Digital pulse shape discrimination applied to capture-gated neutron detectors

P.J. Sellin, S. Jastaniah, W. Catford

Department of Physics
University of Surrey
Guildford, UK

p.sellin@surrey.ac.uk

www.ph.surrey.ac.uk/cnrp

Contents

An overview of the neutron detector work carried out recently at the University of Surrey:

- Background to the project:
  - Pulse shape discrimination (PSD) in liquid scintillators
  - Digital PSD algorithms
  - 10^{B}-loaded scintillator for capture-gated fast neutron detection
- Results from the digital system:
  - Digital PSD from integrated and current pulses
  - PSD Figure of Merit (FOM)
  - capture-gated neutron detection
- Conclusions
- References: this presentation covers data recently published:

SD Jastaniah and PJ Sellin, "**Digital pulse-shape algorithms for scintillation-based neutron detectors**", IEEE Trans Nucl Sci 49/4 (2002) 1824-1828.

SD Jastaniah and PJ Sellin, "**Digital techniques for n/g pulse shape discrimination and capture-gated neutron spectroscopy using liquid scintillators**", submitted to NIM A.

Introduction

Motivation for this work:

- Development of digital neutron monitors for neutron field measurements, homeland security, and neutron dosimetry

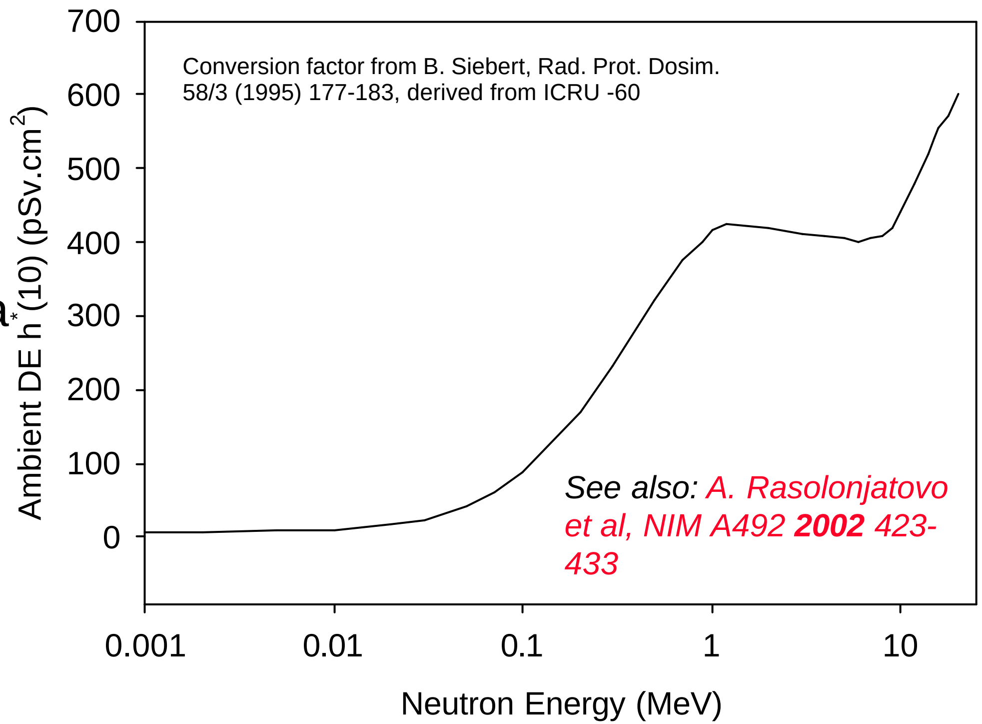
- Portable instruments can take advantage of compact digital pulse processing technology

- Emphasis on fast computationally-simple digital algorithms suitable for field instruments

- Efficient n/γ discrimination is essential - the extraction of a weak fast neutron flux against a strong gamma ray background

- Full-energy fast neutron spectrometry has particular advantages for dosimetry detectors:

Neutron Fluence to Ambient Dose Equivalent conversion factor



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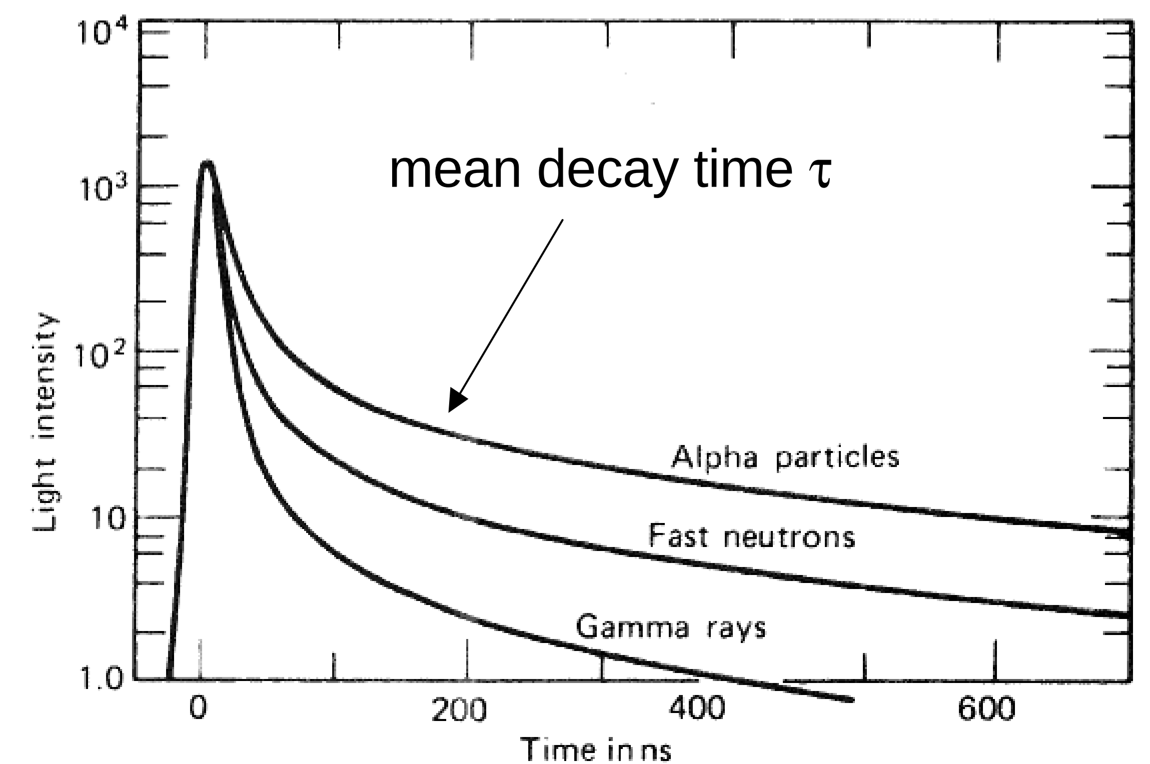
Pulse shape discrimination

- Pulse shape discrimination (PSD) in organic scintillators has been known for many years - particularly liquid scintillators (NE213 / BC501A)
- PSD is due to long-lived decay of scintillator light caused by high $^{de}/_{dx}$ particles - neutron scatter interactions events causing proton recoils:



Integrated vs current pulses

Extraction of scintillation decay lifetime t depends on the RC time constant of the external circuit:

Large time constant RC>>t**:**

integrated pulse - event energy extracted from pulse amplitud

t extracted from pulse risetime:

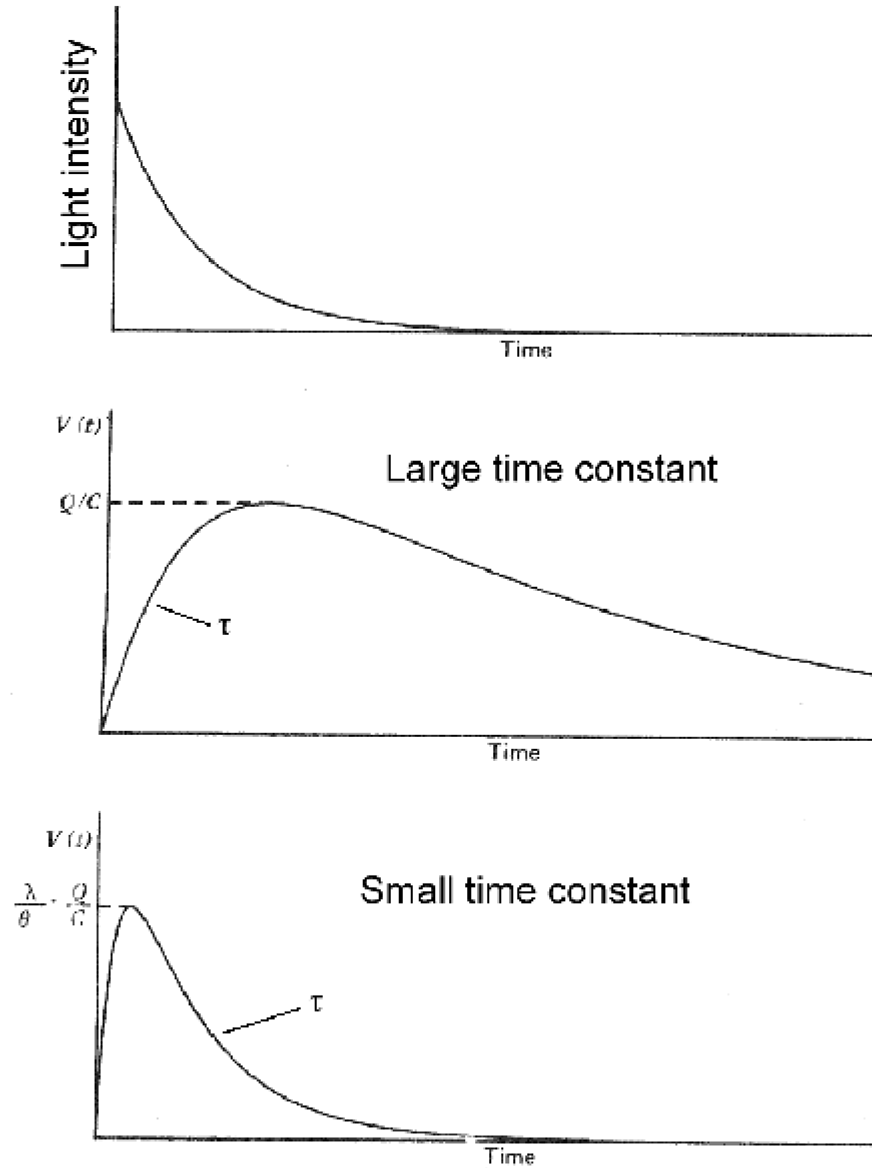
$$v(t) = \frac{Q}{C}\left(1 - e^{-\frac{t}{t}}\right) \quad for \;\; t << RC$$

Short time constant RC<<t**:**

current pulse - event energy extracted from pulse integral

t extracted from pulse decay time

$$v(t) \propto Q e^{-\frac{t}{t}} \quad for \;\; t >> RC$$



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Pulse risetime algorithms

Integrated pulses - using a PMT preamplifier

Improved signal-noise ratio

Risetime limited by preamp (~10ns)

Þ **10-90% risetime algorithm**

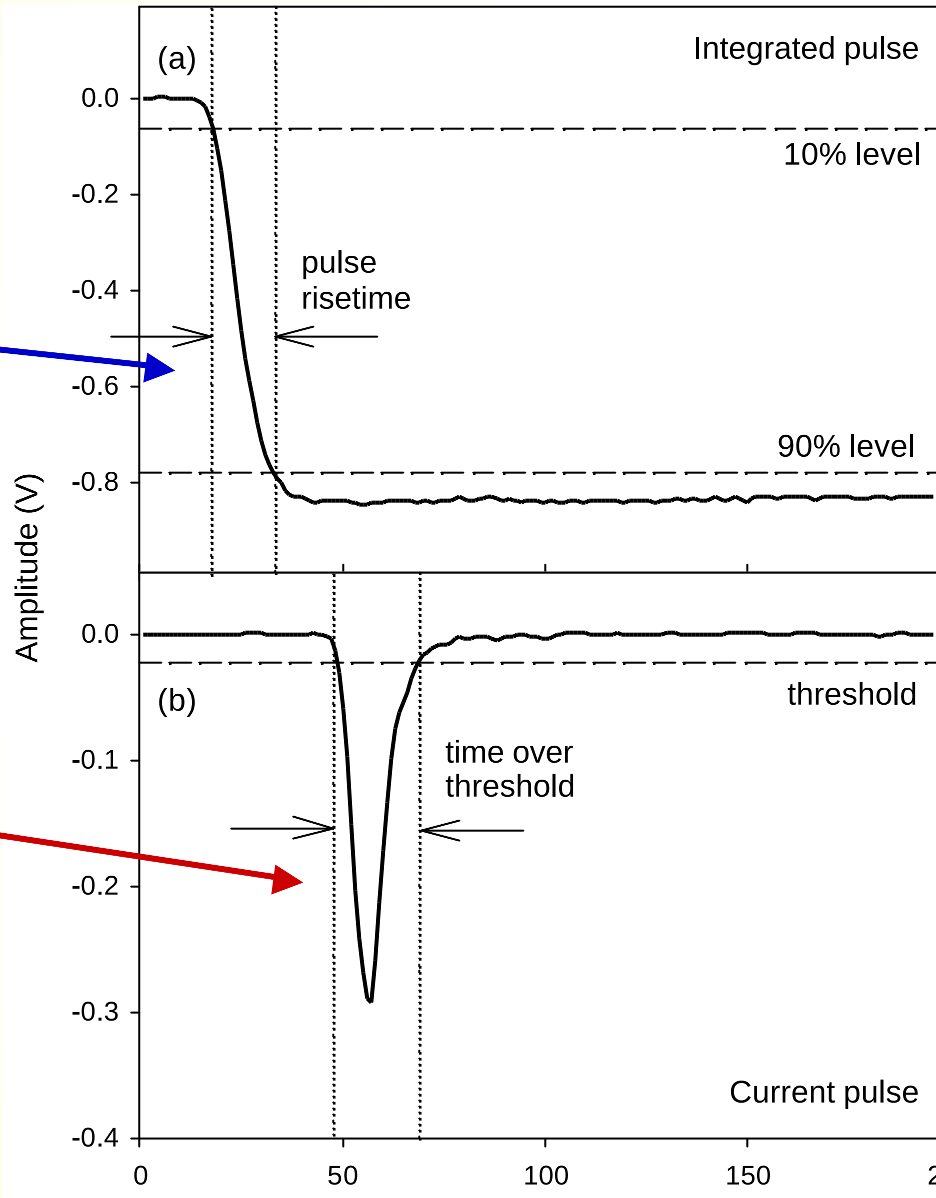
Current pulses - anode connected directly to 50Ω

Simple circuitry, fastest response

PSD algorithm affected by signal noise

Þ **'time over threshold' algorithm**

Other techniques use a full least-squares fit to the pulse shape, eg. N.V. Kornilov et al, NIM A497 ***2003*** *467-478.*



^{10}B loaded liquid scintillator

We have investigated liquid scintillator enriched with ^{10}B - BC523A

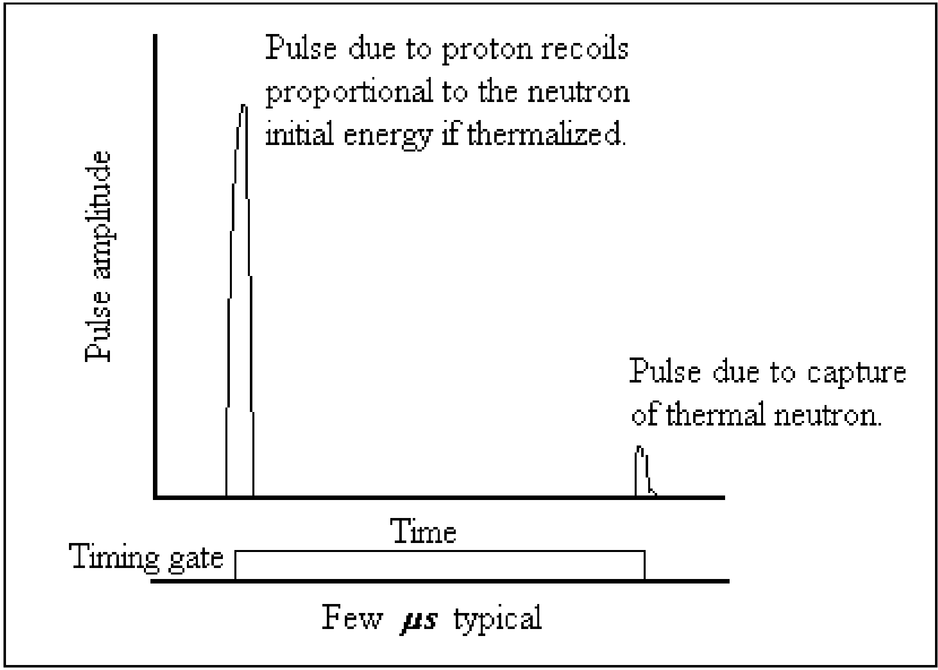
Often used for thermal neutron detection, 10B-loaded scintillator can also be used for 'capture-gated' neutron spectroscopy:

Characteristic **double-pulse sequence** of moderation + capture provides clean fast neutron signature.

Capture pulse has fixed amplitude (10B+n Q value)

Amplitude of **moderation pulse** gives incident neutron kinetic energy

$\Rightarrow$ true 'full energy' neutron spectrometer



Waveform Digitiser

High speed waveform digitisers now provide 1ns sampling times (1 GS/s), 8 bit resolution, high speed data transfer to PC:

We use the Cougar system from Acqiris - www.acqiris.com

4 channel compactPCI crate-based system, expandable up to 80 channels

Single channel specification:

8 bit resolution

1 GS/s, 500 MHz

2 Mpoints waveform memory

80 MB/s sustained data transfer rate to PC

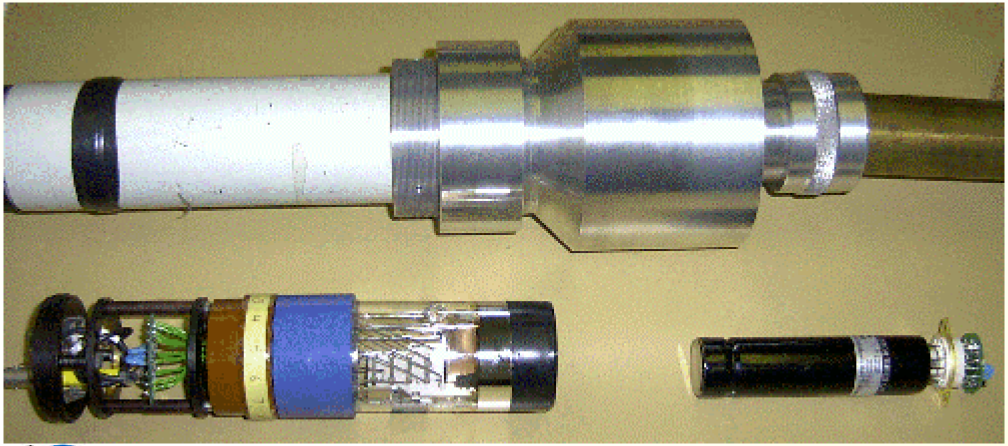
(12 bit cards, up to 400 MS/s also available)

Custom LabView software for real-time pulse analysis and histogramming

Detector Cells

Various liquid scintillator cells were made (100 ml and 700 ml), containing BC501A and BC523A

When filling the cells, the scintillator was bubbled with N_2 gas to purge the oxygen.



A two-detector cell was made, with a BGO embedded in the BC523A to detect coincident 478 keV gamma rays from ^{10}B reaction

Energy Calibration

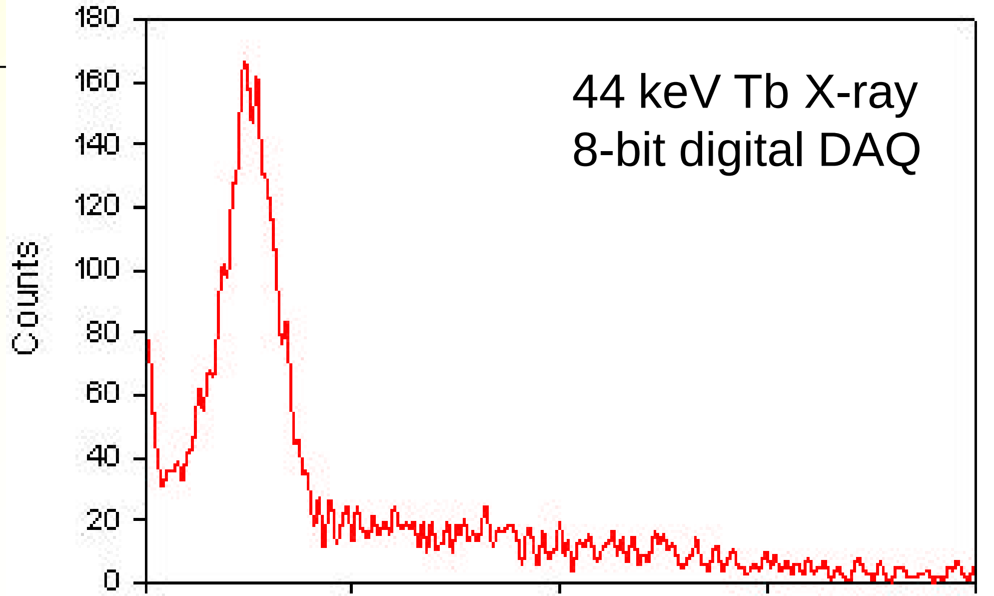
Liquid scintillator operated at 2 gain settings, with separate energy calibrations:

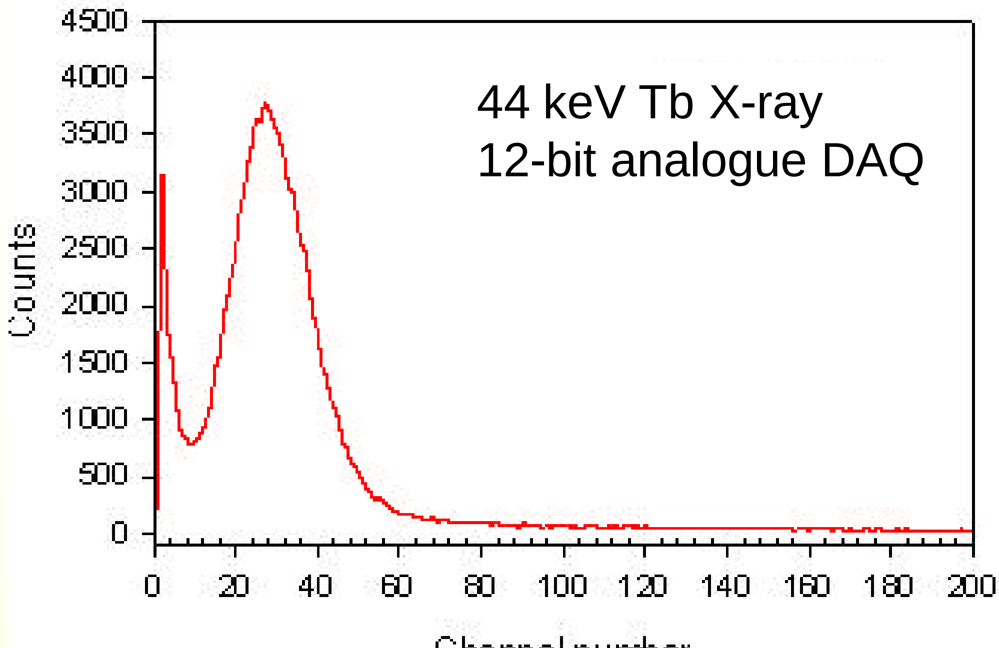
High Gain:

- photopeak for X/γ-rays < 60 keV:
  - Ba, Tb K X-rays
  - 241Am γ-ray

Low Gain:

- Compton edge for high energy γ-rays:
  - ^{57}Co
  - ^{137}Cs
  - ^{60}Co





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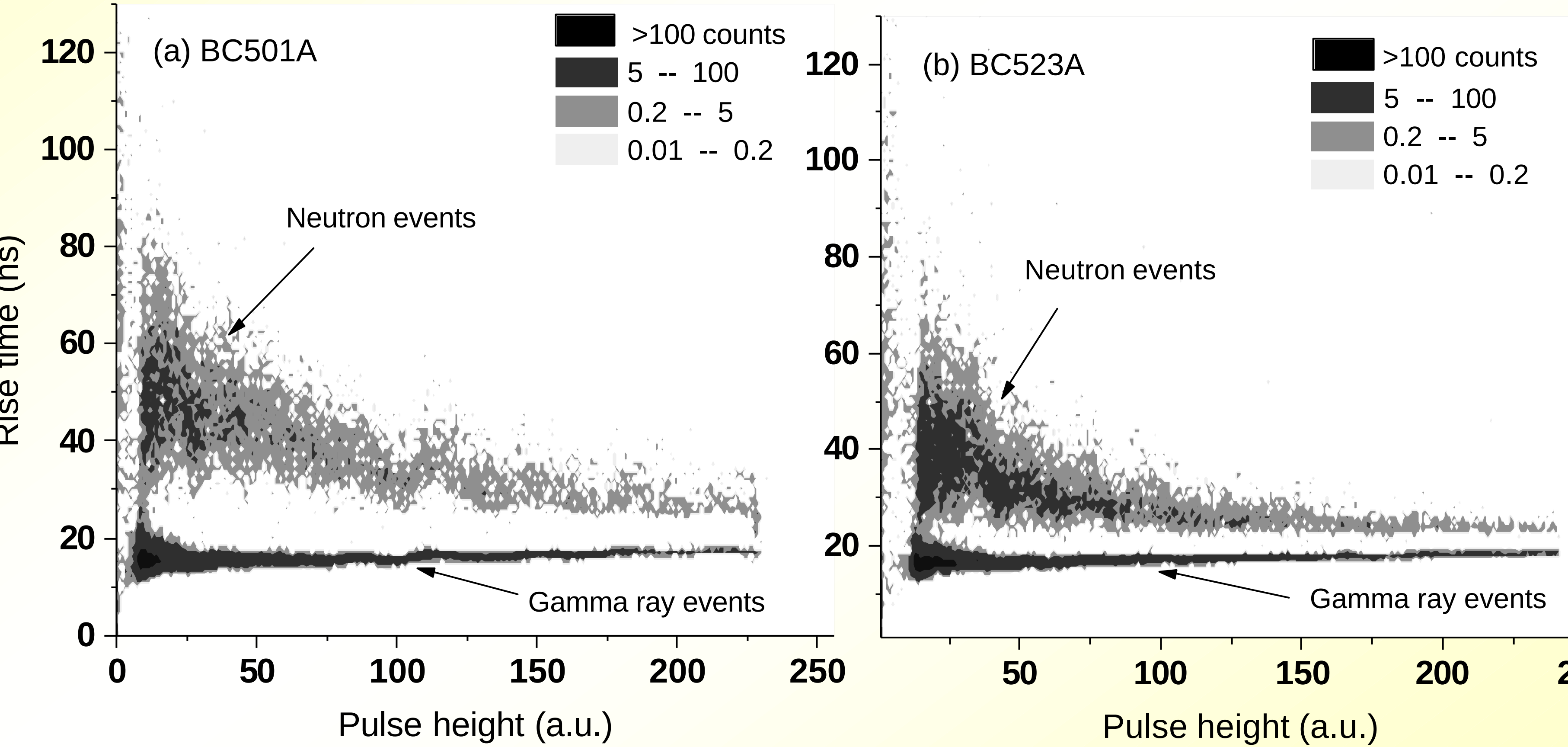
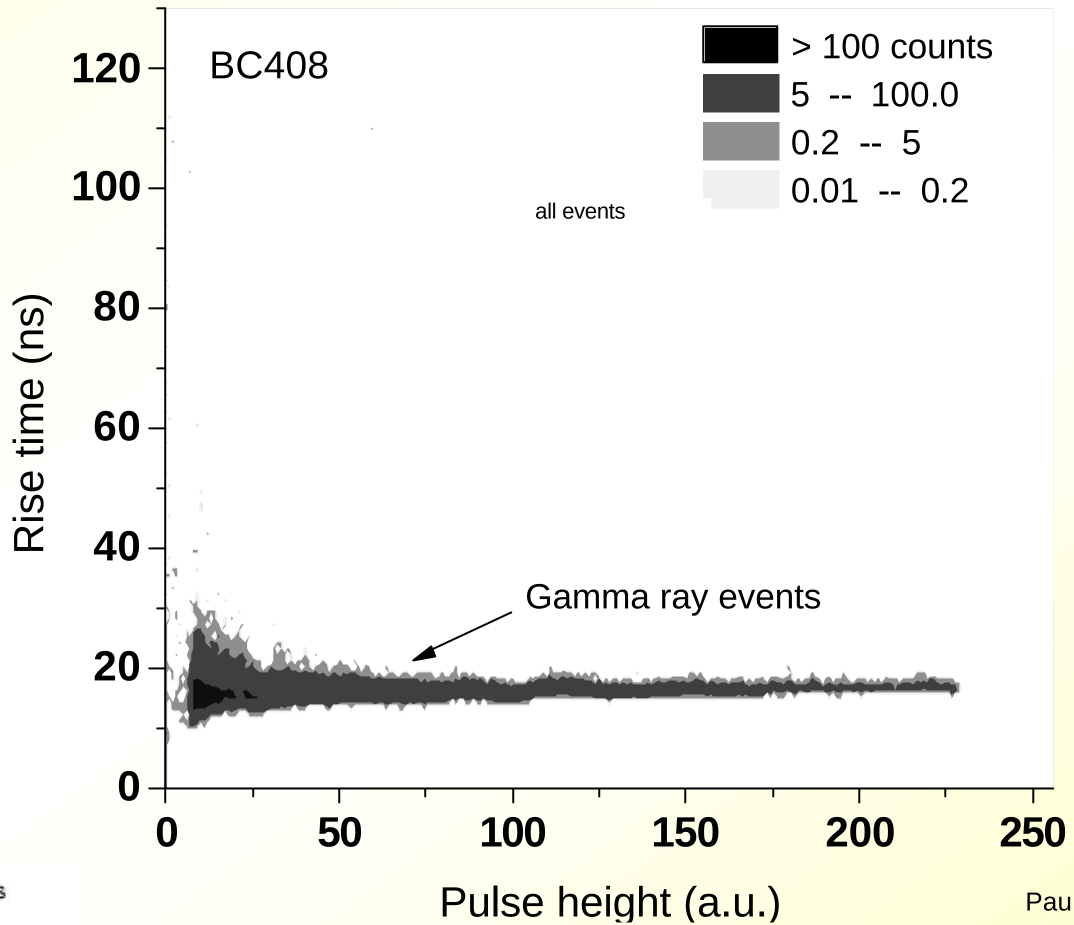
PSD at low gain

Risetime versus pulse height plot at low gain setting showing n/γ PSD from (a) BC501A, and (b) from BC523A.



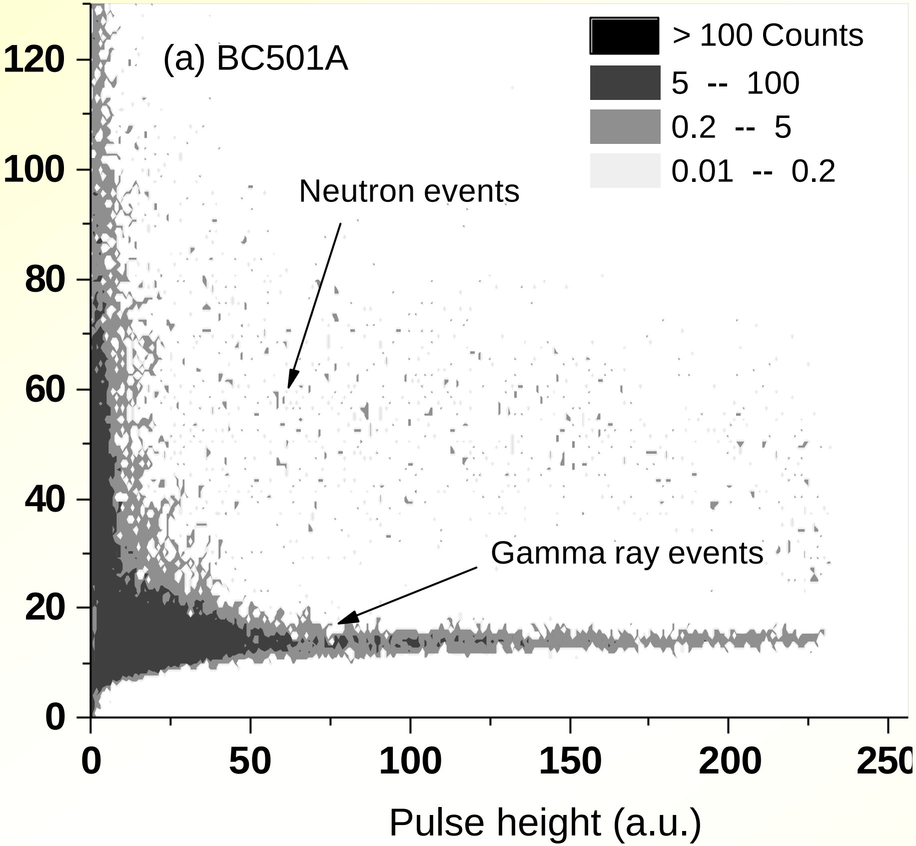
No PSD in plastic BC454

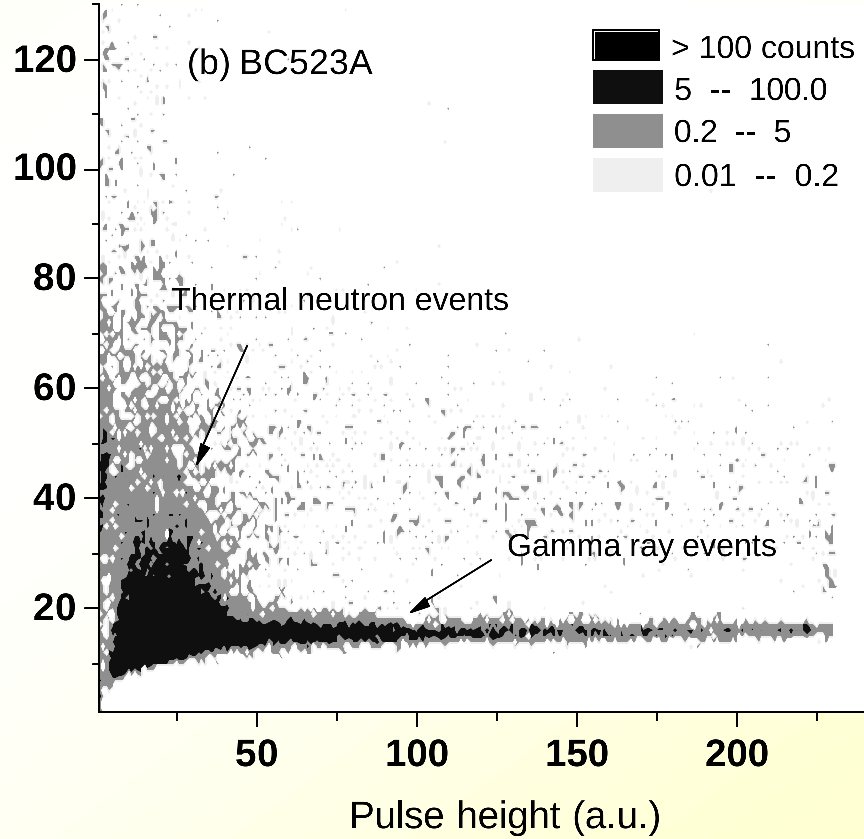
We also tested PSD in plastic scintillator BC454 - no discrimination was seen for neutron scatter events



PSD at high gain

At high gain, the ^{10}B capture peak is visible due to simultaneous detection of ^{7}Li and $\alpha \Rightarrow$ no significant PSD is observed





Lack of PSD is due to quenching of slow component from heavy ions - alpha particle PSD has been seen in 'special' ^{10}B-loaded scintillator

S. Normand et al, NIM A484 ***2002*** *342-350*

PSD Figure of Merit

Quality of PSD is described using a Figure of Merit (FOM):

$$FOM = \frac{S_{ng}}{F_n + F_g}$$

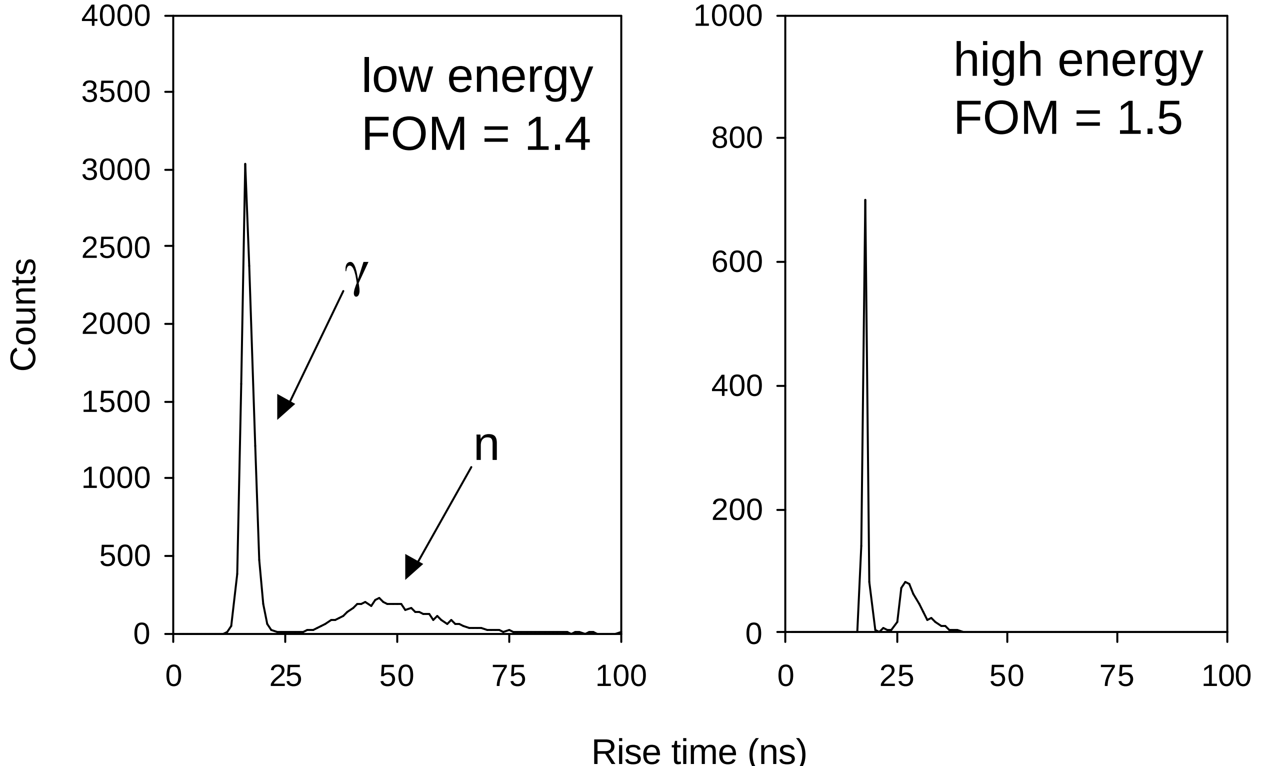
S_{ng} = separation of two peaks
$F_{n,g}$ = n,γ peak centroid position

Vertical 'slices' from the 2D spectra give risetime histograms:

Method is similar to conventional analogue PSD techniques

FOM is extracted digitally in software

FOM>1 required for 'good' PSD



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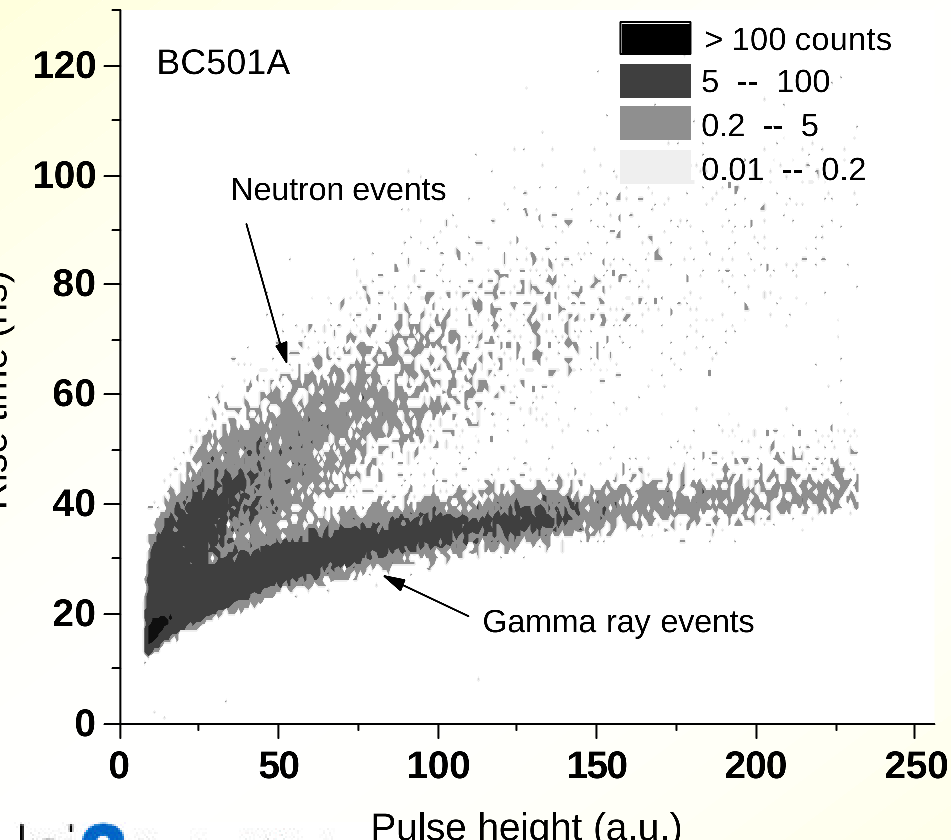
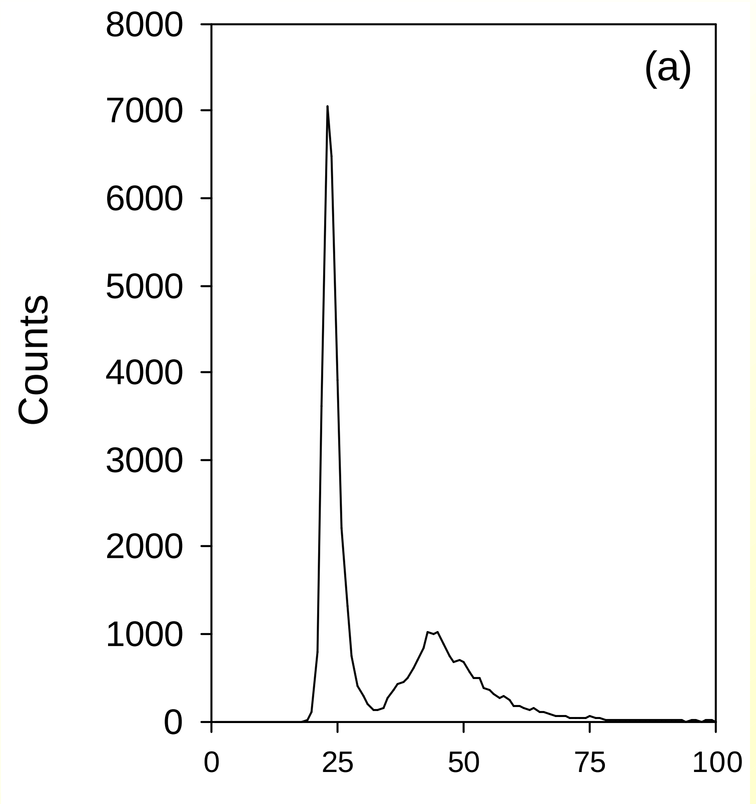
PSD from current pulses

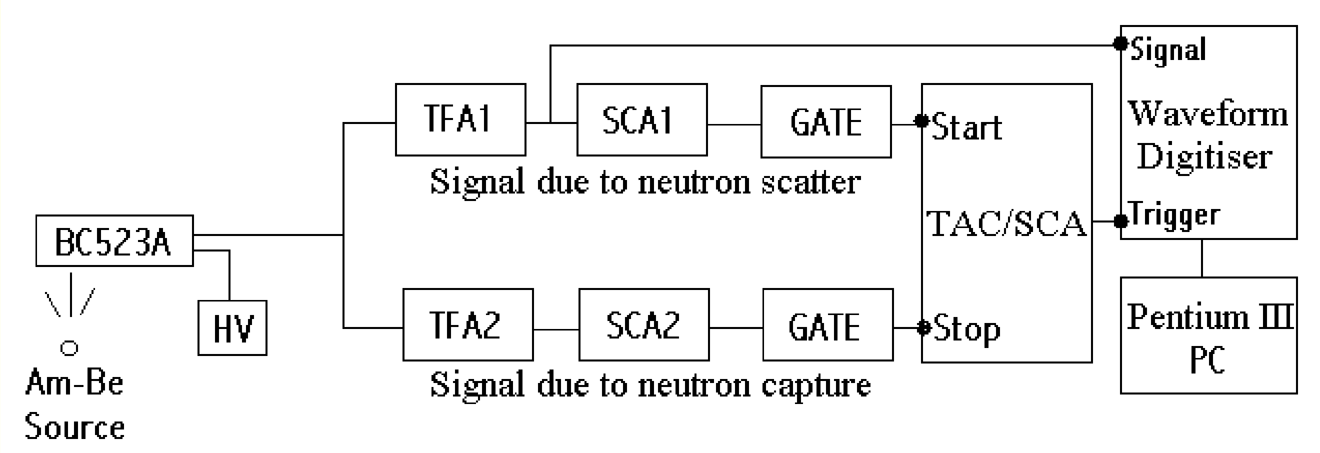
Current pulses use ‘time over threshold’ in place of risetime - the 2D plot has a different shape

FOM is slightly worse than for integrated pulses (1.1 - 1.2) with poorer valley separation





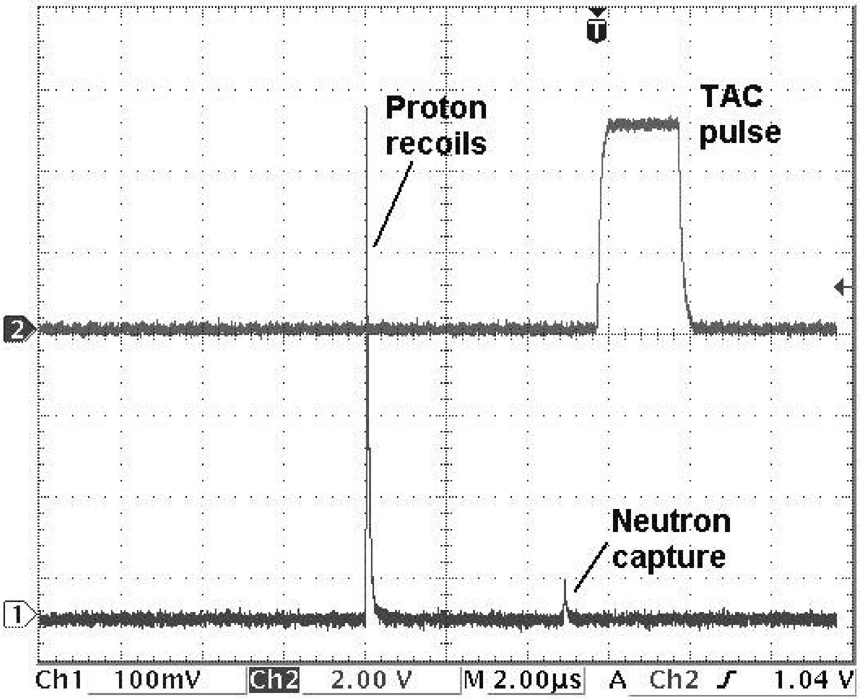
Capture-gated neutron detection



Capture-gated neutron detection gives very clean fast neutron signature

Trigger event rate is low, requiring full moderation of neutron within the scintillator ⇒ volume dependant

PSD can be used to further reject false TAC start pulses



Fast neutron capture lifetime

Fast neutron capture lifetime τ has an exponential distribution:

$$p(t) = t^{-1}\exp(-t/t)$$

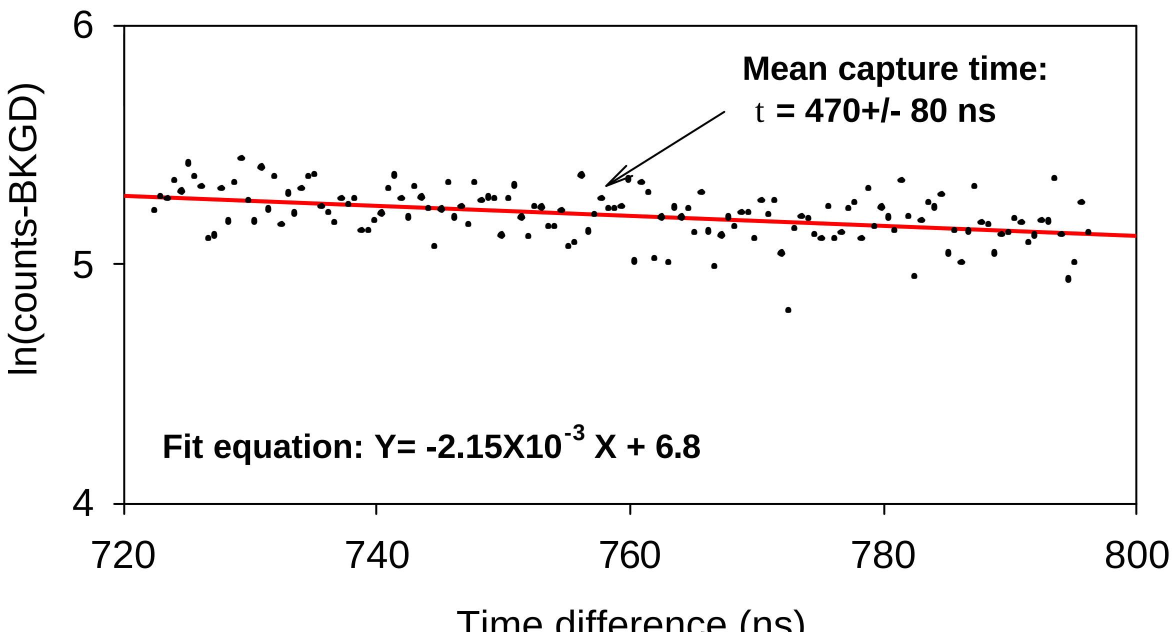
where τ depends only on 10B concentration, since σ ∝1/v:

$$t = \left[N_{10B}\, s\, n\right]^{-1}$$

Scintillator	^{10}B (%)	t (μs)
BC523A	~ 5	0.49
BC523	~ 1	2.25
BC454	~ 1	2.13

Short neutron capture times allow high event rates for the capture-gated detection mode

Event rate with our 10GBq AmBe neutron source: ~20Hz for 700ml BC523A cell



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Conclusions

- High speed waveform digitisers are opening up new techniques for neutron and gamma ray detection in fast organic scintillators
- The performance of 1 ns sampling time, 8-bit resolution, digitisers has been successfully demonstrated
- Good n/γ PSD has been demonstrated using computationally-simple digital pulse risetime algorithms
- The application of digital techniques to capture-gated fast neutron detection is a powerful technique for fast neutron monitors

Issues for the future:

- Multi-channel 1 GS/s digitisers are still expensive
- Digitisers are not yet available in a ‘laptop’ format
- True neutron spectroscopy from capture-gated ^{10}B-loaded scintillator is currently limited by the non-linear light output of these materials
- New loaded scintillators need to be developed offering good PSD of the neutron capture reaction (eg. ^{7}Li+α from ^{10}B).