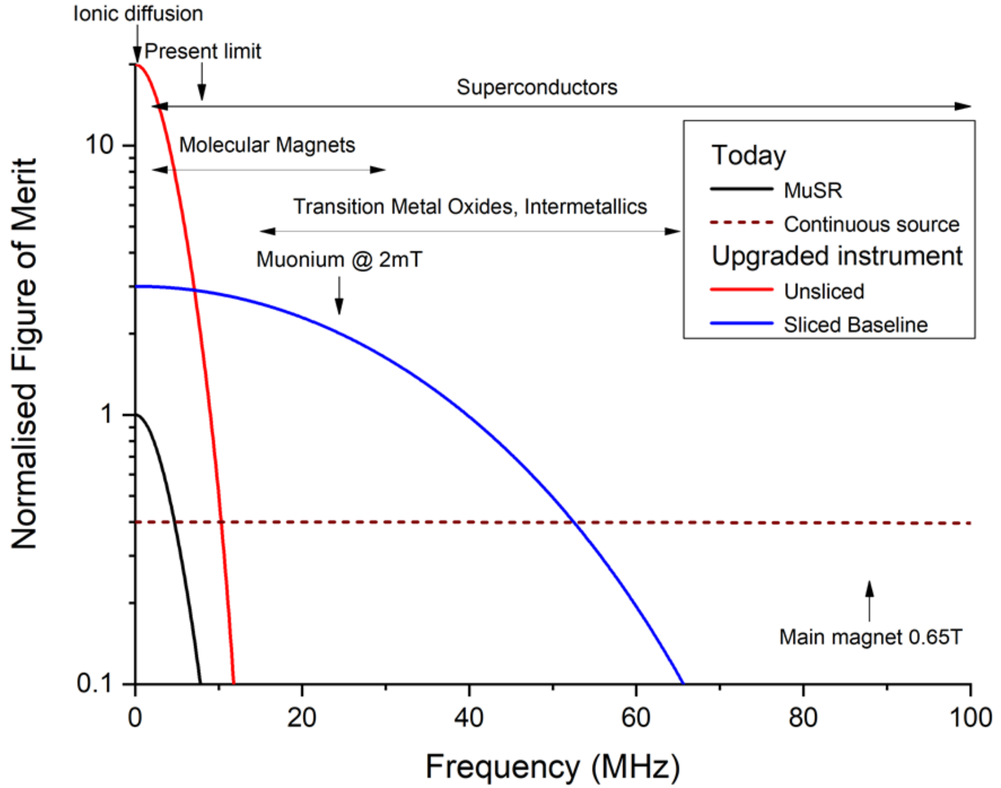


Super-MuSR



Now:
Slits
Quad Doublet
MuSR
Future:
Slits
Spin Rotator
Quad Triplet
Slicer
Spin Rotator
Quad Triplet
Super MuSR

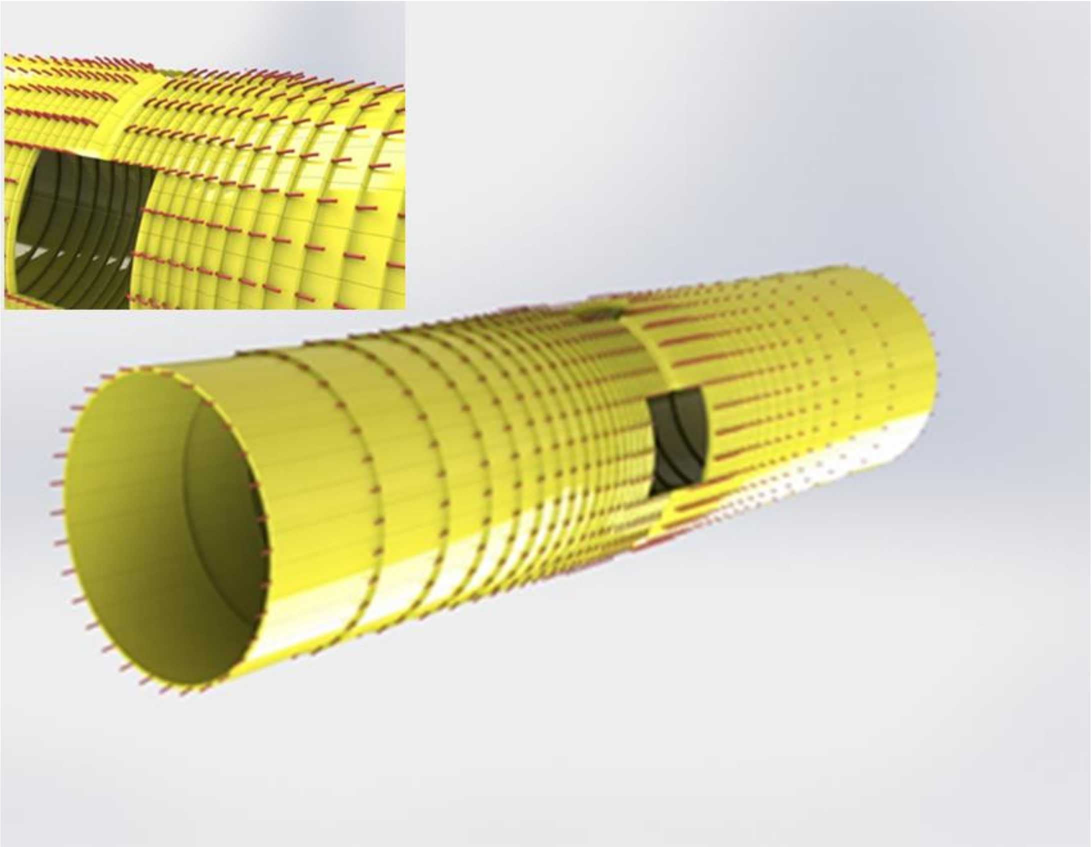
Super-MuSR



Ionic diffusion
Present limit
Superconductors
Molecular Magnets
Transition Metal Oxides, Intermetallics
Muonium @ 2mT
Main magnet 0.65T
Today
MuSR
Continuous source
Upgraded instrument
Unsliced
Sliced Baseline
Normalised Figure of Merit
10
1
0.1
0
20
40
60
80
100
Frequency (MHz)

Super-MuSR

- 20x data rate
- High density array (for muons)
- 1200 detectors
- Outline design complete
- Prototypes tested
- Model section to be built this year



	Muon Instruments at ISIS				
	MuSR	EMU	HIFI	ARGUS	CHRONUS
Beam type / momentum (MeV/c)	μ^+ / 28	μ^+ / 28	μ^+ / 28	μ^+, μ^- / 20-120	μ^+, μ^- / 20-120
Number of detectors	64	96	64	192	606
Detector solid angle (sr)	1.6π	2.2π	1.3π	0.8π	π
Data rate[1] (Mev/hr)	60	150	80	50	50
Data quality (a_0^2.rate)	4.7	8.3	3.5	2.6	2.0
Beam utilisation[2] (%)	8	25	20	80	80
Temp range (K)	0.025 – 1000	0.025 – 1400	0.025 – 1400	0.025 - 600	0.3 - 600
LF field range (T)	0.3 (0.6)[3]	0.5	5	0.4	0.4
TF field range (T)	~0.06[4]	0.015	0.01	0.01	~0.06[4]
Upper frequency (MHz)	~8	~8	~8	~8	~8
Flypast (small samples)	N[5]	Y	Y	Y	Y
Fast change ULT[6] sample environment	Y	N	N	Y	Y
Laser capability	N	N	Y	Y	N
Gas phase capability	N	Y	Y	Y	N
Pressure capability	N	N	N	Y	Y

Notes:

- Data rate represents the maximum data rate for undistorted time differential measurements of typical length
- Percentage limit of available muons that can be counted while minimising detector deadtime effects, based on current detector solid angle
- Longitudinal field limited by current detector configuration/technology
- Field limited by reduction of asymmetry due to the finite muon pulse width
- The beam spot size in MuSR is significantly smaller than for the other instruments, allowing comparatively small samples to be run with good results
- Cryostats have their own vacuum jacket, allowing working system to be moved

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)