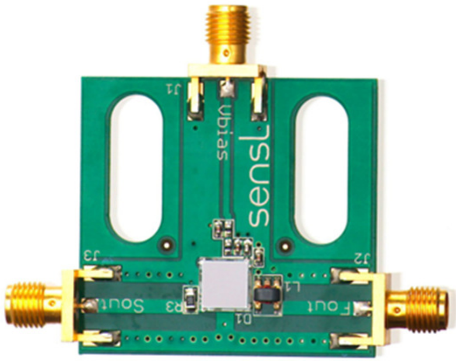
Work Package 9 - Detectors

Task 4. Emergent Detector Technologies for neutron scattering and muon spectroscopy

Sub Task .3 - Silicon photomultipliers for muon spectroscopy



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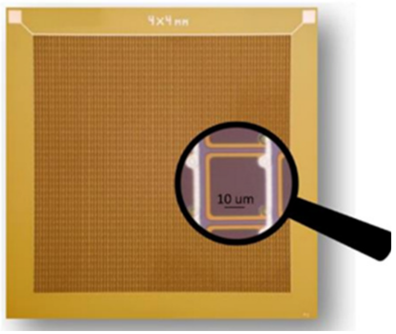


SINE 2020

Wednesday September 7th, 2016

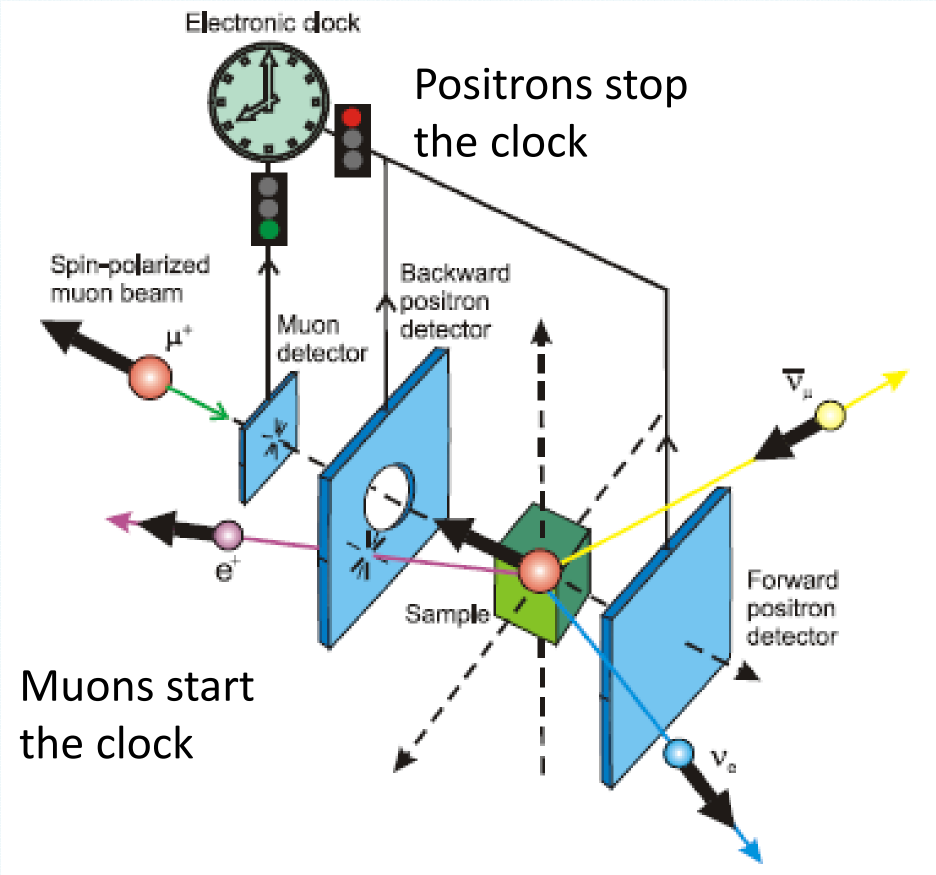
Science & Technology Facilities Council

ISIS

Implementing the MuSR technique;

consequences for detector technology

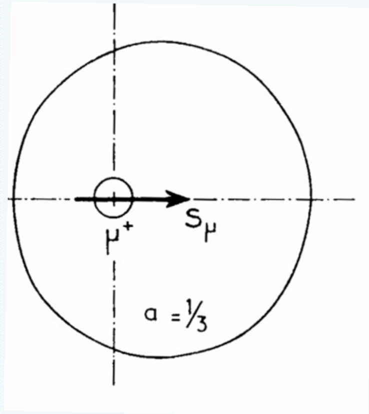
The Experiment…

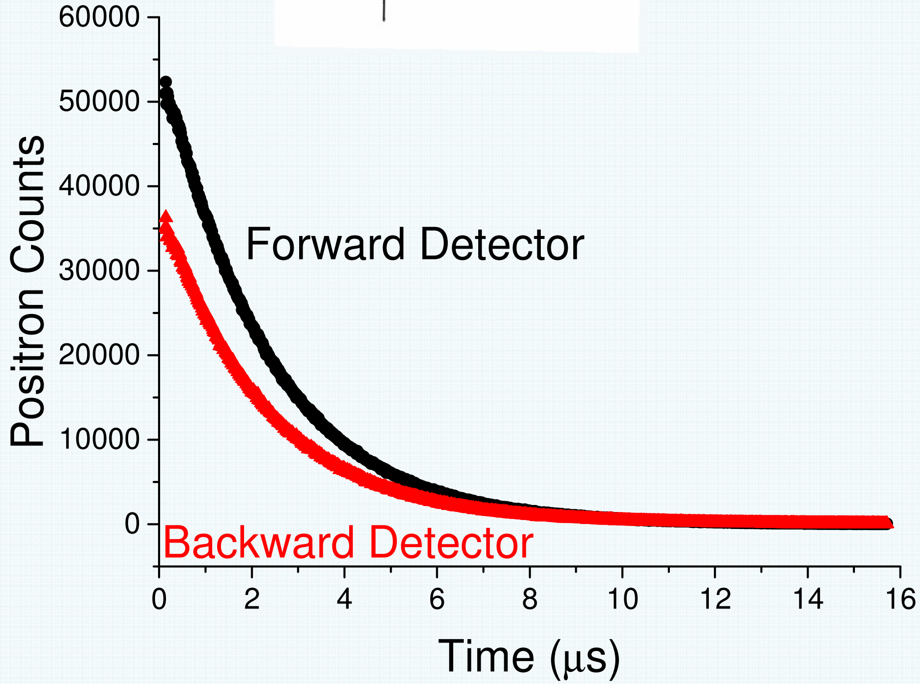


Positrons stop the clock

Muons start the clock

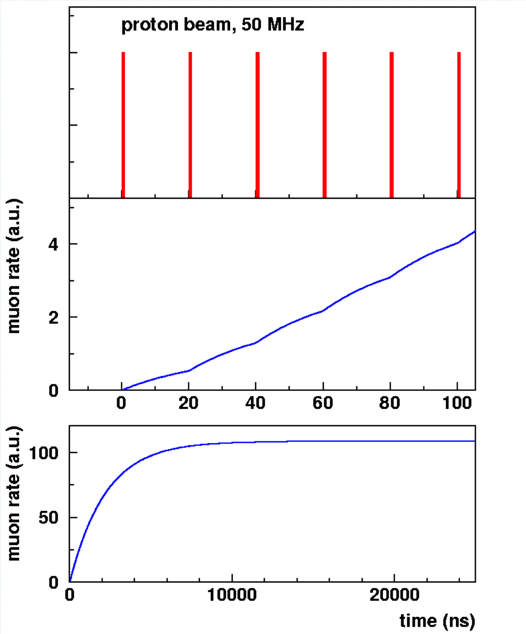
Asymmetric positron distribution





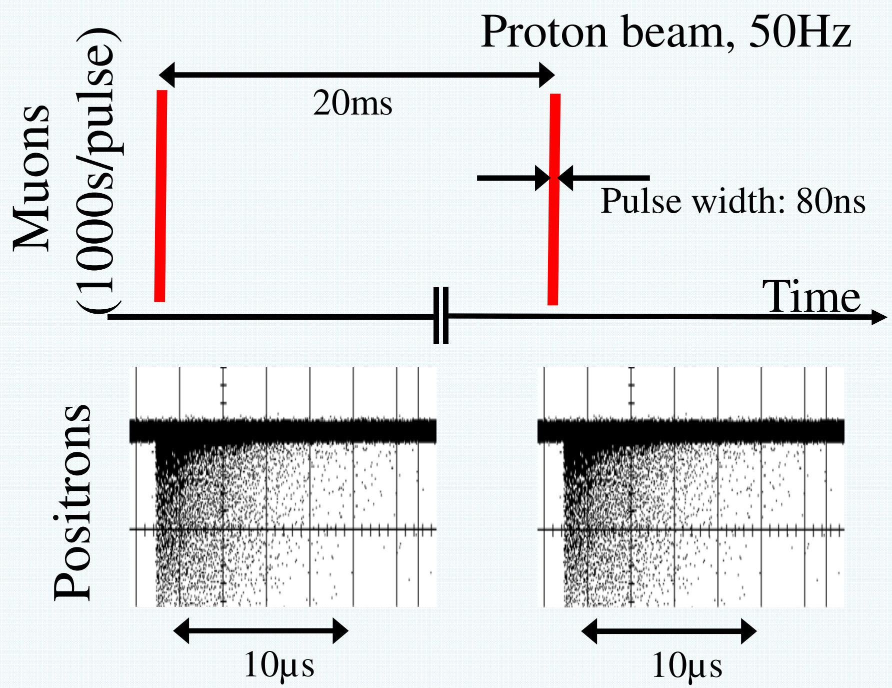
Beam Structure…

at a 'continuous' source…



Muon rate of 10^5/s;
Average time between muons 10 μs;
Measure one muon at a time!

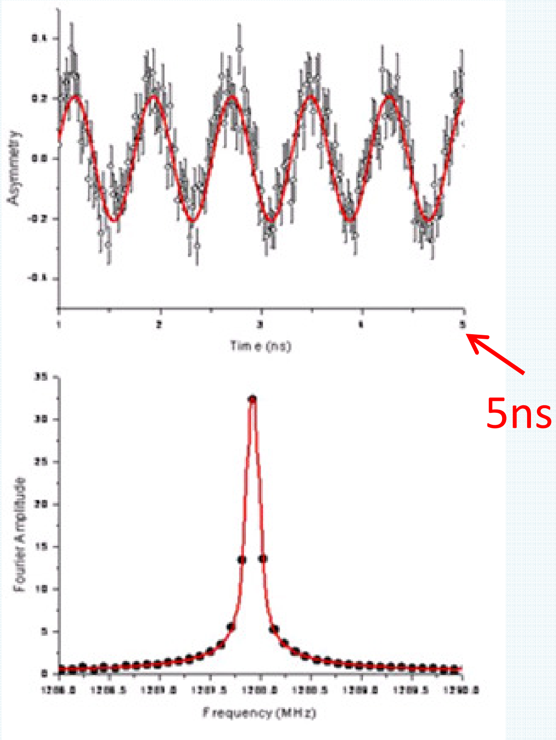
at a 'pulsed' source…



Implant 1000s muons/pulse;
Measure 1000s muons simultaneously!

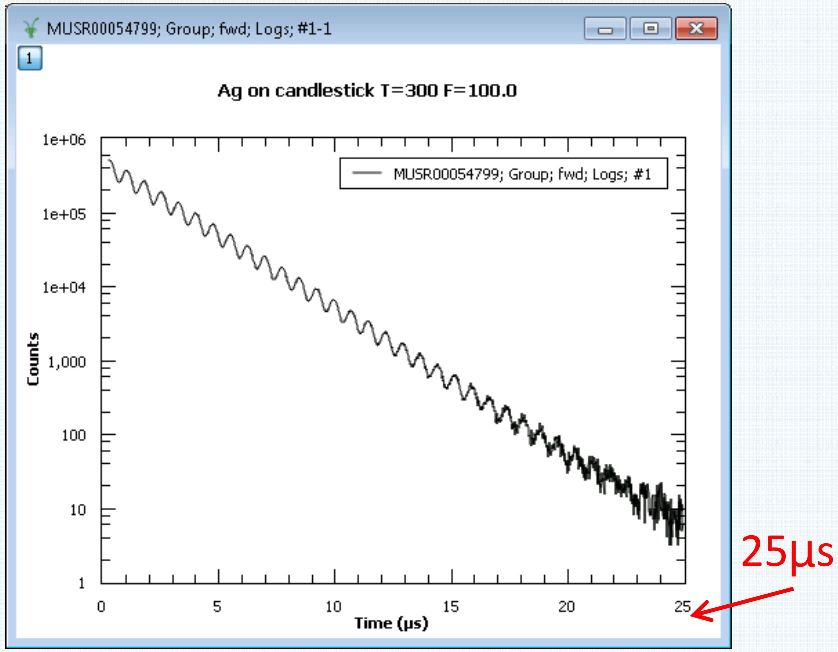
Data...

at a 'continuous' source...



Muon precession
~1.3GHz, 9.8T

at a 'pulsed' source...



Clean data to >10$\times\tau_{\mu}$ in ~1.5 hrs
(250Mev)

Detector Requirements: timing properties

at a 'continuous' source...

- Excellent timing resolution.
- Deadtime not important as only one muon counted at a time.

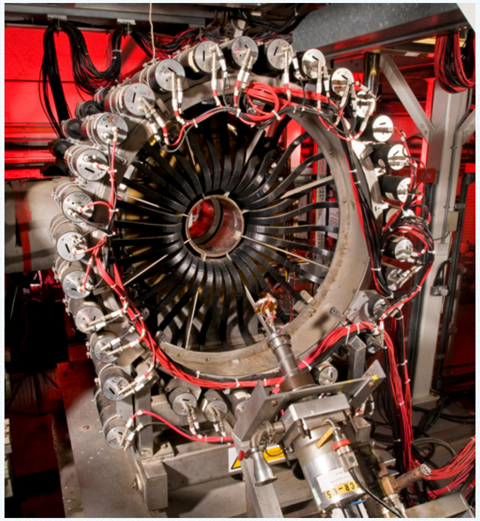
at a 'pulsed' source...

- Timing resolution requirements easily achievable as the source/pulse width is the limiting factor .
- Must handle very high instantaneous flux (all muons implanted at time-zero) so minimised deadtime is crucial.

The focus of our R&D and this talk!

Deadtime reduction by independent channels:

Pixelate the detector array



MuSR 64

EMU = 96

- Cost per channel
- Active volume effects
    - Positron traversing multiple elements
    - Dead space
- Difficult assembly

But there is a limit ….

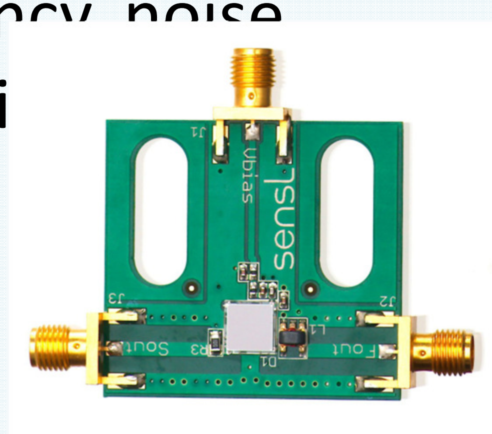
Can higher count rates be achieved by further optimisation of single channel dead time and higher pixilation?

-> probably only small advances.

Is there a disruptive technology?

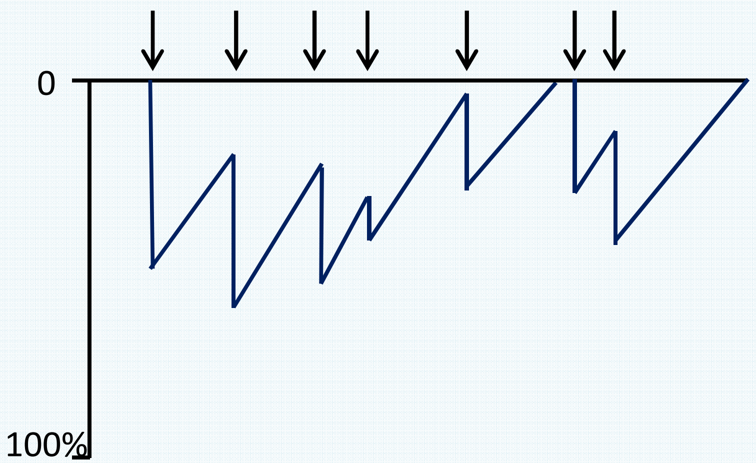
- Commercially available & Cost efficient
- Magnetic insensitivity
- With equal gain, quantum efficiency, noise discrimination, temperature stabi of a PMT … … …Etc

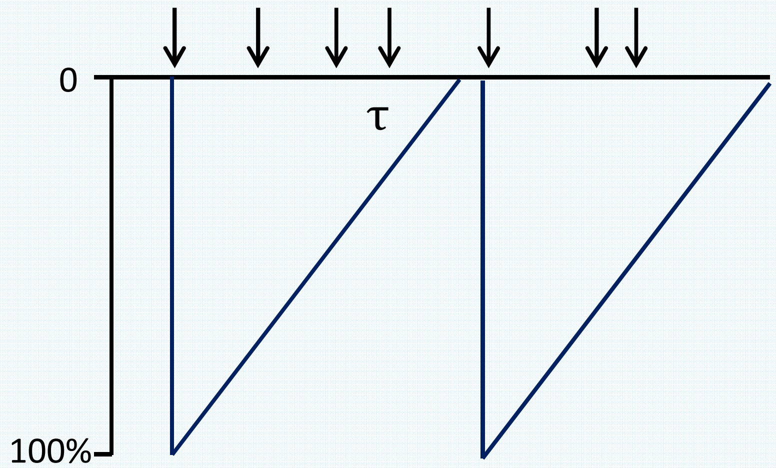
Possibly SiPM’s



What is the Deadtime of a SiPM?

Minimal	Long (100’s of ns)
Lowering fraction of SiPM cells discharging per muon hit gives reduction in deadtime	Higher fraction means deadtime tends toward cell recovery time





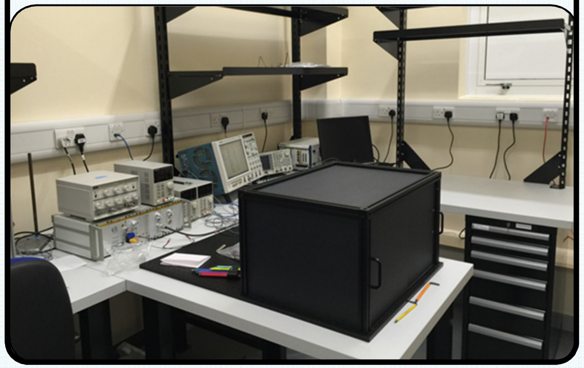
Three experimental threads

MuSR Beamline

- Detector chain can be constructed and investigated in a realistic environment.

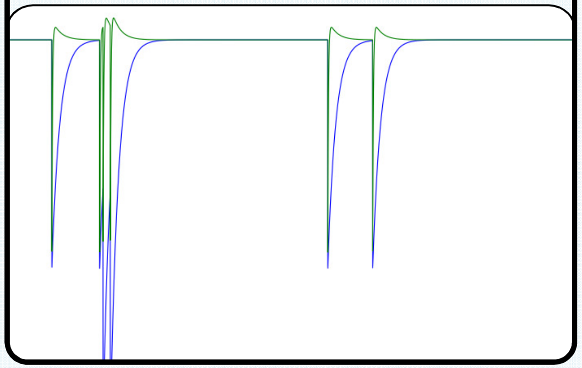
Optical Investigation

- Photon flux accurately parameterised within a controlled environment.



Monte Carlo Simulation

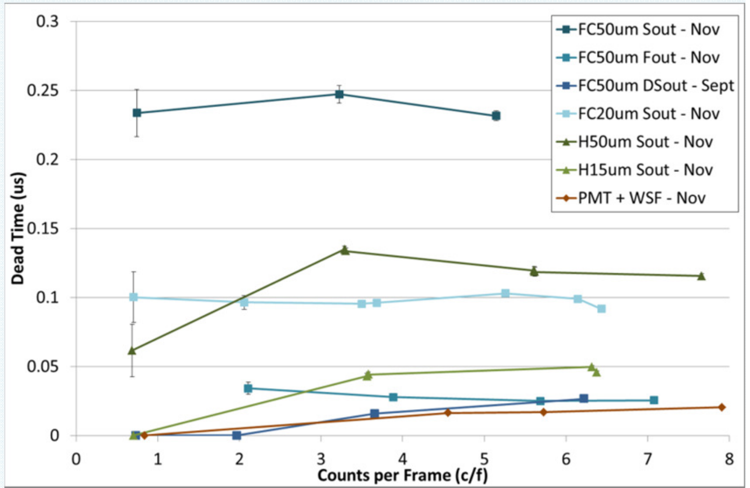
- Accurately simulate a statistical investigation in detector performance.



MuSR Beamline Work

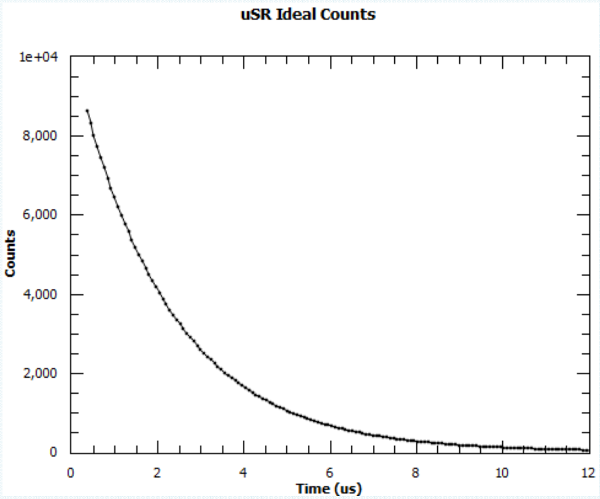
Parameterising the detector performance using a Figure of Merit with MuSR data

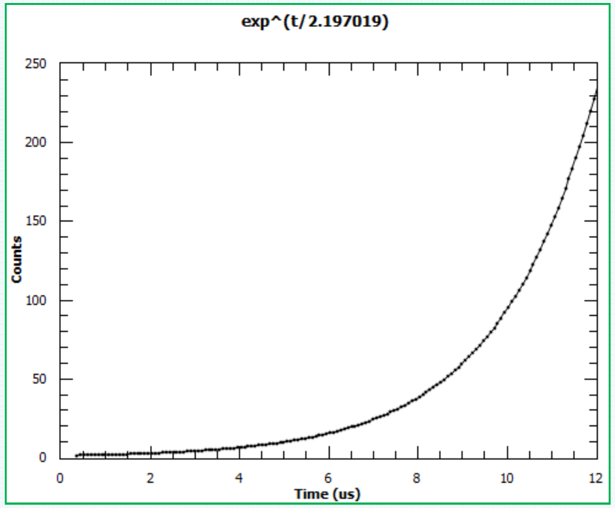
- Intuitive FoM to parameterise the ‘missed counts’ in a MuSR experiment.
- Moved away from non-extendable dead time model as one dead-time value is not appropriate for SiPM (reported at kick off meeting in Abingdon)
- Encapsulates the operational parameters and usability of the detector. For example, ‘any’ detector can count at 1 c/f at a pulsed source!
- Based on realistic ‘user’ experience rather than determining absolute values and comparison to data sheets.

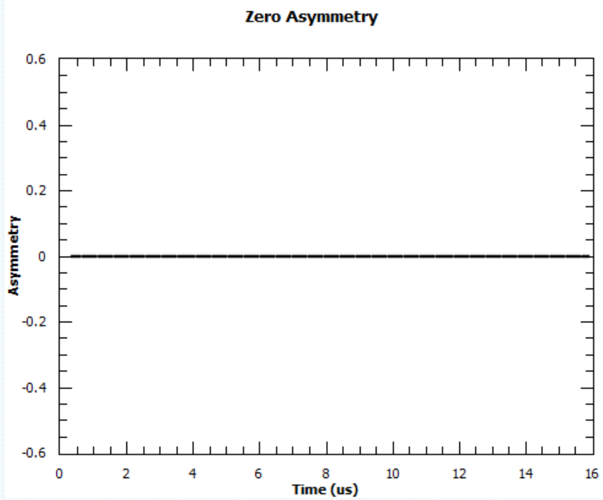


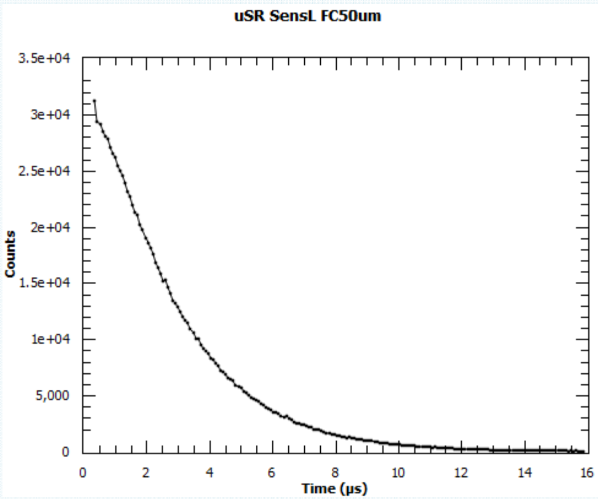
μSR – Asymmetry

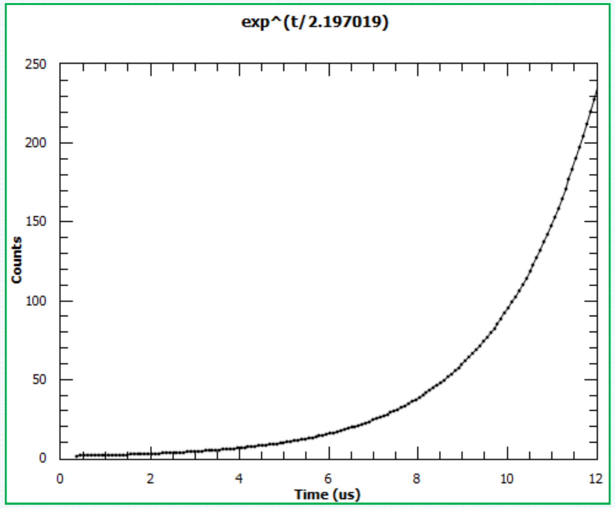
$$Asymmetry = ((Counts \cdot e^{\frac{t}{\mu}})/N_0) - 1$$

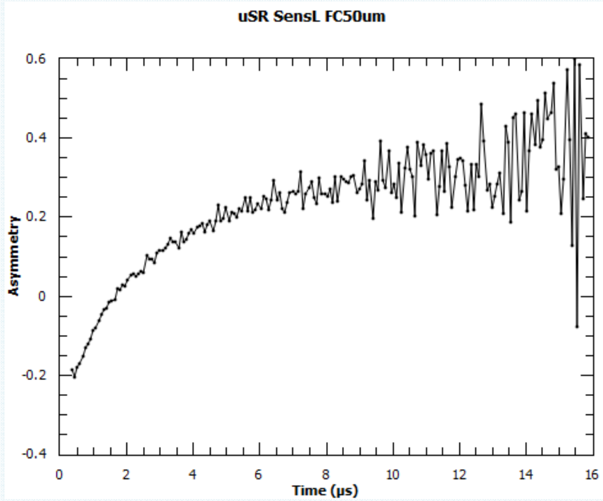








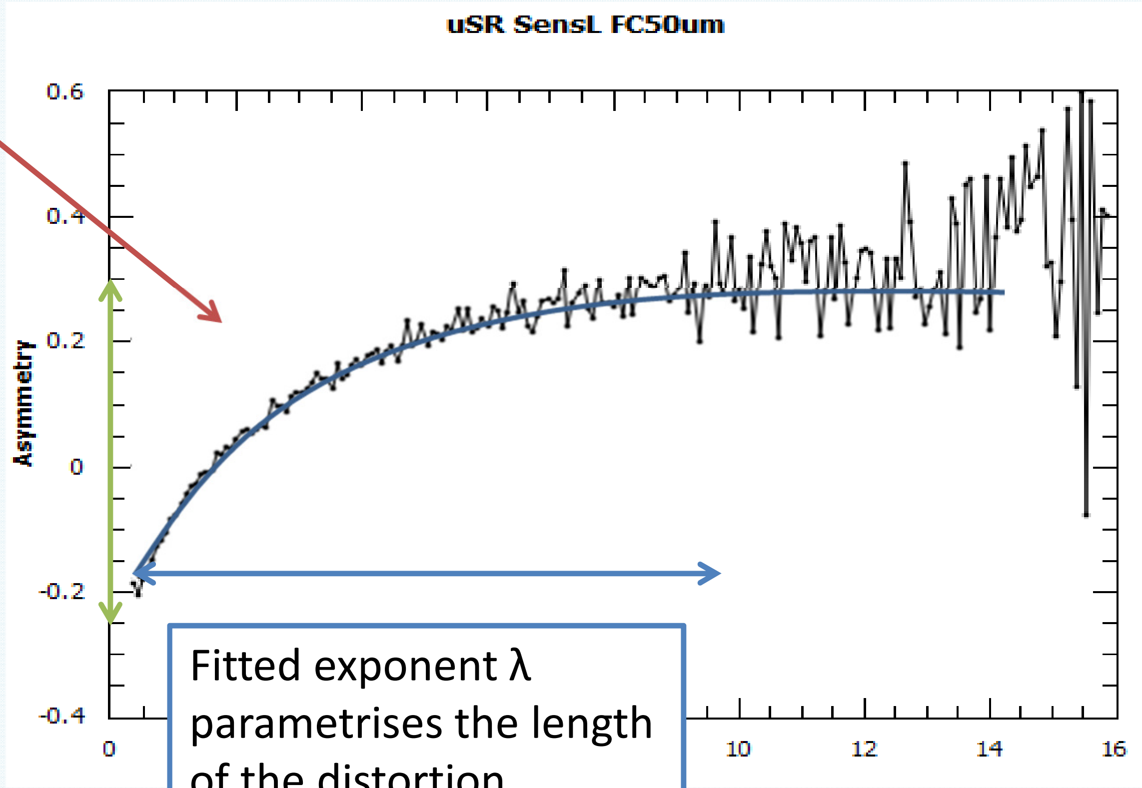




μSR – FoM

Missed counts cause this type of distortion in asymmetry

A_0 parameterises the height of the distortion



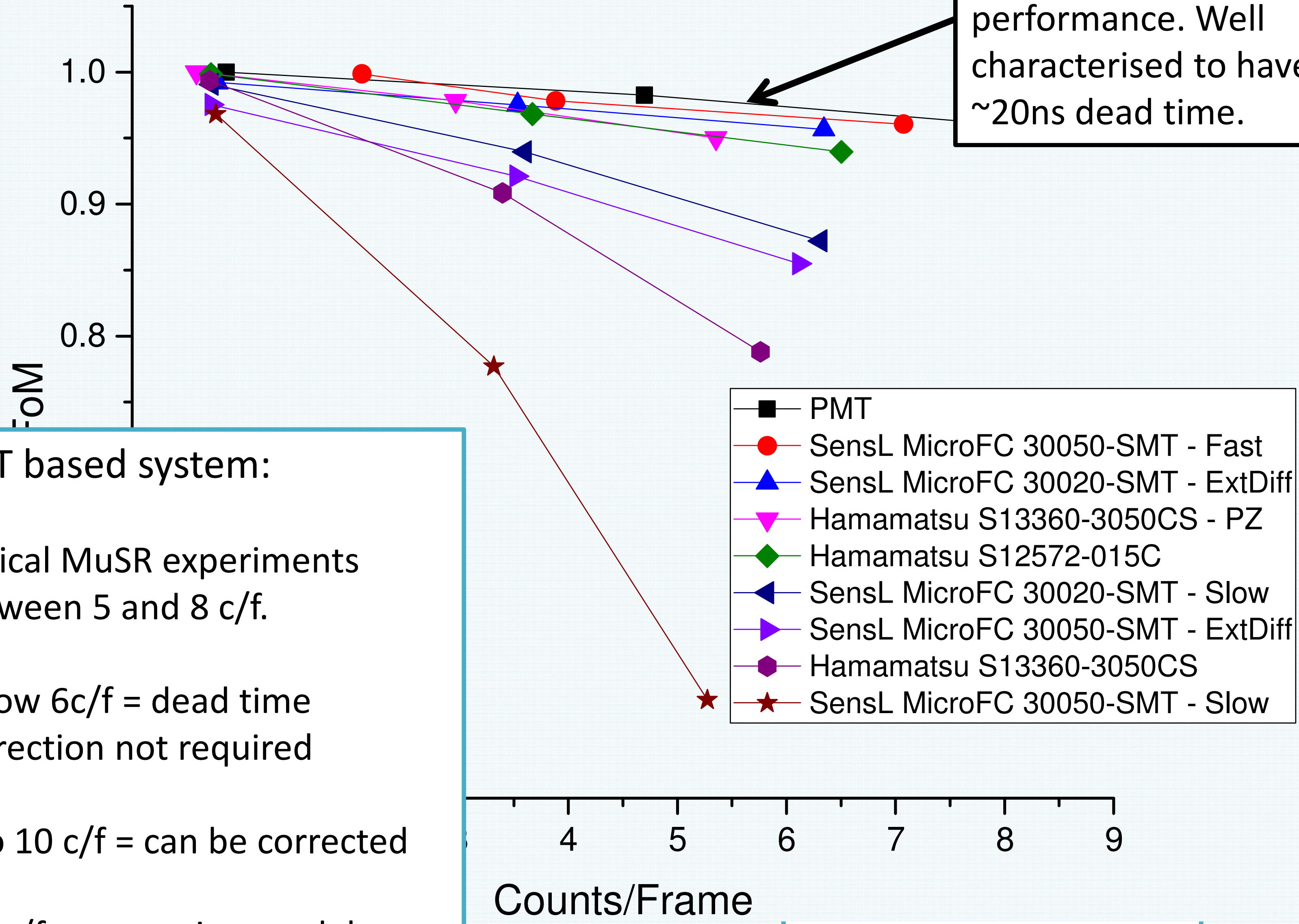
Fitted exponent λ parametrises the length of the distortion

Combine to give: **FOM = 1 - $|A_0 \cdot \lambda|$**

NOTE- μSR scientists will run a detector with some deadtime distortion and correct for this if possible. The FoM allows us to compare the rate at which detectors can be run, which is more useful than absolute deadtime numbers.

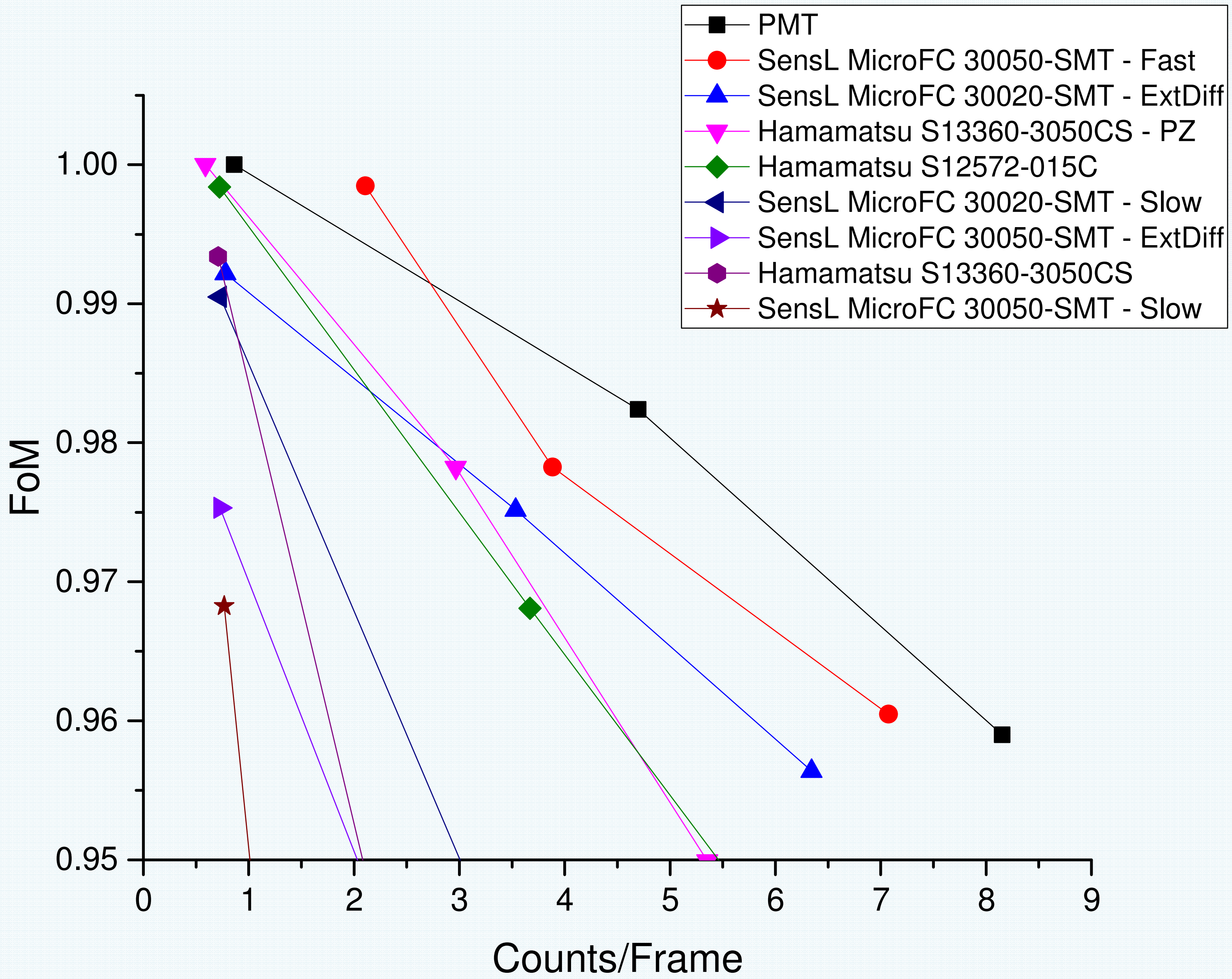
MuSR Data using FoM

PMT + detector chain. Baseline for equivalent performance. Well characterised to have ~20ns dead time.

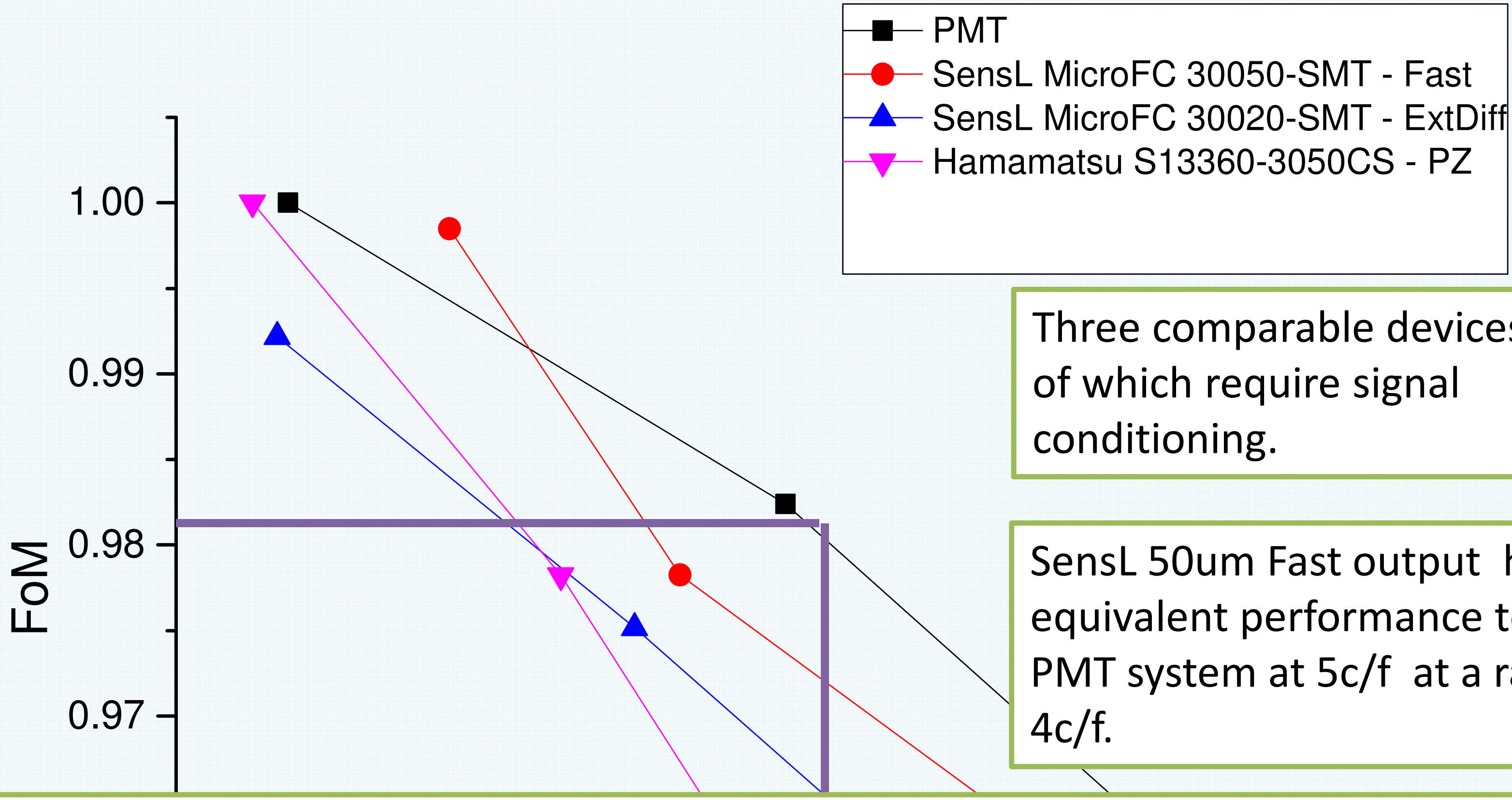


For PMT based system:

- Typical MuSR experiments between 5 and 8 c/f.
- Below 6c/f = dead time correction not required
- 6 to 10 c/f = can be corrected
- 10+c/f = correction models are insufficient/ inappropriate



PMT
SensL MicroFC 30050-SMT - Fast
SensL MicroFC 30020-SMT - ExtDiff
Hamamatsu S13360-3050CS - PZ
Hamamatsu S12572-015C
SensL MicroFC 30020-SMT - Slow
SensL MicroFC 30050-SMT - ExtDiff
Hamamatsu S13360-3050CS
SensL MicroFC 30050-SMT - Slow
FoM
1.00
0.99
0.98
0.97
0.96
0.95
0
1
2
3
4
5
6
7
8
9
Counts/Frame

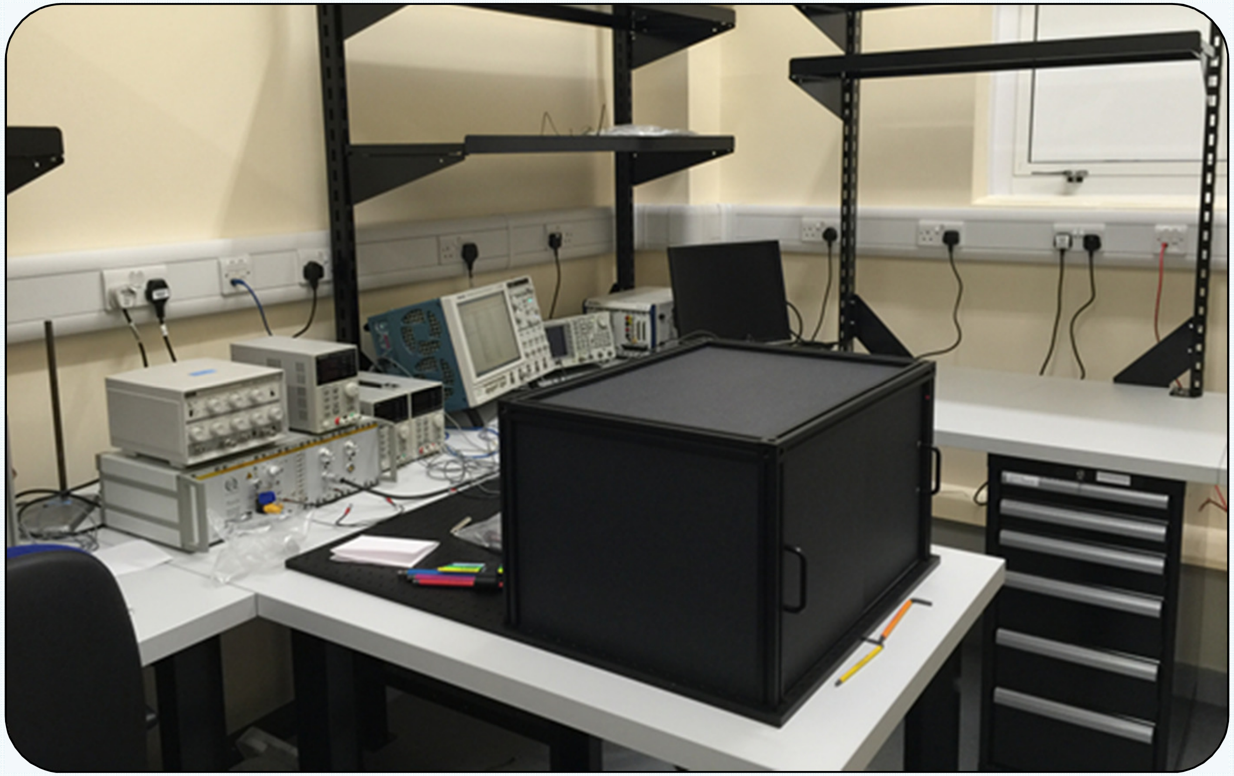


Three comparable devices, all of which require signal conditioning.

SensL 50um Fast output has equivalent performance to the PMT system at 5c/f at a rate of 4c/f.

- Data here does not draw conclusions as not all combinations of sensor and signal processing are reported
- SiPMs can be used with comparable performance but careful work has to be done to match PMT systems.
- BUT..
  - Do these results depend on the photon flux on the SiPM?
  - Are we ‘on the edge’ or can we mass-produce these detectors?

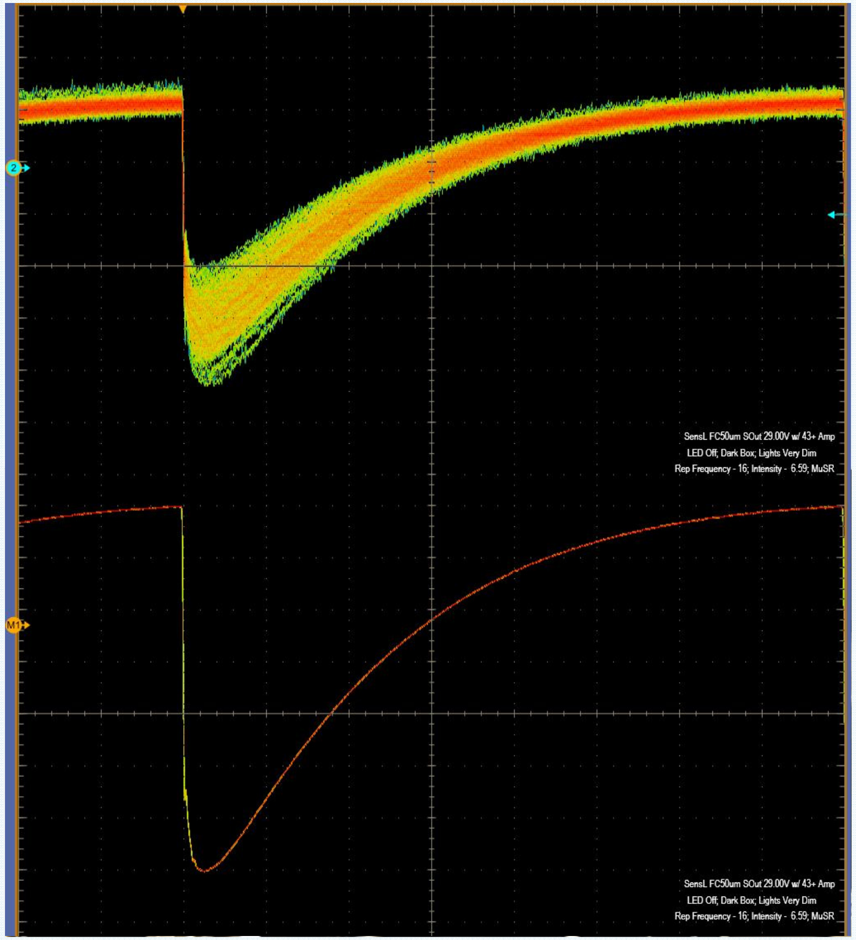
Optical Investigation



Optical Investigation

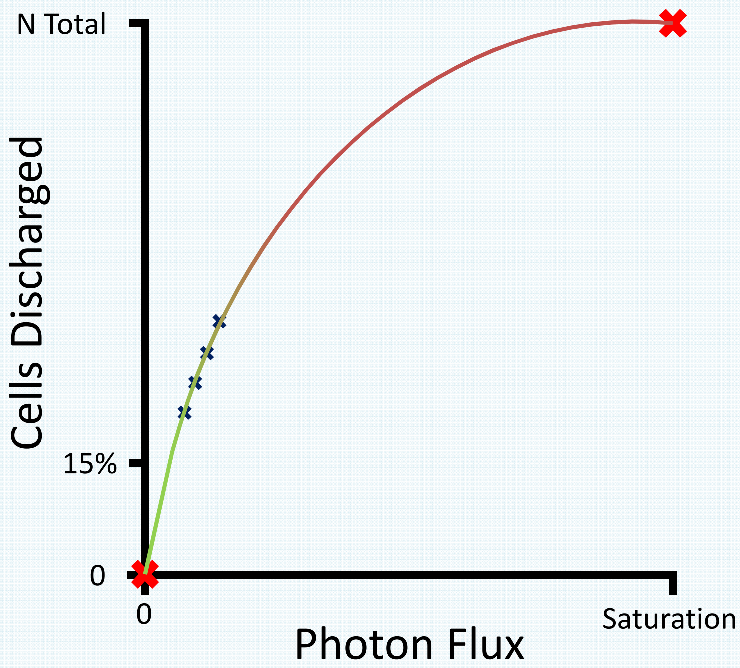
Complete characterisation of:

- Optical components
  - LED drivers and modules
  - Neutral Density filters
- SiPM parameters
  - RC measurements
  - Cell Discharge Fraction as a function of photon flux



What is expected?

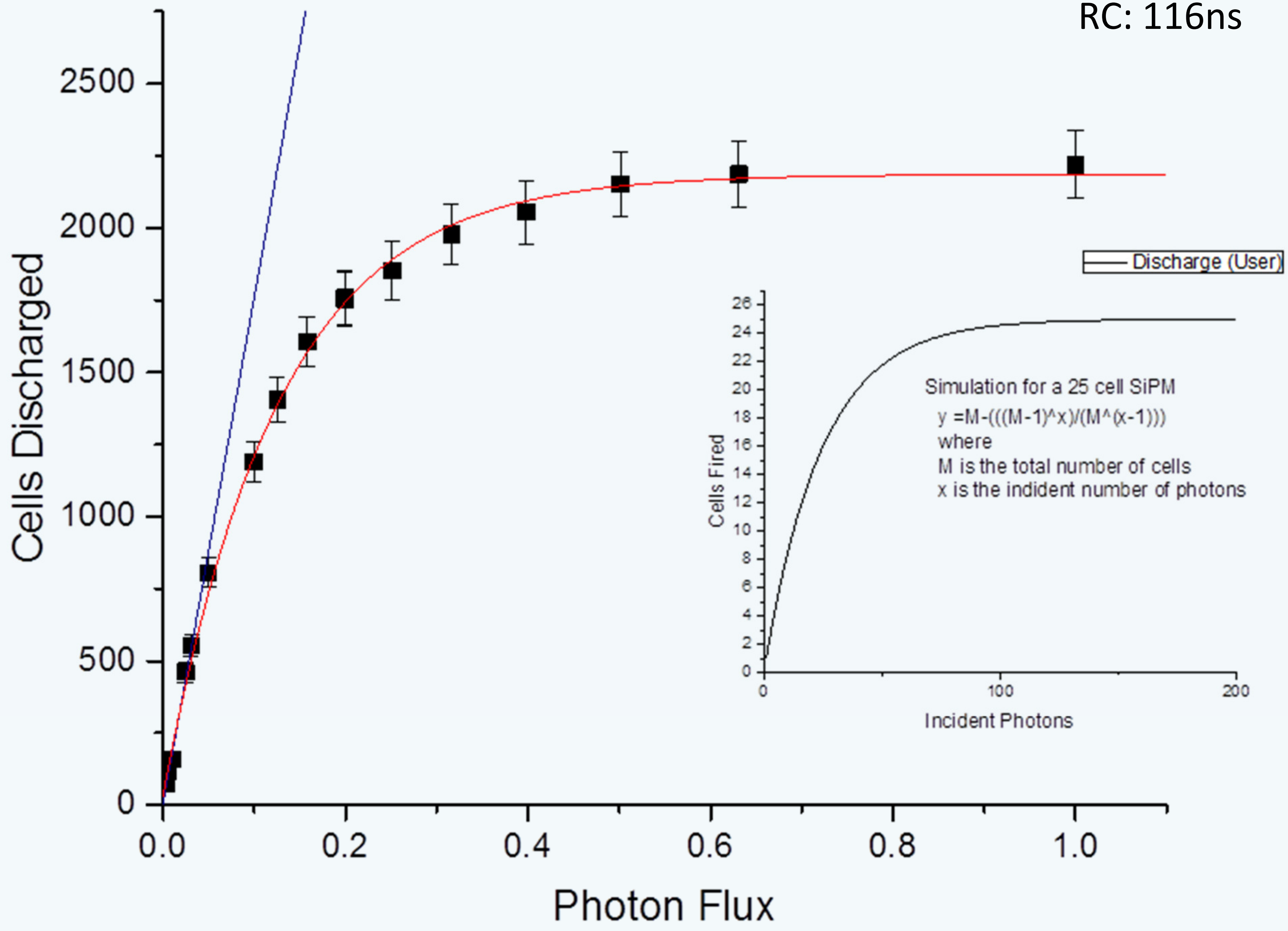
- Zero photon flux should give zero cells fired (Disregarding Thermal).
- Complete saturation should fire all cells in SiPM.
- Low discharge fraction, 0-15% should look ‘linear’.
- As Discharge fraction increases the likelihood of photons landing on the same cell will increase
- As Photon Flux is increased, cells discharged should tend to total available cells in the SiPM.



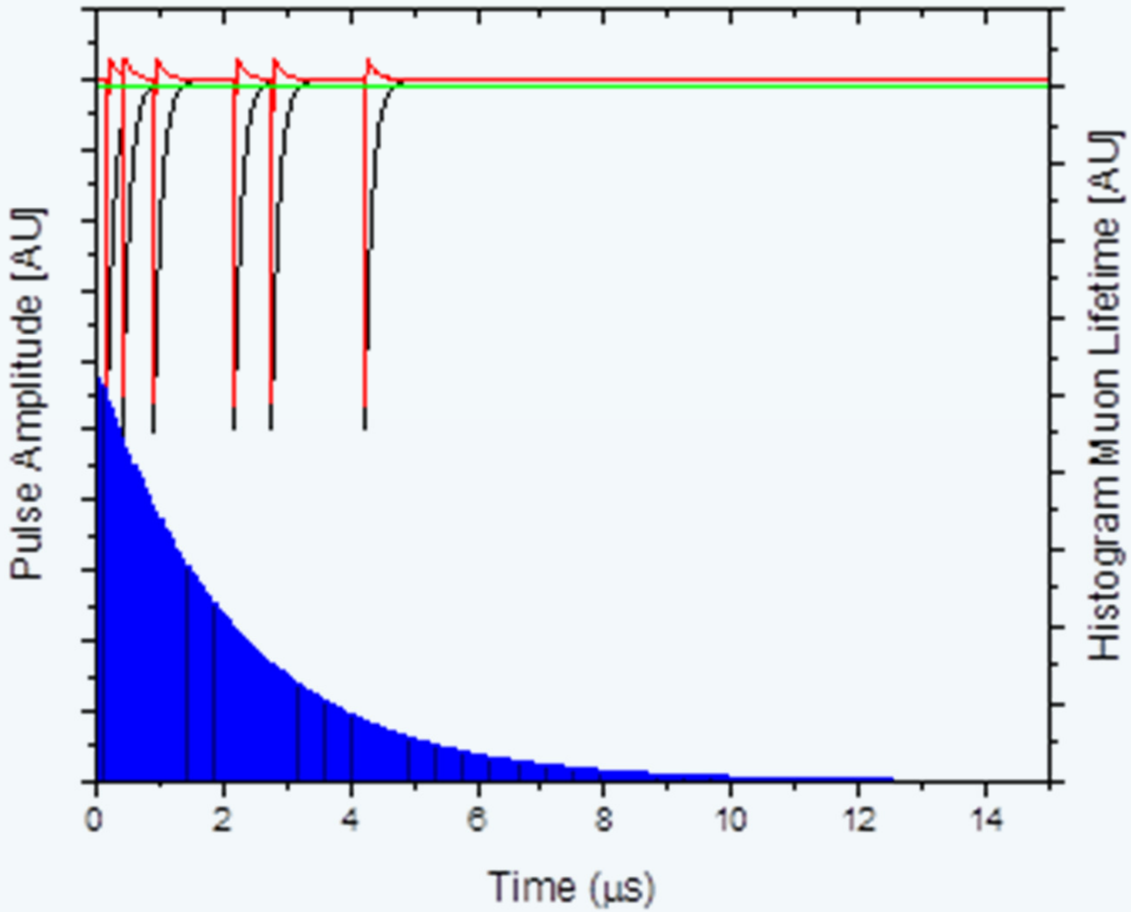
Experimentally the difficulties were around normalisation and reduction of systematic errors.

Cells fired – optical investigation

SensL FC50um
Cells 2668
RC: 116ns



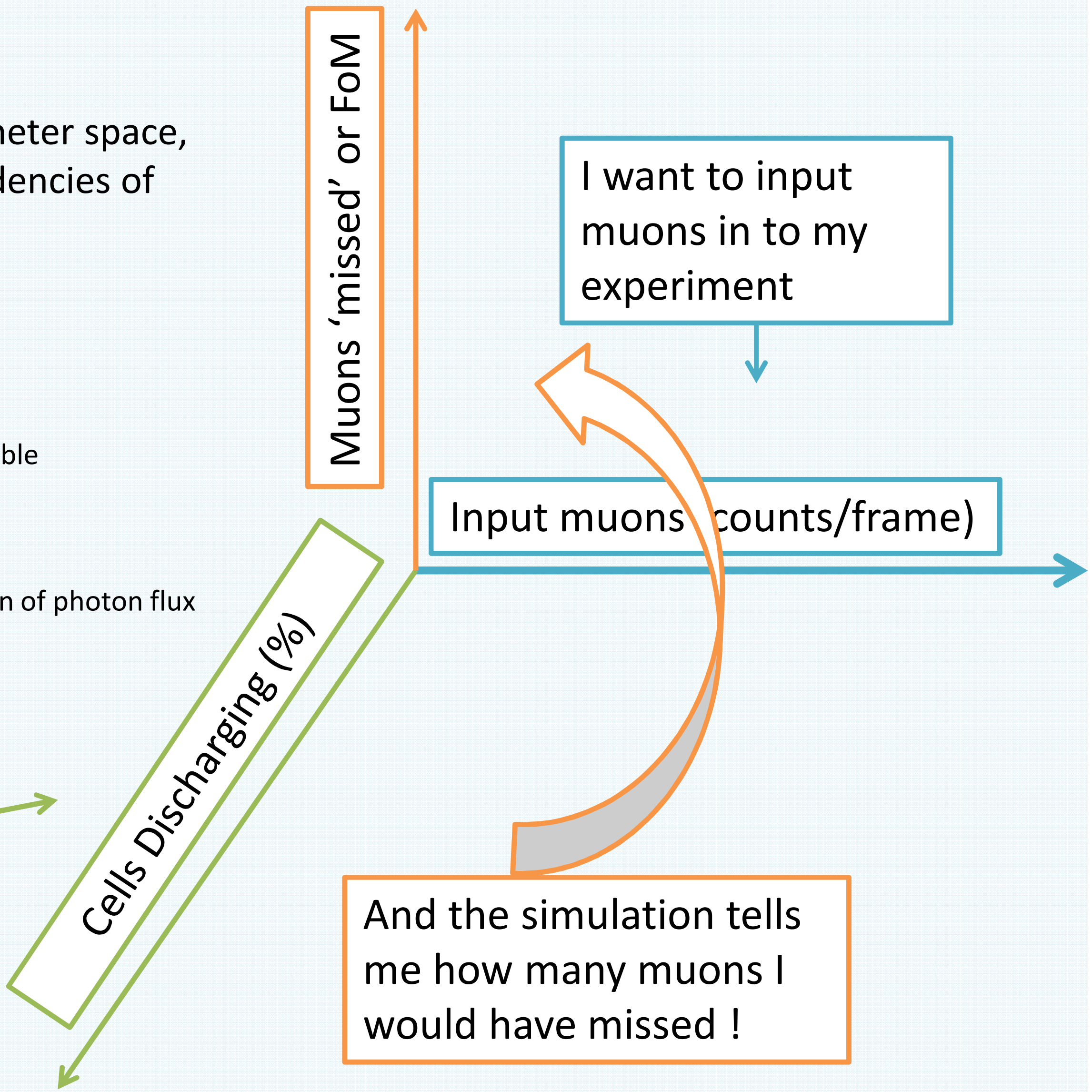
Monte Carlo Simulation



Outline of Monte Carlo Simulation

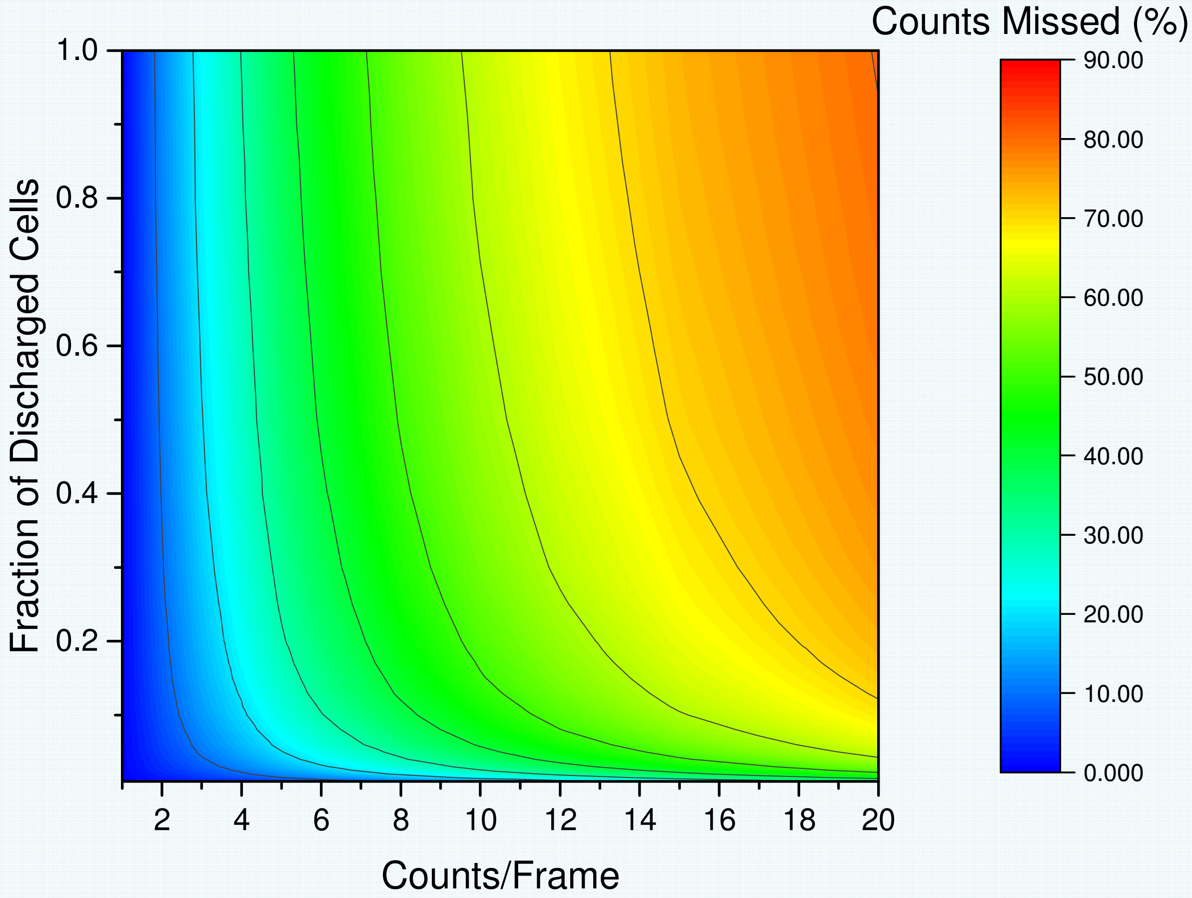
- Motivation
  - Complete control over the parameter space, capable of simulating the dependencies of each parameter.
- Take information from:
  - MuSR Investigation
    - Realistic count rates
    - Severity of dead time correction capable
  - Optical Investigation
    - SiPM RC values
    - Cell discharge probability as a function of photon flux

With a controllable amount of the cells being discharged per muon event



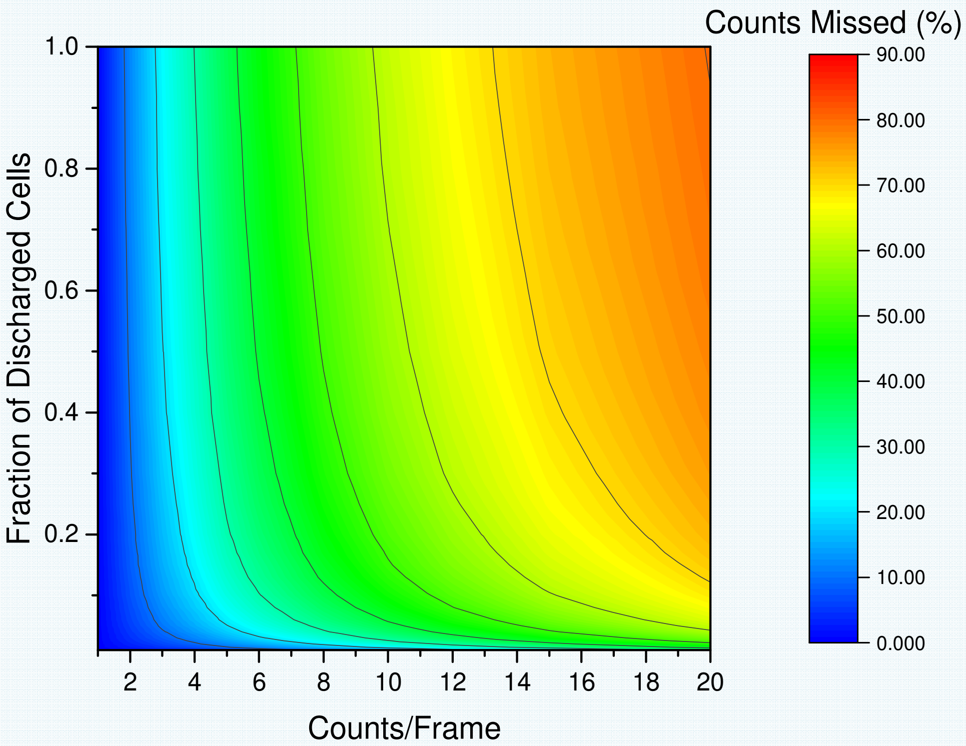
Missed Counts – SOut

- Simulation Setup
  - SensL FC50um
  - Cells 2668
  - RC: 116ns
- Frames ran to get statistical validity.

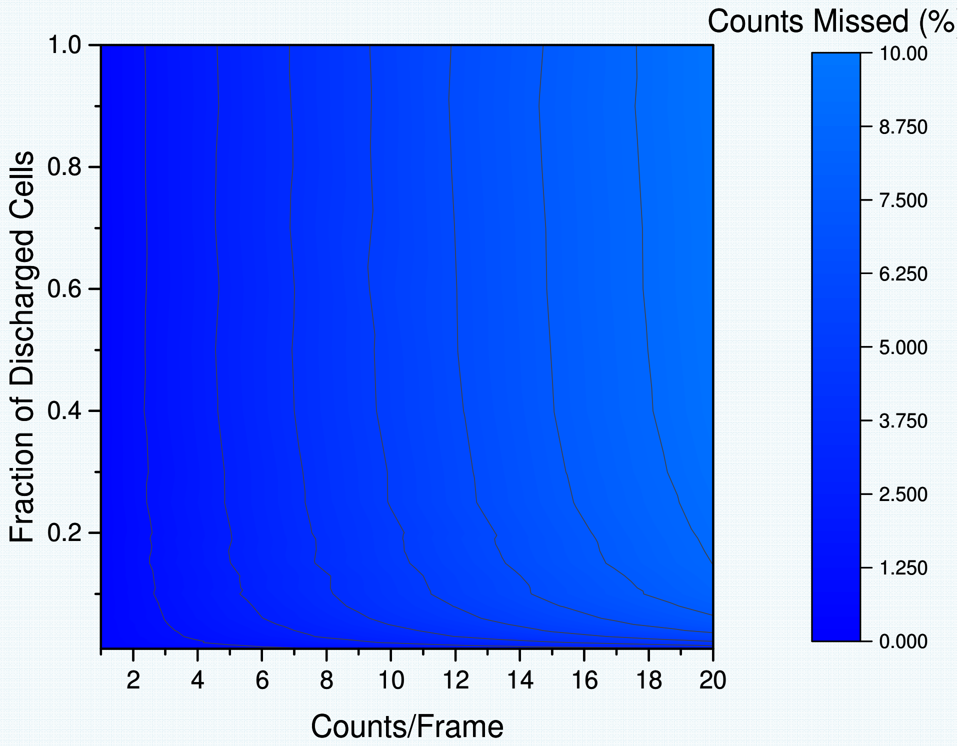


Missed Counts - Comparison

SensL FC50um – SOut



SensL FC50um – DSOut



Conclusions

MuSR Investigation

- Optimised measurements for reliable determination of dead time
- Comprehensive data analysis of muon asymmetry and dead time corrections
- Quantitative measurements of detector performance as a function of rate, manufacturer , cell size and signal processing.

Monte Carlo Modelling

- Complete simulation of SiPM based detector.
- Fully parameterised the photon flux and count rate space
- Validated all features observed from MuSR experimental data

Laser Characterisation

- Parameterised signal shapes and recharge time constant(s)
- Demonstrated relationship between pixels fired and incident photon flux and linked to continuous probability model.

Overview

- Laser characterisation provided accurate numerical values for input into Monte Carlo modelling and validated the operational conditions for the SiPM when coupled to a scintillator.
- Deeper understanding was gained of our MuSR results via the Monte Carlo modelling. In particular the model has validated the operational range for the experiments and parametrises the feasible count rates.
- On track to deliver comprehensive report evaluating SiPM’s satisfying deliverable 9.8 in month 24 as agreed.

Additionally

- Outcome of the three investigations has lead to a robust understanding of results; which are being prepared for publication.
- GSPC Detector development has kicked off (see deliverable 9.13, due month 48)
- Continuing collaboration with JPARC (also a intense pulsed muon source), working toward a fundamental understanding for the implementation of SiPM’s at pulsed sources.

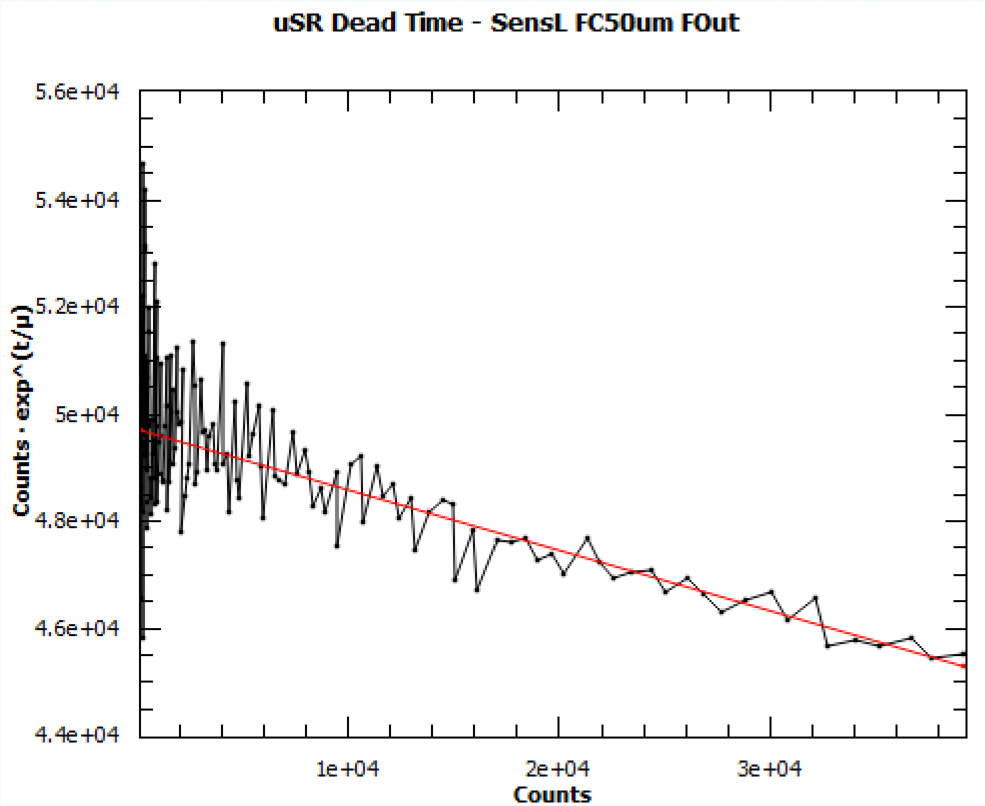
Thank you for your attention

Backup slides

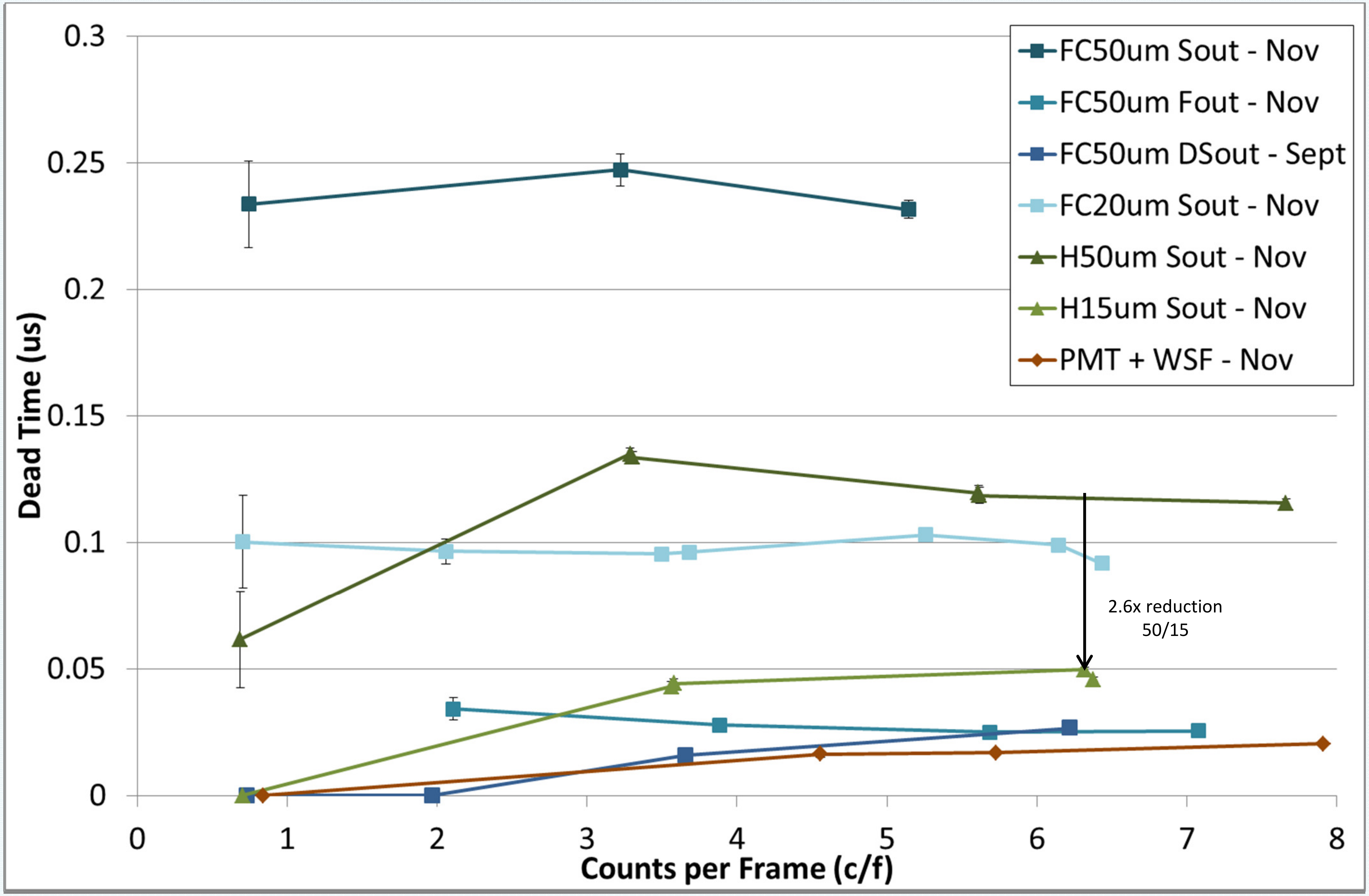
µSR – Dead Time

$$Counts \cdot e^{\frac{t}{\mu}} = N_0 - Counts\left(\frac{t_{dead}}{t_{bin}F}\right)$$

Non-Extendable Dead Time Correction Model



Selected MuSR Results



SINE2020:
Emergent Detector Technologies...

Tasks

9.4 Emergent Detector Technologies for neutron scattering and μSR

9.4.3 Silicon Photomultipliers for μSR

Deliverables

D9.8 (Y2, Q4): Report discussing an evaluation of commercial SiPMs for muon spectroscopy detector arrays

D9.13 (Y4, Q4): Report discussing alternative detector technologies for scintillation-based arrays for muon spectroscopy

Coordinator: STFC, Partner: PSI