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ISIS Neutron and Muon Source
UK Research and Innovation

SINE 2020

Work Package 9 - Detectors
Task 4.3 - Silicon photomultipliers for muon spectroscopy

Daniel Pooley
Steve Cottrell
Davide Raspino
Peter Baker
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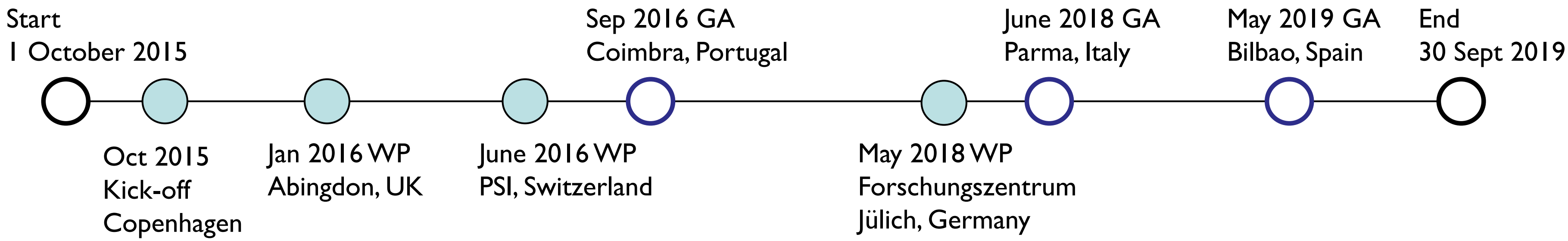
Final SINE2020 General Assembly
Bilbao Spain
Monday 27th – Wednesday 29th May 2019

Timeline, deliverables and workflow



D9.8 Report discussing an evaluation of commercial SiPMs for muon spectroscopy detector arrays (month 24).

D9.13 Report discussing alternative detector technologies for scintillation-based arrays for muon spectroscopy (month 48).

- Scintillator Arrays and Optical Components
- SiPM Evaluation
- Gas Detectors
- Flat Panel Photo-Multipliers (64 Channel)
- Large Scintillator Arrays

This talk:

Progress since last WP meeting

Two highlight slides

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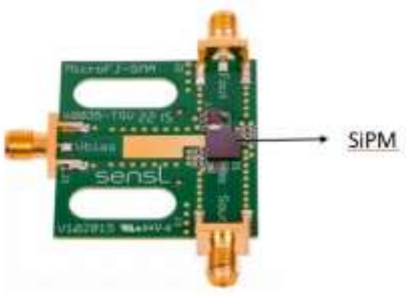
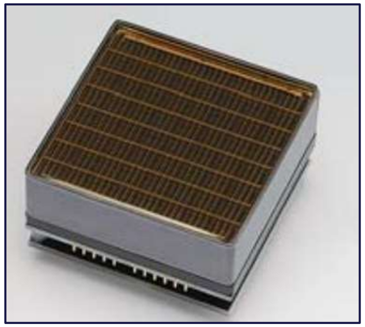
..since last WP meeting

- Completed SiPM evaluation
- Progressed onto H12700 Flat Panel Photo-Multipliers (64 Channel)
  - Installed 3 element prototype on 'EMU' spectrometer
  - Investigation into optical and timing properties of FPPMT for MuSR application





To meet specification of Super-MuSR spectrometer

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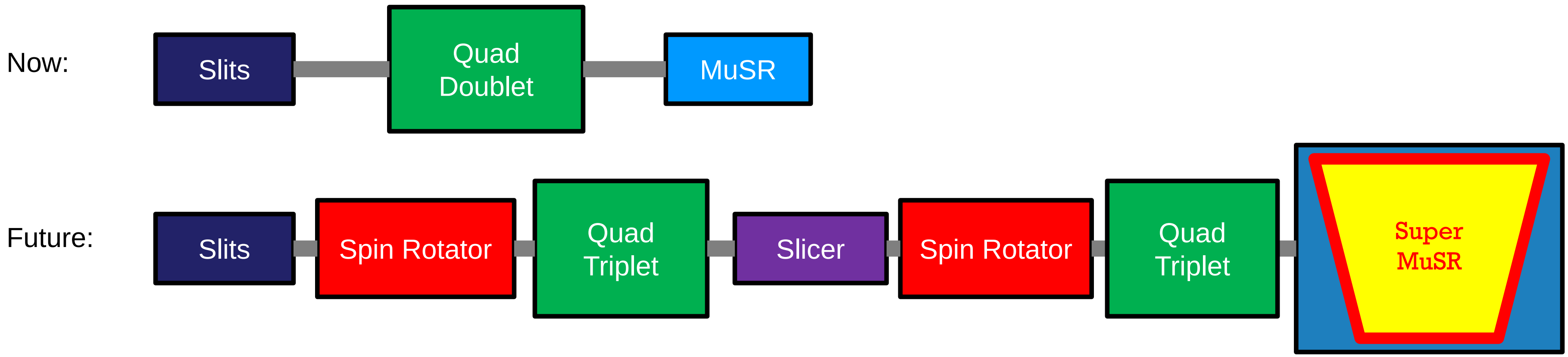
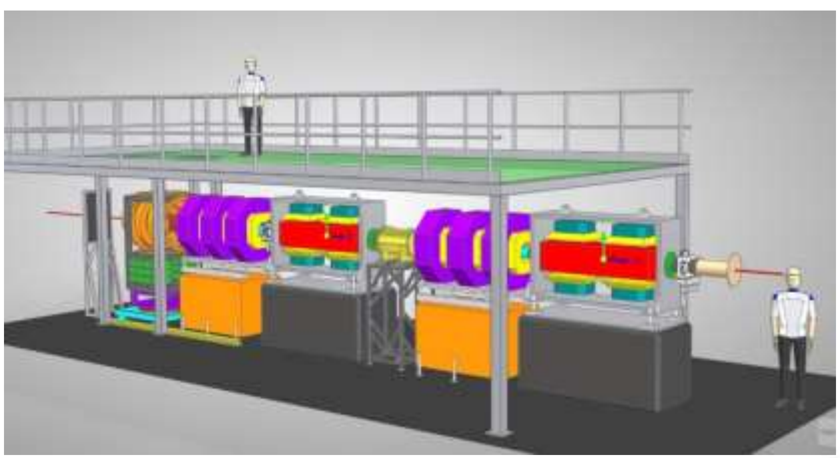
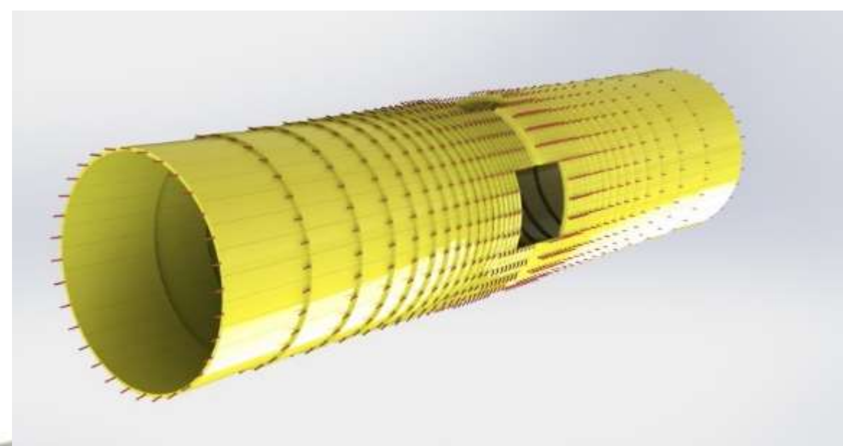
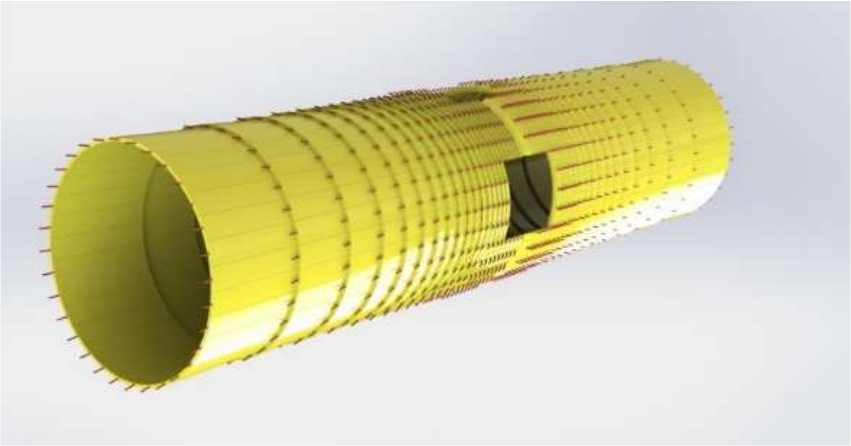
Super-MuSR specification







Super-MuSR: Specification



	Today	Proposed	Benefit
Detectors	64	~1216	15-20x data rate
Muons admitted	10%	100%	Best use of larger samples
Solid angle coverage	40%	75%	Best use of muons available
Maximum resolvable frequency (field)	8 MHz (0.06T)	~80 MHz (~0.6T)	Enables experiments not previously done at ISIS
Spin rotation	None	60°	Higher field TF
Maximum field	0.35T	0.64T	Broader range of experiments
Min sample size (mm)	15x15	5x5?	Single crystal measurements
Detector timing resolution	-	1 ns	To maximize the benefit of the pulse slicer

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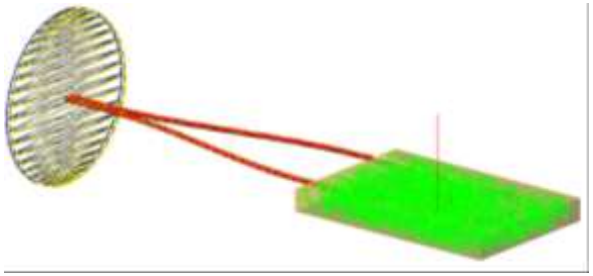
Signal Characteristics of Detector Components

Super_MuSR detector element should have a **timing resolution of ~1ns** and **pulse-pair resolution of ~10ns.**



Relatively Well Known:

Timing Resolution (or at least the rise time) of:

BCF92 fiber
BC408 scintillator
Single pixel on a FPPMT (TTS)

Pulse Pair (or at least the fall time) of:

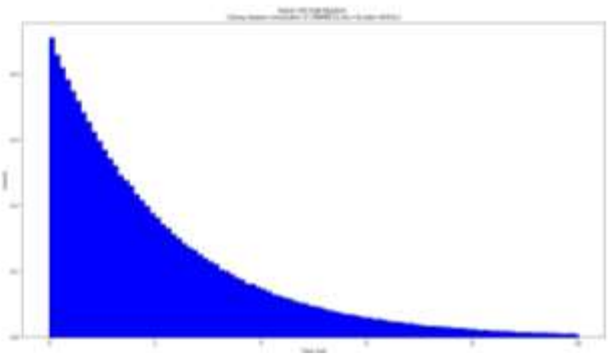
BCF92 fiber
BC408 scintillator
Single pixel on a FPPMT

Cross-talk and signal shape

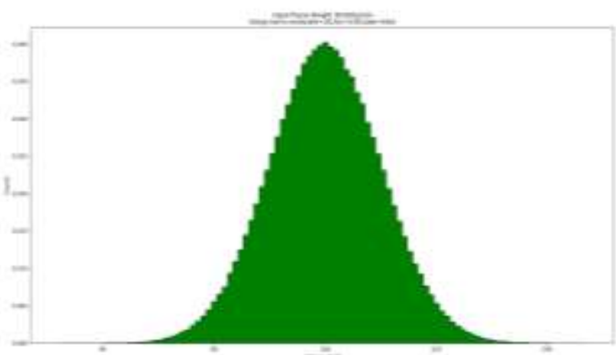
But muon application his its own subtleties.

What is the effect of going from 'flood field' illumination (all fibres at same time) to isolated 'single pixel' events in ~10μs ?

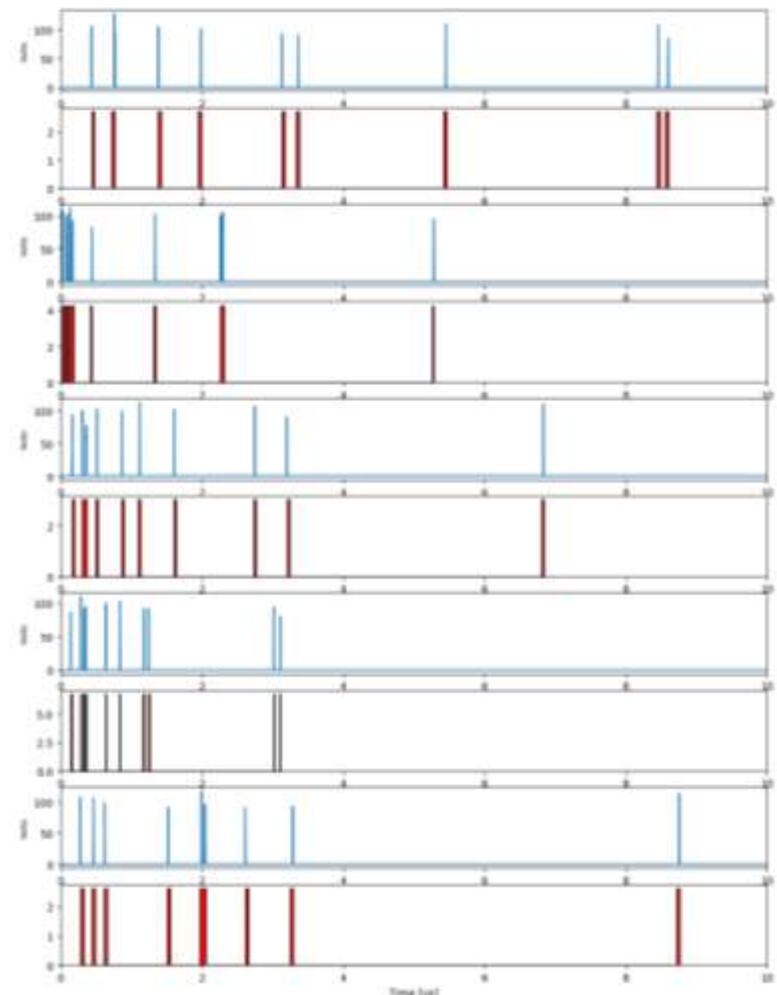
Pixels hit at the “same time” at early time-of-flight, with exponentially increasing probability.



Draw random numbers with a exponential distribution



and with a normal PHS



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Potential Application of H12700 to Muon Spectrometers

The Development of Flat Panel PMT

H. Kyushima, H. Shimoi, A. Atsumi, M. Ito, K.Oba and Y. Yoshizawa
Hamamatsu Photonics K.K., Electron Tube Center
314-5, Shimokanzo, Toyooka Village, Iwata-gun, Shizuoka pref., Japan 438-0193

Abstract

In High Energy Physics (HEP) experiment and scintillation counting application, a photodetector, which can cover large area and has small dead space, has been desired. It should be compact and should have multi-anode in some cases.

Hamamatsu has developed a Flat Panel Photomultiplier (PMT) to meet the demand. If many of Flat Panel PMTs are placed closely, they can cover large area as one photodetector.

The Flat Panel PMT has 51.7 x 51.7 x 12.4 mm metal package and 8 x 8 matrix multi-anode. Some prototypes were made, and it was confirmed that a ratio between external size and useful area was 90 % and gain of 3x10^6 was achieved. Its structure and basic feature are discussed in this paper.

Followings were considered to achieve large useful area compared with an external size of an envelope as well as compact size in Flat Panel PMT.

1) to use a square metal package as a side envelop
2) to minimize curvature at each corner
3) to make short length less than 15 mm
4) to couple an input window directly with a side envelope
5) to delete flange between a side envelope and metal plate at a bottom
6) to use laser welding method to avoid heating problem while sealing process

The schematic cross-section of the Flat Panel PMT is

H. Kyushima, H. Shimoi, A. Atsumi, M. Ito, K. Oba and Y. Yoshizawa, *2000 IEEE Nuclear Science Symposium. Conference Record* pp. 7/3-7/7

Characterization of the Hamamatsu H12700A-03 and R12699-03 multi-anode photomultiplier tubes

M. Calvi[a,b], P. Carniti[a,b], L. Cassina[a,b], C. Gotti[a,b], M. Maino[a,b], C. Matteuzzi[a] and G. Pessina[a,b]

Published 29 September 2015 • © 2015 IOP Publishing Ltd and Sissa Medialab srl
Journal of Instrumentation, Volume 10, September 2015

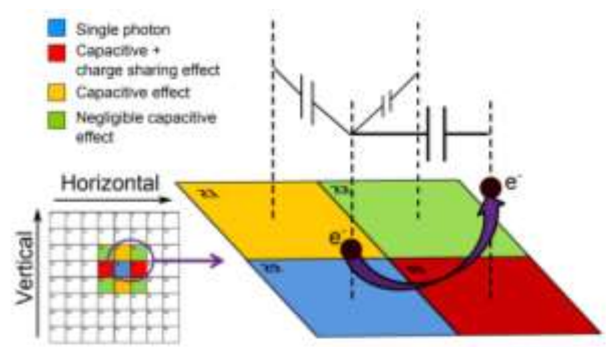
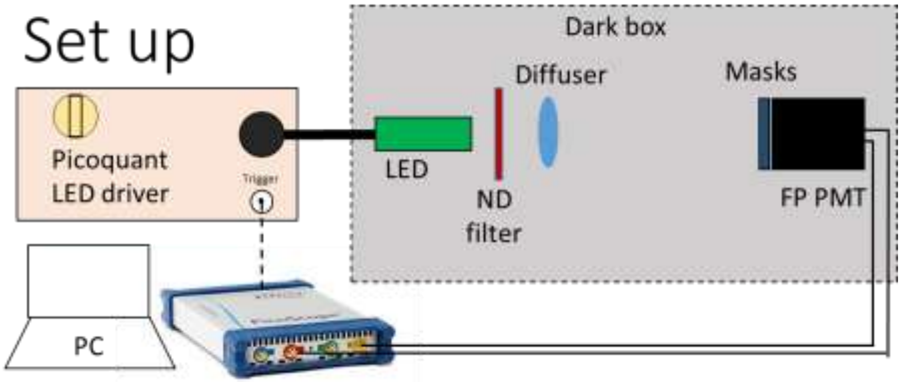


Figure 6. Schematic representation of the different sources of cross-talk usually affecting a MaPTM. This scenario is compatible with the results of the cross-talk measurements.

Timing Resolution Set Up



- Can either use two pixels or the output trigger and one pixel
- Use variety of masks to control pixels illuminated

Some of the masks used

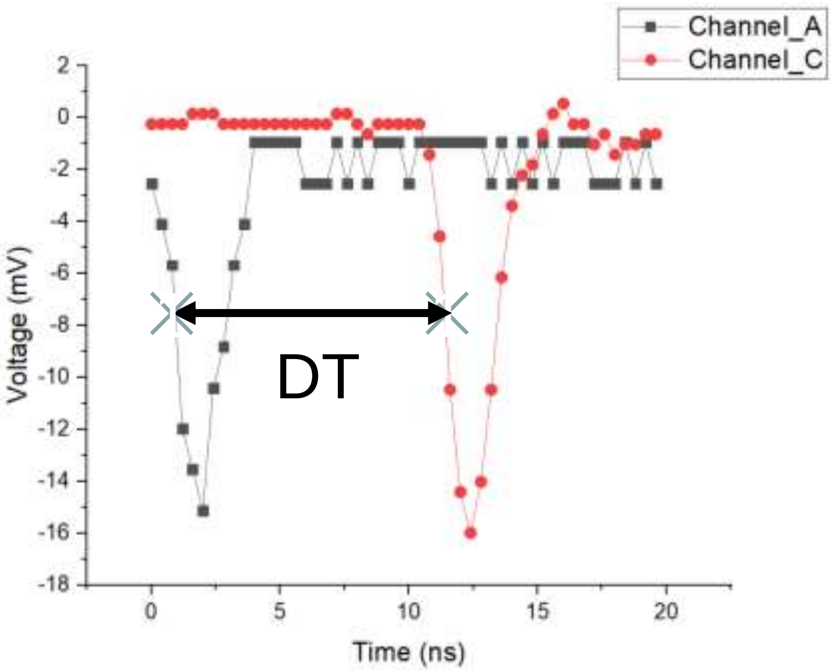
Single pixels mask

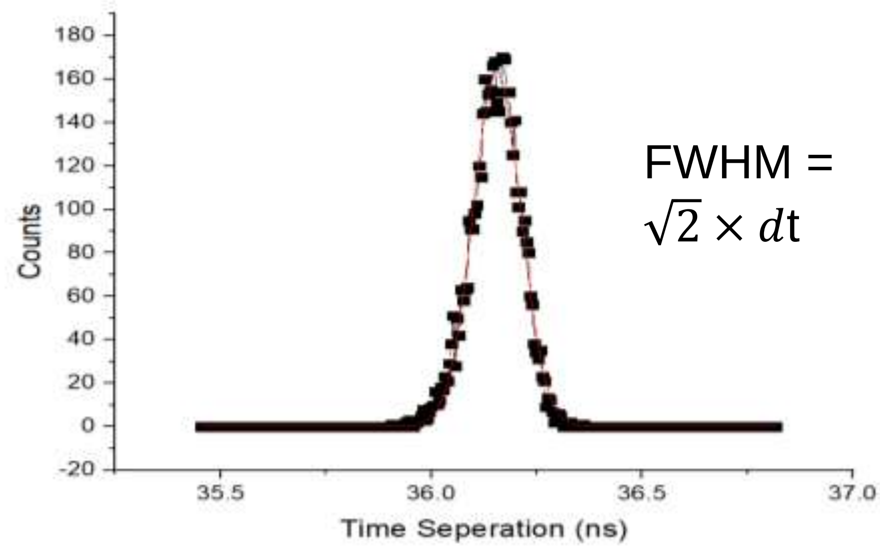
Checkerboard mask

no mask

All exposed

Data and Analysis





FWHM = $\sqrt{2} \times dt$

- Trigger at 50% signal amplitude
- Digitised all data so can perform variety of offline analysis

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Timing resolution scales with intensity

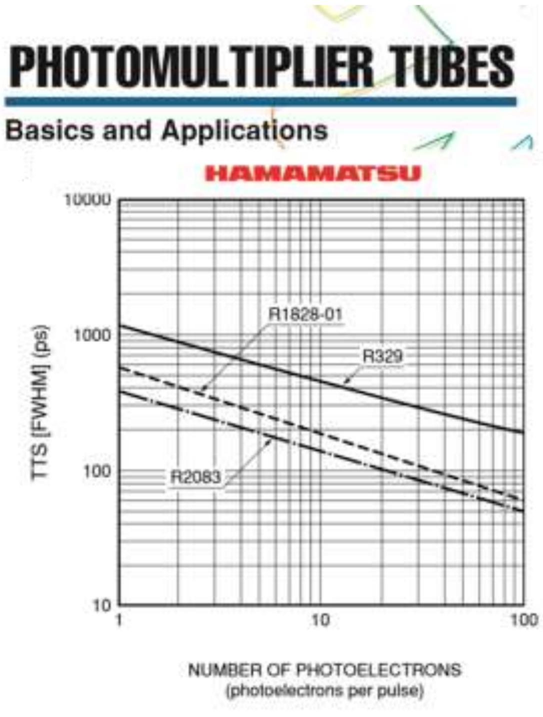
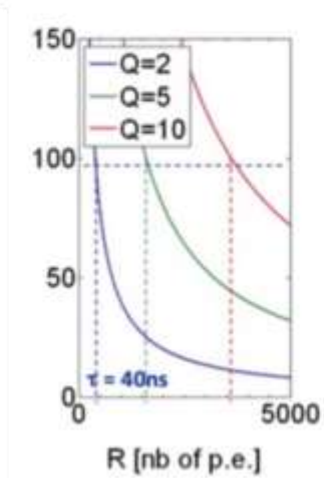


Figure 4-20: TTS vs. number of photoelectrons



Timing resolution dependence on the light output from scintillator (number of photons)

Typical muon signals 50 to 150 mV.

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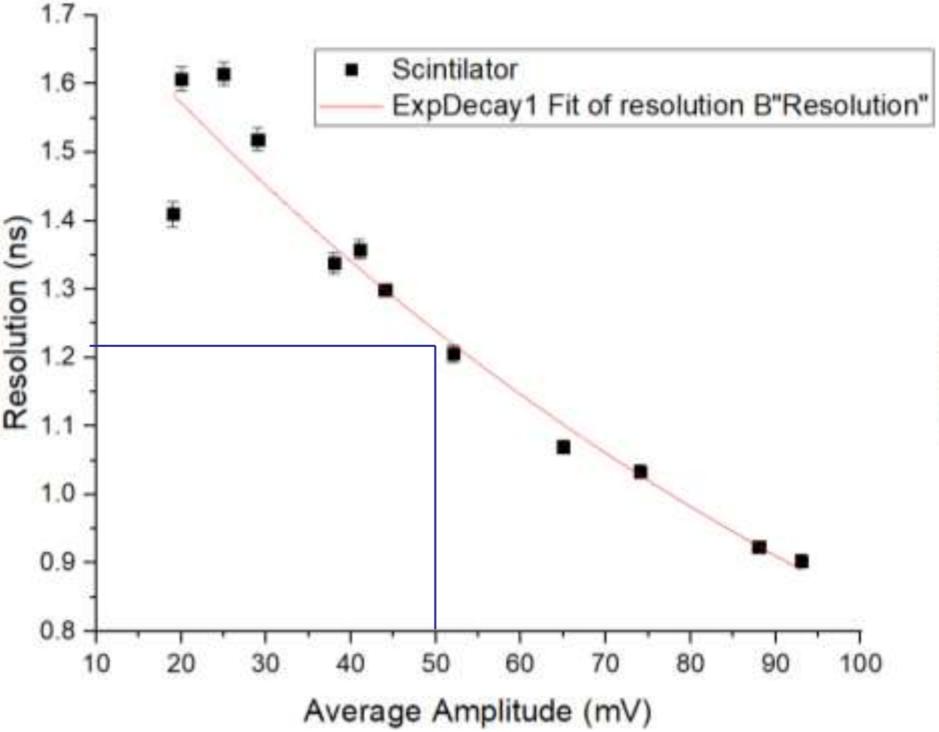
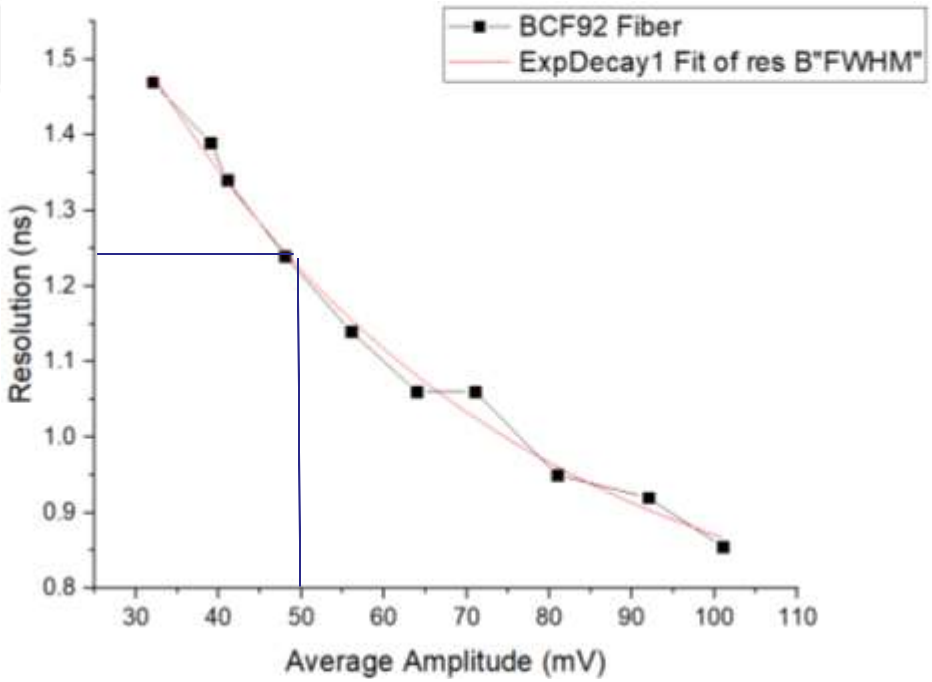
Timing Resolution

BC408 Scintillator



BCF92 Fibre



FPPMT contribution included

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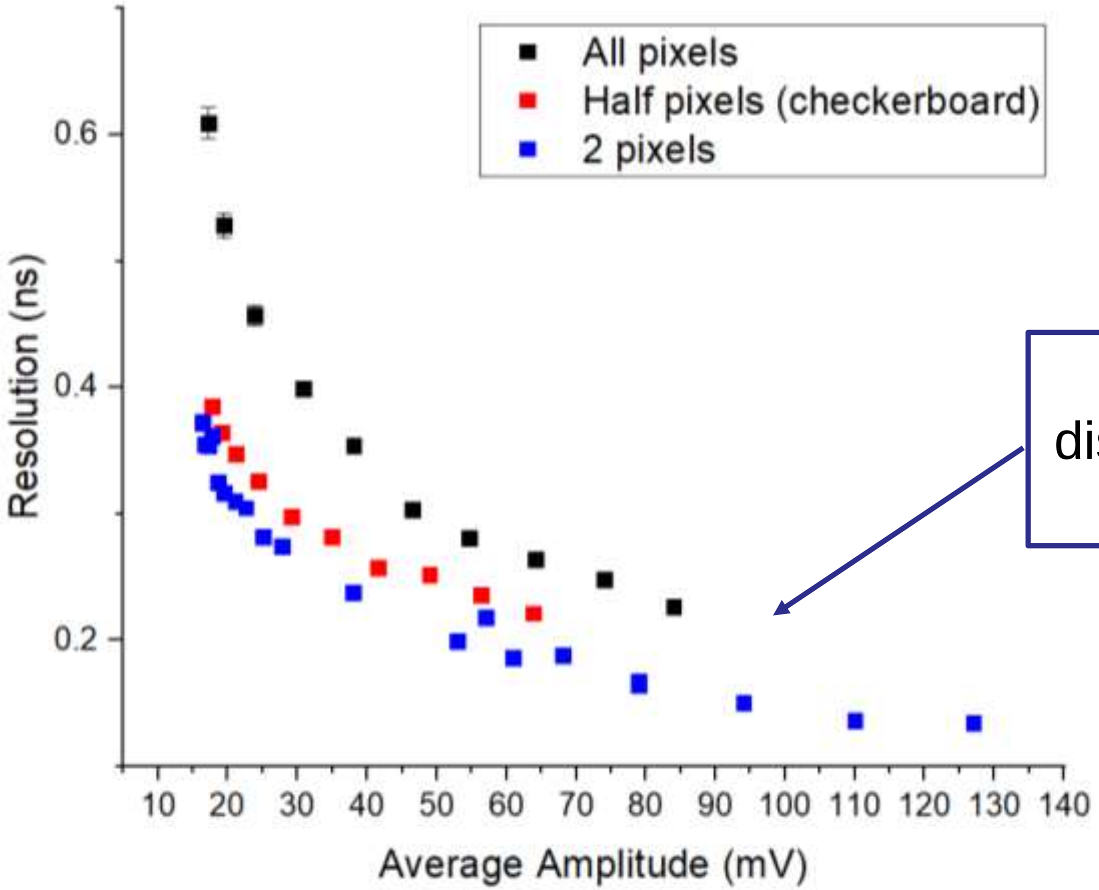
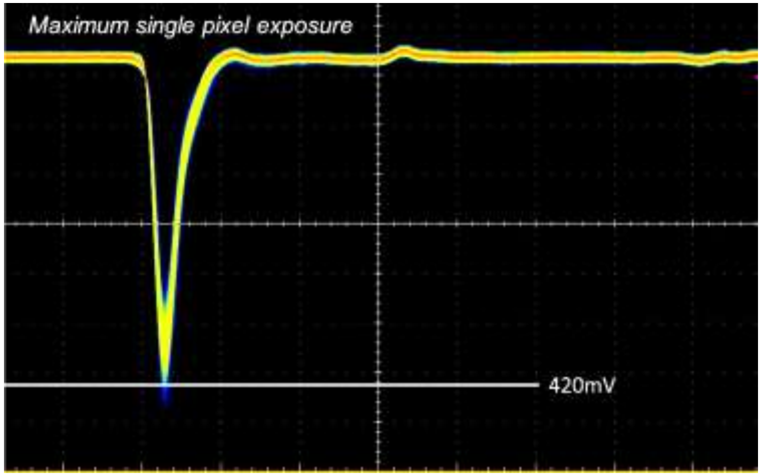
Timing resolution of FPPMT with number of pixels



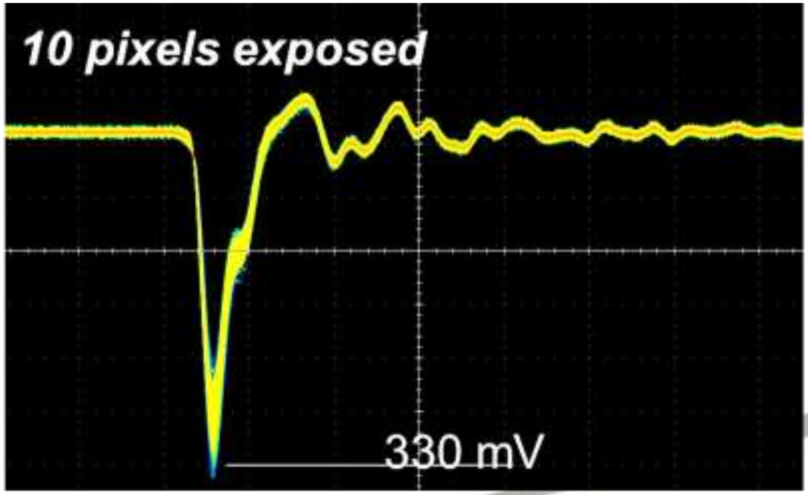
Further investigation into the distortion in flood field signals was required.

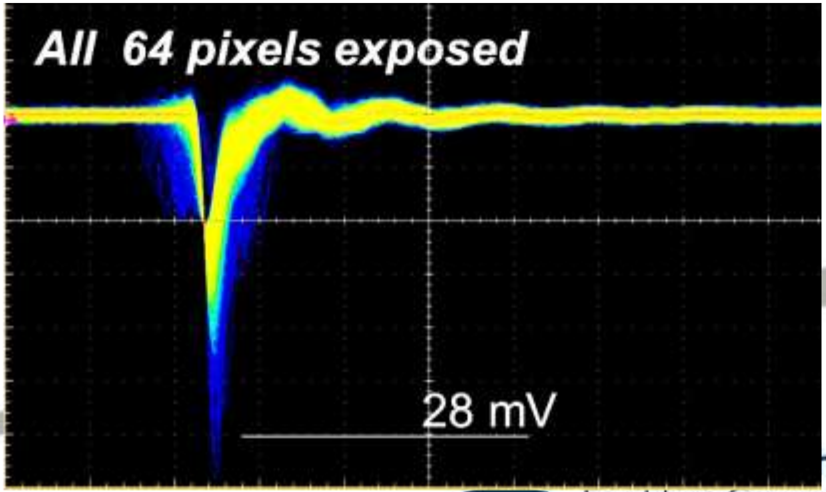
Resolution against amplitude of signal of PMT for different pixel exposure numbers.

Distorted signals

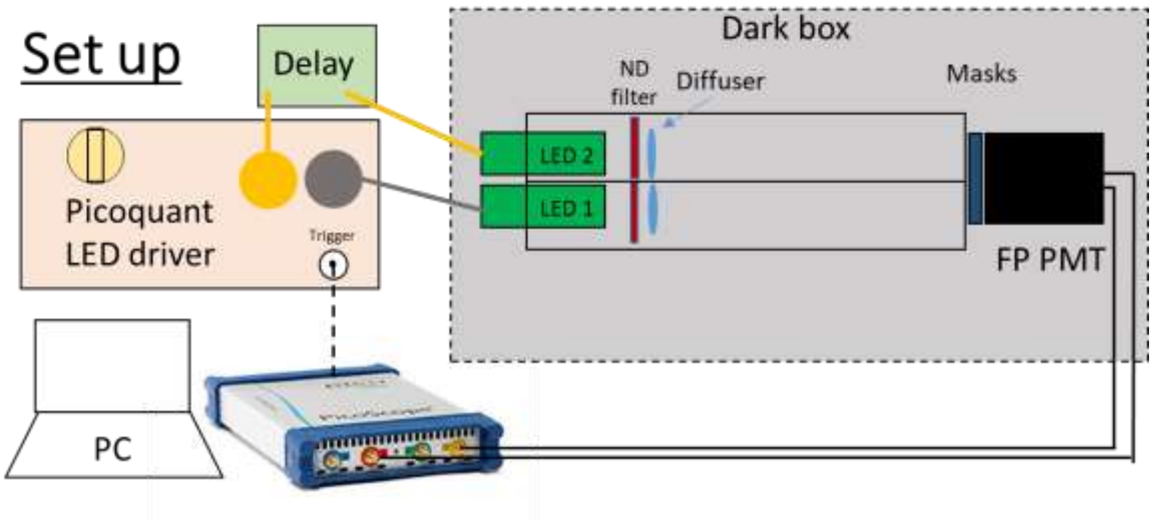


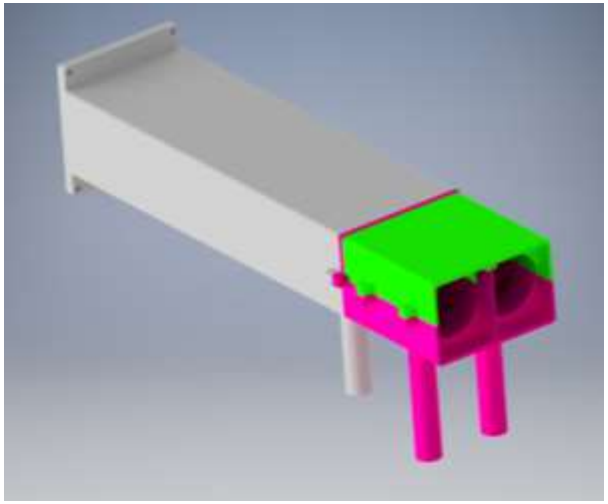
- Signals from the PMT **distort** as more pixels are exposed.
- Doubling the **cable length** had **no impact, not reflections**
- The period of the ringing is about **5ns** and occurs after a rising edge.
- This did not impact the timing resolution measurements.
- However there **is** an impact on the **pulse pair resolution**.





Distorted signals- Investigation of spatial and temporal dependency





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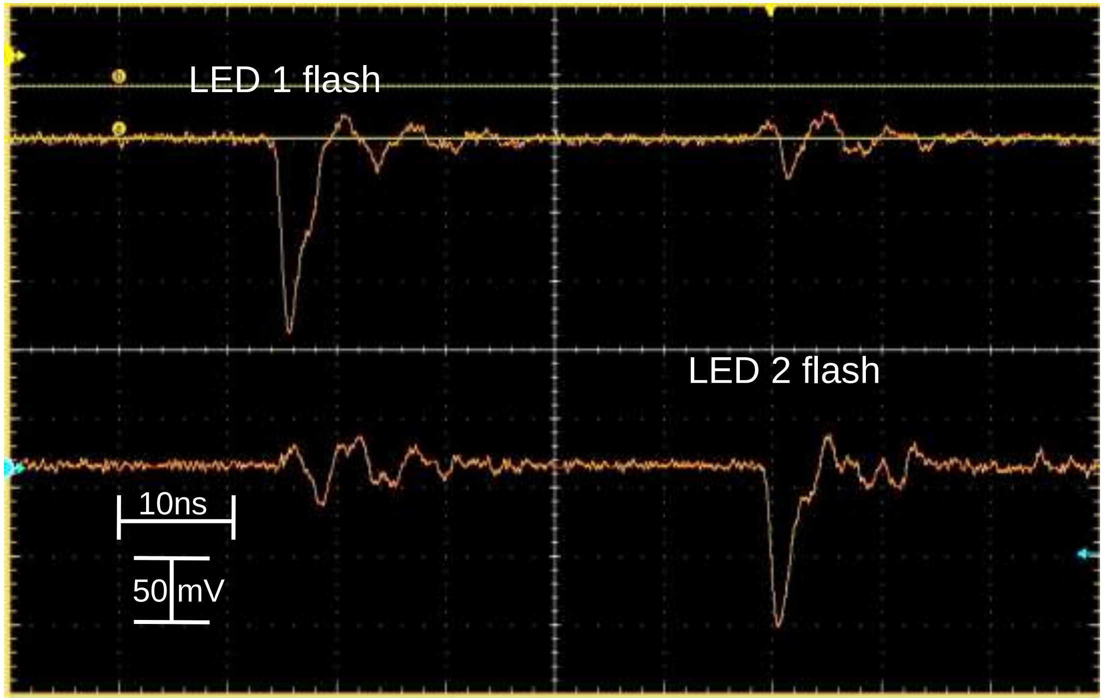
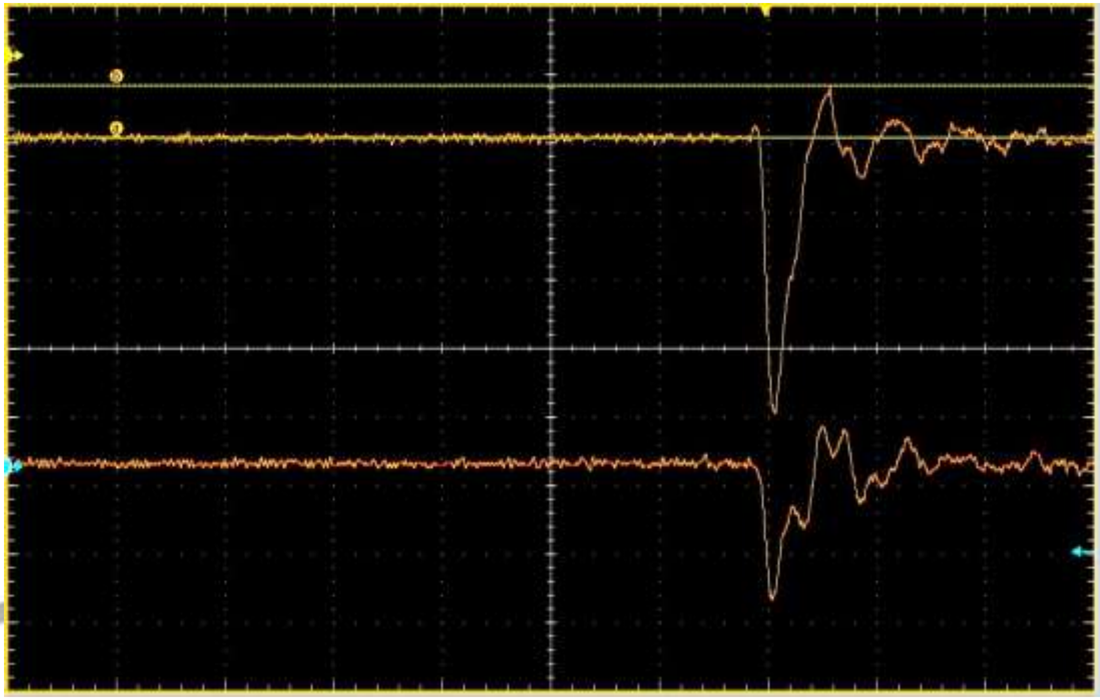
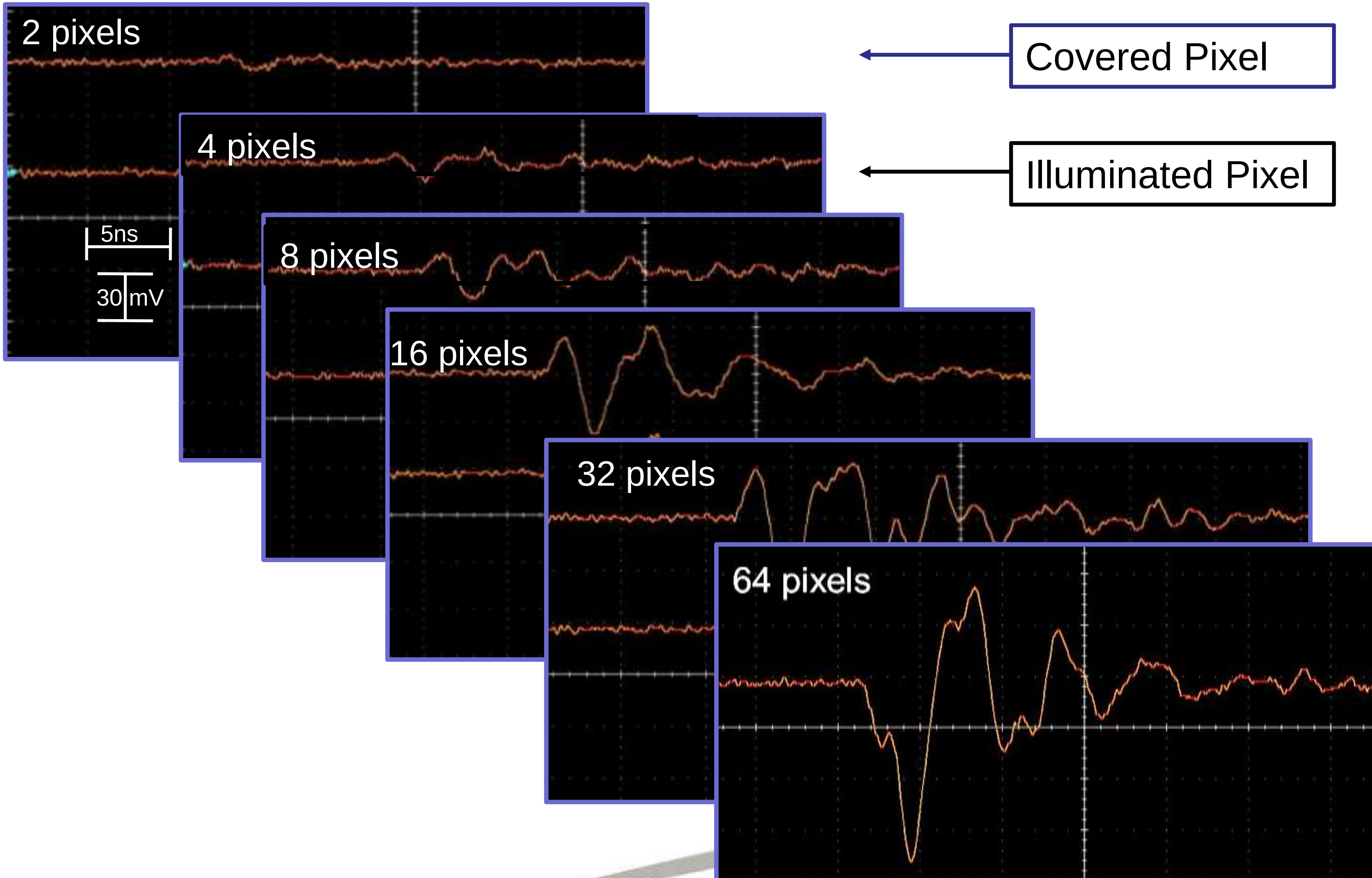
Flashing sets of 10 pixels

Reading from 2 pixels while alternating flashing LED on a independent group of 10 pixels around them

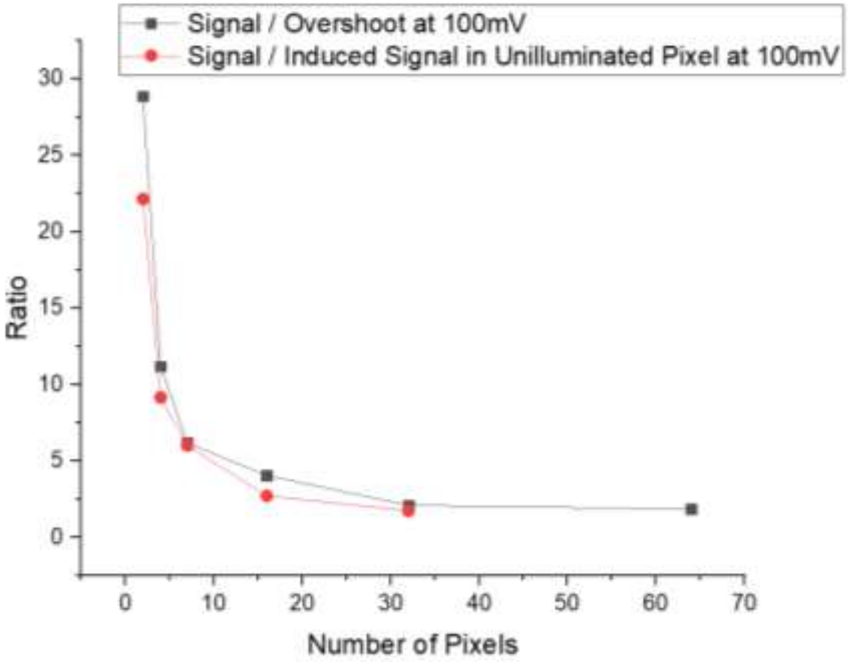


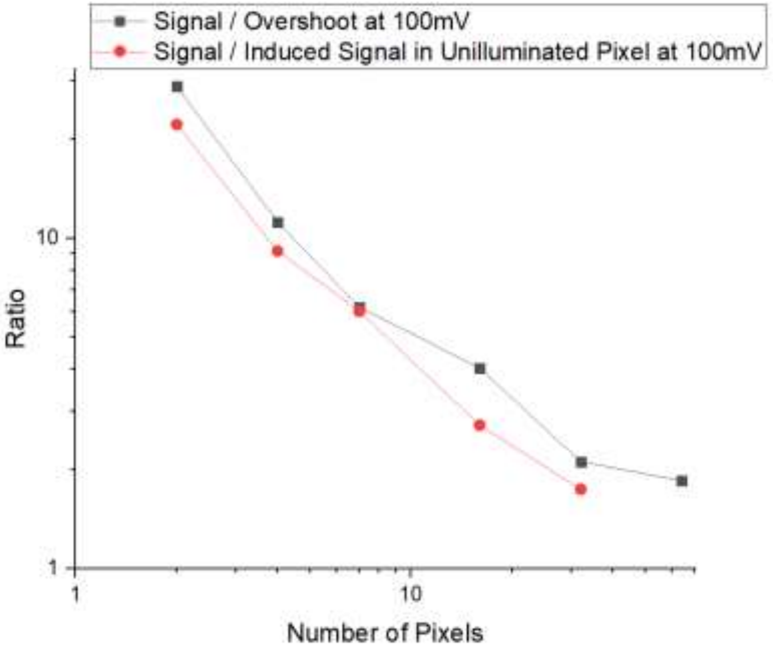
Phase the delay to be the same time, 20 pixels hit at once giving constructive/destructive interference.




2 pixels
5ns
30 mV
4 pixels
8 pixels
16 pixels
32 pixels
64 pixels
Covered Pixel
Illuminated Pixel

Signal to Noise Ratio
(peak to peak amplitude)





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Pulse pair resolution: single pixel VS flood field

Super_MuSR requirement: 10ns

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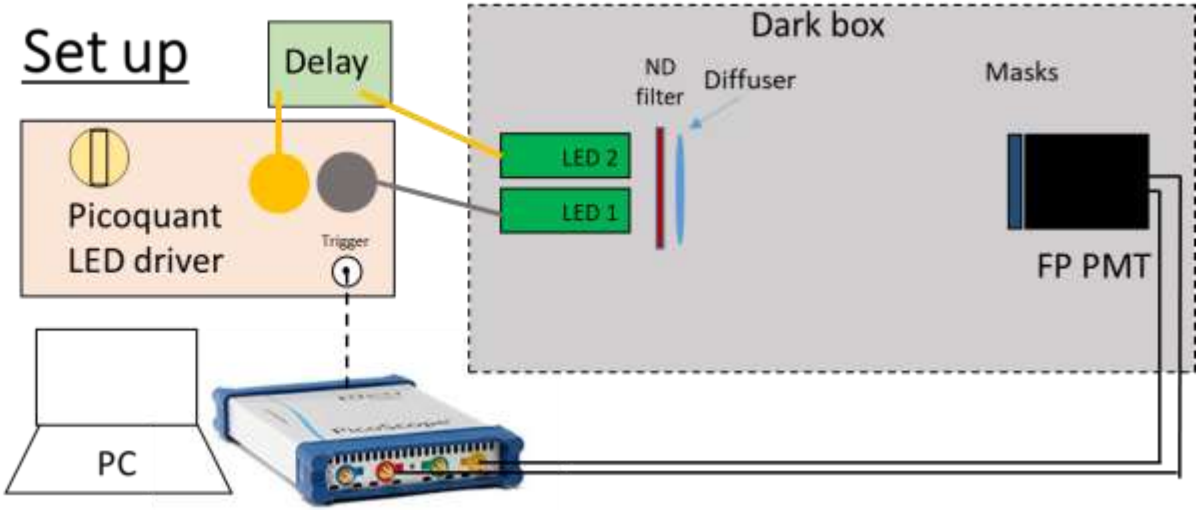
Setup



- LED pulses with a pair separated by a variable amount. (range of 0.0ns to 6.0ns)
- The pairs of pulses are separated by 50us.

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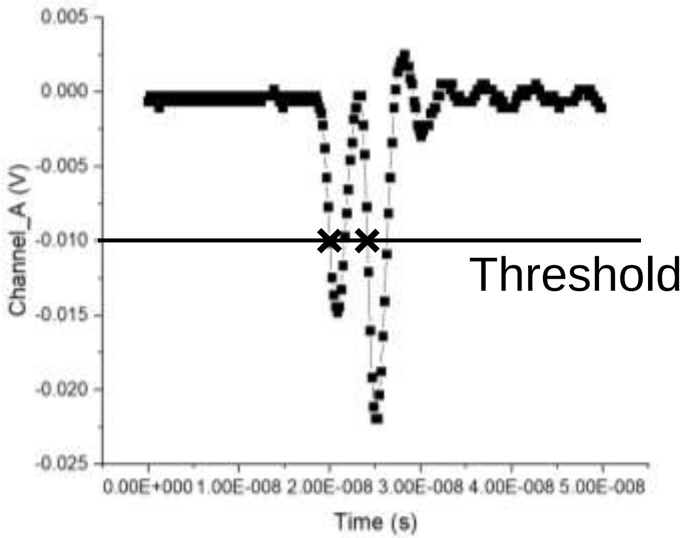
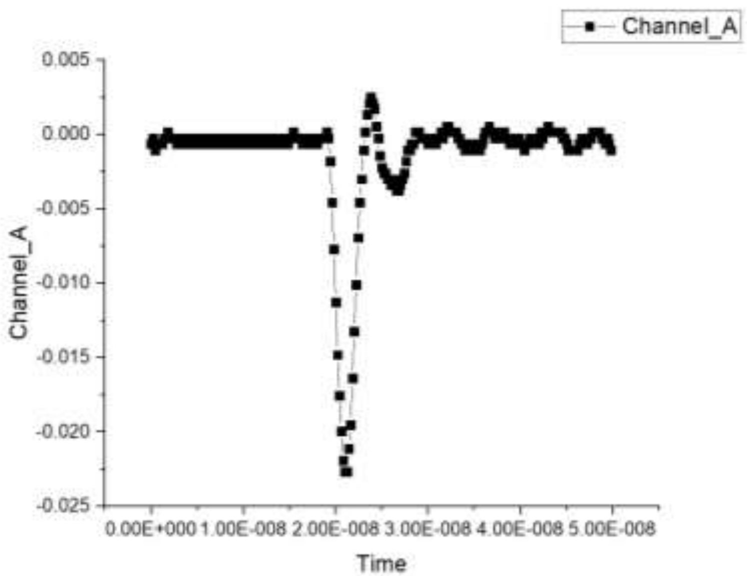
Measurement of Pulse Pair Resolution



This would give a separation



This would not give a separation

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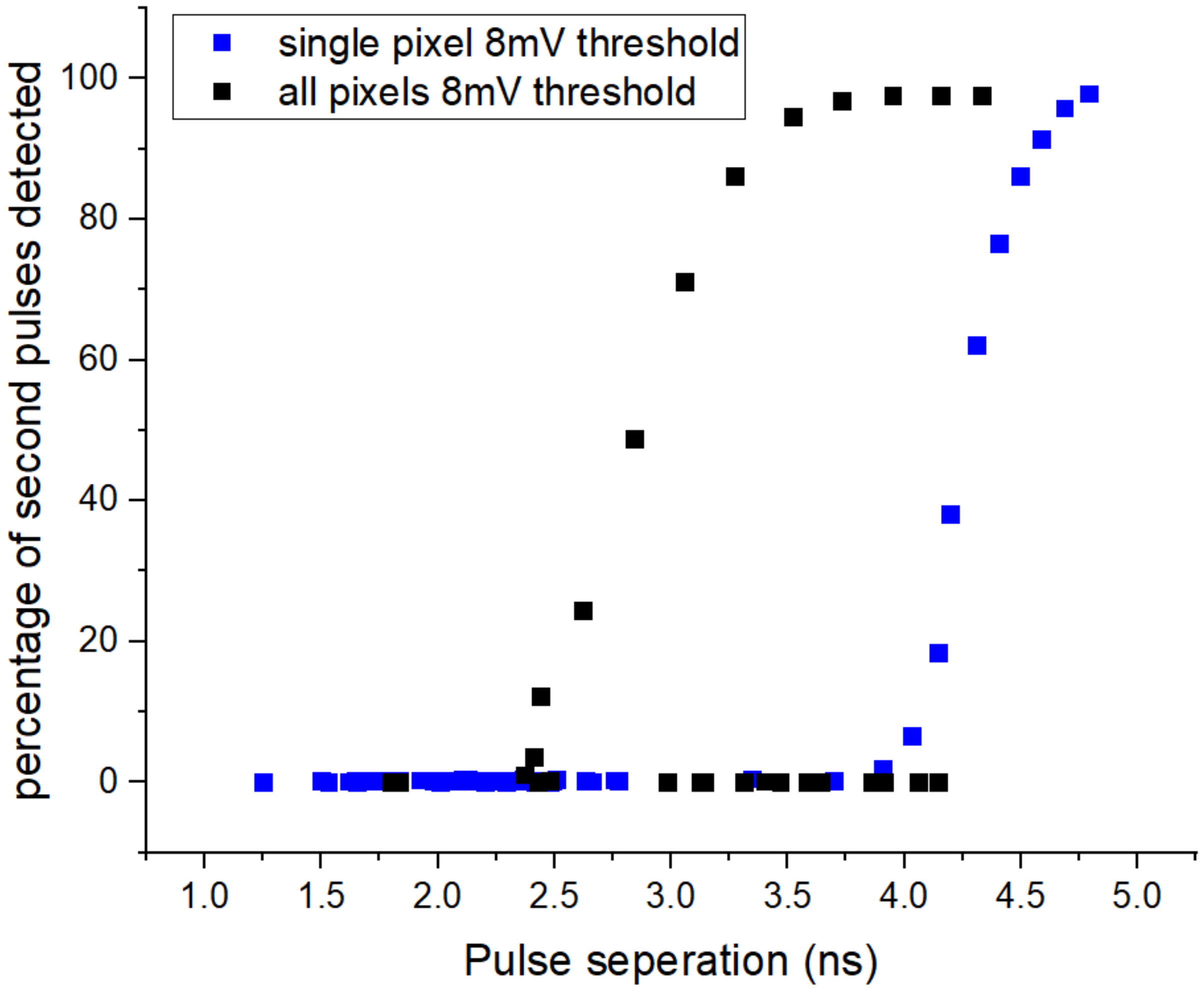
Results



Pulse separation is good enough for Super_MuSR but measurement performed **at extremely low light levels.**

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Timing and Signal Shape Summary

- $dt = \sqrt{dt_{PMT}{}^2 + dt_{Fiber}{}^2 + dt_{Scintillator}{}^2}$

Amplitude	dt_{PMT}	dt_{Fiber}	$dt_{Scintillator}$	dt
60mV	0.1944 ns	0.981 ns	1.1395 ns	**1.52 ns**
100mV	0.1474 ns	0.735 ns	0.7892 ns	**1.09 ns**

- Timing resolution as a function of WSF length measured to be negligible.
- Pulse pair resolution (count rate) meets specification for small signals
- Needs further prototyping.

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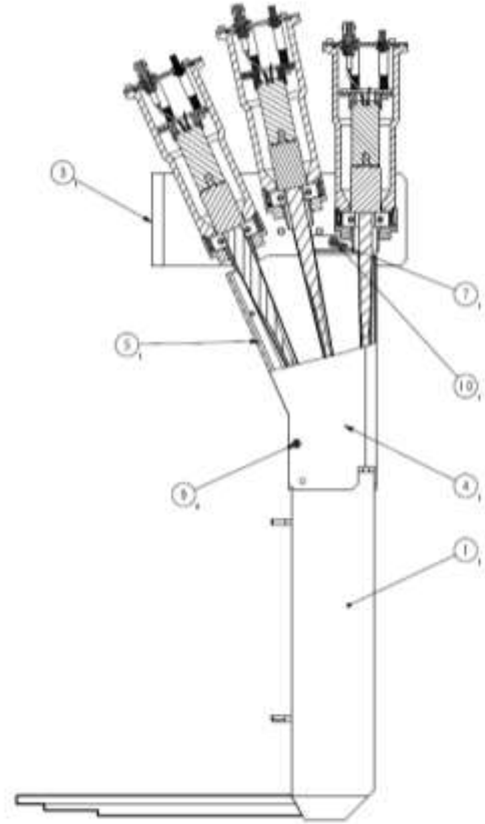
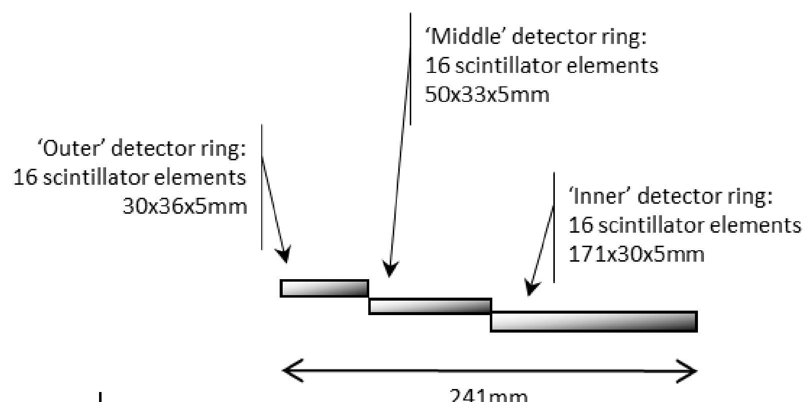
Prototype detector module or EMU Spectrometer





3-element Prototype using H12700 on EMU spectrometer

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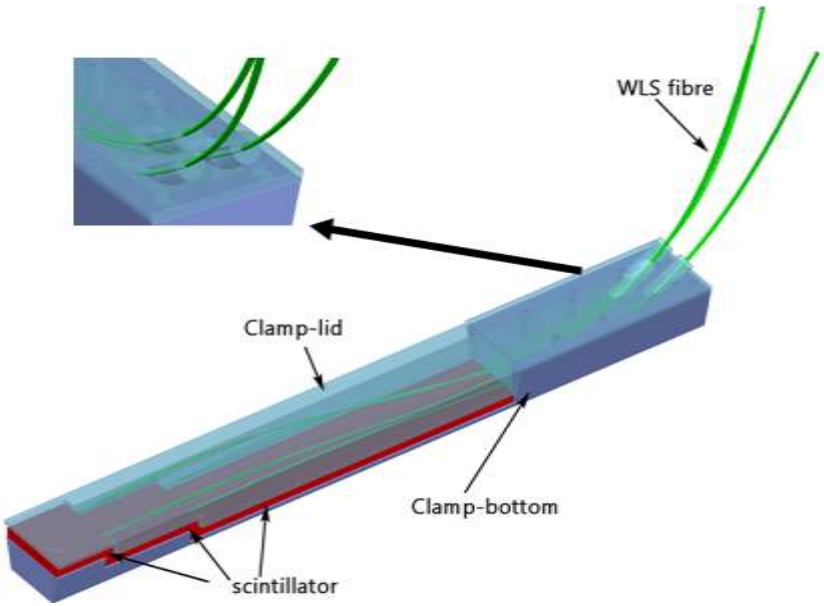
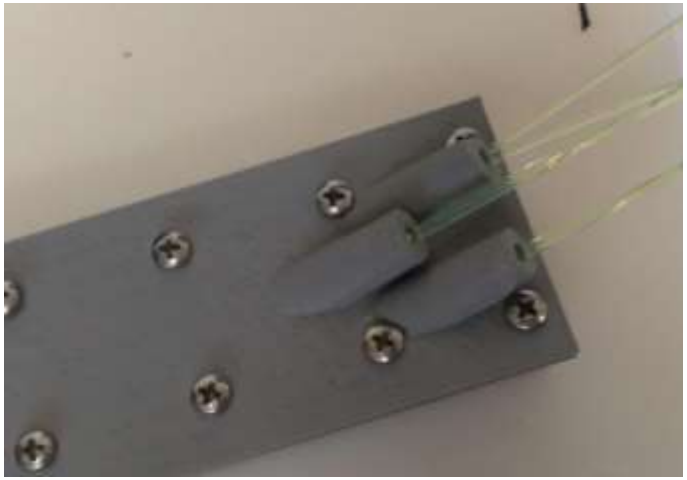
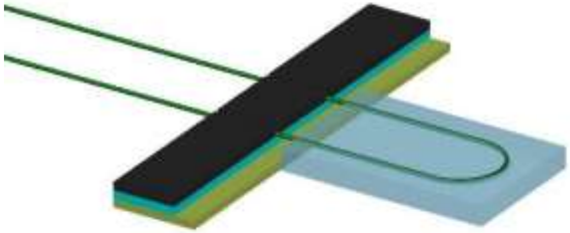
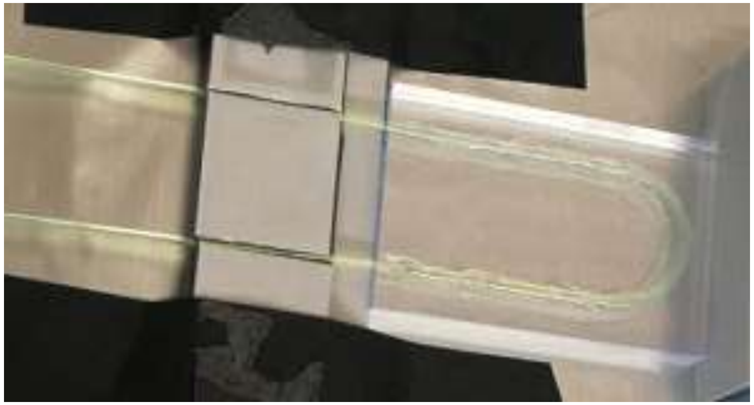
Building compatible detector

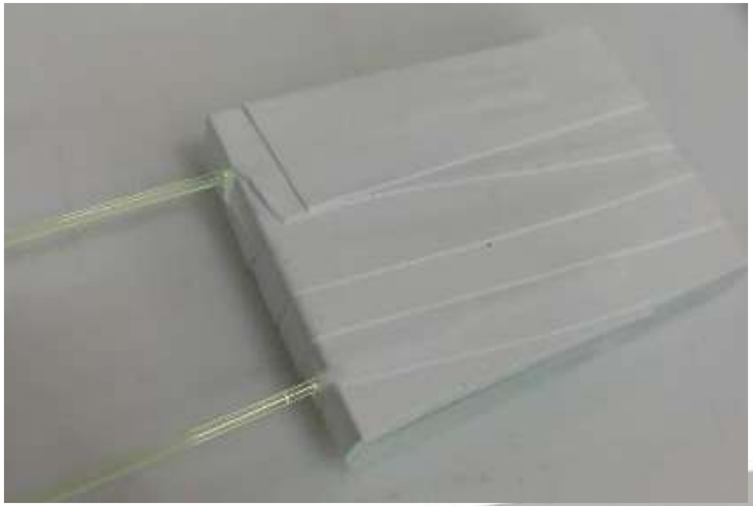




Building compatible detector







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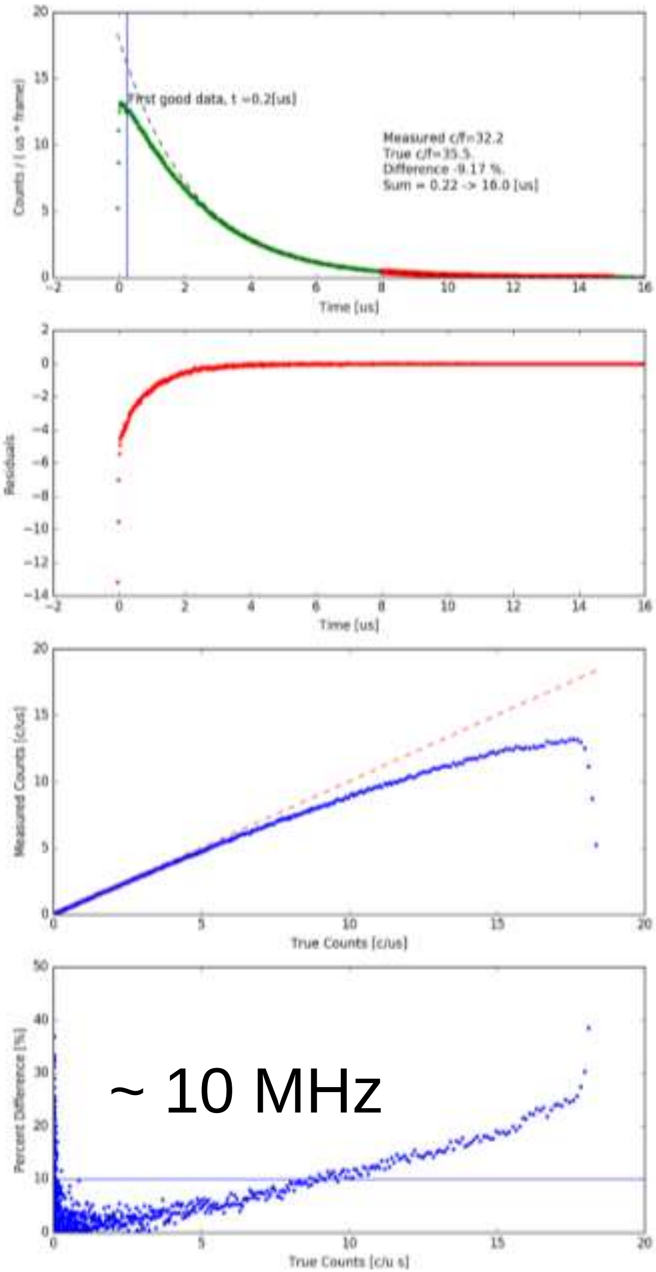
Compare Detectors:

EMU H5505

FPPMT

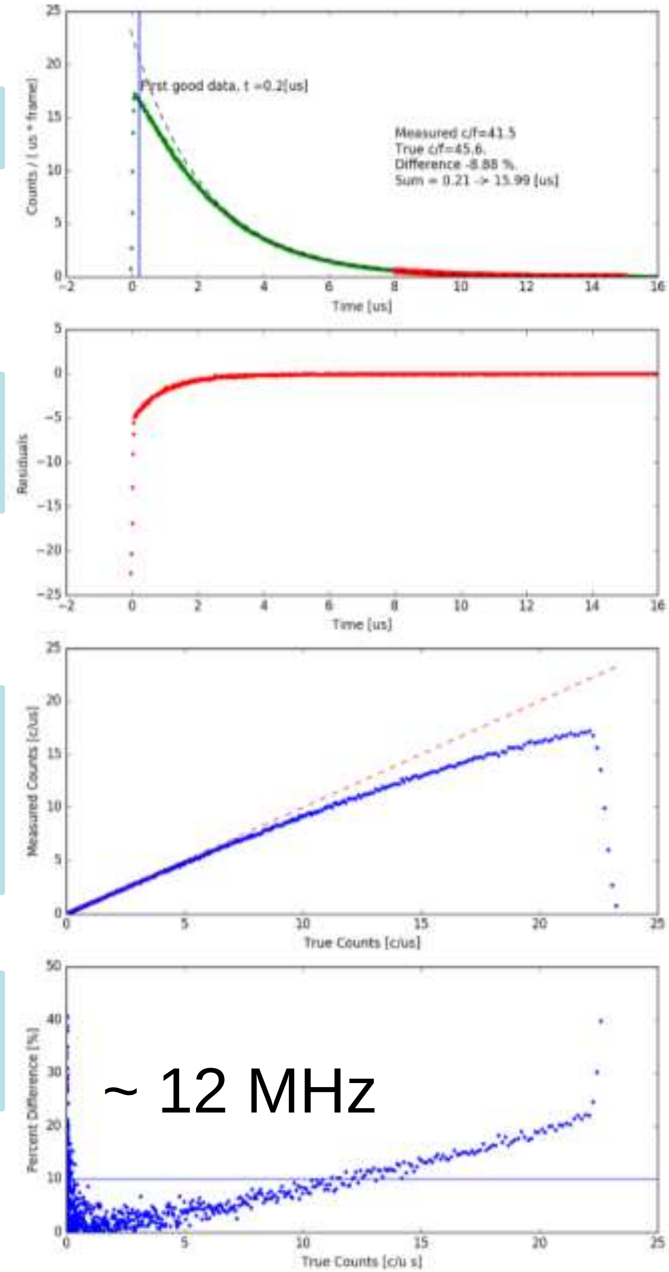


Muon Lifetime Histogram

Check residuals for good fit

Plot measured rate Vs true rate and y = x

10% dead time for comparison



Detector Build Summary

- First prototype installed and demonstrated to work at required rates and resolutions.
- Trouble magnetically shielding (not shown) but have good experience with neutron applications and from the literature.
- Will scale up with 64ch demonstrator in final months (and future).

Some closing highlights

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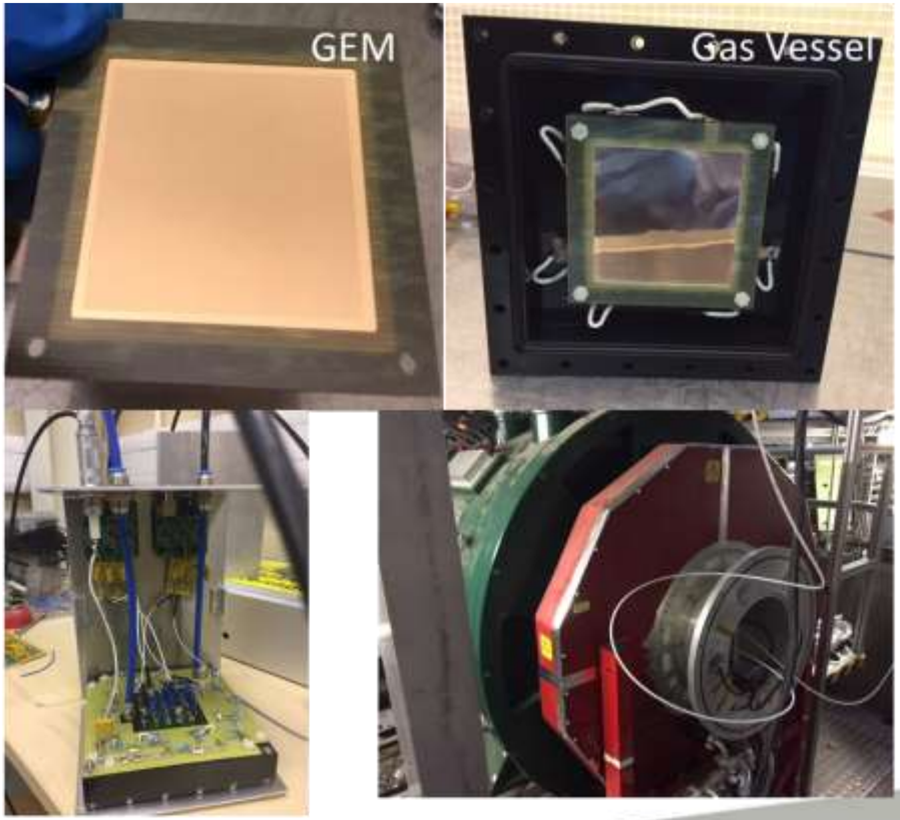
GEM gas detector
Davide Raspino

- The triple GEM detector is able to provide a positron efficiency comparable to the existing scintillator detectors

- The triple GEM detector is fundamentally insensitive to magnetic fields up to 5 T

- More work is needed on the electronics to reduce the time width of the signals and consequently reduce the dead time



Electronics

Prototype under test on HiFi

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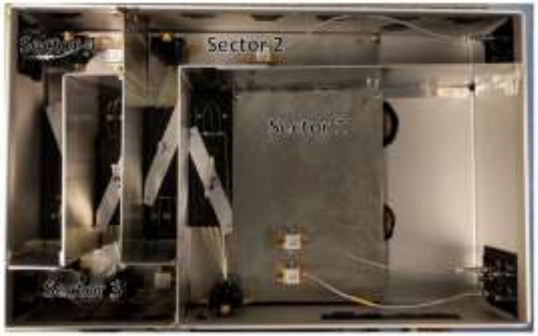
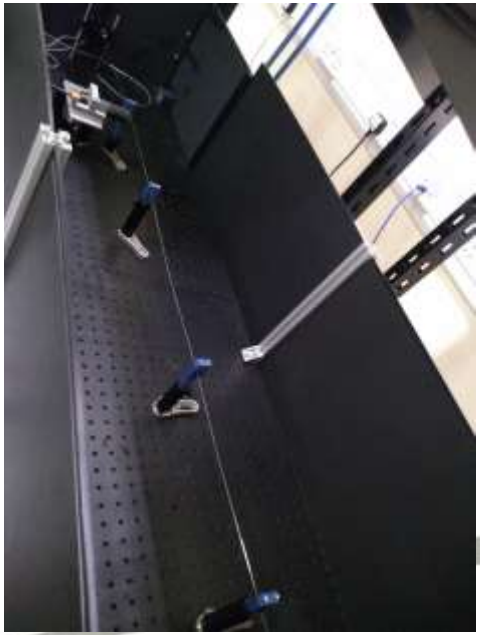
IMPACT: SINE2020 evaluation of detectors steering Super-MuSR development strategy

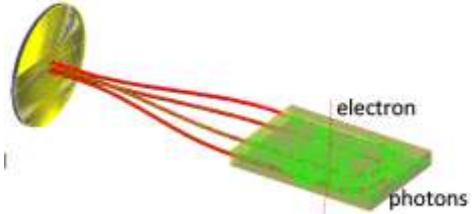
Beamline Tests

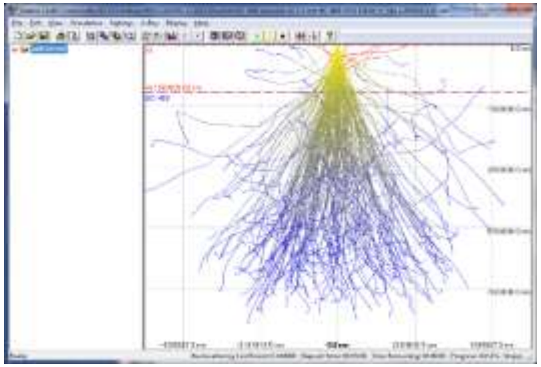


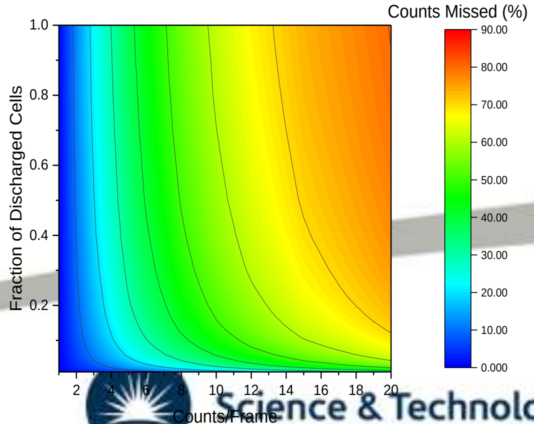
Optical Investigation



Simulation







IMPACT: Education & Training

Jacob Young

Lakshan Ram Mohan

Ziwen Pan

Myron Huzan

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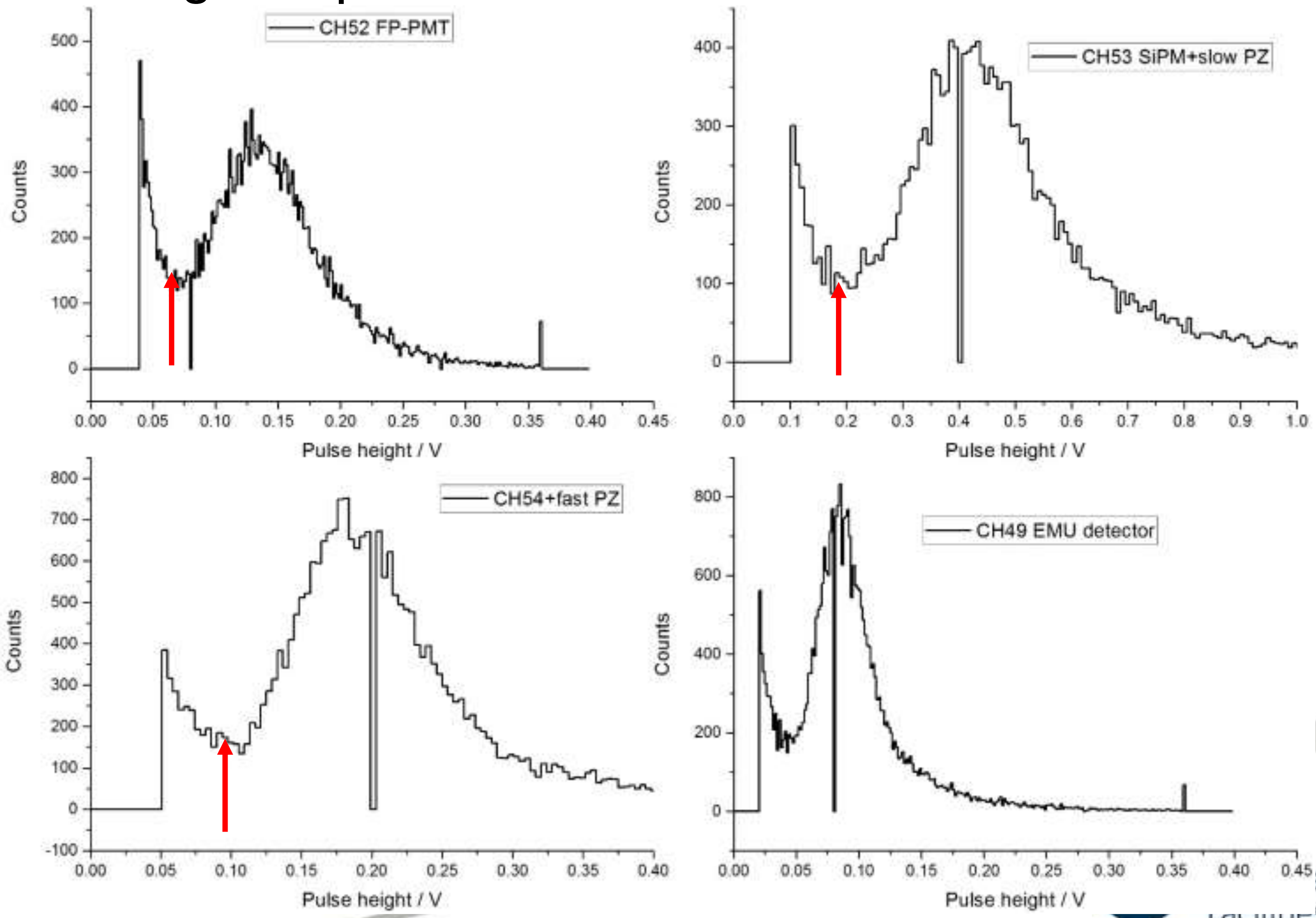
Thank you, Question?

Additional Material

2 Beam test for EMU detector box

Pulse height sepctrum



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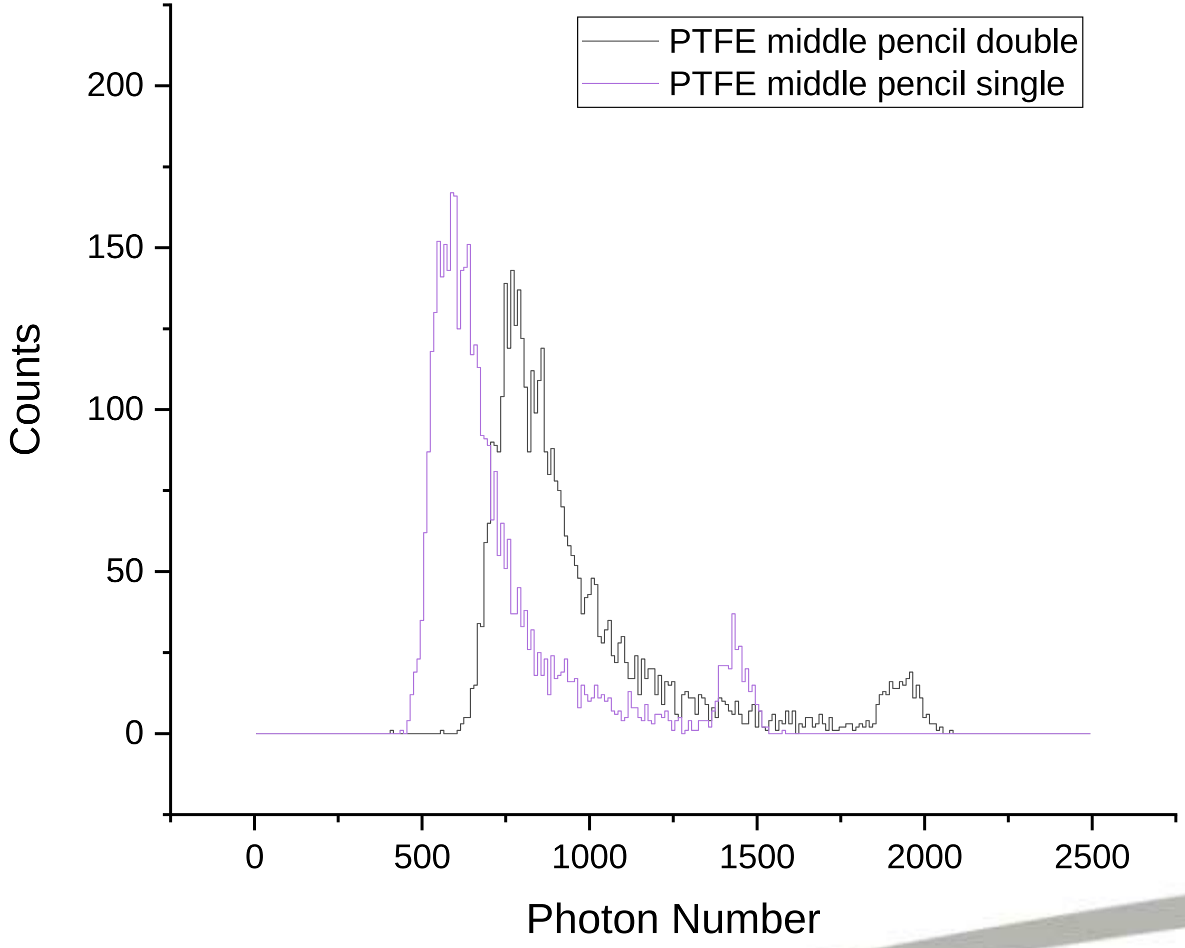
Light collection with fibre number



Going from 2 to 1 fibres ~ -25%

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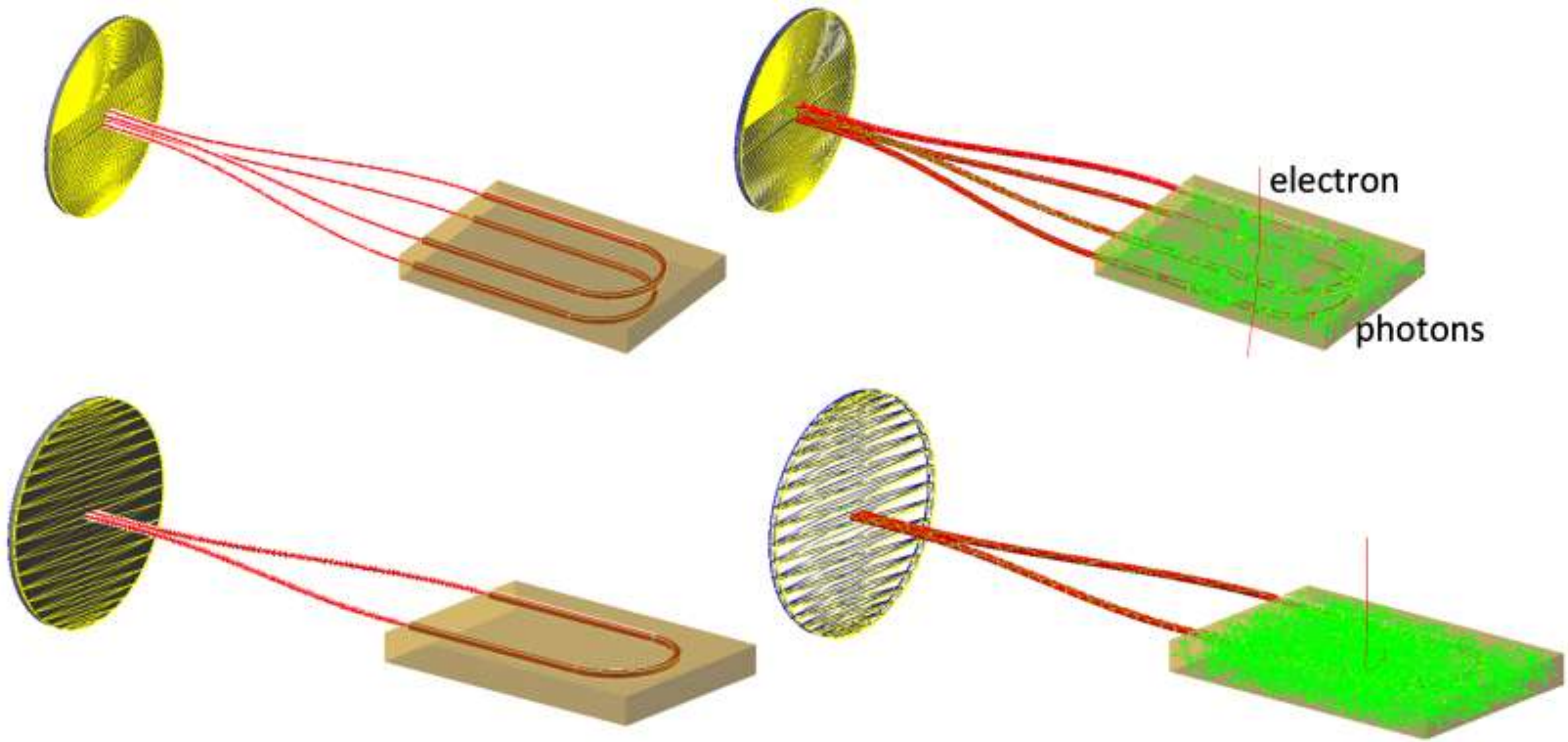
Zi-Wen Pan

Simulation of reflectors and light collection



Investigate reflectors, fibre number, and homogeneity.

Material	Refractive index	Bulk absorption length / cm	Wave length of maximum emission / nm	Light yield Counts/MeV	Decay time / ns	Rise time / ns
BC408	1.58	380	425	10000	2.1	0.9
Air	1.0	Very long (1000m)	-	-	-	-
BC600	1.56	12.5	-	-	-	-
grease	1.47	20	-	-	-	-
BCF-92	1.59	3.5	492	-	2.7	-

Zi-Wen P

Simulation of reflectors and light collection

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 59, NO. 3, JUNE 2012

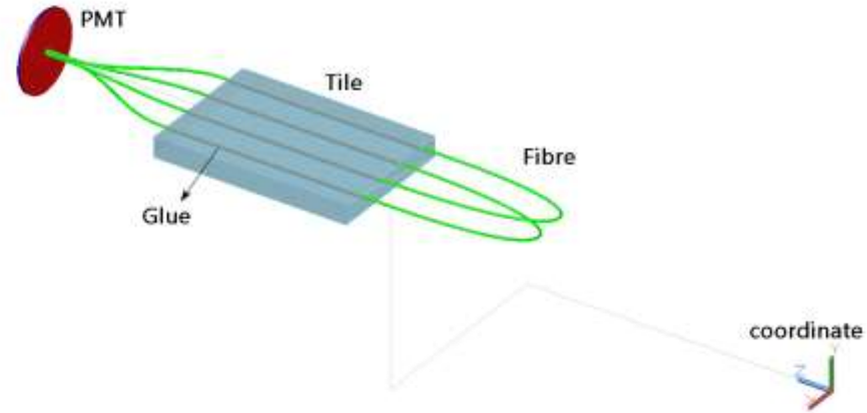
Reflectivity Spectra for Commonly Used Reflectors

Martin Janecek

TABLE I
EXAMINED REFLECTORS

Reflector	Refl. Coeff. @ 440nm	Thickness [mm]	Source	Refl. Ref.
SRS-99 (White Standard)	0.988	10	Labsphere, Inc. North Sutton, NH	*company**
Spectralon (WS-1-LS)	0.993	10	Ocean Optics, Inc. Dunedin, FL	*company**
Teflon® tape (matte)	0.99	*n* x 0.06	ACE Hardware Oak Brook, IL	[18-20]
PTFE tape (glossy)	0.99	*n* x 0.08	*unknown origin*	[18-20]
Tetratex® film (matte)	0.99	*n* x 0.16	Tetratec™ Corp. Feasterville, PA	[18-20]
Titanium dioxide paint	0.955	0.14–0.18	Saint-Gobain Hiram, OH	*company**
Magnesium oxide	0.98	1.0	Mallinckrodt, Inc. Paris, KY	[11, 15]
GORE® diffuse reflector	0.99	0.50	W.L.Gore & Associates, Inc. Newark, DE	*company**
Nitrocellulose	1.02†	0.12	Advantec MFS, Inc. Dublin, CA	*measured*
Lumirror®	0.98	0.24	Toray, Japan	[7]
Melinex®	0.98	0.125	Dupont™ Wilmington, DE	[7]
Tyvek® paper	0.97	*n* x 0.11	Dupont™ Wilmington, DE	[7]
ESR film	0.985	0.065	3M St. Paul, MN	*company**, [25]
Aluminum foil	0.78	0.025	Kaiser Foil Northbrook, IL	[7]

** the reflection coefficient data provided by the manufacturer were used*
† the reflection coefficient was measured to be 103% of the reflection coefficient of four layers of ACE Teflon® tape at 440nm (i.e., 1.03 x 0.99) [7]



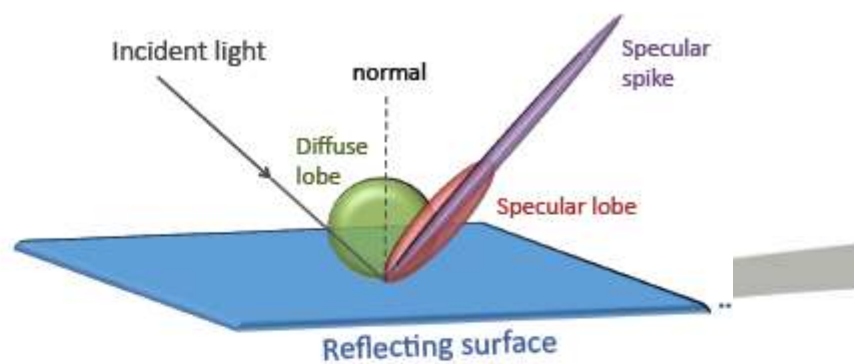


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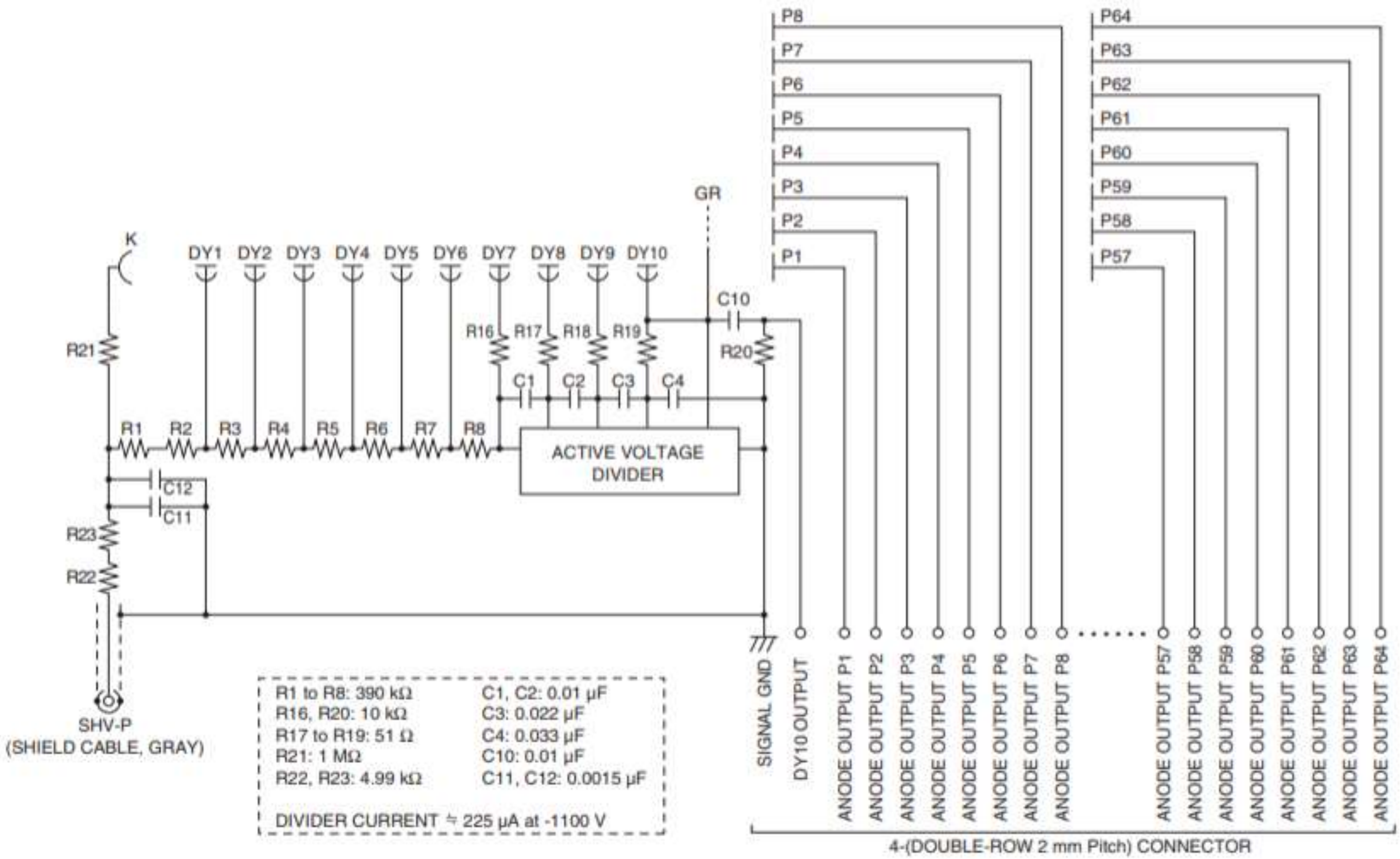
Figure 7: Internal circuit

H12700A / H12700A-03



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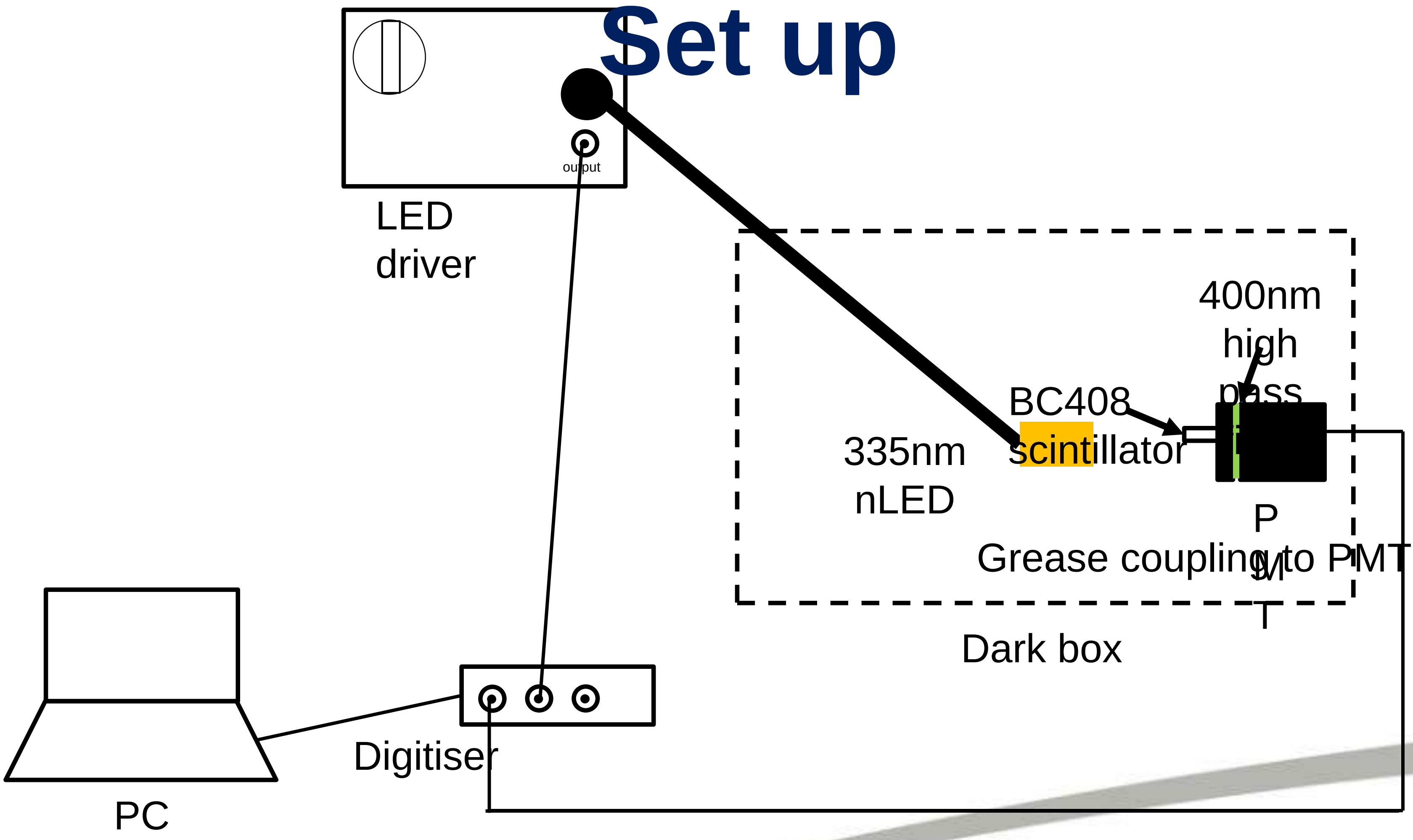
Set up



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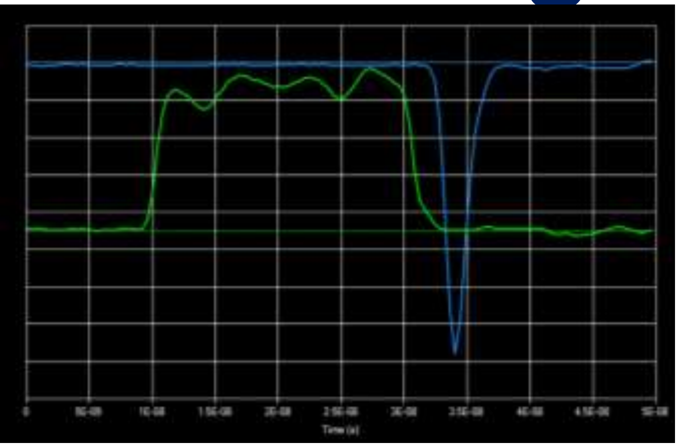
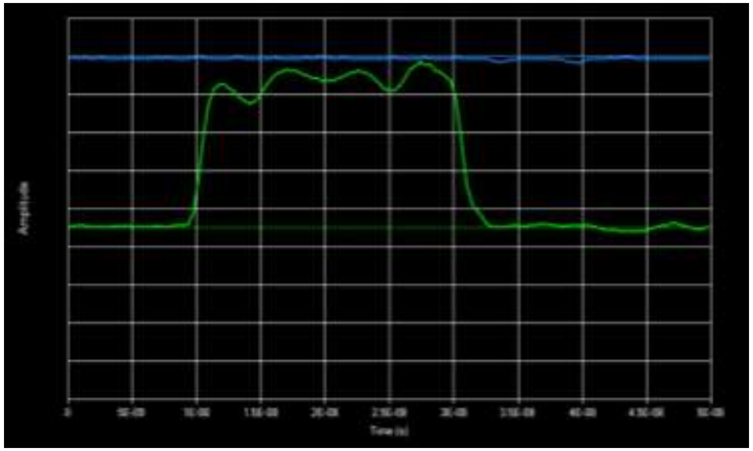
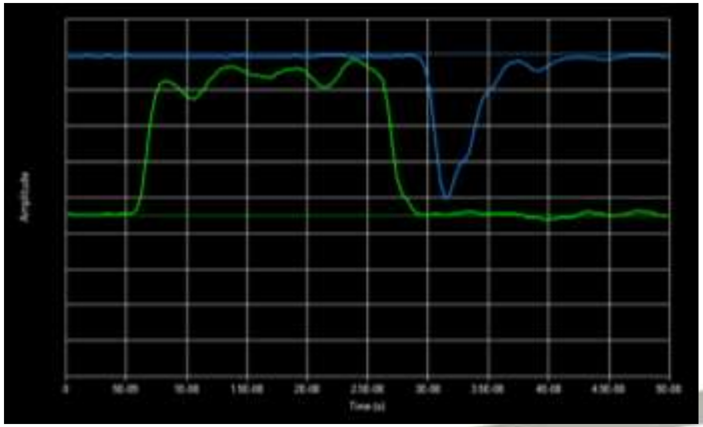
High pass



1) Trigger signal and PMT signal from nLED.



2) Trigger signal and PMT signal from nLED with high pass filter on PMT.



3) Trigger signal and PMT signal from scintillator.

Note: the scale of each channel is different.

Timing Resolution of Wavelength Shifting Fiber

Sources of Resolution Loss	
Unrelated to Fiber Length	**Related to Fiber length**
Initial scintillation process in fiber.	Attenuation of photon count.
	Wavelength dispersion in the fiber.

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Attenuati

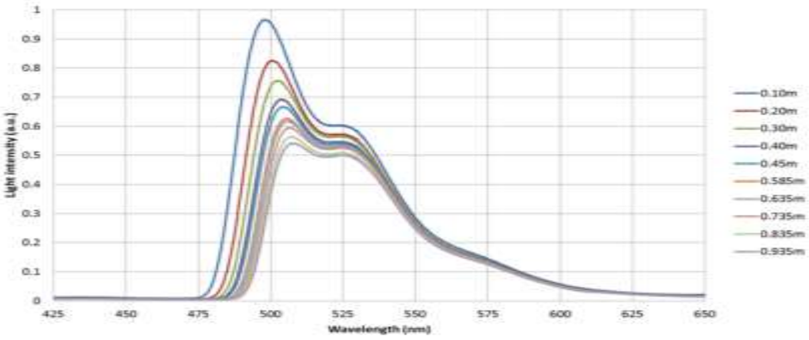
- 2 mechanisms for attenuation in the fiber:

1) Self-absorption

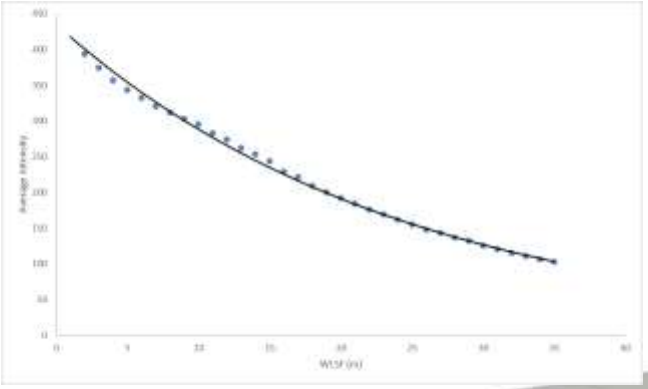
- The shorter wavelengths in the emission spectrum have a higher probability of being reabsorbed along a longer fiber, causing a shift in the wavelength peak emitted from the end of the fiber.

2) **Light leaks**

- The fiber leaks light causing a reduction in signal size across all wavelengths.
- Since the relationship between fiber length and signal size is well understood, this was not tested.
- As previously discussed – smaller signals give poorer resolution.



Plot of intensity against wavelength for different fiber lengths (data taken by Quintino Mutamba)



Plot of light intensity against length of the fiber – data taken by Quintino Mutamba.

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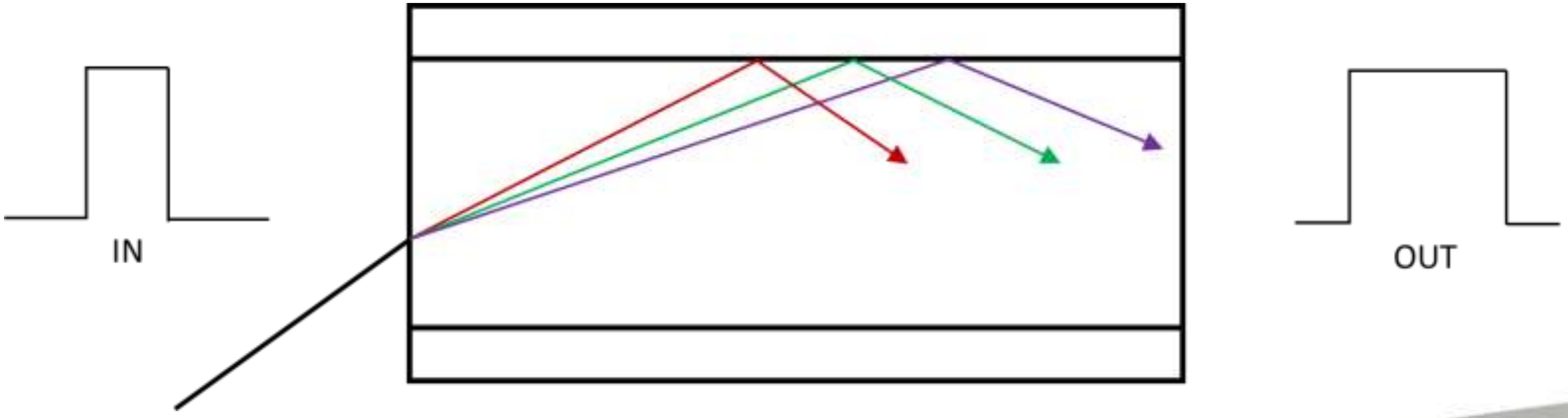
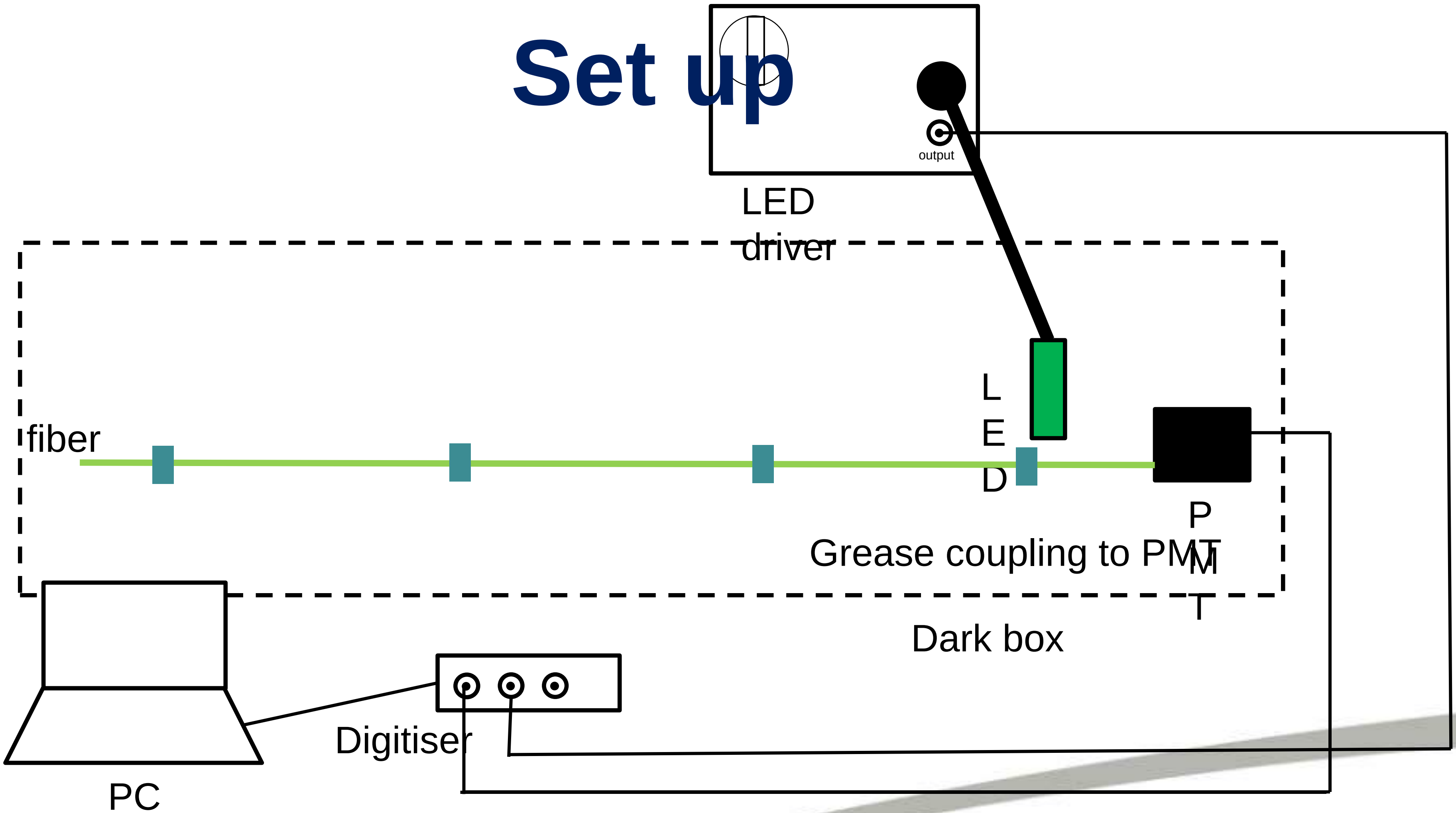
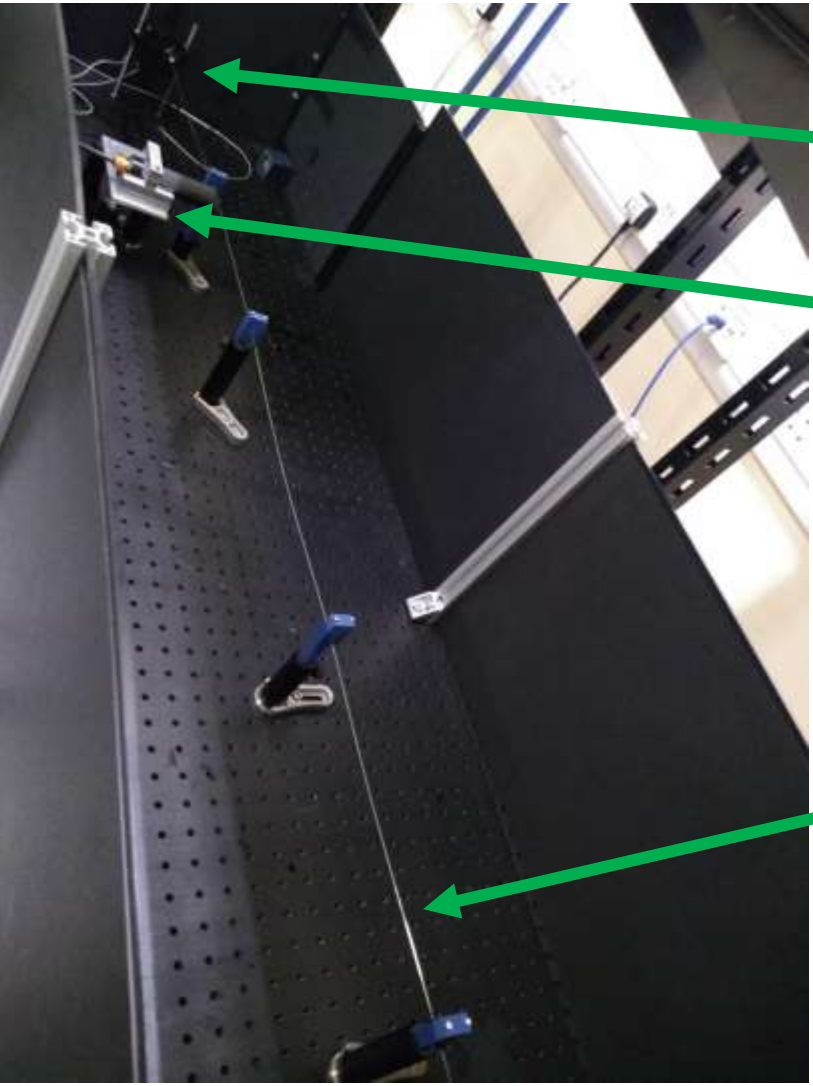
Wavelength based dispersion

- The speed of light in a fiber is a function of wavelength.
- This could cause a broadening of the light pulse with fiber length and affect the timing resolution.



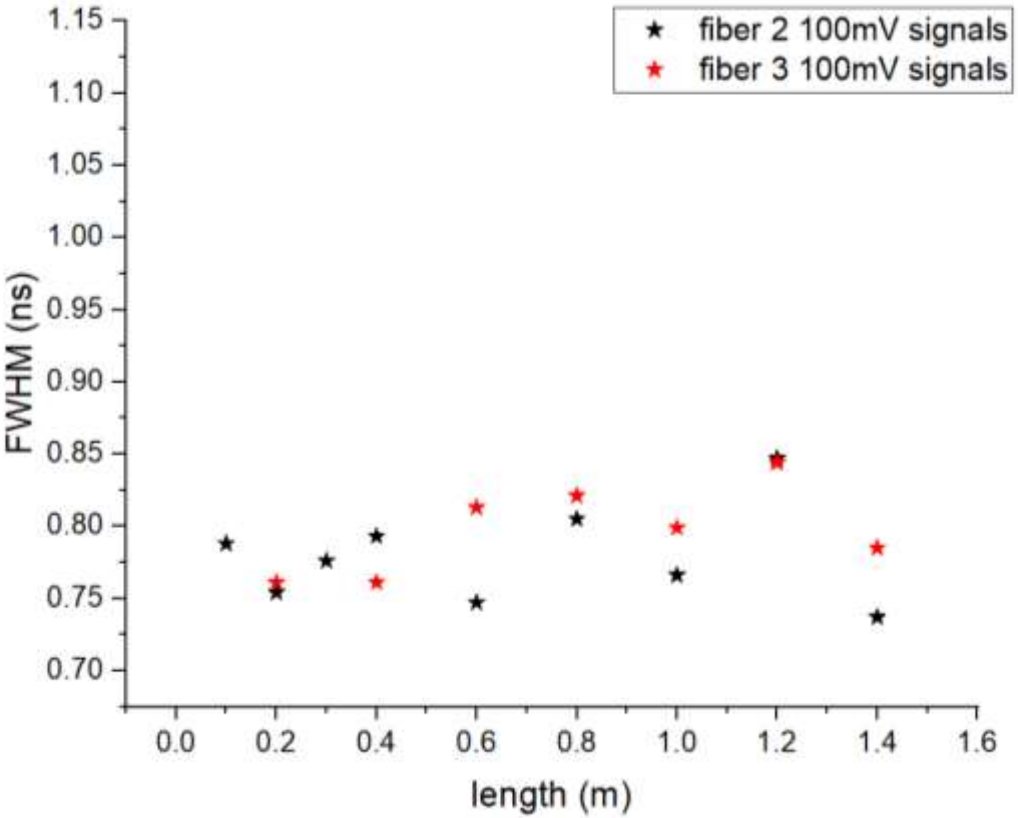
Set up


output
LED driver
fiber
L
E
D
P
M
T
Grease coupling to PMT
Dark box
Digitiser
PC



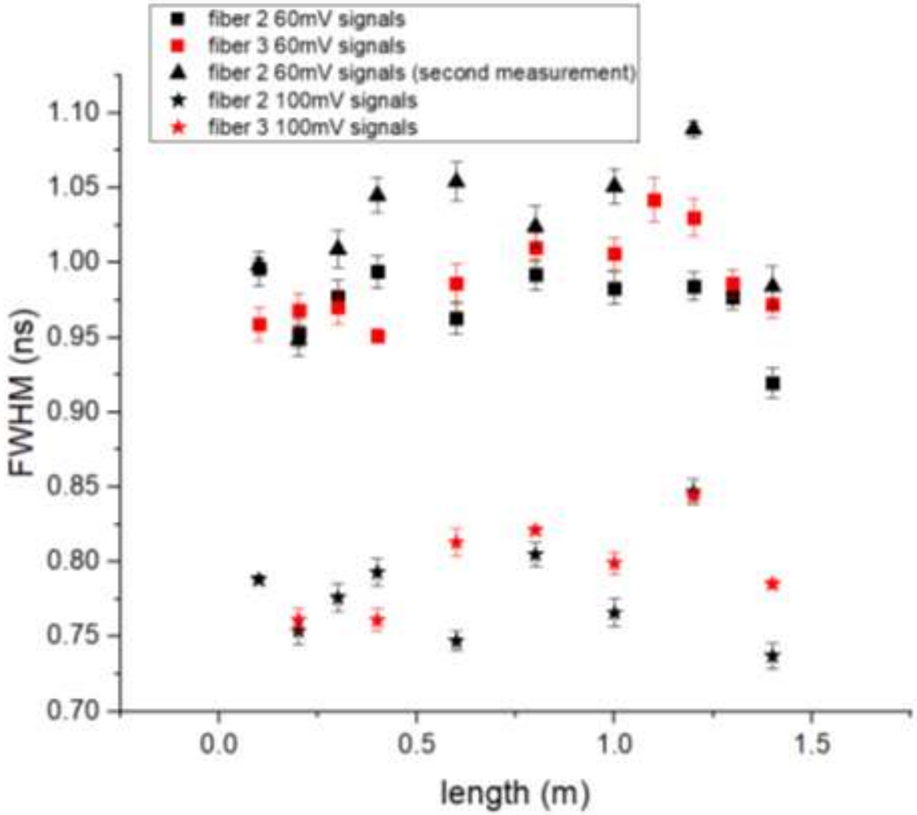
Fiber prepared in stand

Resolution of Fiber Due to length



resolution against fiber length for 100mV signals

- 2 different fibers with approximately 100mV signals being output from the PMT.
- Timing resolution around 0.77ns. Along all lengths



- At 60mV resolution is around 1ns.
- Length has no impact on resolution up to 1.4m
- Wavelength based dispersion and self absorption do not affect resolution.