# Muon Experiments

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# Outline of talk

- μSR – technique, experiment and data
- Applications of the Technique
- Sources, Instruments and Detectors
- Projects in NMI3 and SINE2020

# Introduction

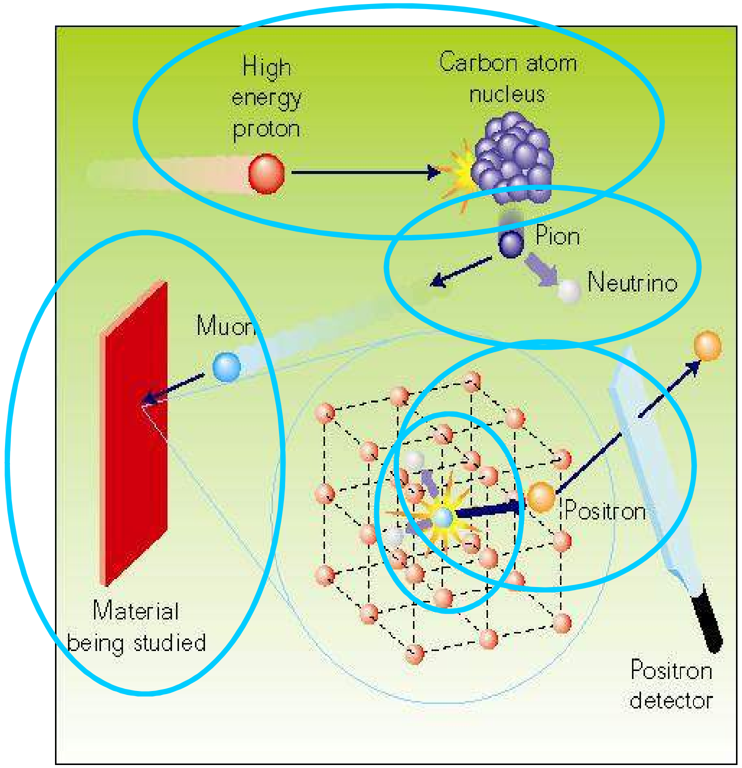
# The μSR technique…

High energy protons
(800 MeV at ISIS)

**Stop in sample**,
(stopped in ~1mm water)

**Stop as $\mu^+$ or**
**Muonium (Mu: $\mu^+e^-$)**

**Evolve in local**
**environment**



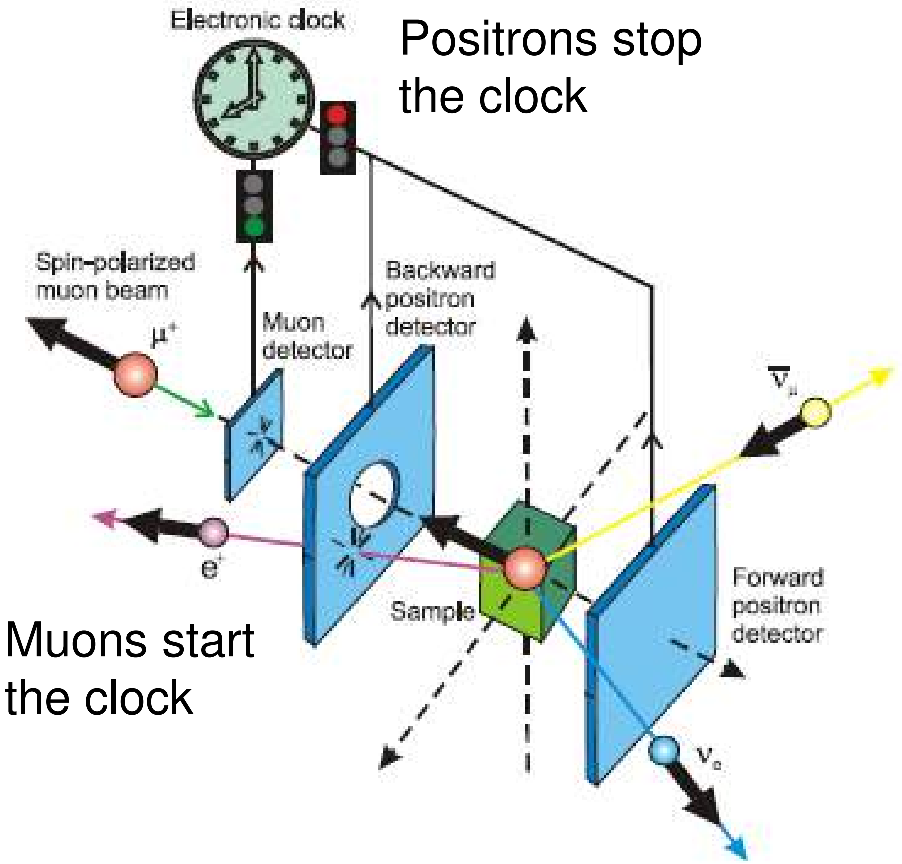

$\pi^+ \rightarrow \mu^+ + \nu_\mu$
4 MeV **muons** are
**100% spin polarised**
spin ½, mass $0.11m_p$

**Decay**, lifetime ~2.2μs
$\mu^+ \rightarrow e^+ + \nu_e + \nu_\mu$
**Detect Positrons**

Positrons preferentially emitted
in direction of muon spin
**Follow Muon Spin Polarisation**

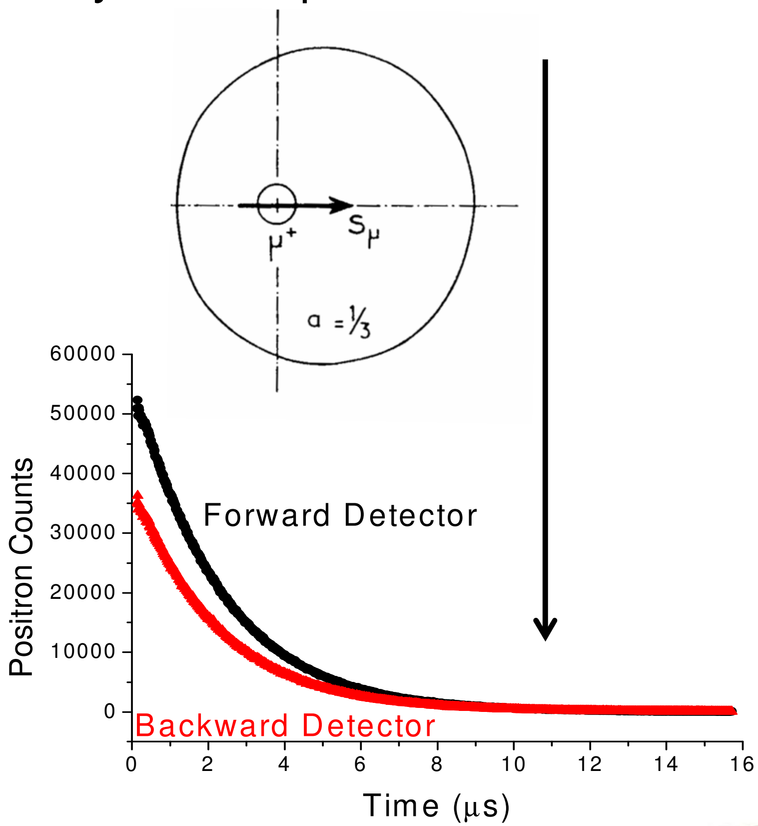
# The Experiment…

Positrons stop the clock

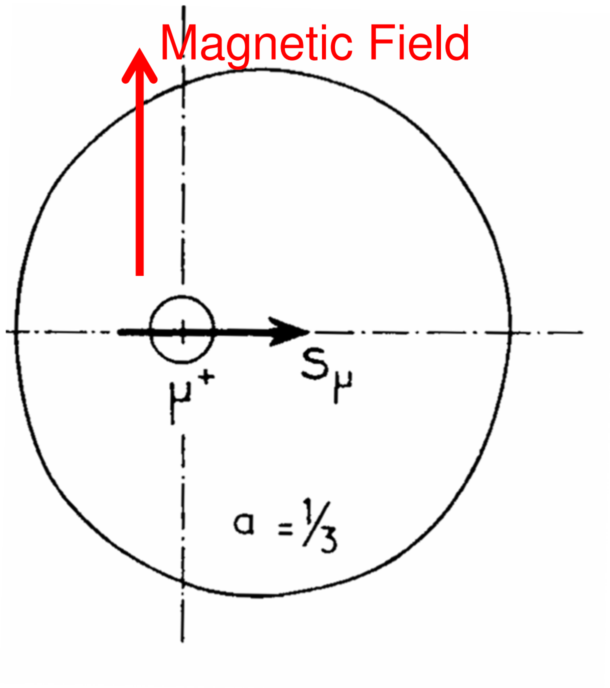



Muons start the clock

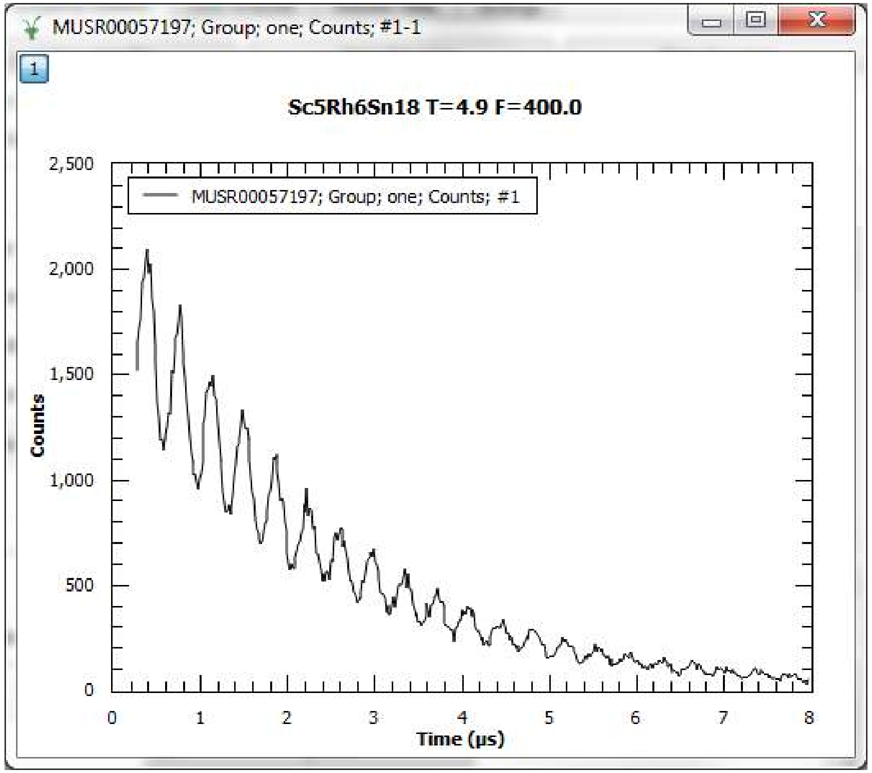
Asymmetric positron distribution



# Data…



Magnetic Field
$\mu^+$
$S_\mu$
a = 1/3

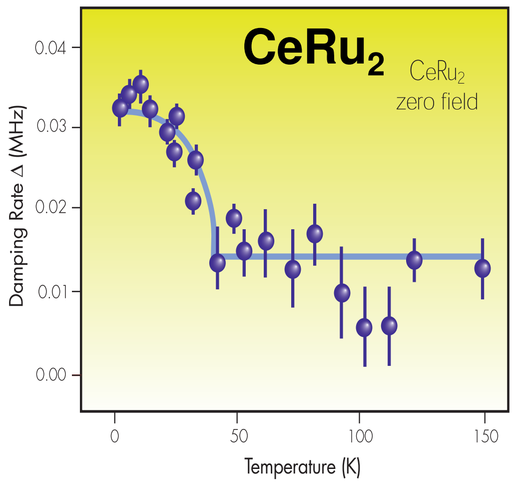



MUSR00057197; Group; one; Counts; #1-1
Sc5Rh6Sn18 T=4.9 F=400.0
MUSR00057197; Group; one; Counts; #1
Counts
Time (μs)
2,500
2,000
1,500
1,000
500
0
0
1
2
3
4
5
6
7
8

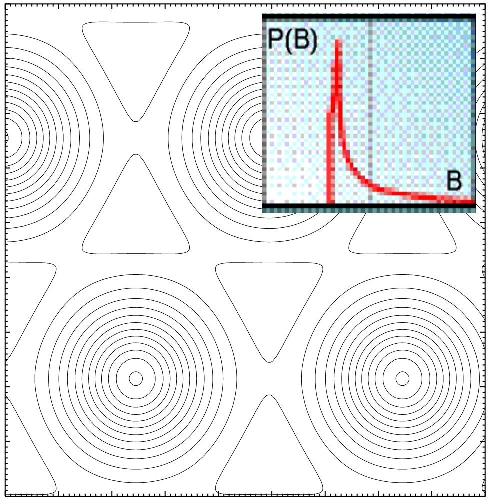
# Applications of the Technique

# Applications of μSR …
# The muon as a magnetometer

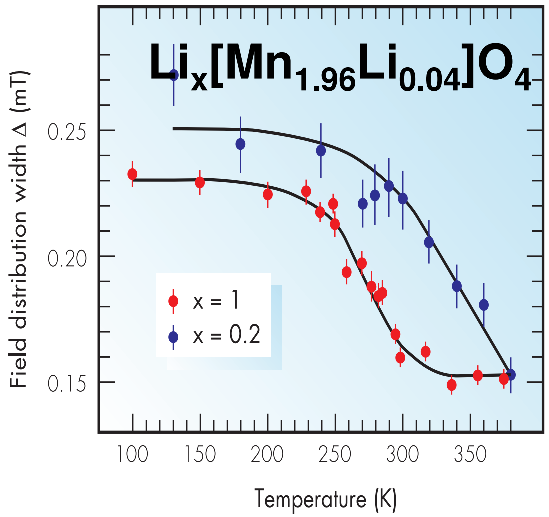
## Magnetism




## Superconductivity




## Ionic Conductors




**Probe internal fields**:

sensitive to small moments (nuclear and electronic) and spin fluctuations

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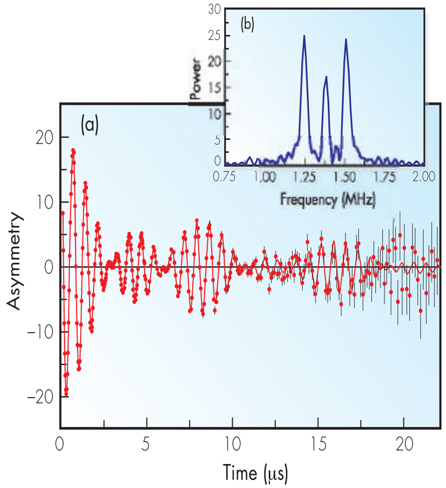
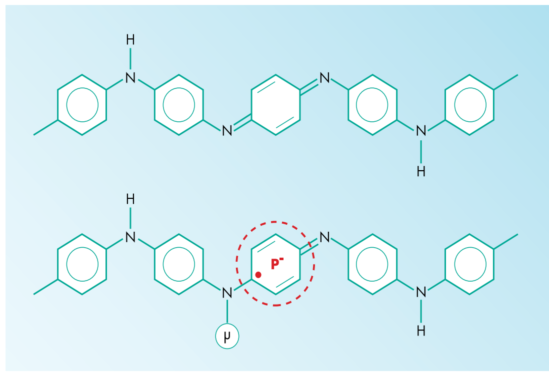
# Applications of μSR …
# The muon as an analogue for ‘H’

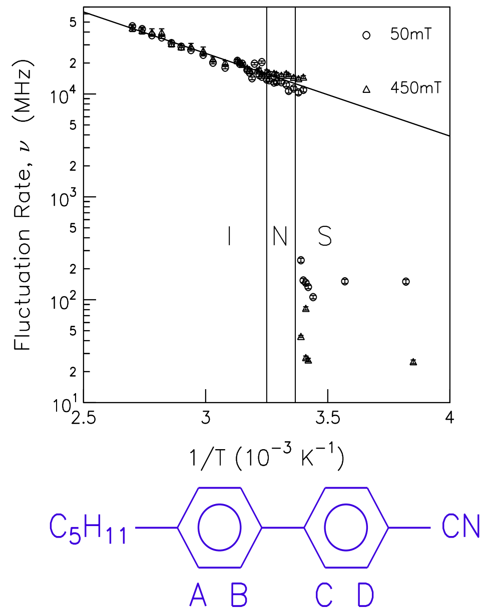
## Semiconductors




## Polaron/Soliton Motion

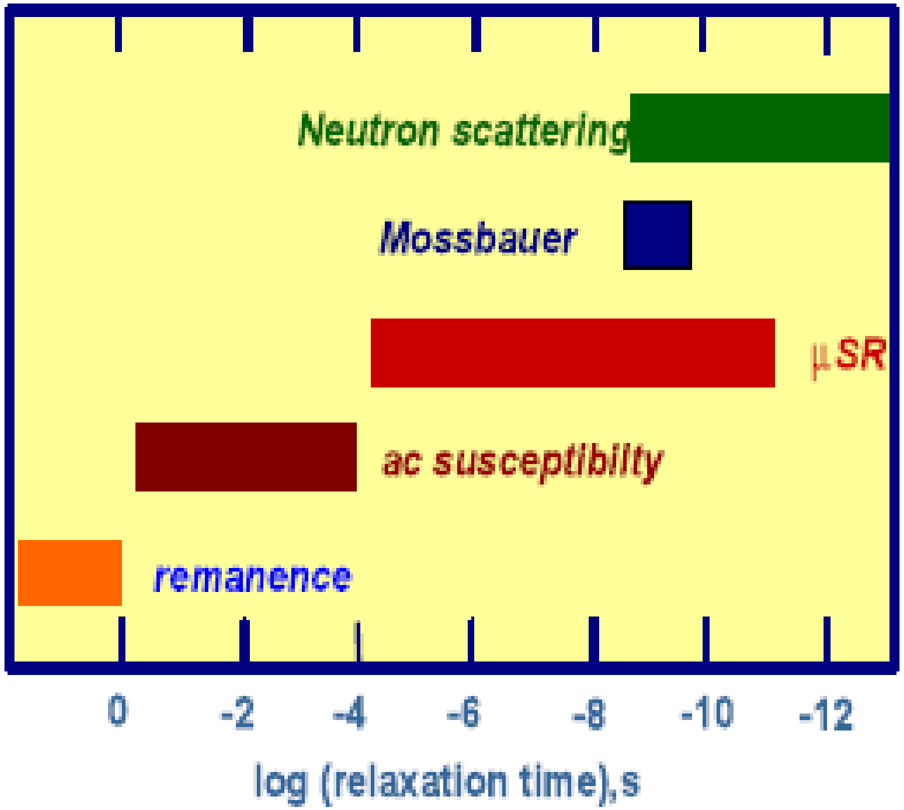



## Molecular Dynamics




**Probe for ‘hydrogen’ states and reactions**:
sensitive method of studying charge states, dynamics and reactions

# A Complementary Technique…



# Sources, Instruments and Detectors

# Where we do muon experiments…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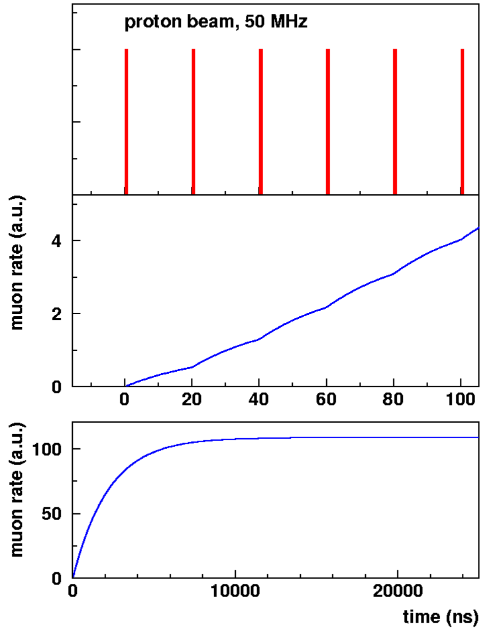
**But not all facilities are equal...**

The **beams** at:
**ISIS and JPARC** are **'pulsed'**
**PSI and TRIUMF** are **'continuous'**

**What does this mean for μSR?**

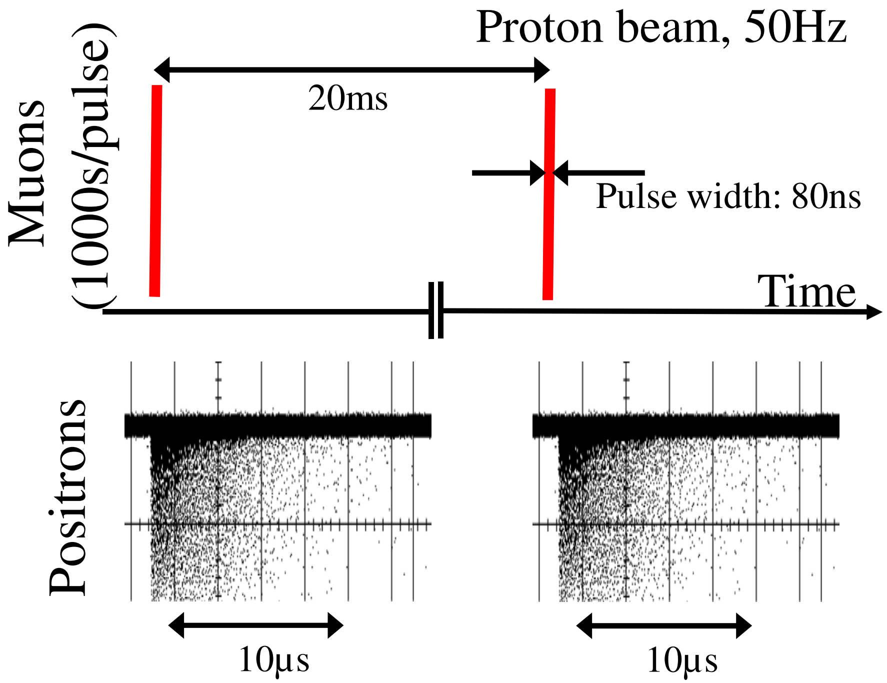
# Beam Structure…

*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!**

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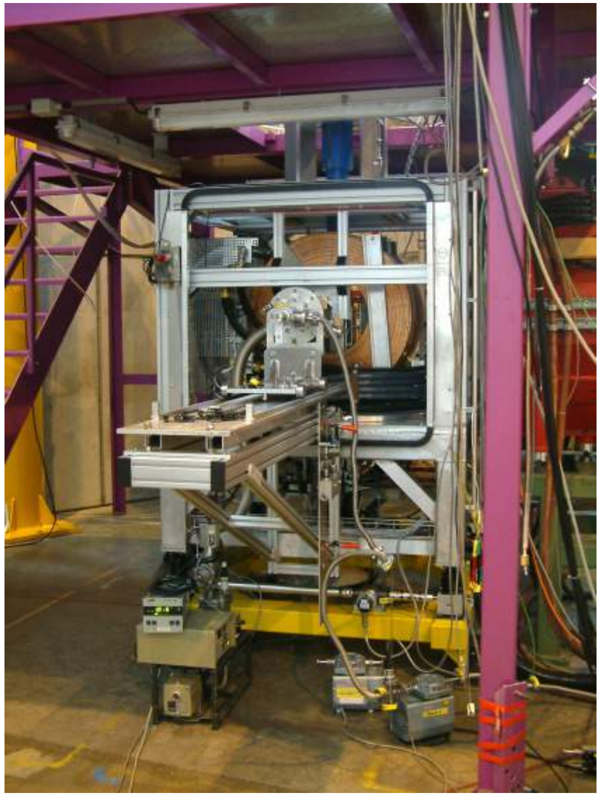
# Instruments...

at a ‘continuous’ source...



**GPD (PSI)**

at a ‘pulsed’ source...


**EMU**

High instantaneous rates at pulsed sources require a  highly pixelated detector array

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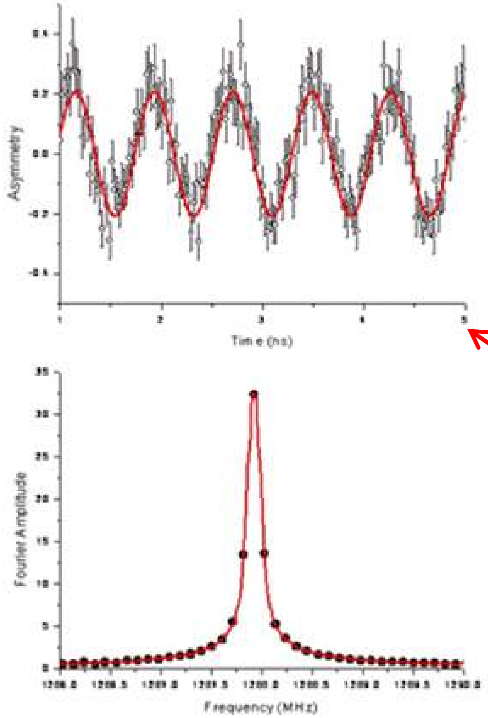
# Experiment…

| at a ‘continuous’ source... | at a ‘pulsed’ source... |
| --- | --- |
| • High time resolution, (> 4 GHz) | • Time resolution limited by muon pulse width (Δt 80ns → ~10 MHz) |
| • Random background distorts spectra at long times | • Low background, measurement of μSR signal to long times |
| • Rate limited (no second muon/positron in observation window) | • High rate (full beam intensity usable if you have enough detectors with a short dead time!) |

# Data…

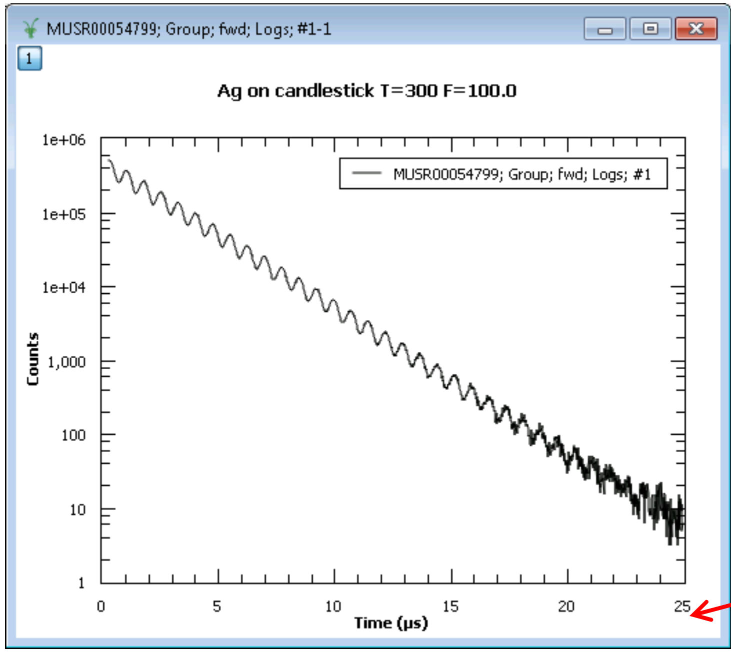
at a ‘continuous’ source...




5ns

Muon precession
~1.3GHz, 9.8T

at a ‘pulsed’ source...




25μs

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

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**Sources are complementary**

**Detector requirements quite different**

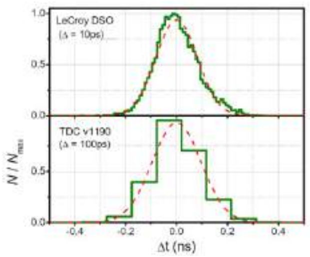
# Projects in NMI3 and SINE2020

# NMI3-I:
# SiPMs for High Field Instruments at PSI

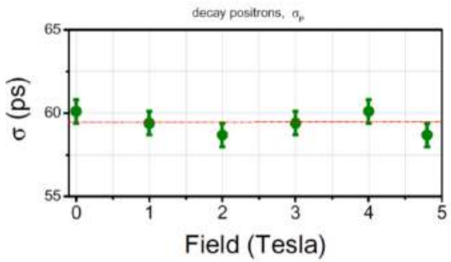
SiPM detectors developed at PSI to meet challenging requirements of new High Transverse Field Instrument

**Focus on *timing resolution* and *performance in a magnetic field***:

SiPM Detector array




Detector resolution better than 100 ps




Resolution independent of field

Very successful for measuring at PSI with a *continuous* beam structure

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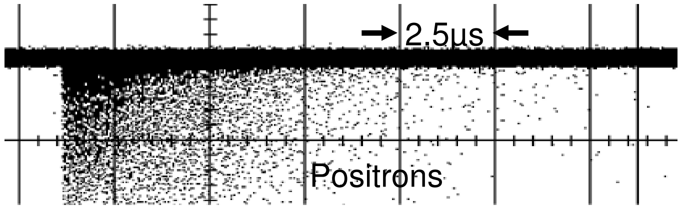
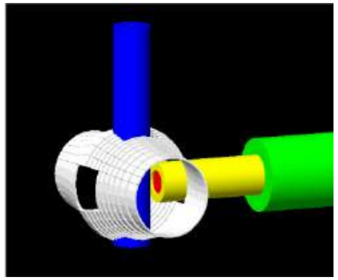
# NMI3-II:
# SiPMs for 'Pulsed' beams

Applying SiPM technology at pulsed sources brings new challenges …




Very high instantaneous rates demand:

- High detector segmentation ✓
- Short detector deadtimes following each 'hit' ?



Future MuSR Detector Array

Currently studying the suitability of SiPMs for pulsed muon beams …
**Focus on *deadtimes***

(see later talk by Dan Pooley)

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# 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

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