High rate wavelength shifting fibre coupled $ZnS:Ag/^6LiF$ neutron detectors at ISIS

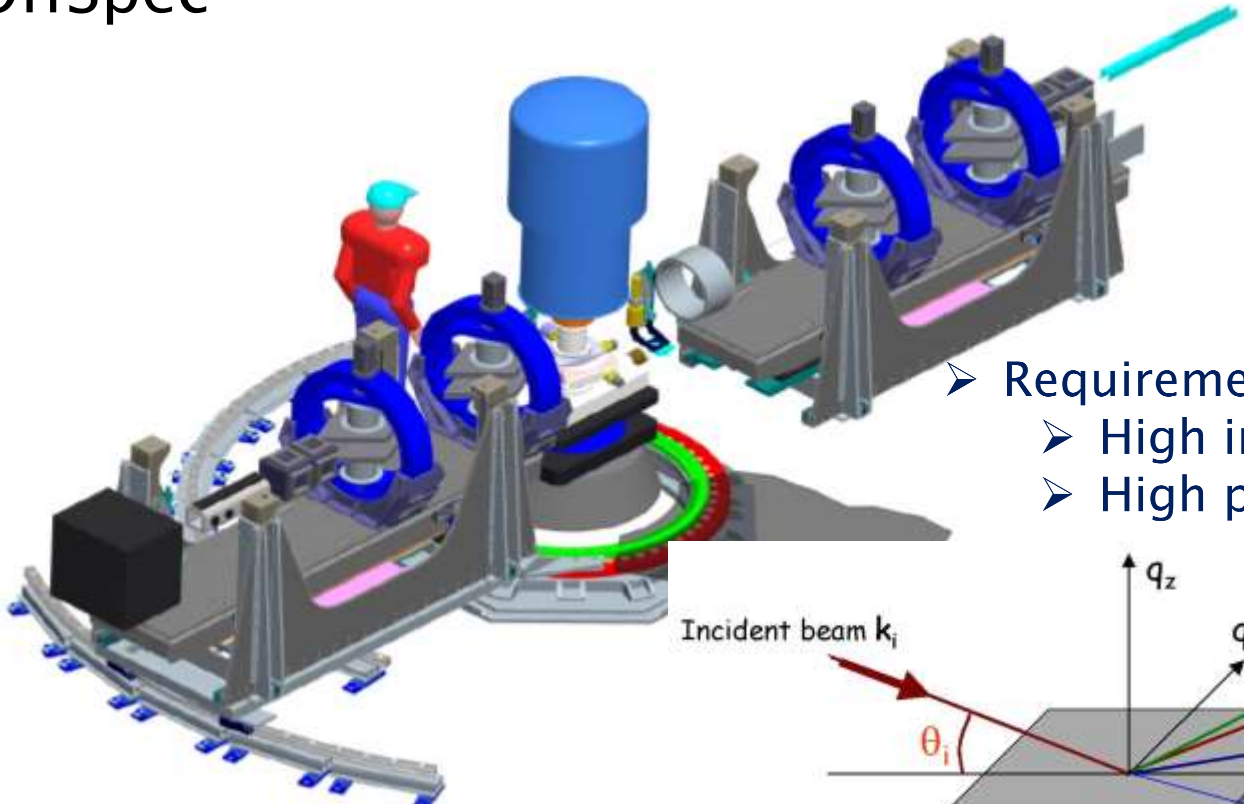
G. Jeff SYKORA, Erik M. SCHOONEVELD, Nigel J. RHODES and Nick FERGUSON

[1]Science and Technology Facilities Council, ISIS facility, Rutherford Appleton Laboratory, Harwell Oxford, United Kingdom

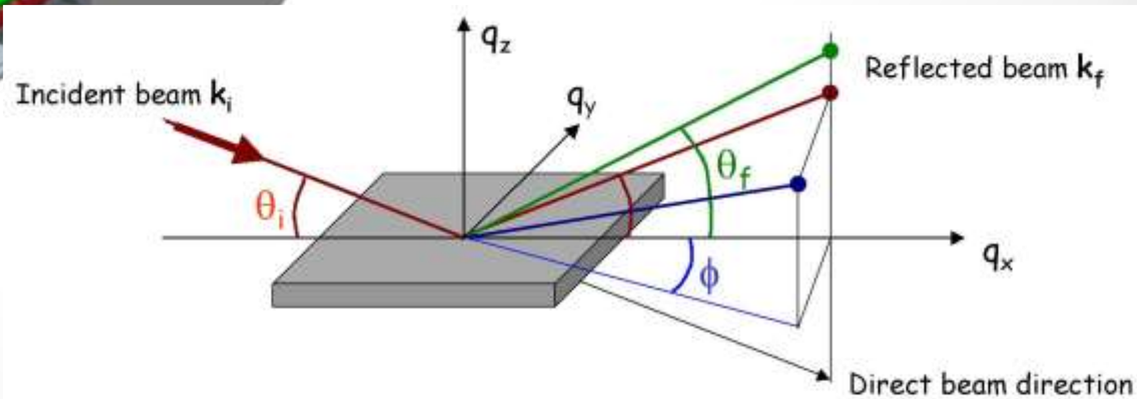
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654000.

Motivation
Reflectometers

OffSpec



- Requirements
  - High instantaneous count rates
  - High position resolution



Motivation
Reflectometers

- High rate reflectometers
  - Need 10’s kcps locally
  - Typical ZnS:Ag/^{6}LiF detectors are too slow
  - … but also reliable, simple and relatively inexpensive

- High position resolution
  - Cover more range in Q
  - Maintain cost-effectiveness
  - Extend into 2D (GISANS)

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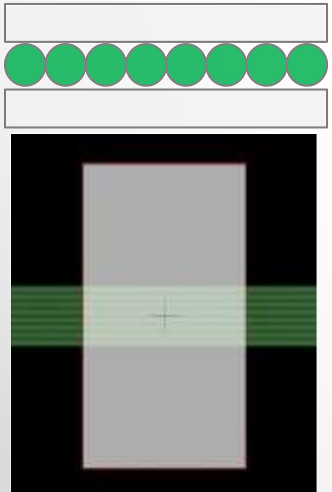
State of the art WSF detectors for Reflectometry on ISIS

- $^{6}LiF/ZnS:Ag$
- Linear PSD
- 380 mm linear coverage
  - Continuous scintillator
- 16 ch MAPMT readout – 192 PMT channels
- Functioning well on OffSpec

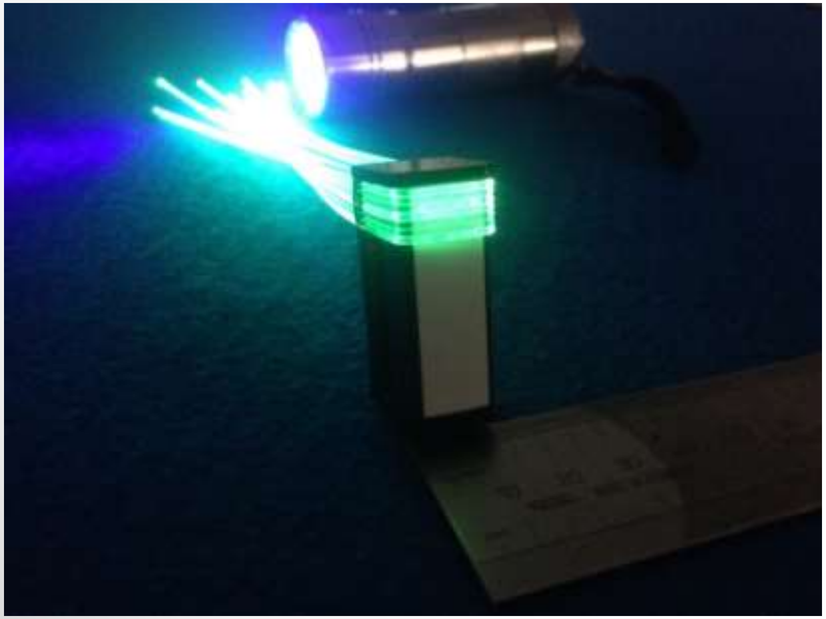
- 0.5 mm position resolution
- ± 7% non-uniformity
- 16 kcps local peak rate (per PMT)
  - 60mm^2 area for narrow beam



Combatting rates

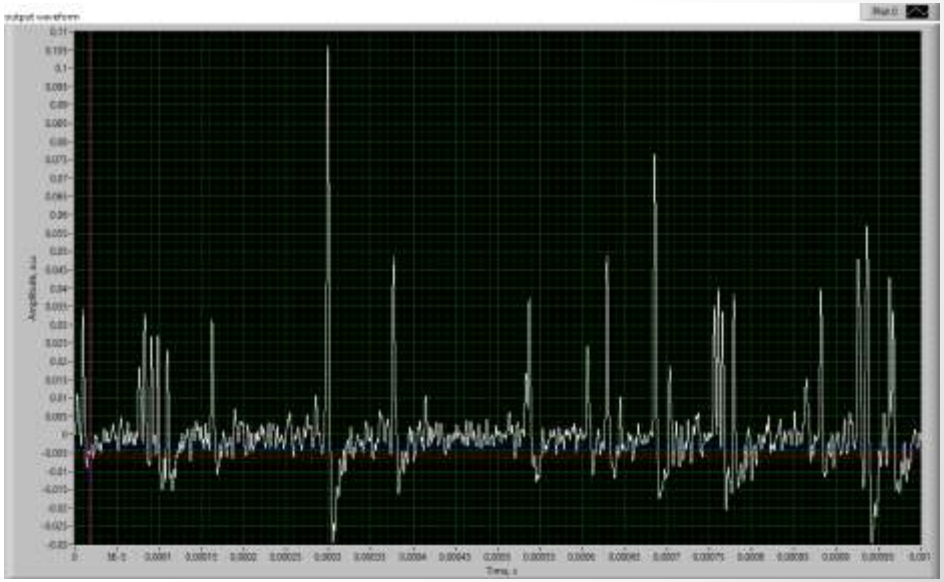
Segmented high aspect ratio 2D (SHARD)

- More PMT channels
- Maintains simplicity



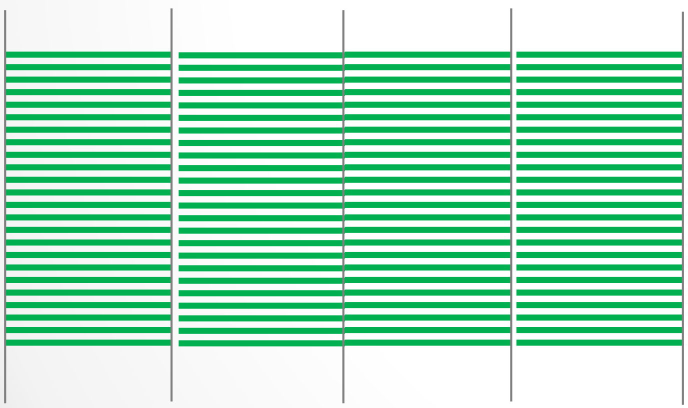
Fundamental

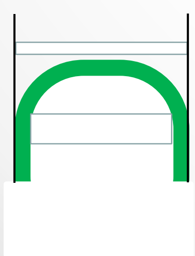
- Scintillators
- Signal processing
  - Compromises?

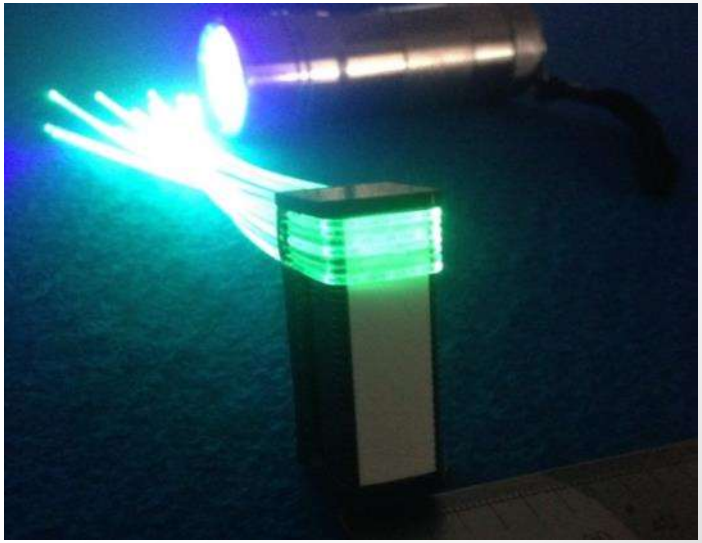


SHARD concept

- Solution for global rate limitations:
  - High aspect ratio 2D
  - Limits number of possible fibre combinations
  - Optically isolated rows for coarse pixilation
  - 2.5mm bend radius fibres for close packing

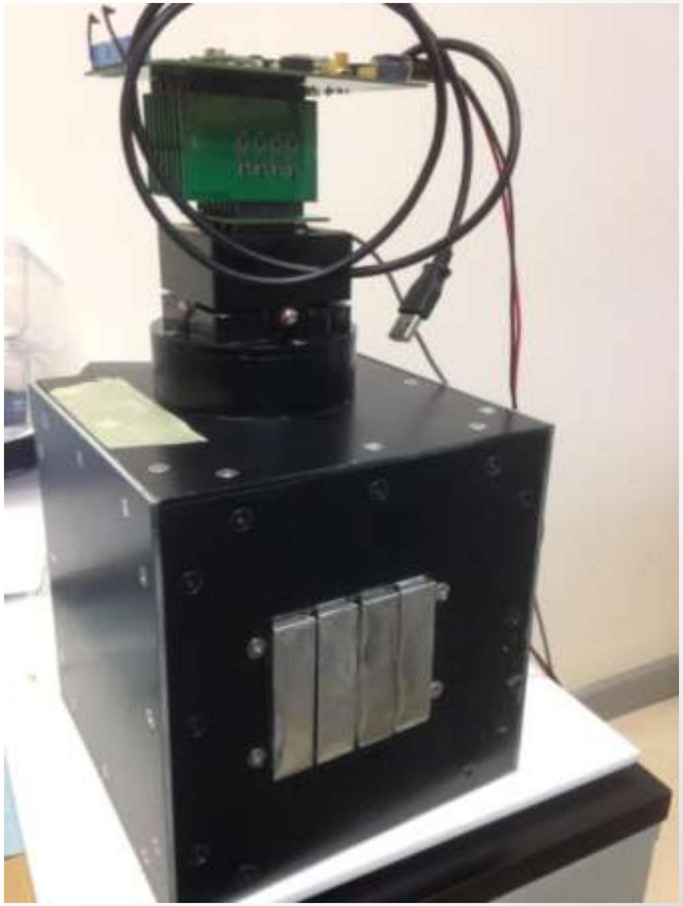






SHARD
Configuration

- 1 mm fibres – 16 mm wide
- Individual segments
  - Optically divided
  - Supports
    - 3D printed
  - Strips of scintillator front and back
- Single 64 ch FP-PMT per segment



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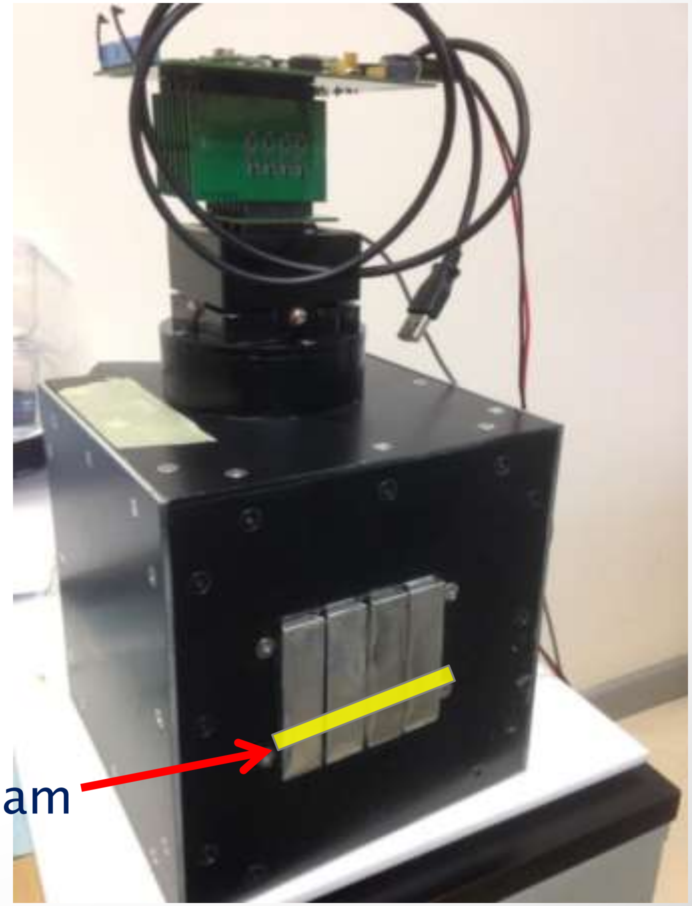

Neutron beam

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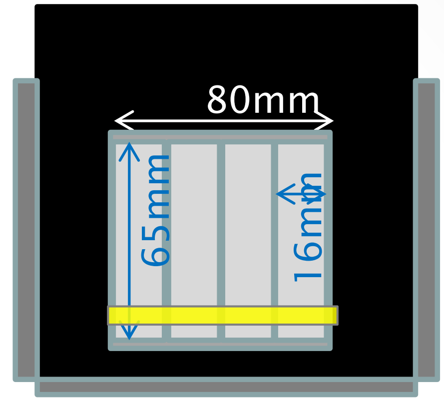
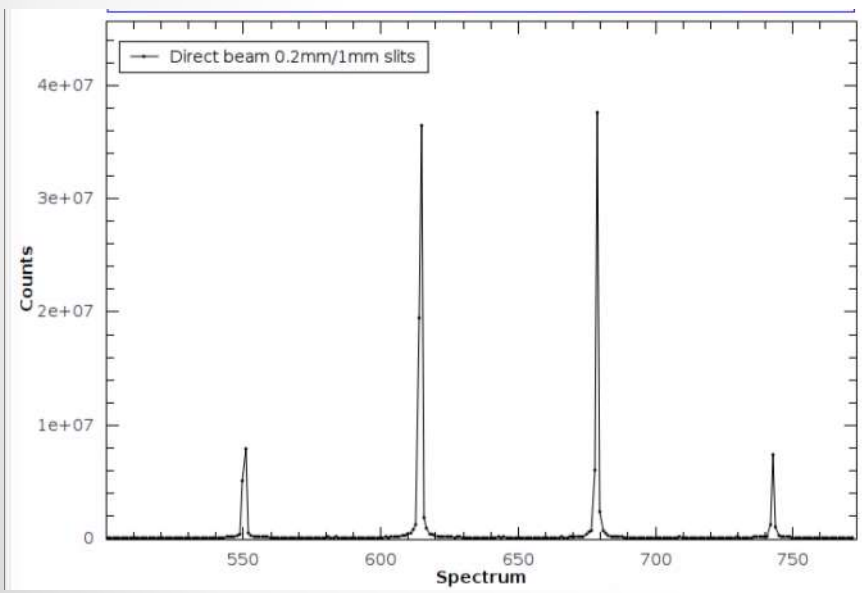
SHARD
Testing

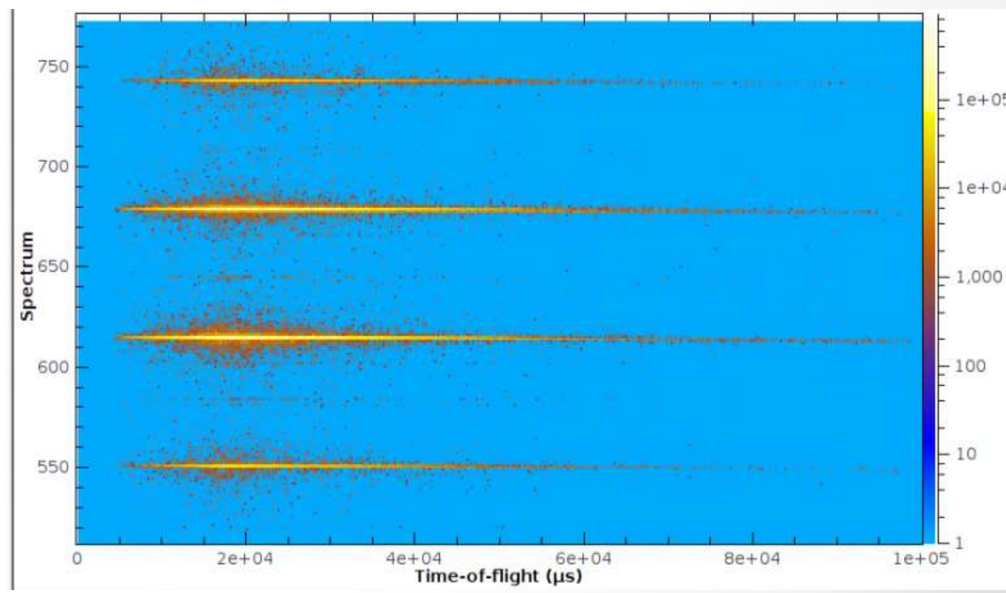
- OffSpec reflectometer
  - Efficiency
  - Rate capability
  - Ghosting

OffSpec
Results

- Detector in direct beam
  - Measure efficiency
  - Global and local peak rates



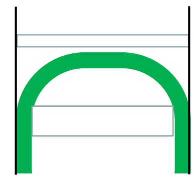




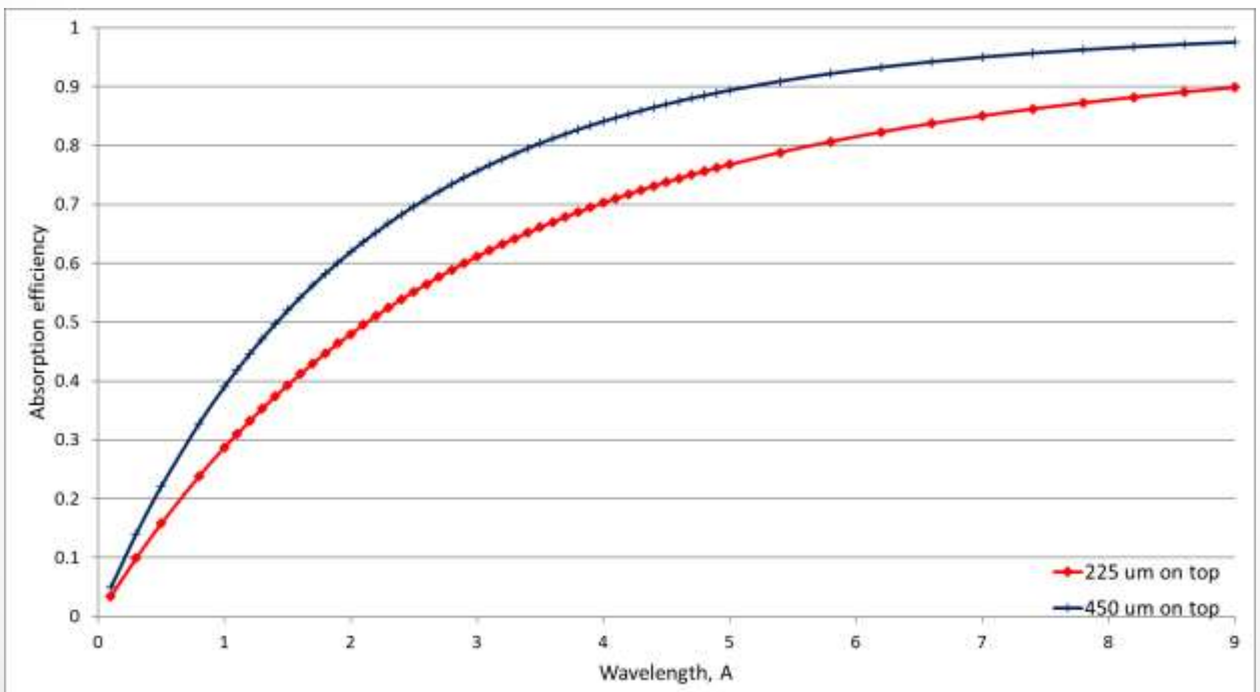
Efficiency

What you expect

- Top scintillator thickness?
  - 450 μm
  - 225 μm



Absorption efficiency

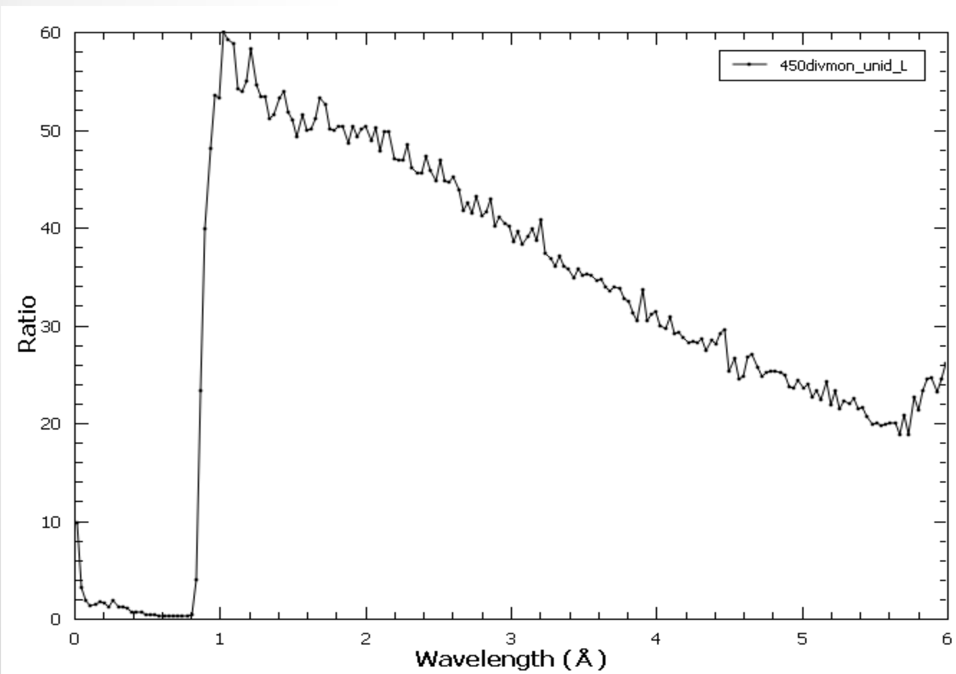


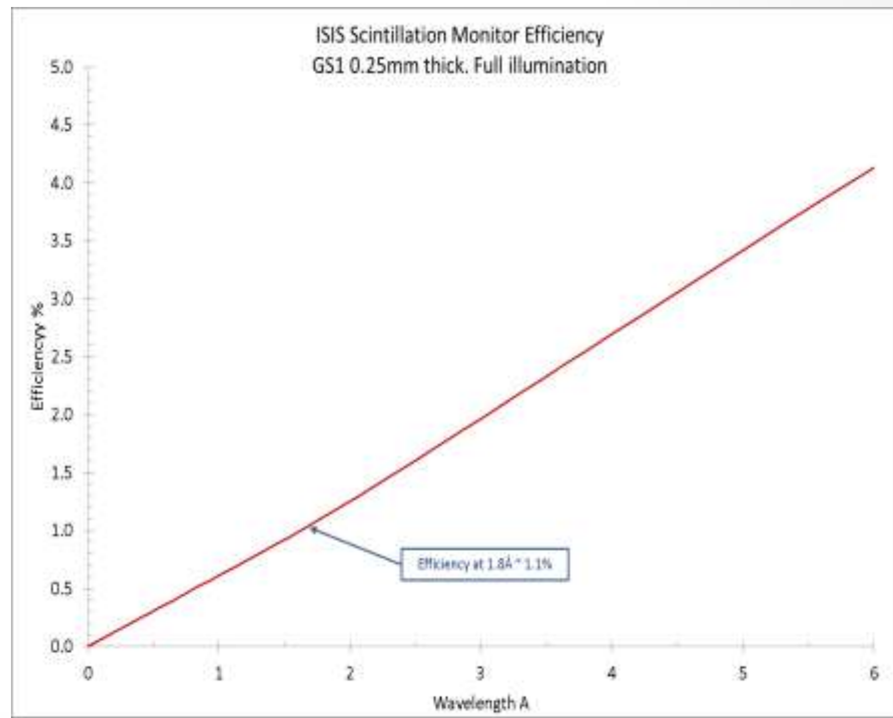
Efficiency

Relative to known monitor

450 μm thick scintillator divided by monitor counts

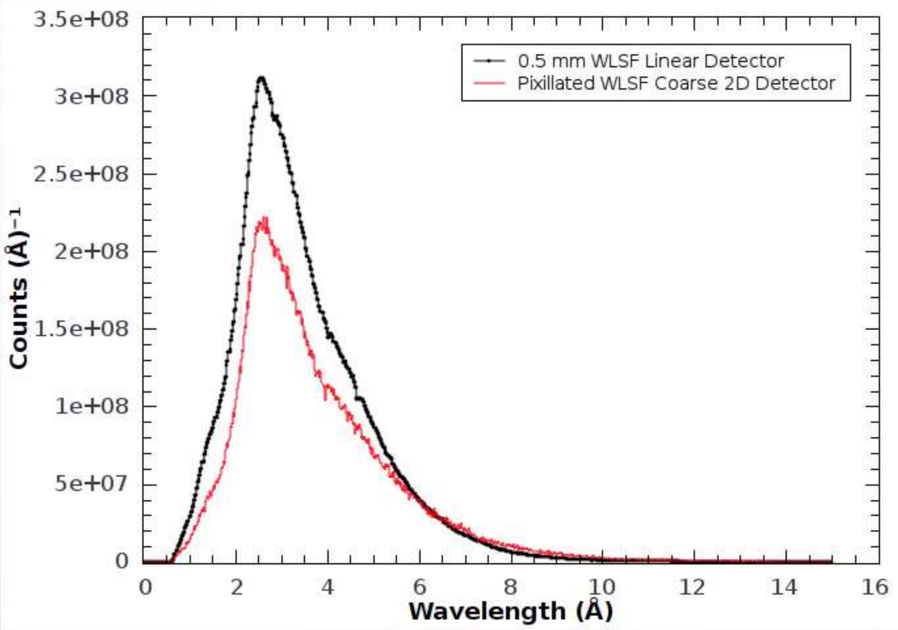
~60% efficient at 1.8Å
~80% efficient at 6.0Å

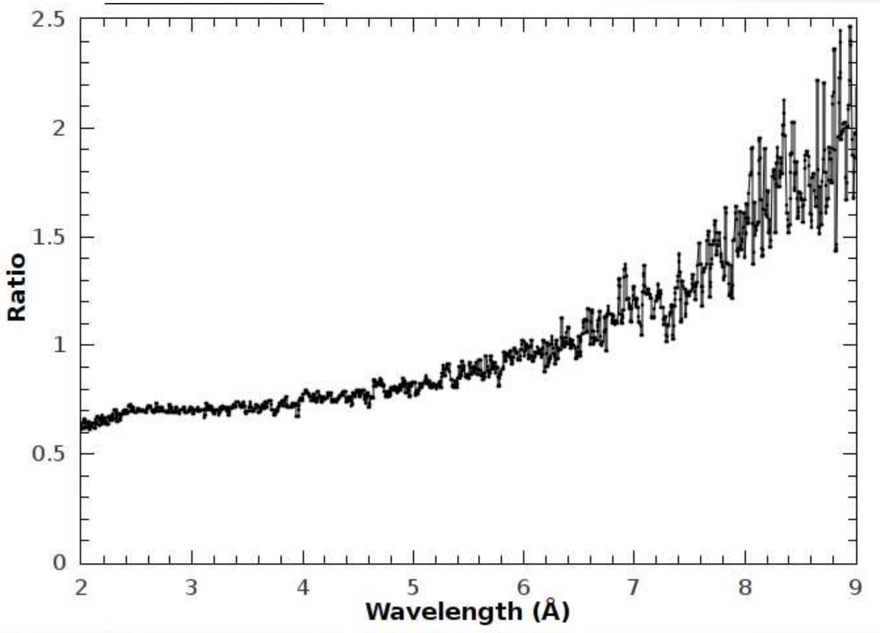




Efficiency

- Thin scintillator on front face or standard thickness?
  - Flat geometry
  - Which wavelengths are more important?





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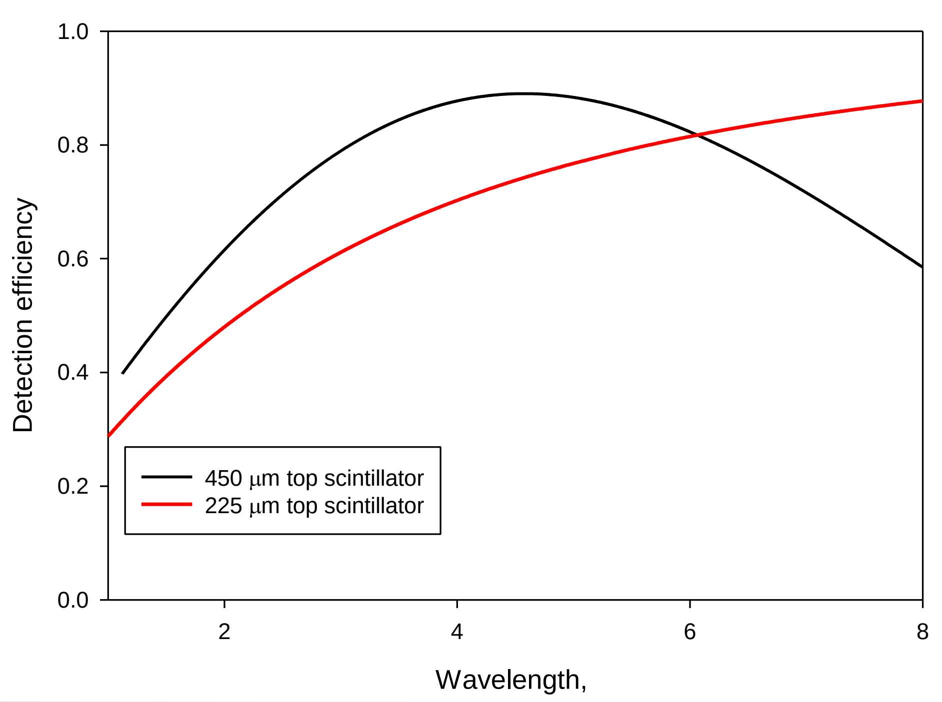
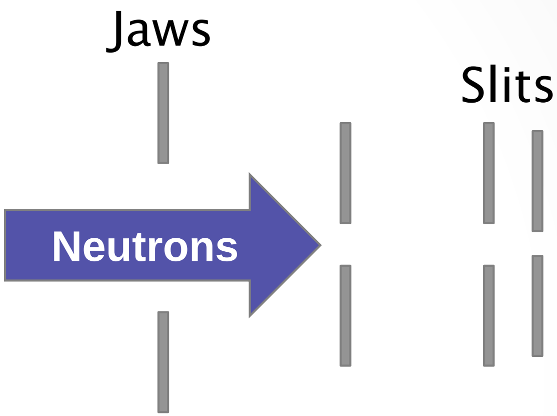


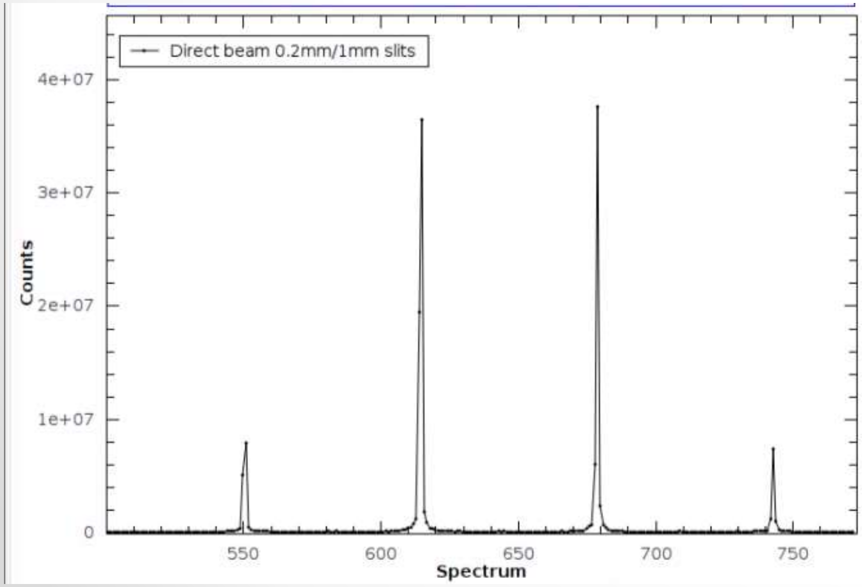
- 0.25mm front scintillator + 0.45 back scintillator is ~90% efficient at 9 Å
- 0.45 front scintillator efficiency drops to 45% at 9 Å

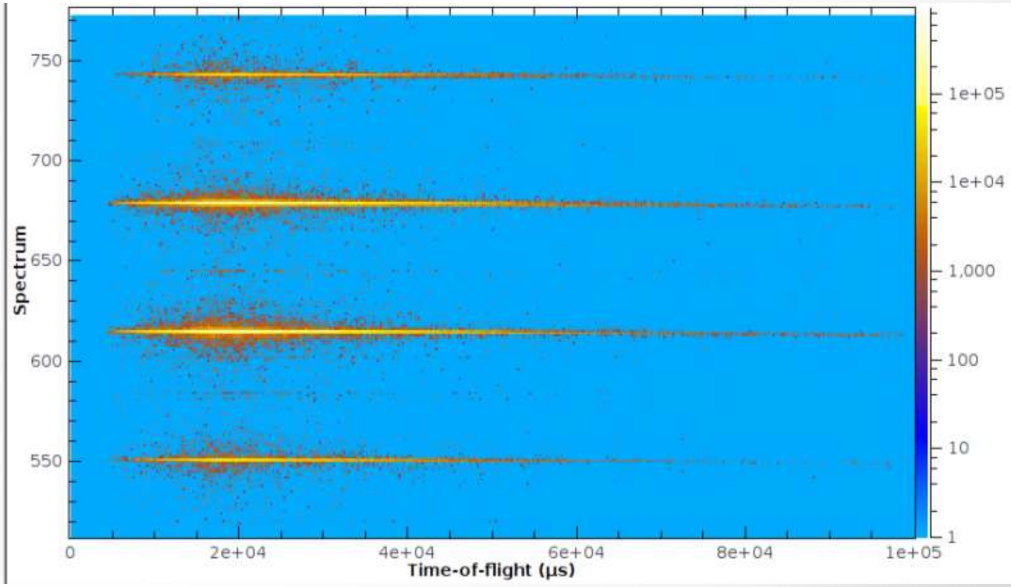
SHARD

Rates

- Detector in direct beam
  - Measure efficiency
  - Global and local peak rates



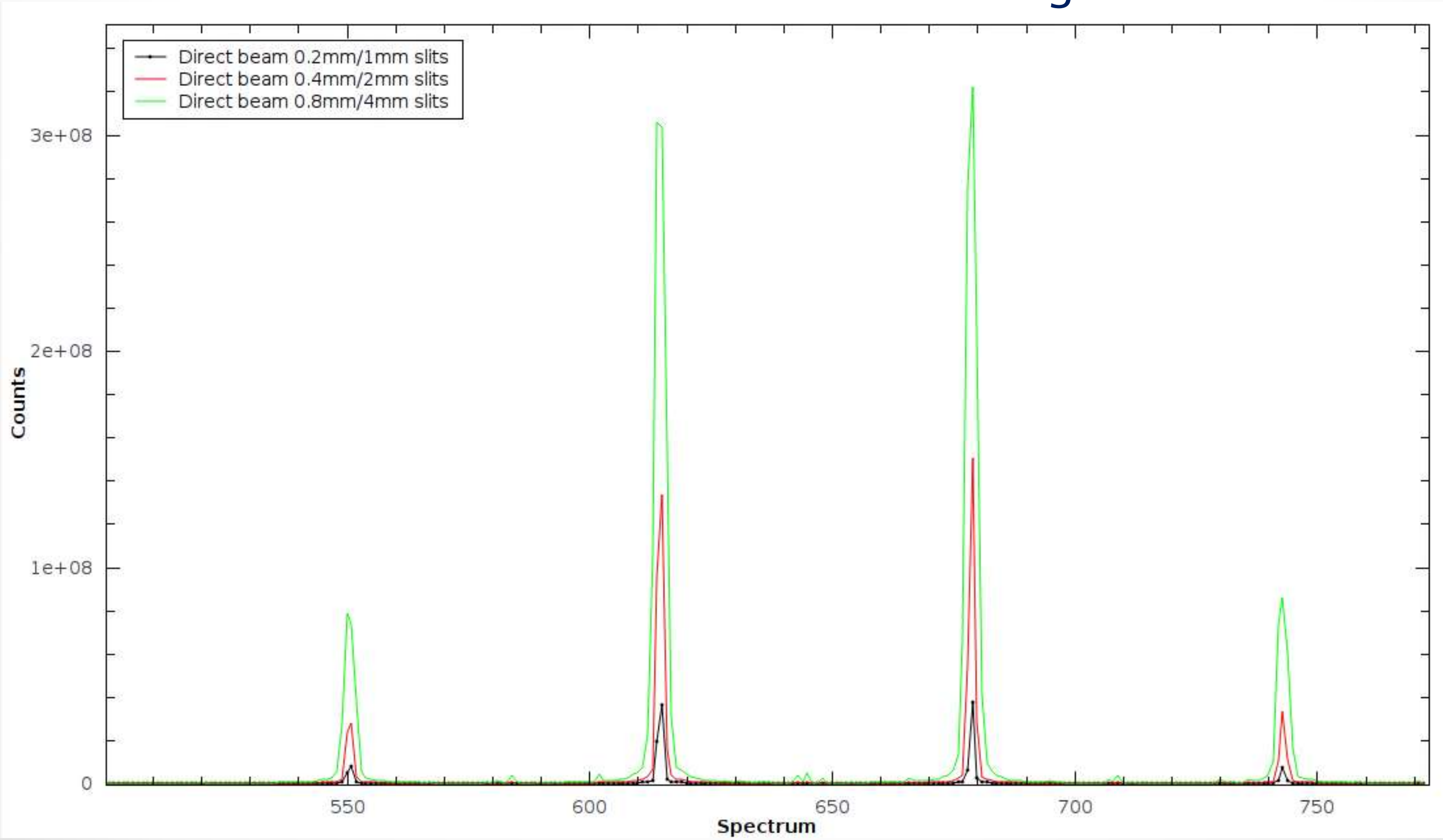




SHARD
Rates

- Detector in direct beam
  - Increase incident slits

Integrated over ToF



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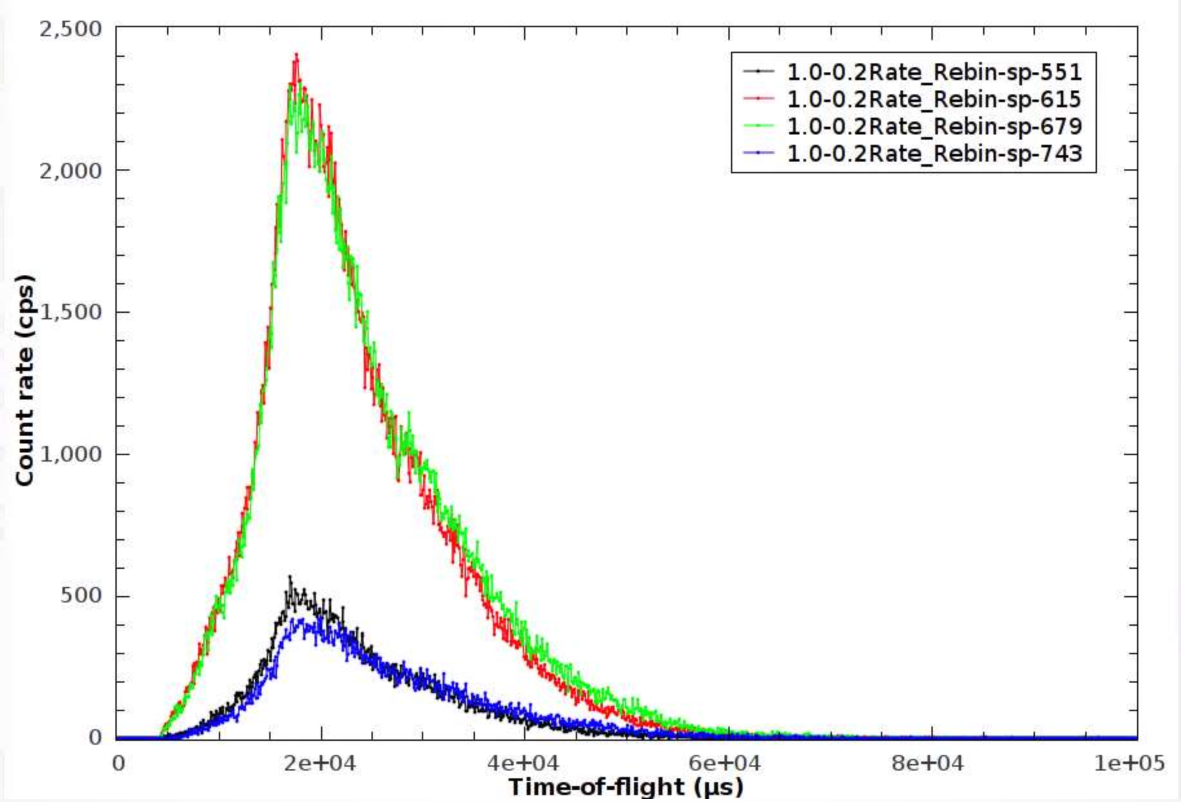
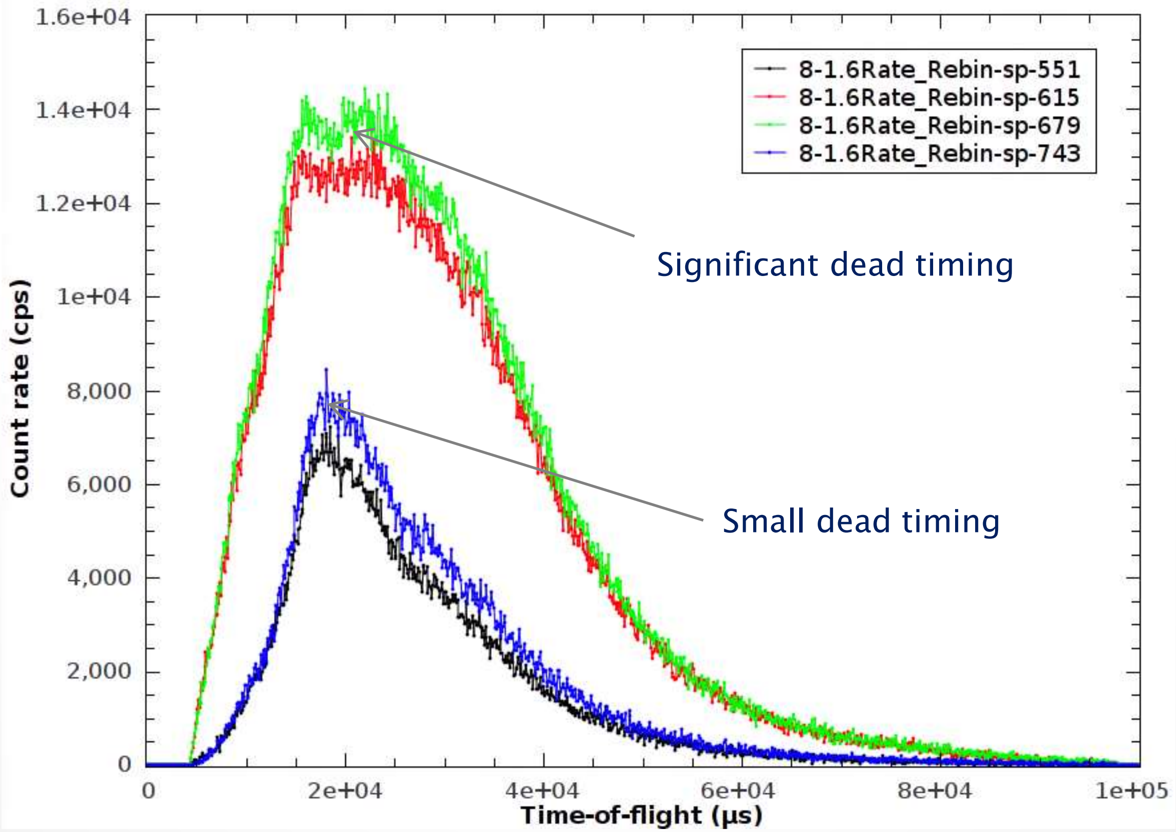
SHARD
Rates

- Detector in direct beam
  - Increase incident slits 1mm / 0.2mm



SHARD
Rates

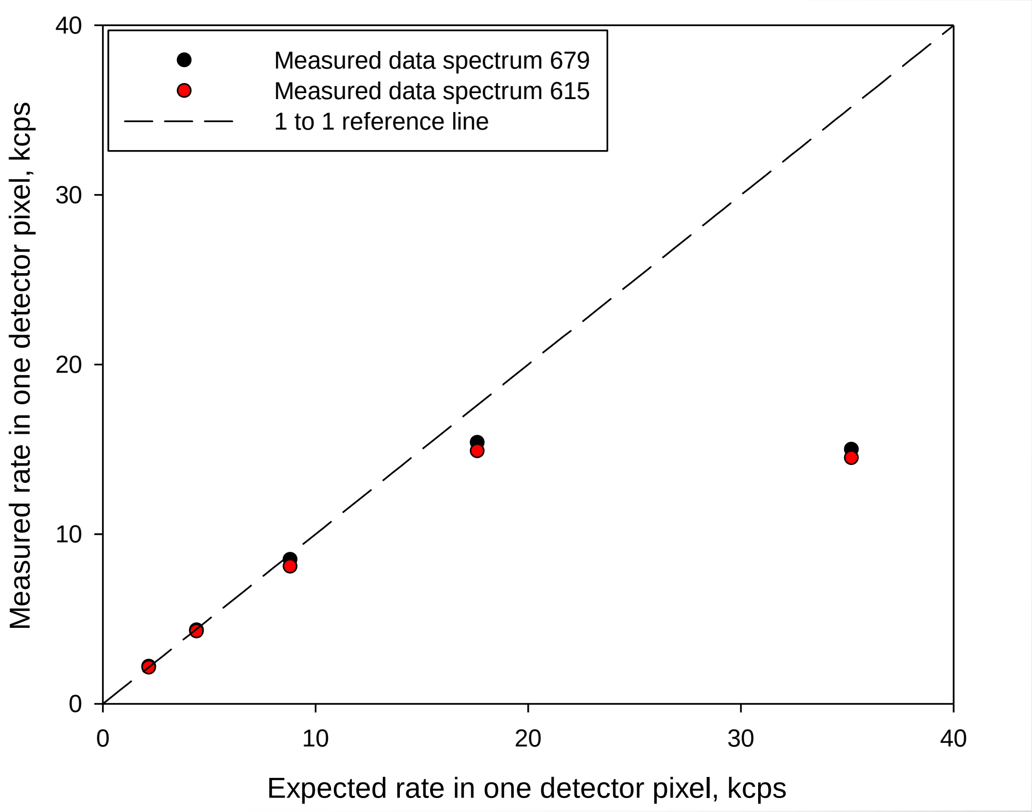
- Detector in direct beam
  - Increase incident slits 8mm / 1.6mm



SHARD

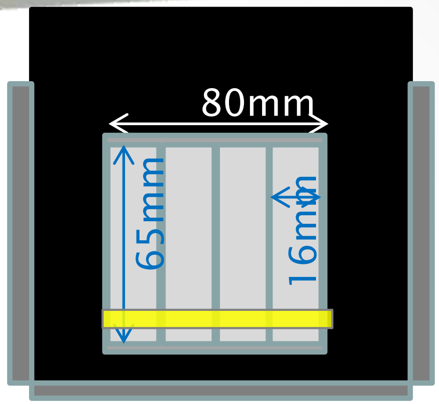
Rates

- Local instantaneous peak rates
  - Single pixel peak rates linear until 16 kcps
  - Consistent with other ZnS:Ag/^{6}LiF detectors

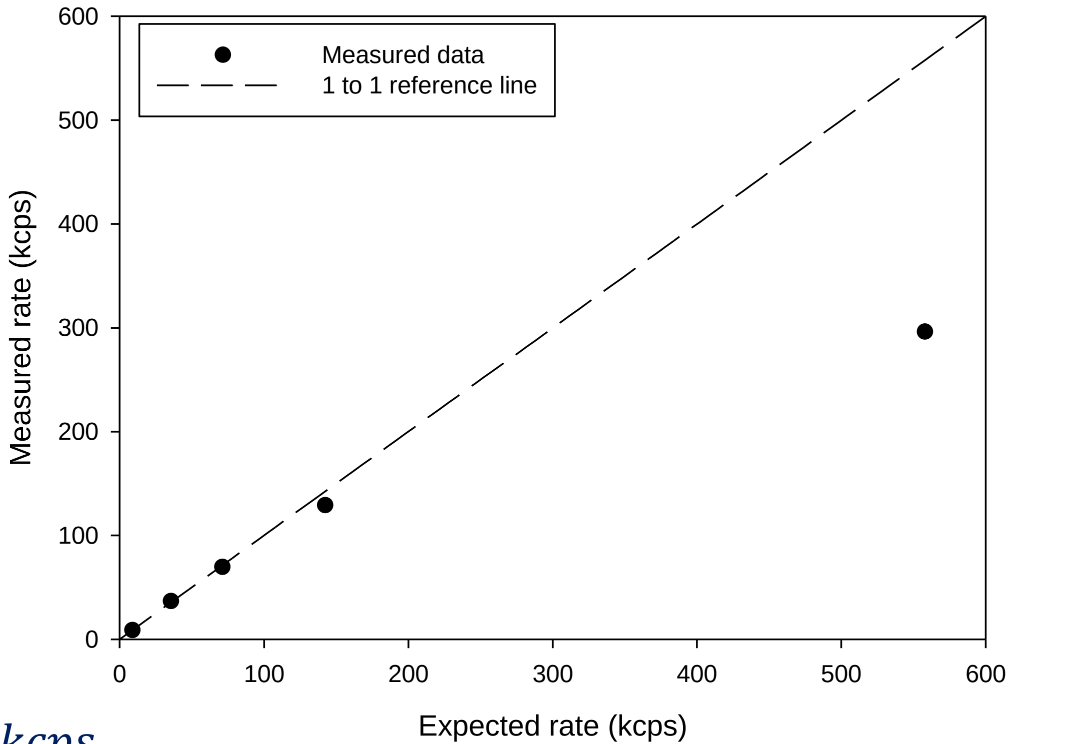


SHARD

Rates



- "Local" (within beam area) instantaneous peak rates
  - Linear until ~160 kcps
- Global (across detector) instantaneous peak rates
  - Limited to 320 kcps

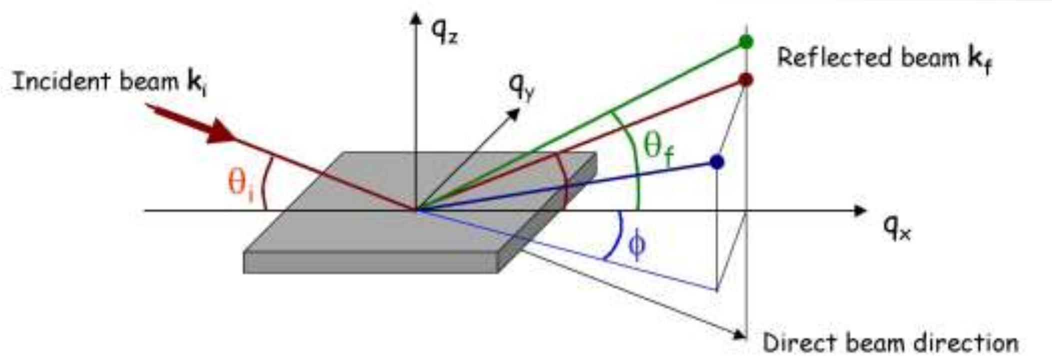


$$Local\ Rate\ limit = n_{seg} \times n_{PMTs} \times 16\ kcps$$

$$Global\ Rate\ limit = n_{seg} \times 80\ kcps$$

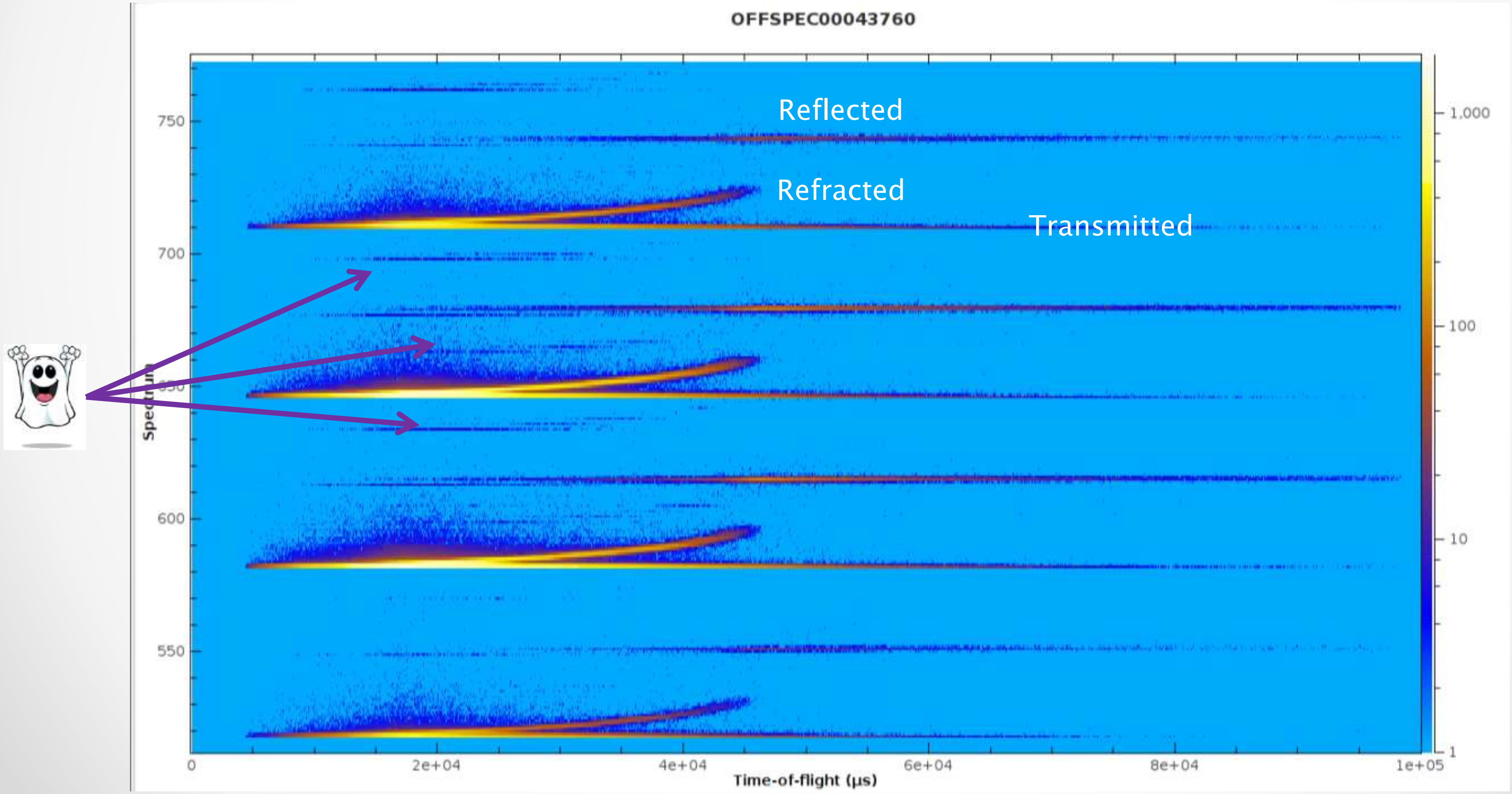
SHARD
Testing

- OffSpec reflectometer
  - Efficiency
  - Rate capability
  - Ghosting



Ghosting

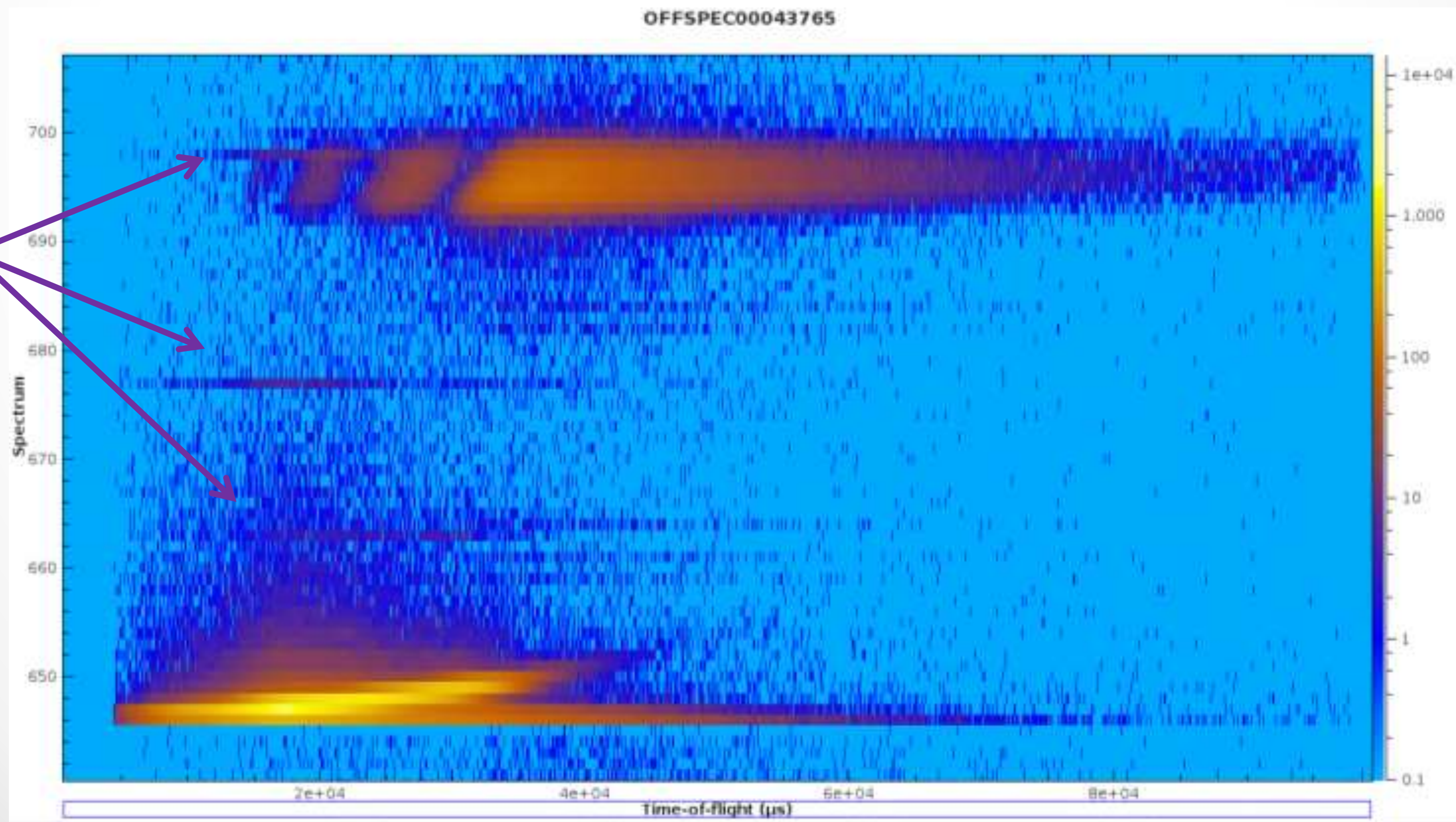
- Si reflectivity



Ghosting

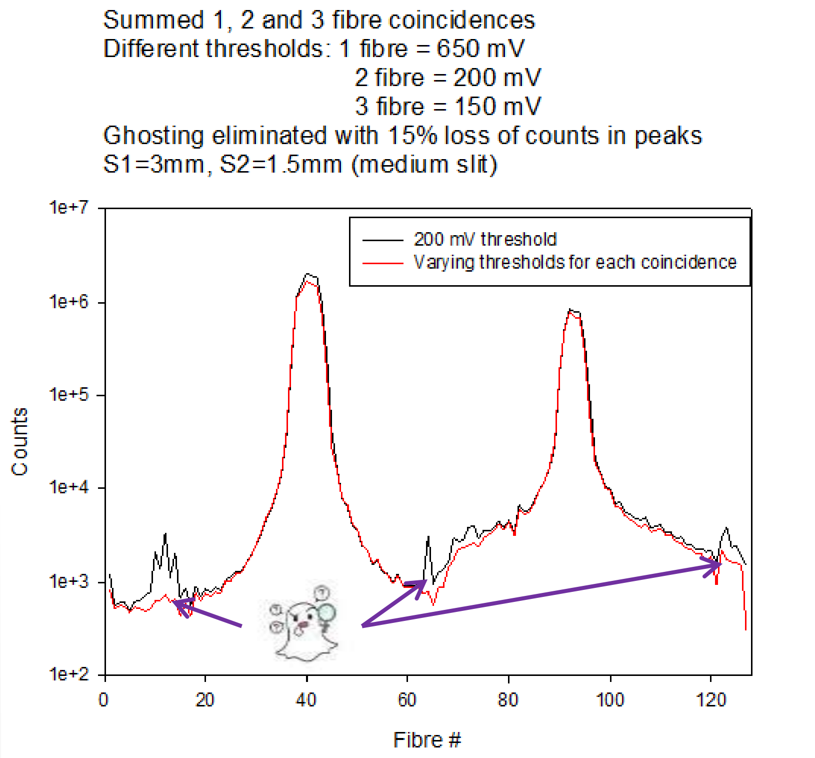
- Ir-600 reflectivity
- Rates not extreme ~9 kcps on a PMT in direct beam

0.01% ghosting



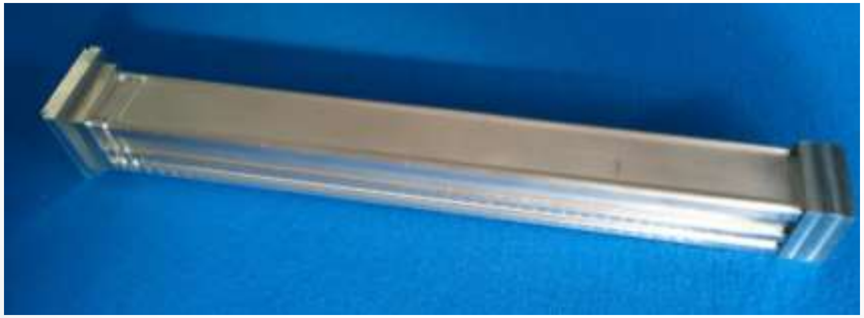
Ghost reduction

- Vary threshold based on number of fibres measuring light
  - Example of 0.5mm OffSpec detector on CRISP



SHARD
Summary

- A segmented approach provides a simple, cost effective solution to increasing rate capability for reflectometers
- Segments can be made in a variety of widths
- Efficiency can be “tailored”
- Some ghosting exists but so do methods of eliminating ghosts.
- Now applying this solution for a detector on INTER



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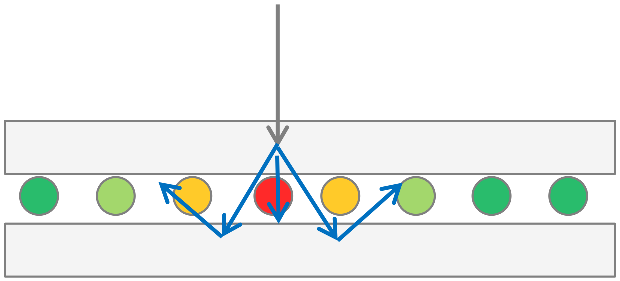
Summary

- A segmented approach provides a simple, cost effective solution to increasing rate capability for reflectometers
- Segments can be made in a variety of widths
- Efficiency can be “tailored”
- Some ghosting exists but so do methods of eliminating ghosts.
- Now applying this solution for a detector on INTER
- Still need (cost-effective) high resolution

Positioning

Nick Ferguson – student working on this project

- Current method – pick brightest fibre



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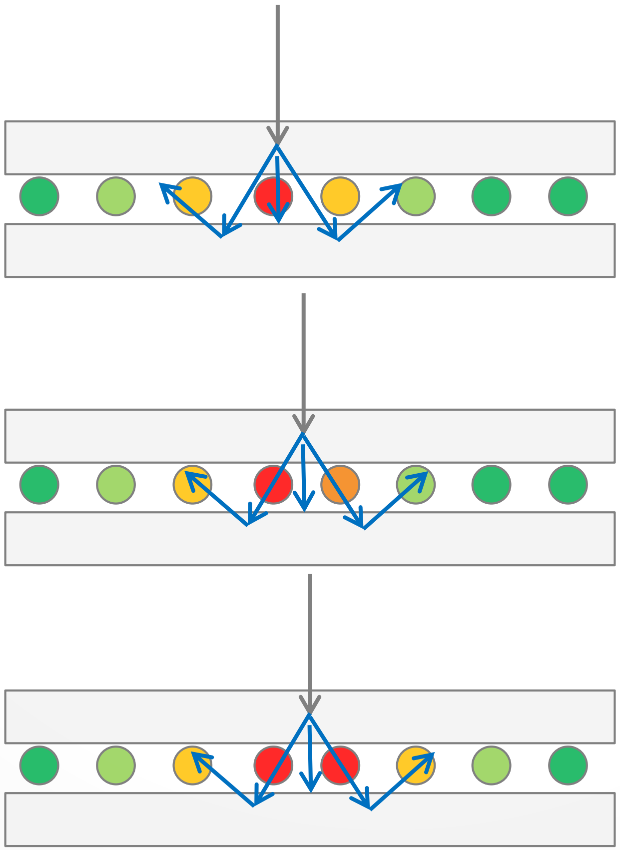
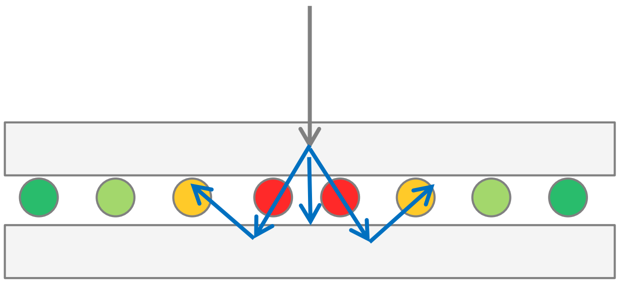
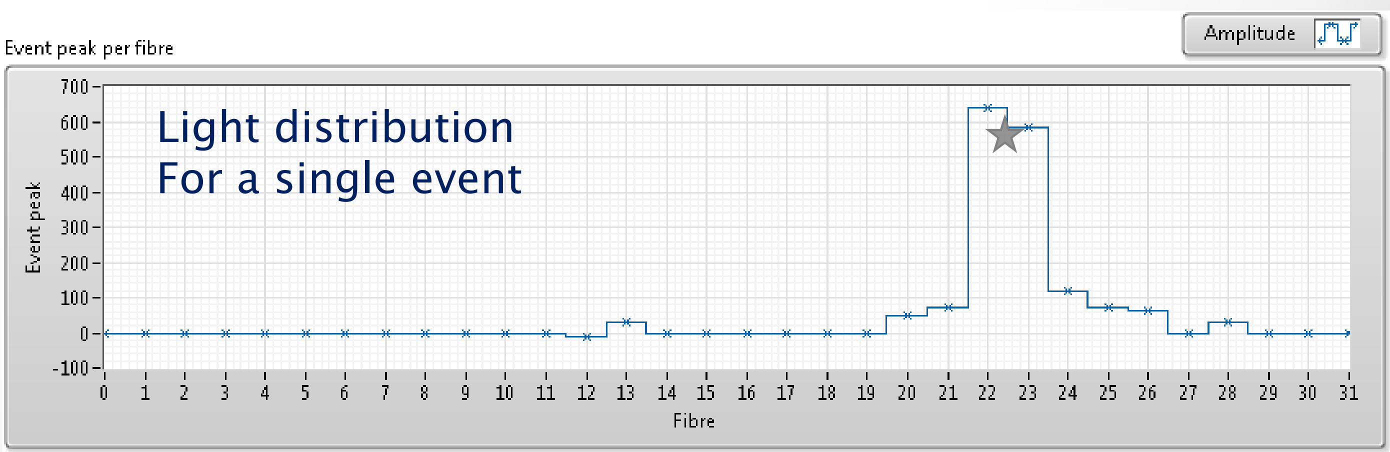


Positioning

- Use simple centre of mass calculation
  - Centre of mass in 7 fibres centralised on fibre with maximum photon density

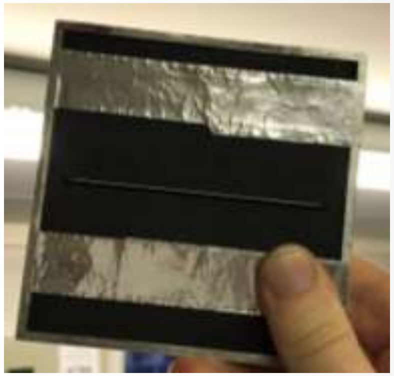


$$x_{interp} = \sum_{i=0}^{n} \frac{a_i x_i}{a_i}$$

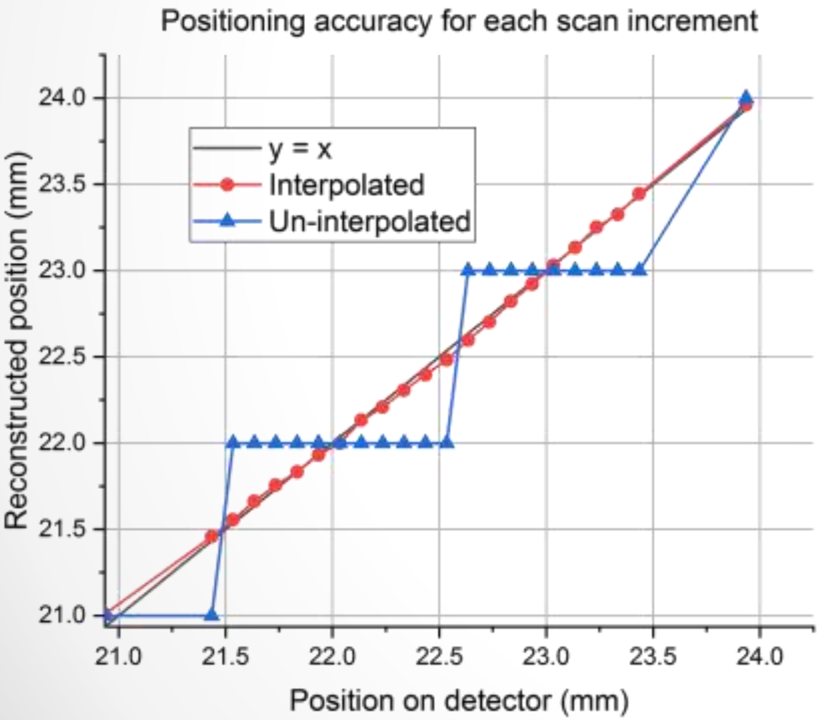


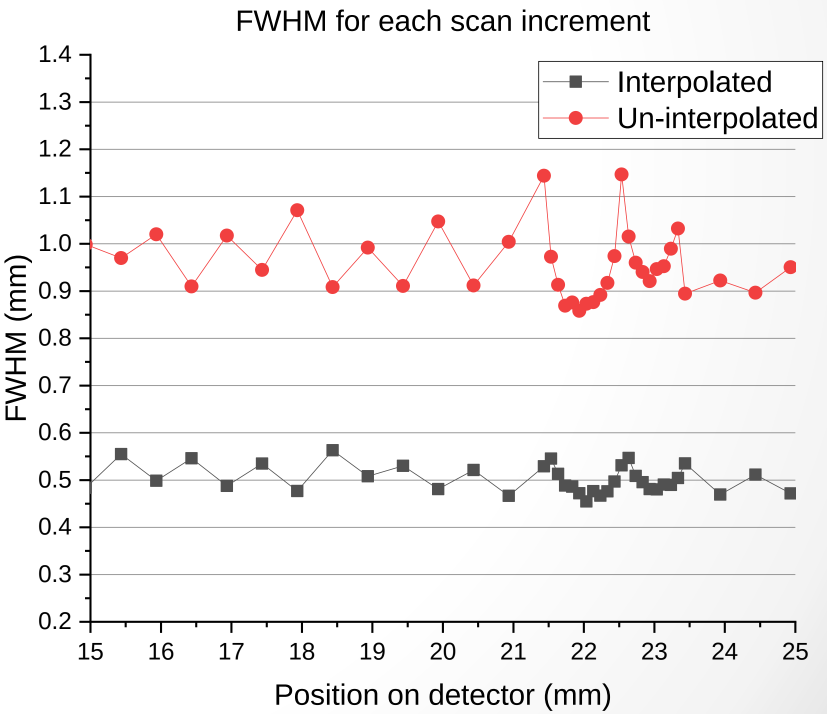
Testing

- CRISP reflectometer on ISIS
- Scan detector across 100 μm beam
  - Detector has 1mm fibre pitch



Results



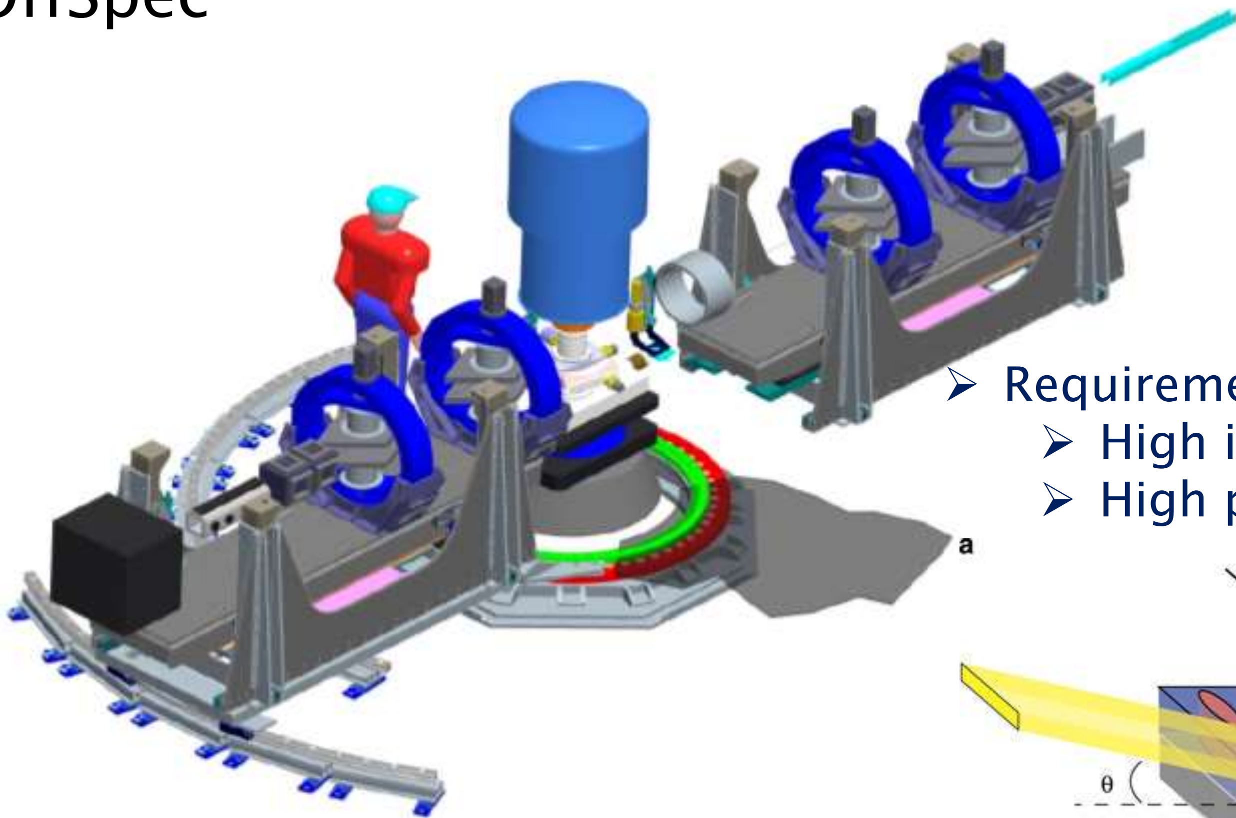


±50 μm accuracy of beam center

500 μm FWHM

Motivation
Reflectometers

OffSpec



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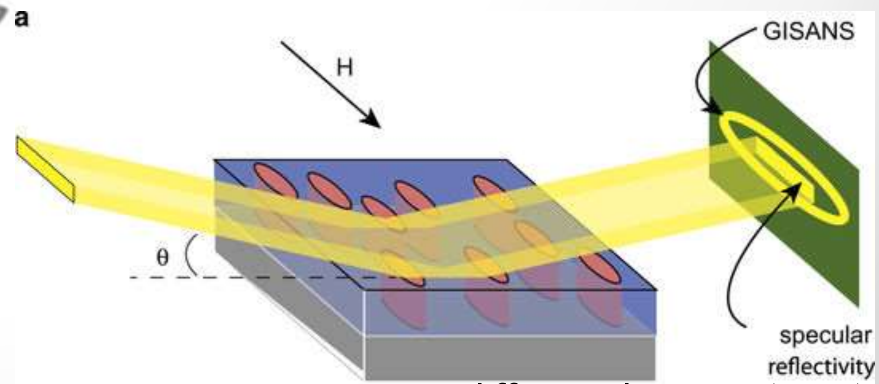
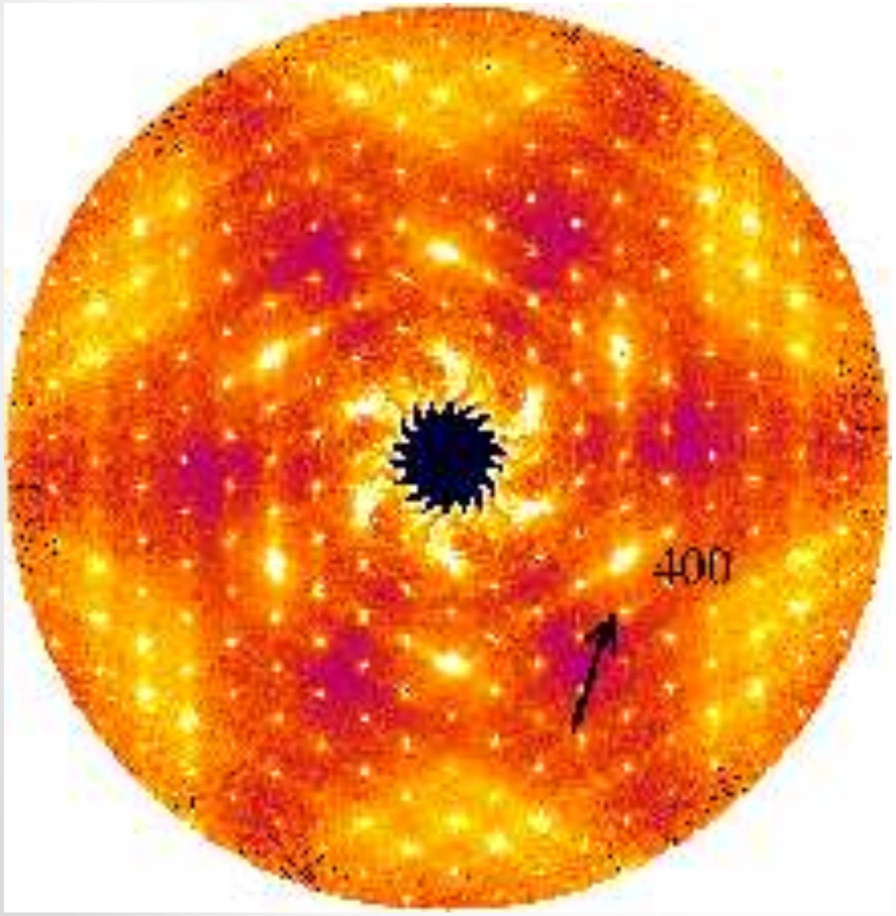
  - High instantaneous count rates
  - High position resolution (2D)



Ratcliffe, et. al, Nature (2016).

Motivation

Single crystal diffraction



- Requirements
  - High instantaneous count rates
  - High position resolution (2D)

Positioning
2 Dimensions

- Use simple centre of mass calculation
  - Centre of mass in 7 fibres centralised on fibre with maximum photon density

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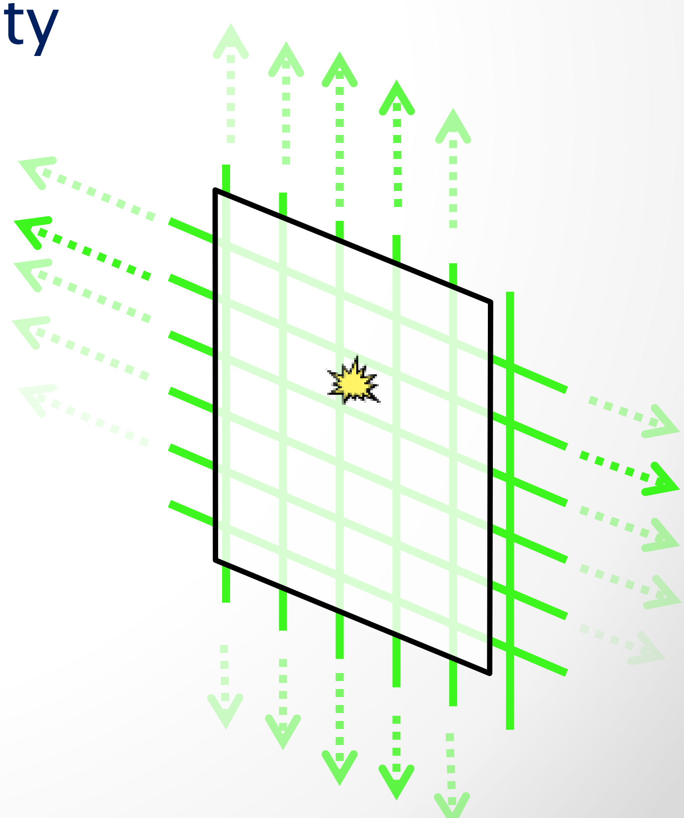
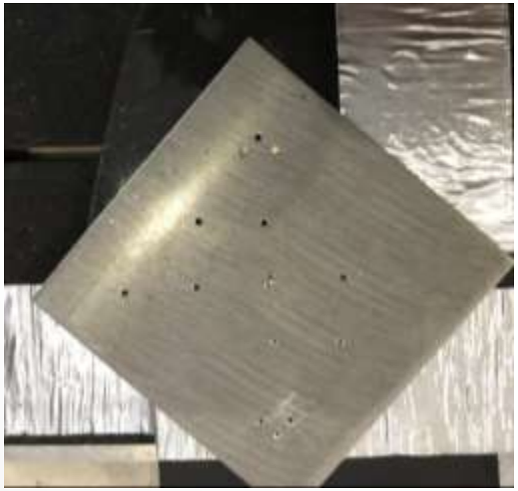


Prototyping

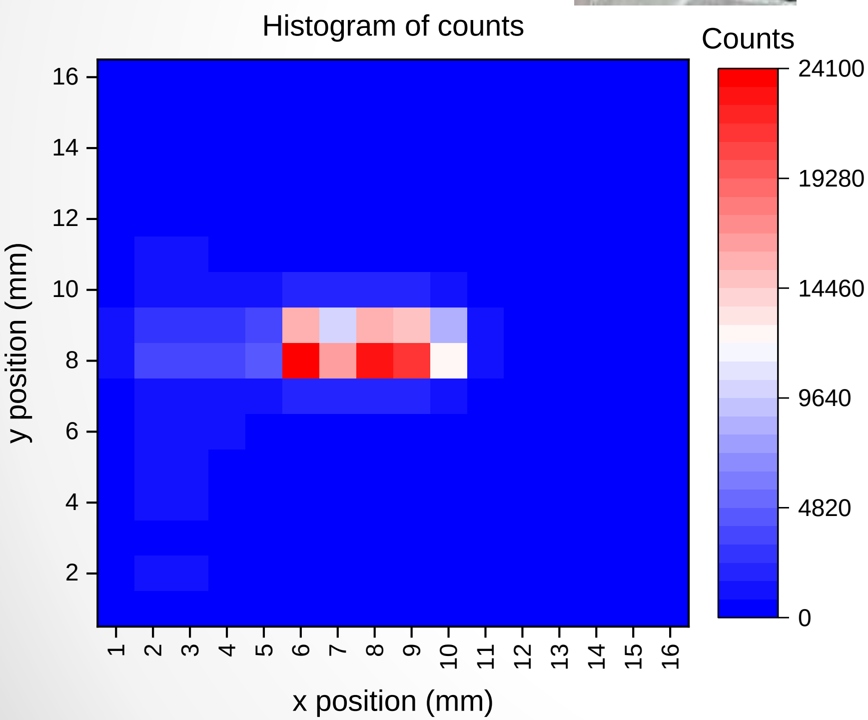
Testing

- 0.5 mm fibres
- 3 mm pitch
- 1.5 mm pitch



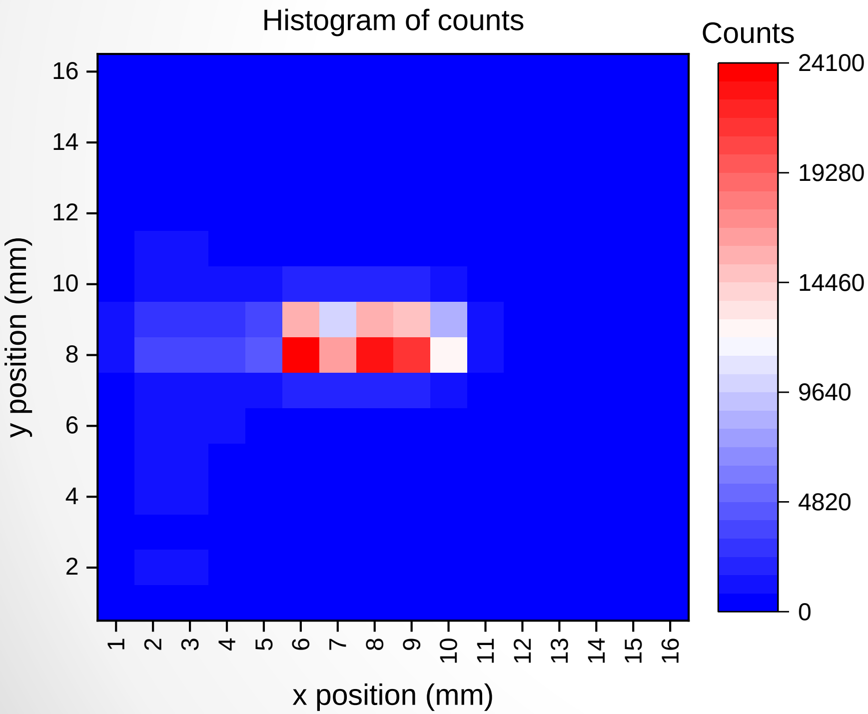
B_4C and Cd test masks

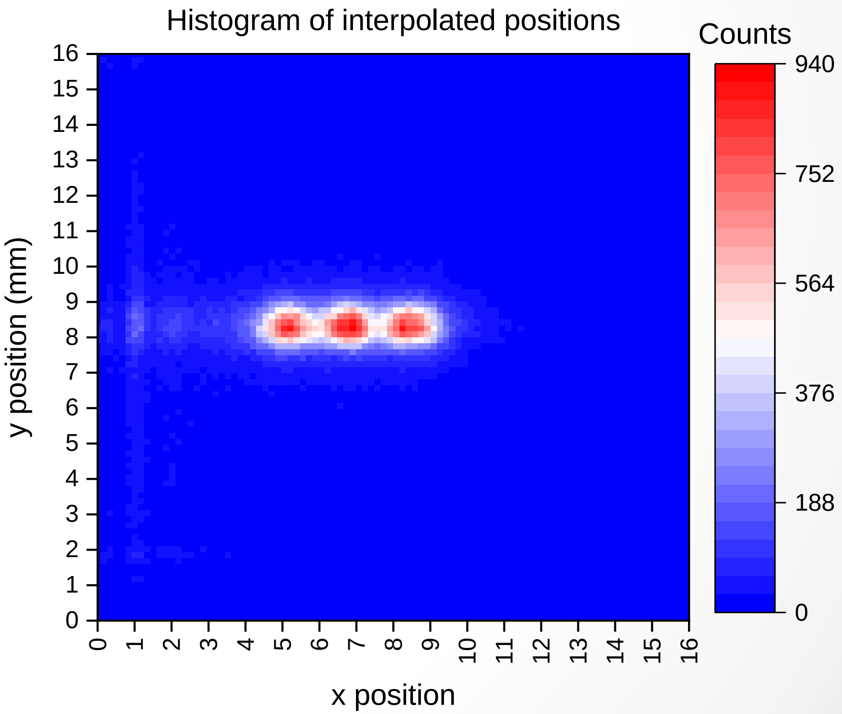
2D interpolation
Results



3 mm pitch standard

2D interpolation
Results





3 mm pitch standard

3 mm pitch
Interpolated to 0.75mm

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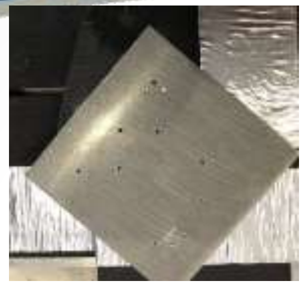
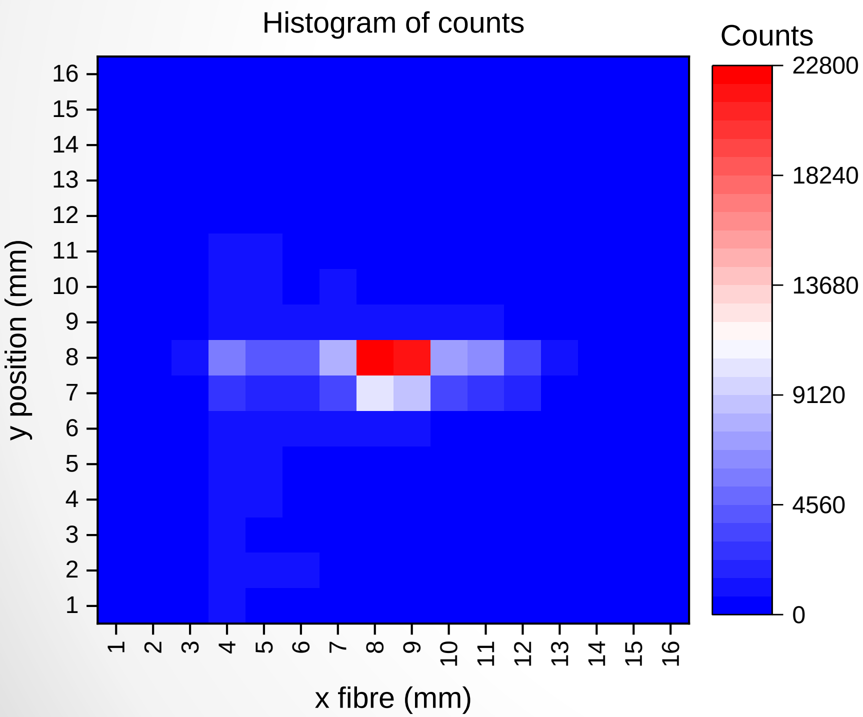
2D interpolation
Results





3 mm pitch standard

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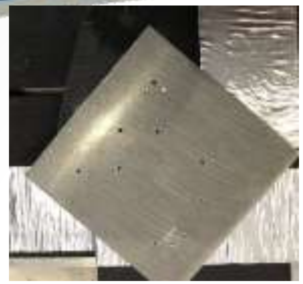
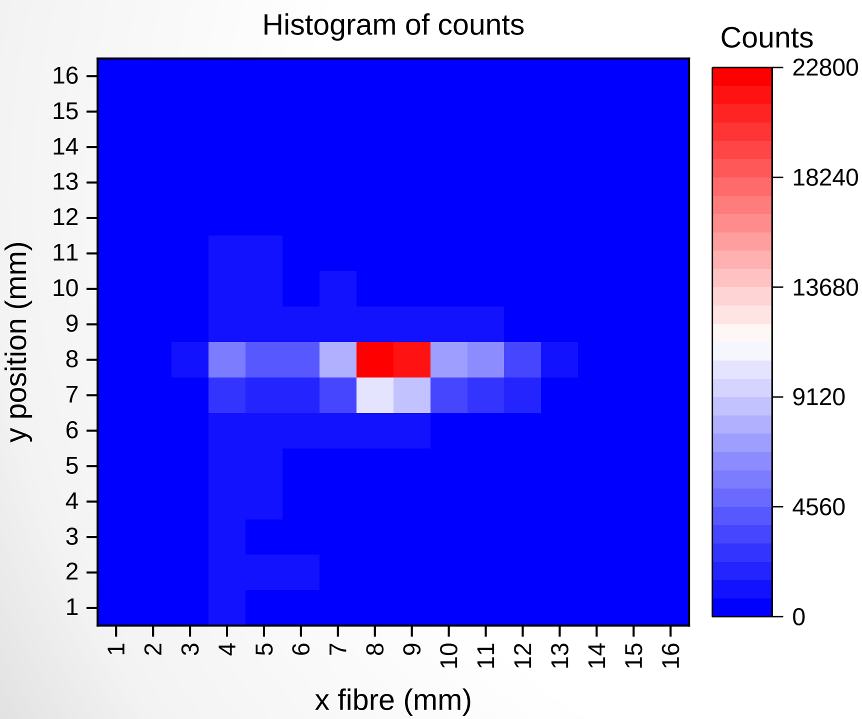
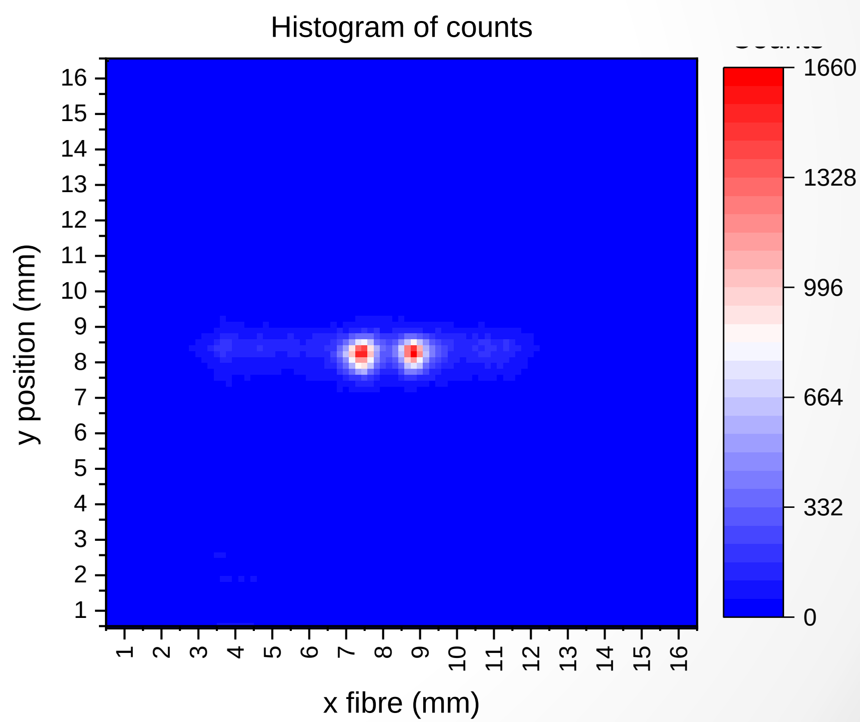


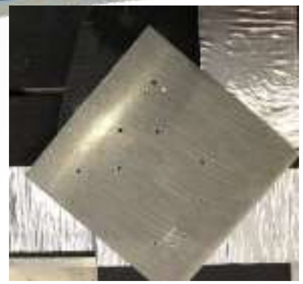


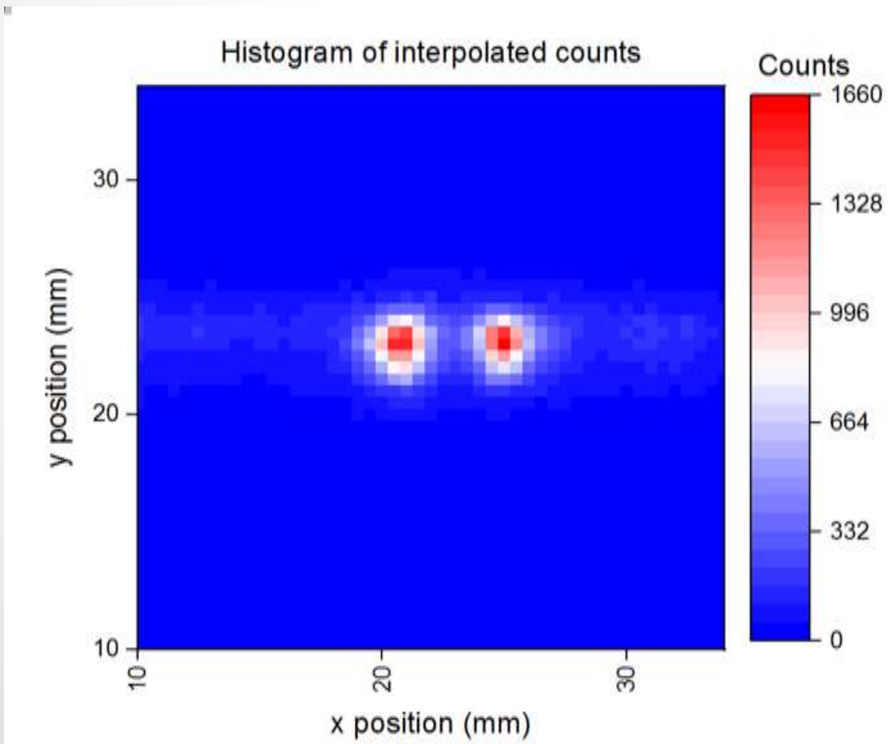
3 mm pitch standard



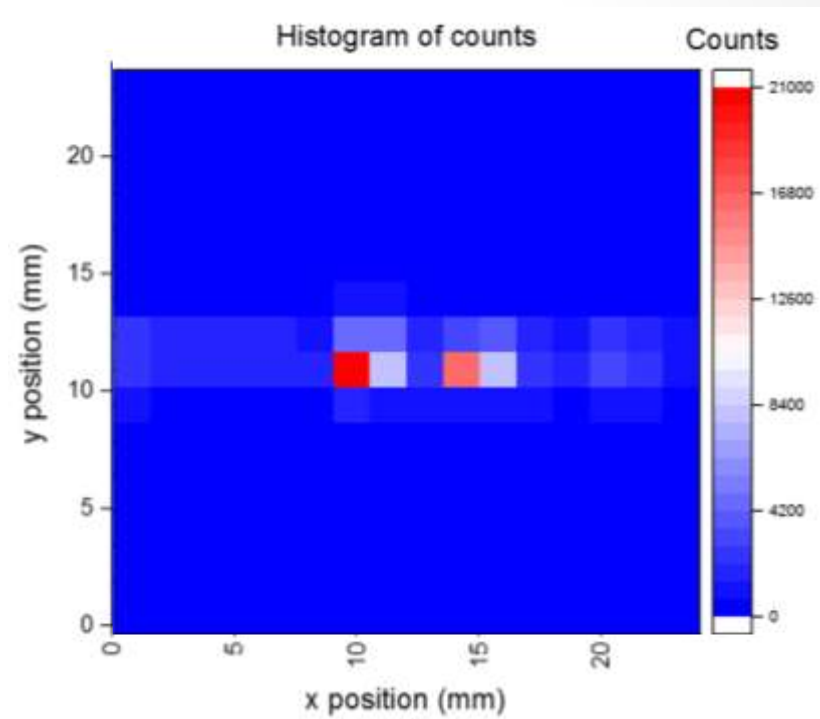
3 mm pitch
Interpolated to 0.75mm

Interpolation vs finer pitch



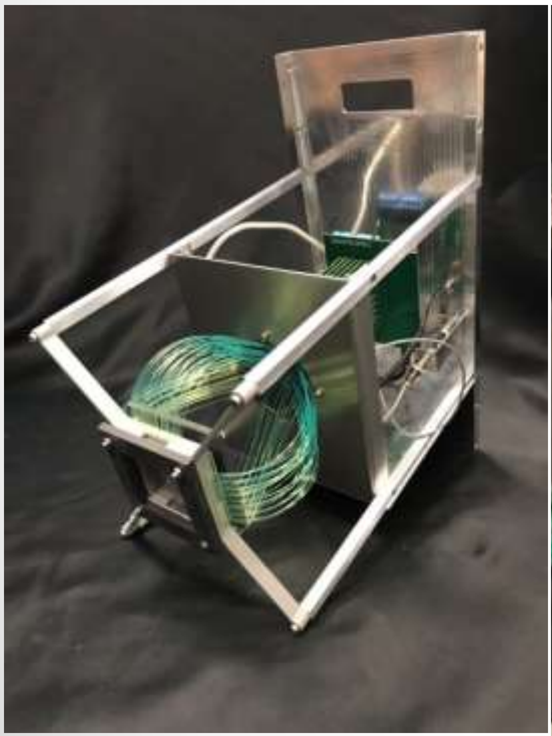


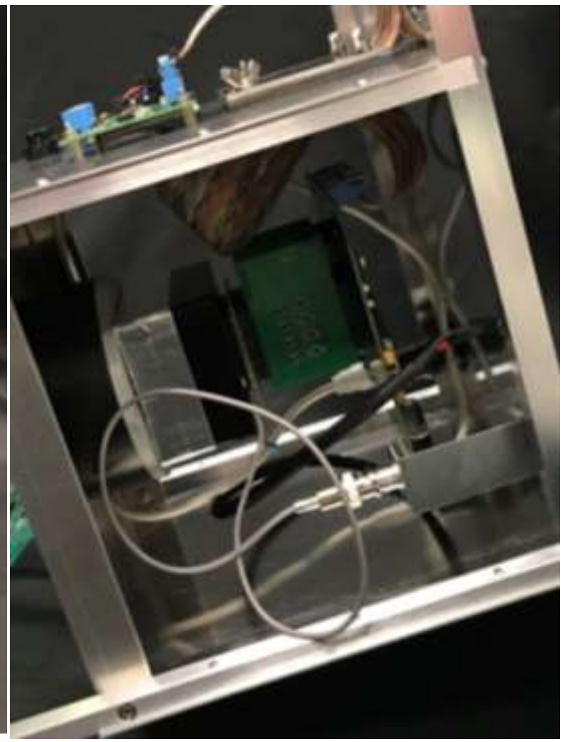
3mm pitch, 0.75mm binning

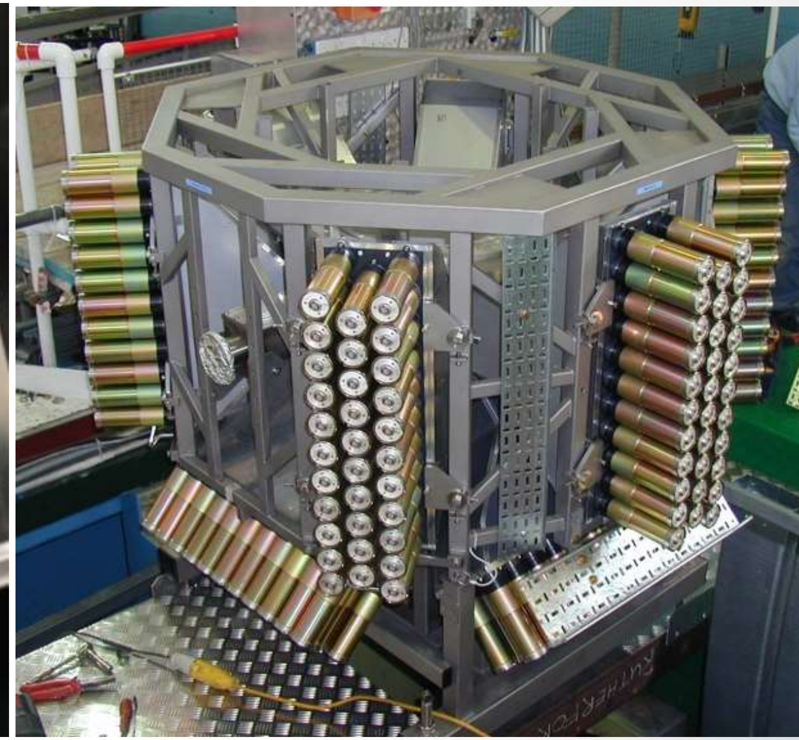


1.5mm pitch, 1.5mm binning

SXD Prototype







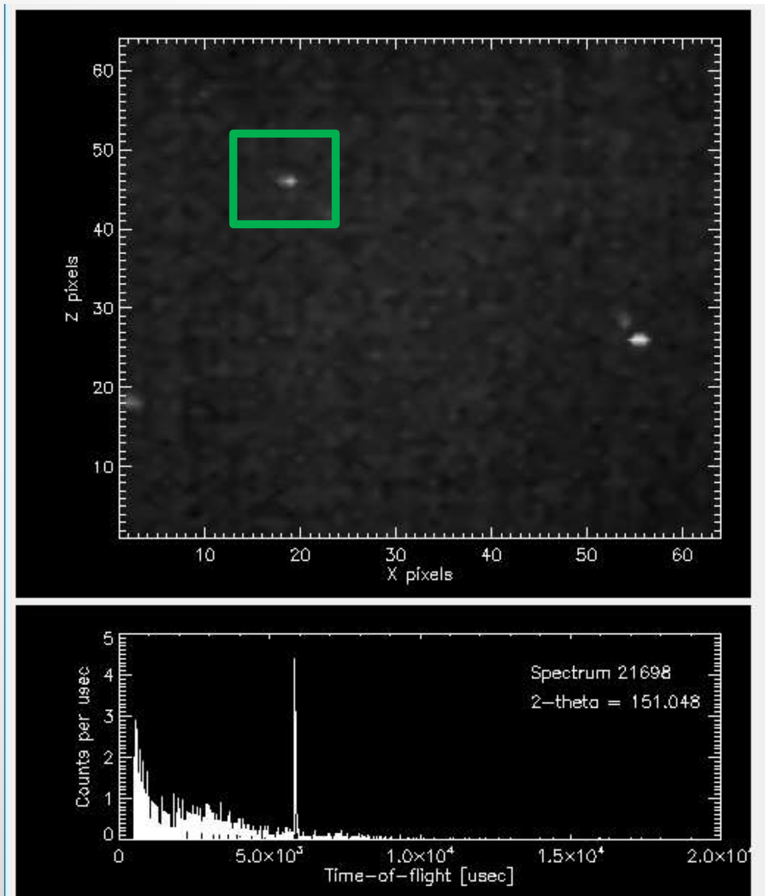
0.5 mm fibres
1.5 mm pitch

SXD Example Data

9,10-Diphenylanthracene

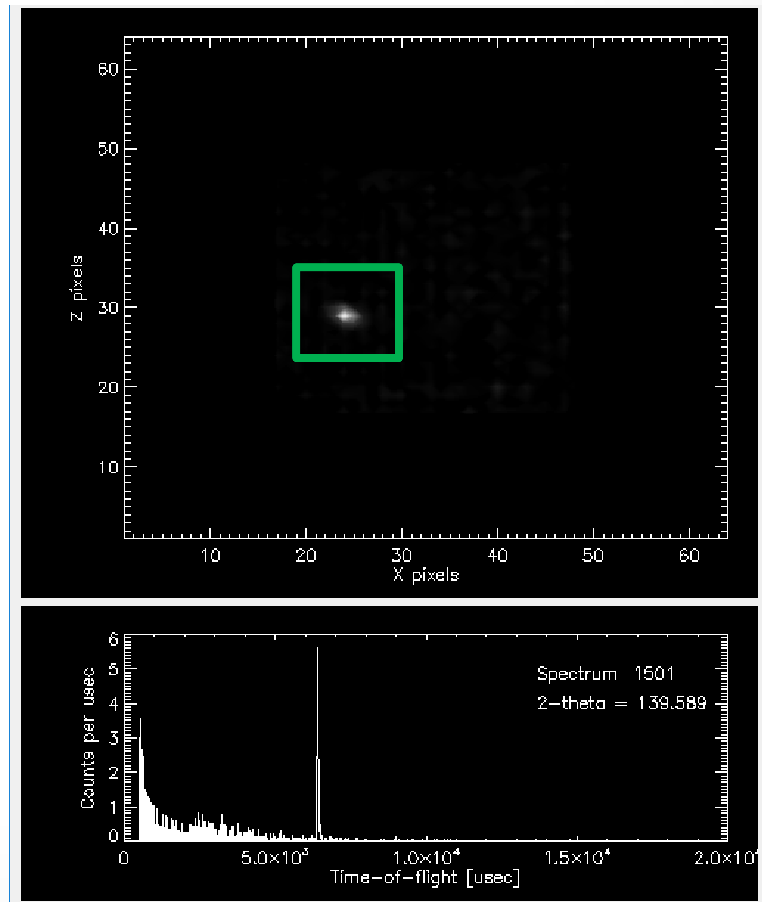
Old detector

3mm x 3mm



WSF detector

1.5mm x 1.5mm



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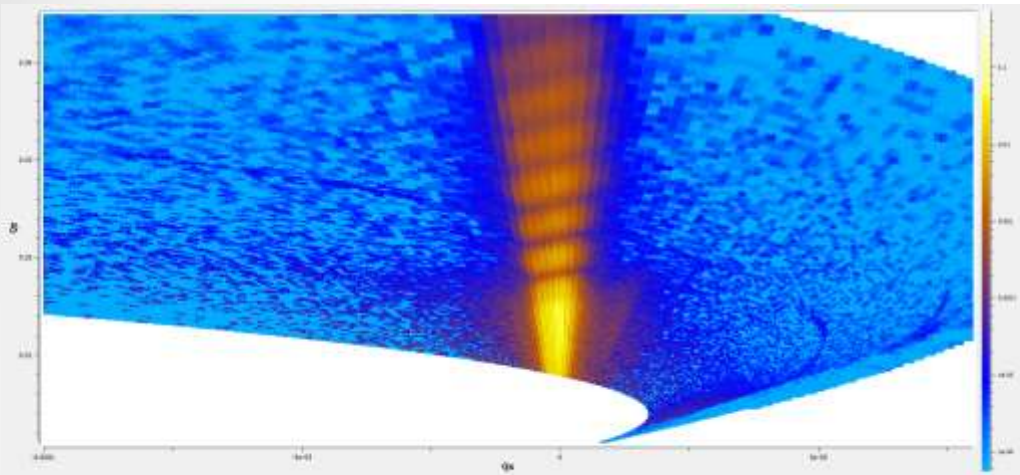
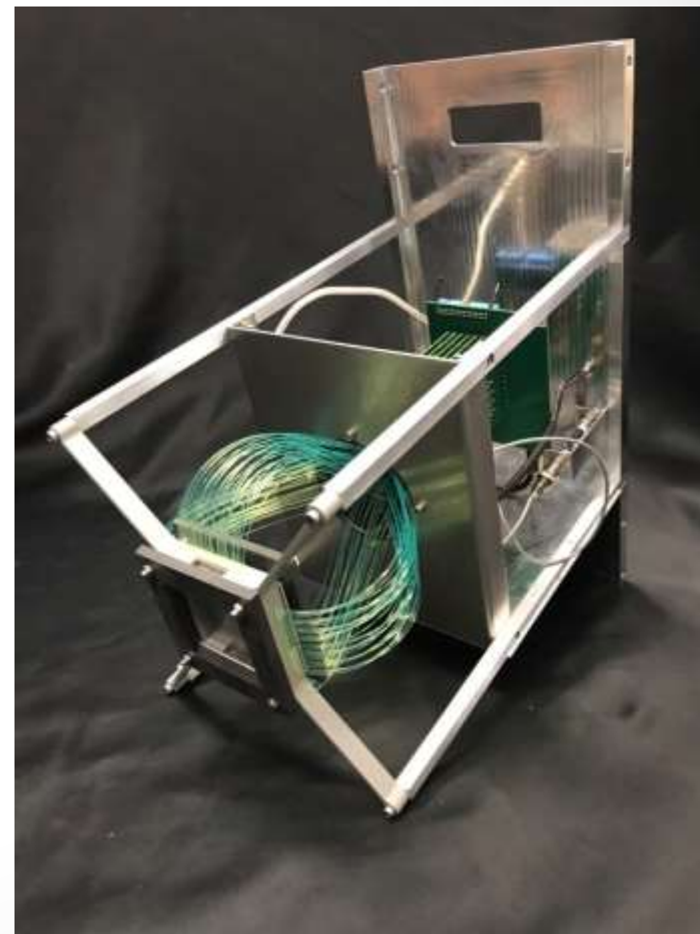
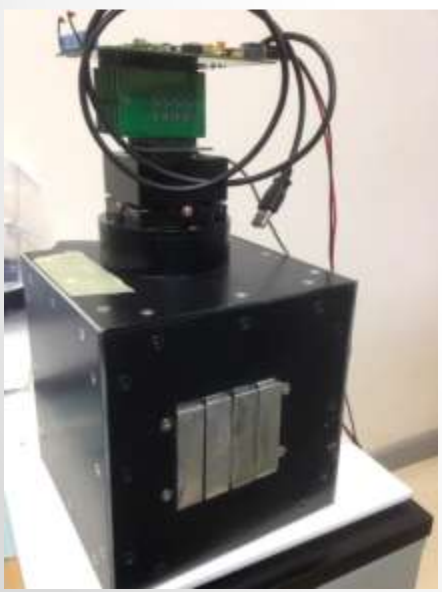
Summary

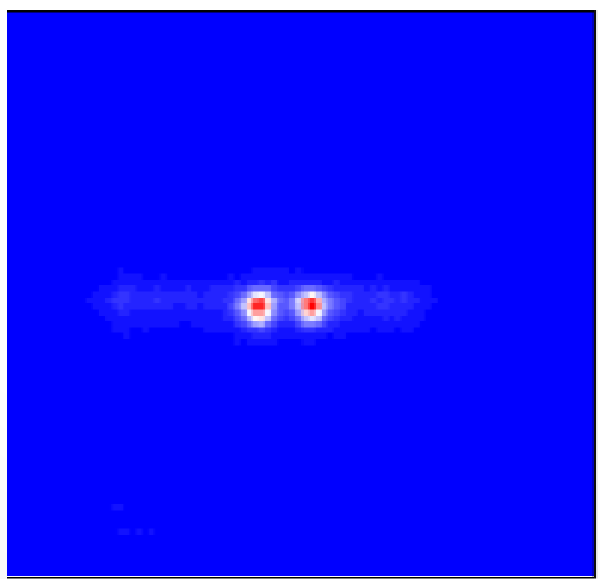
- Interpolation improved FWHM by a factor of 2.
- Positioning improved by over a factor of 4.
- Progress on detectors for reflectometry is directly applicable to others and vice versa.
- We now have viable solutions for the INTER reflectometer AND single crystal diffraction.
- Can we combine them for high rates and high 2D resolution?

Questions?









Ghosting

- Ghosting is an issue with this coding scheme
  - N.B. This was expected
- Example:
- Ghosts caused by :
  - Afterglow
  - Coding
  - Cross-talk

Fibre no.	PMT 1	PMT 2
1	1	9
2	1	10
3	2	10
4	2	11
5	3	11
6	3	12
7	4	12
8	4	13
9	5	13
10	5	14
11	6	14
12	6	15
13	7	15
14	7	16
15	8	16
16	8	9
17	3	9
18	3	10
19	4	10
20	4	11
21	5	11
22	5	12
23	6	12
24	6	13
25	7	13
26	7	14
27	8	14
28	8	15
29	1	15
30	1	16
31	2	16
32	2	9

Direct beam

Location of ghosts

Ghosting

- Ghosting is an issue with this coding scheme
  - N.B. This was expected
- Example:

Fibre no.	PMT 1	PMT 2
1	1	9
2	1	10
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11	6	14
12	6	15
13	7	15
14	7	16
15	8	16
16	8	9
17	3	9
18	3	10
19	4	10
20	4	11
21	5	11
22	5	12
23	6	12
24	6	13
25	7	13
26	7	14
27	8	14
28	8	15
29	1	15
30	1	16
31	2	16
32	2	9

Direct beam

Location of ghosts

- Ghosts caused by :
  - Afterglow
  - Coding
  - Cross-talk

- Methods to reduce ghosting
  - Reduce number of fibre codes used
  - Vary threshold based on number of fibres measuring light
  - Insert reflectors between fibres