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Current Status of Scintillation Detector Development at ISIS

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ICND

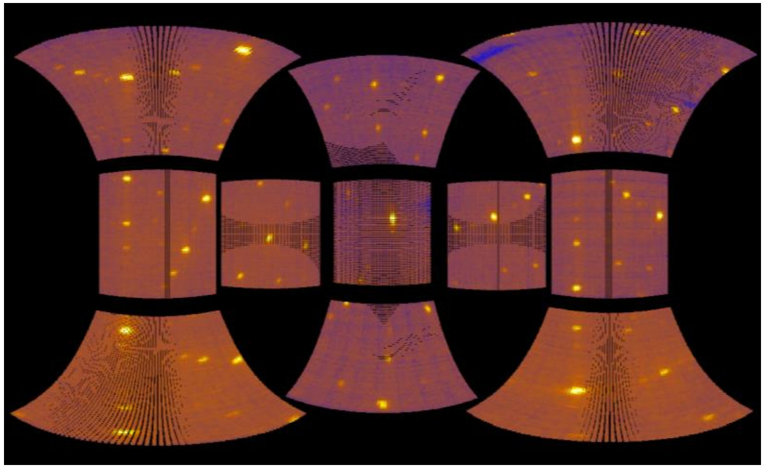
Manchester

27 October 2019

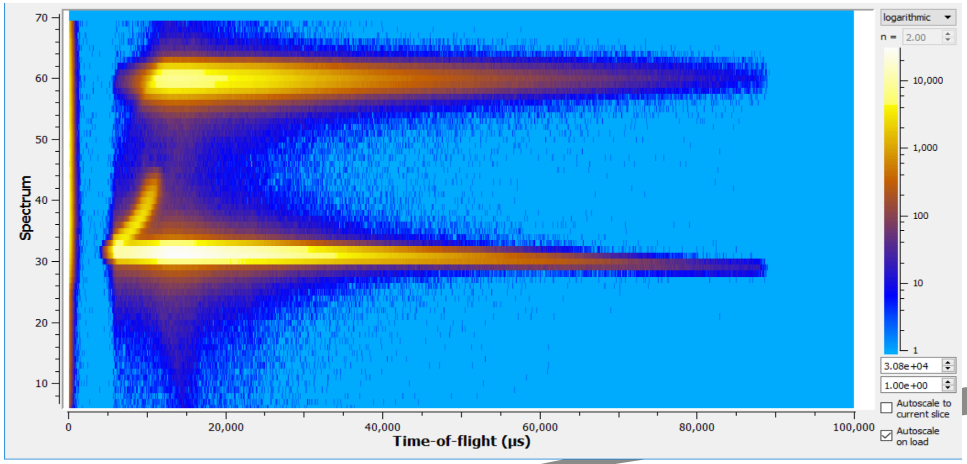
Instrument Development at ISIS

- Single Crystal Diffraction
- Reflectometry
- Powder Diffraction
- SANS/SEMSANS

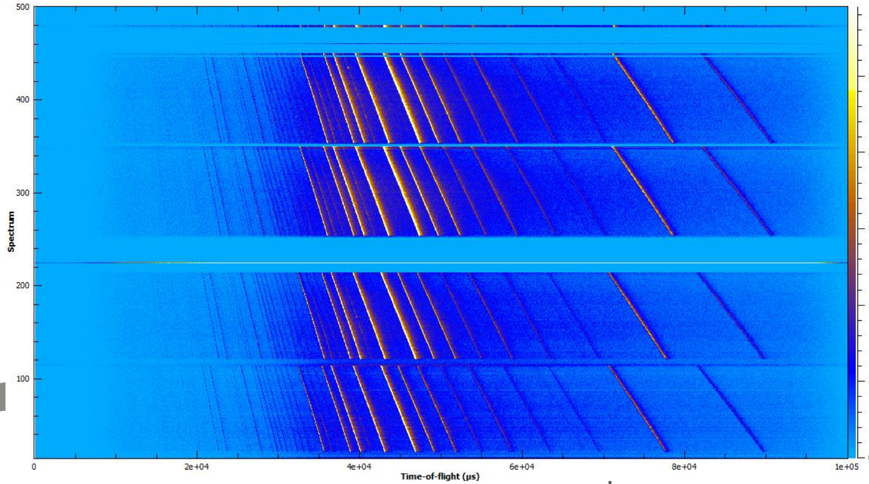
Single crystal diffraction from NiFeCoGa



Low angle reflection, refraction and transmission from Al_2O_3



Powder diffraction from NaCaAlF



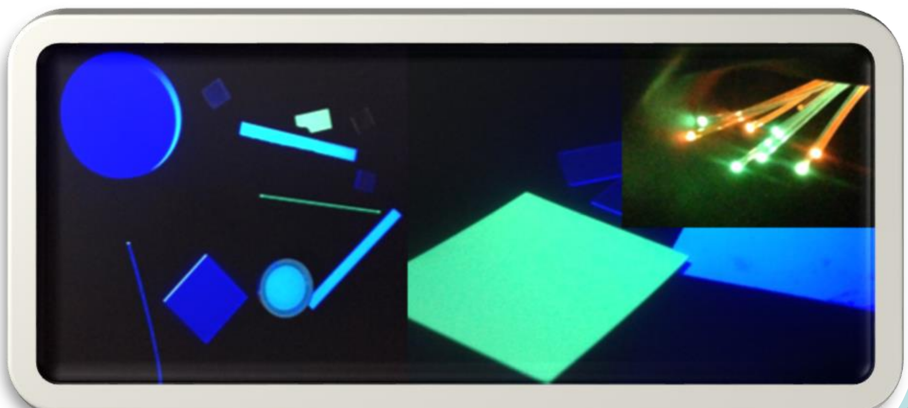
Instrument → Detector Development at ISIS

- Single Crystal Diffraction
- Reflectometry
- Powder Diffraction
- SANS/SEMSANS

- Position Resolution
- Rate capability
- Size/Scalability
- Cost-effectiveness

- Further develop working technology

- Investigate novel approaches



Instrument Development at ISIS

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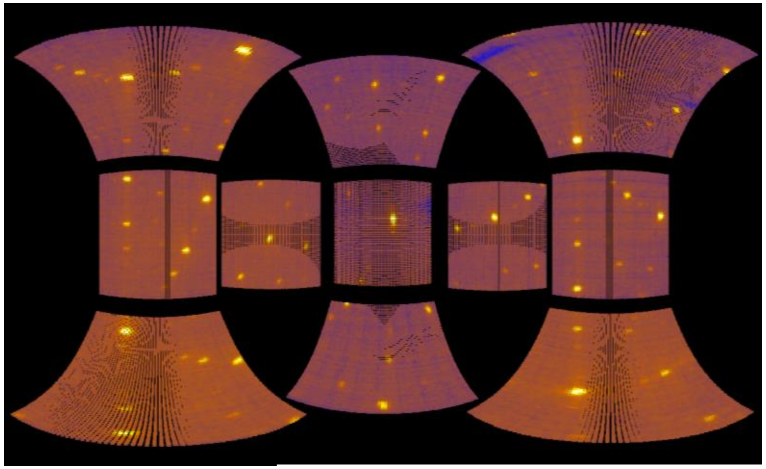
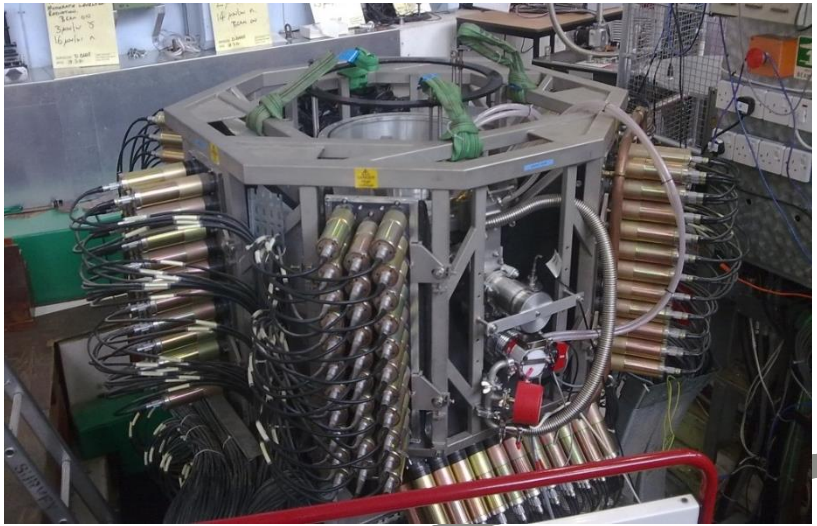
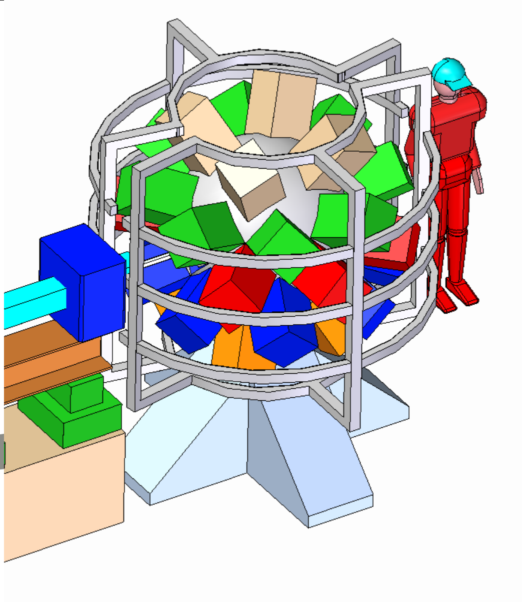
Single crystal diffraction from NiFeCoGa







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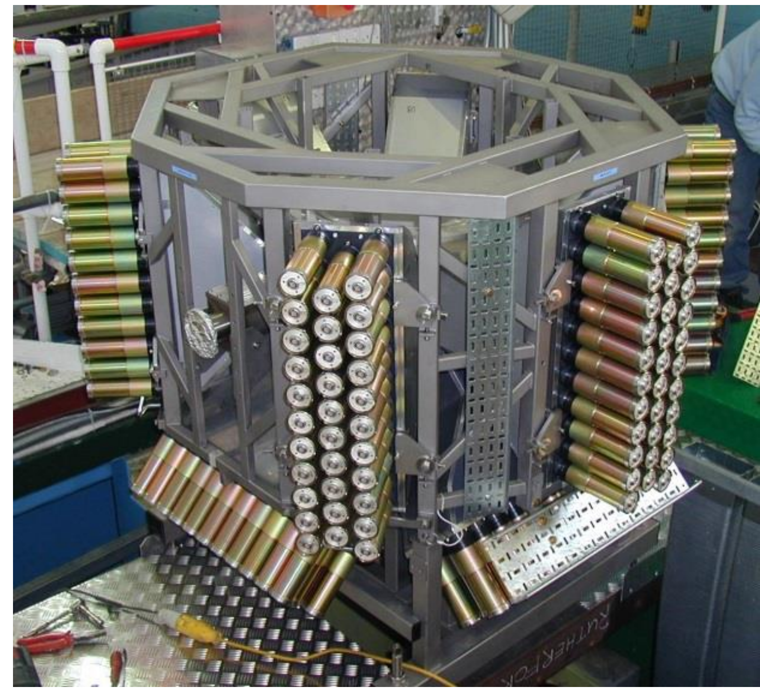
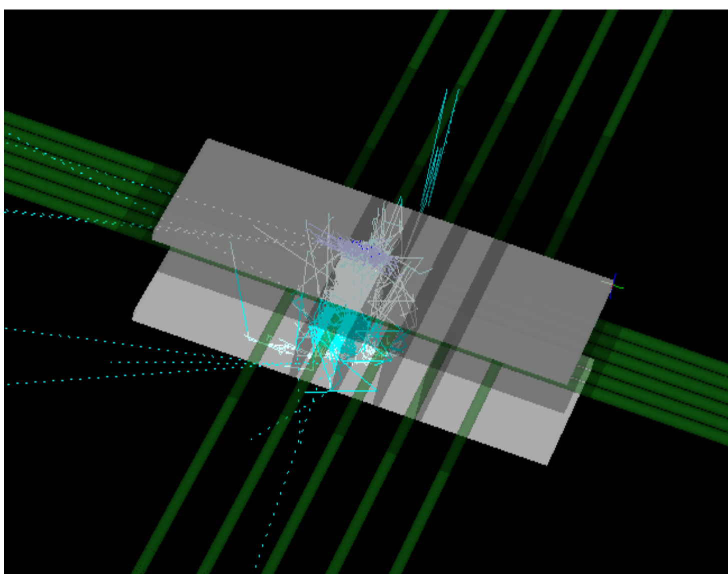
SXD Current Configuration

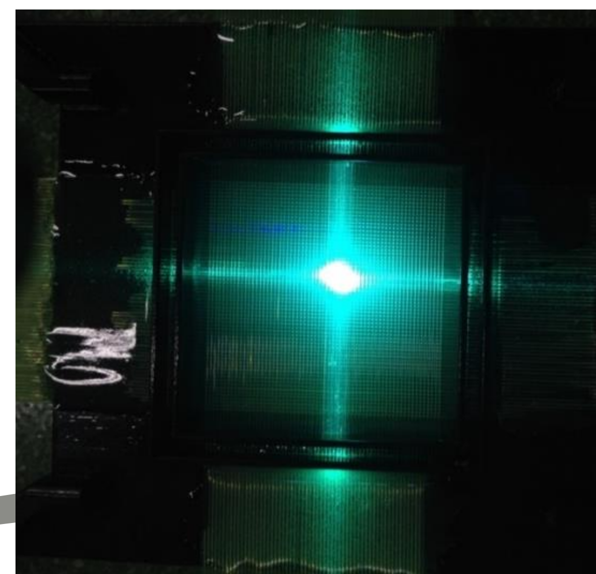
	Current clear fibre detectors (2000)
Neutron detection efficiency @ 1.8Å	21%
Pixel size (mm²)	3 × 3
Active area (mm²)	192 × 192
Number of fibres	16384
Weight (kg)	~70
Total coverage	2π Sr



The 2D Solution

- 2D - Crossed fibre array
- Efficiency
  - 2 x higher lithium content scintillator front and back
  - High light collection
- Rate capability
  - 4x more PMT channels (2×64 ch PMTs vs 32×1 ch PMTs)

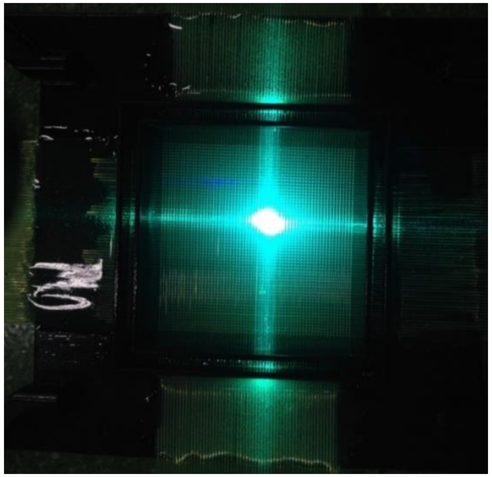


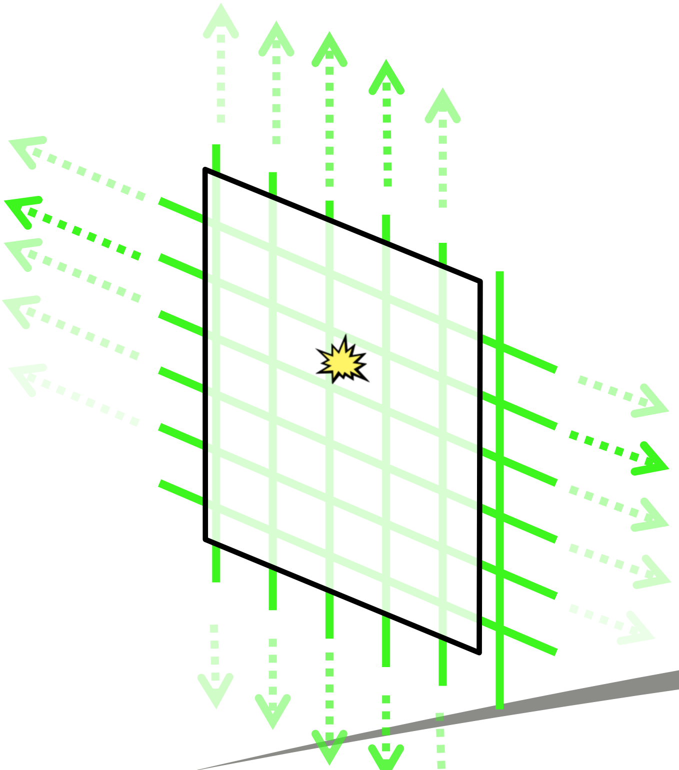


Positioning

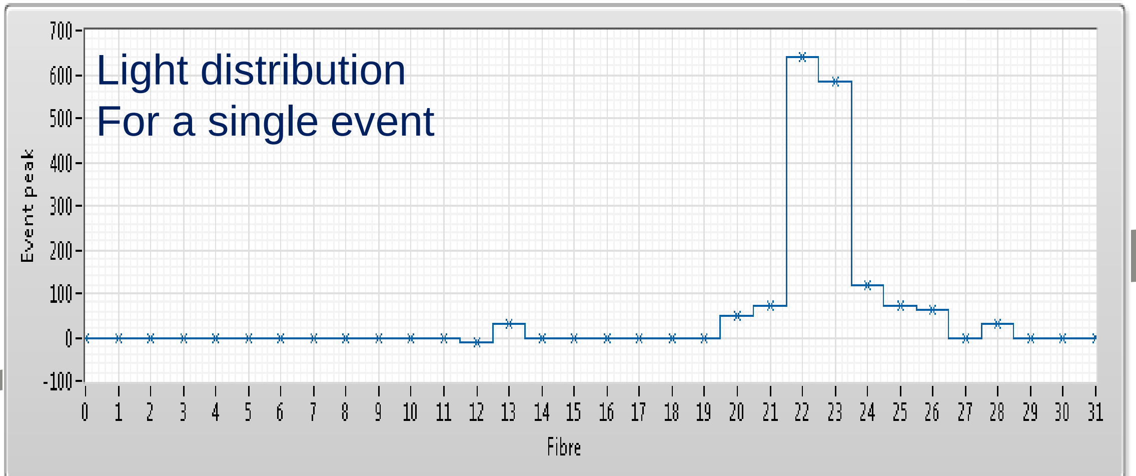
2 Dimensions

- Brightest fibre OR
- Simple centre of gravity calculation
  - 7 fibres centralised on fibre with max photon density
  - Separate (x,y) coordinates



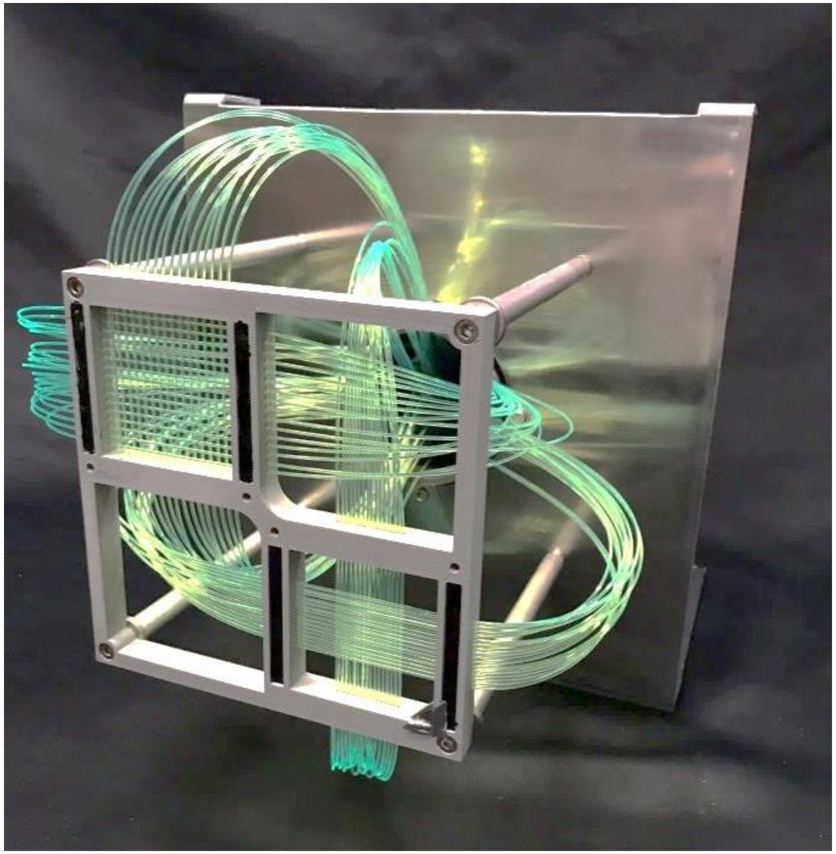


$$x_{CoG} = \frac{\sum_{i=1}^{7} I_i x_i}{\sum_{i=1}^{7} I_i}$$



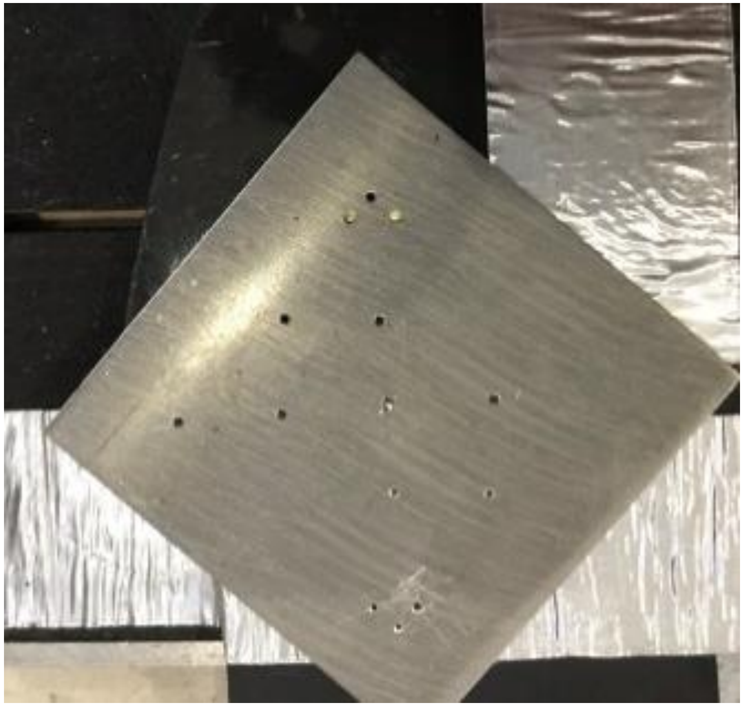
High Resolution Prototyping

- 0.5 mm fibres
- 2 sets of 16 x 16 fibres
  - 1.5 mm pitch
  - 3 mm pitch
- Single 64-channel FPPMT

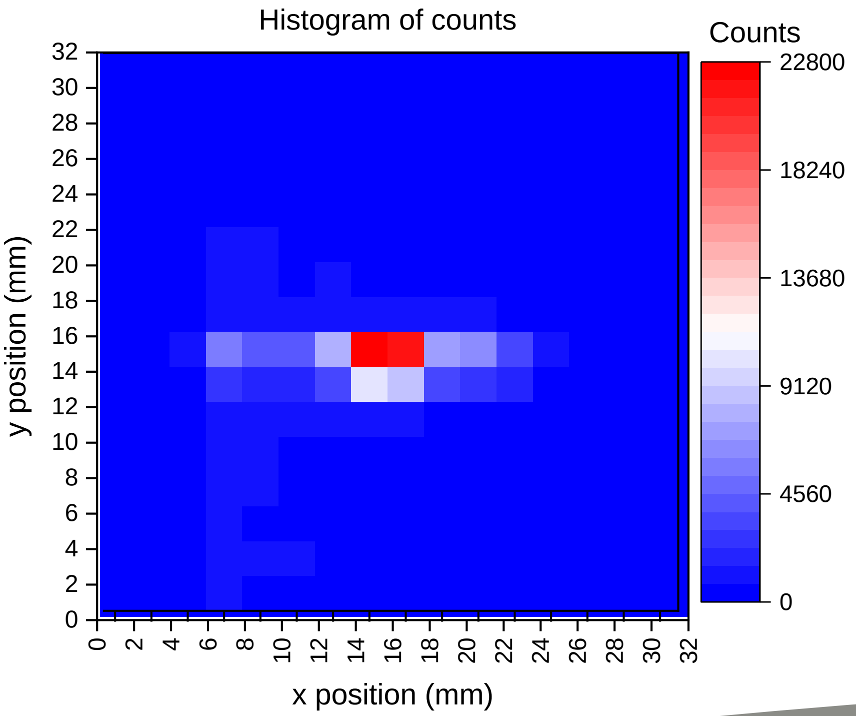


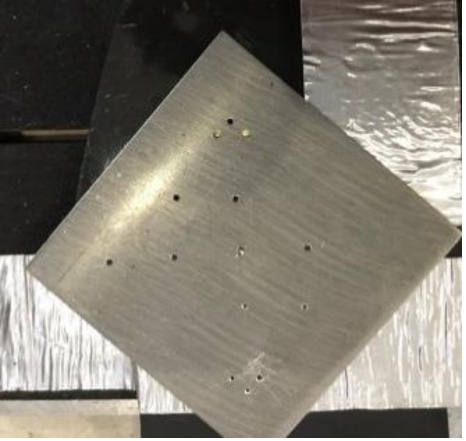
High Resolution
Interpolation

2 ×1 mm holes on 4mm pitch



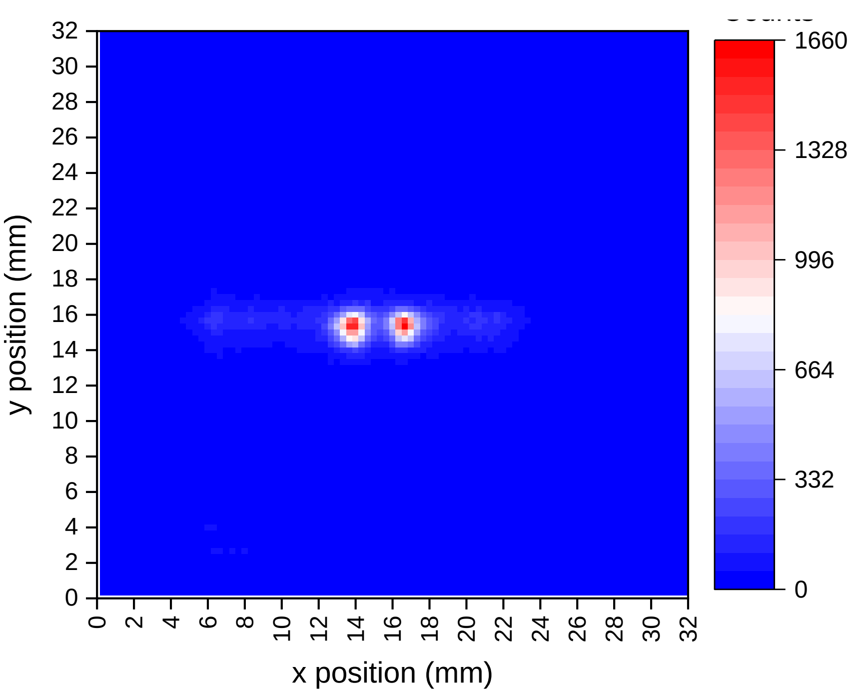
3 mm pitch
Standard positioning

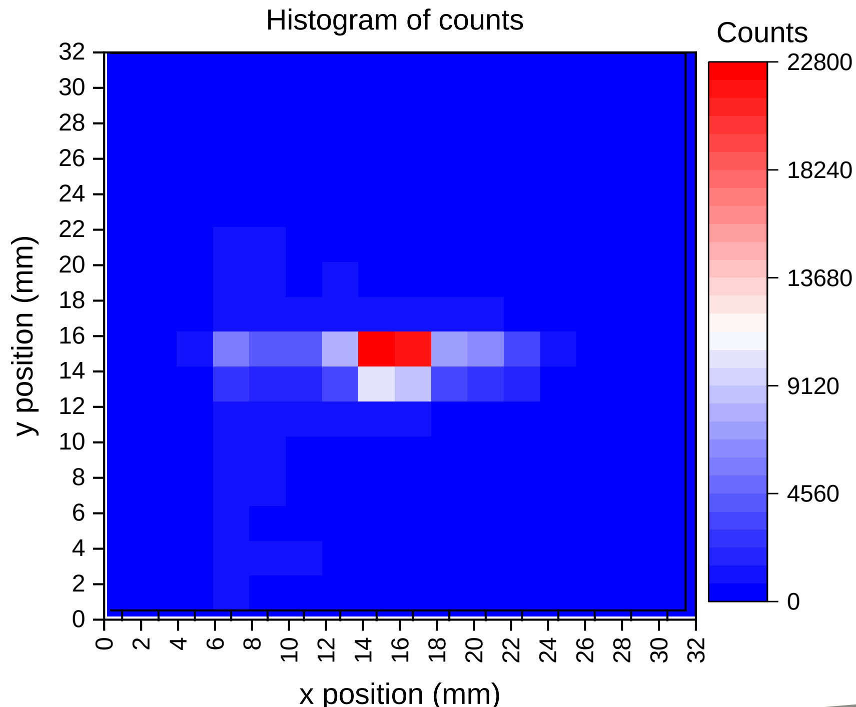




High Resolution
Interpolation

3 mm pitch
Standard positioning





3 mm pitch
0.75 mm positioning

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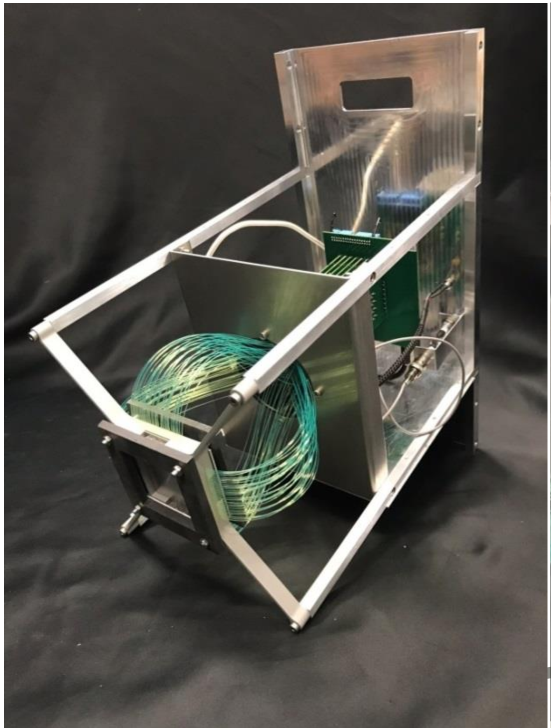
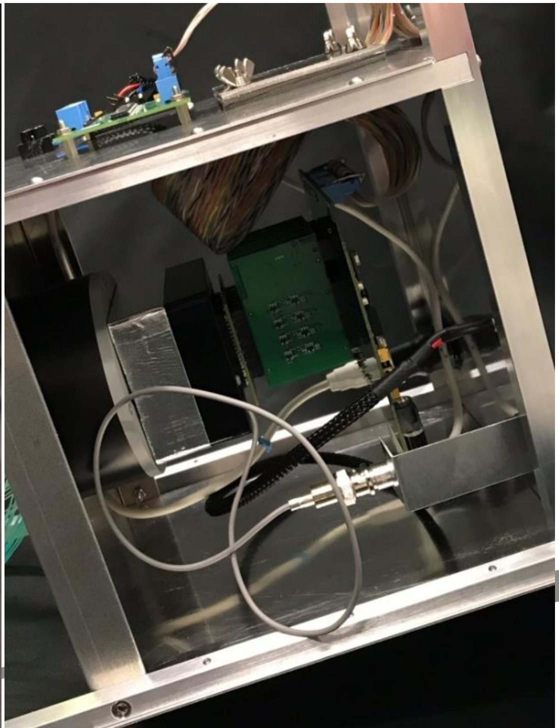
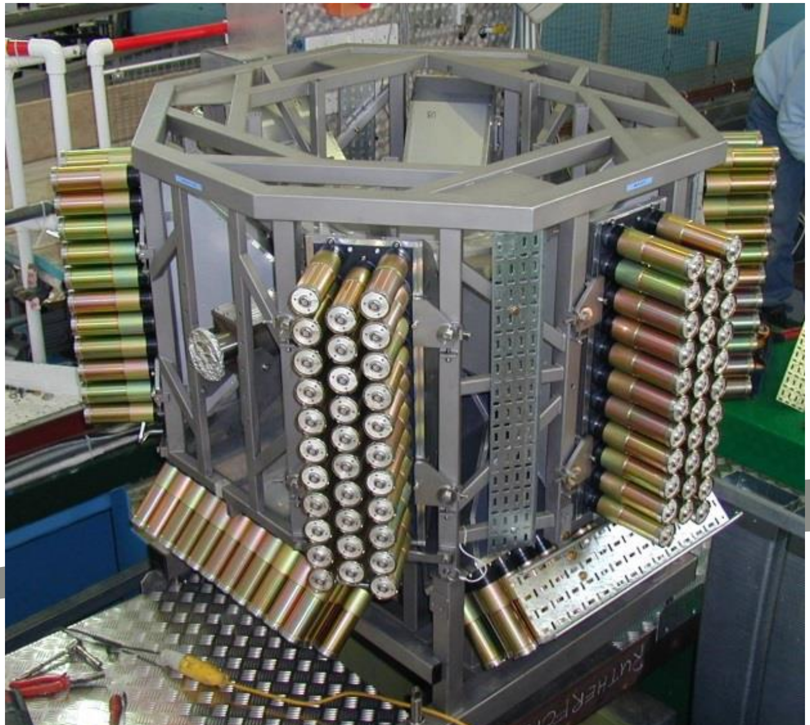
High Resolution

Trial on SXD

- 0.5 mm fibres
- 32 x 32 fibres
- 1.5 mm x 1.5 mm resolution
- Single 64-channel FPPMT

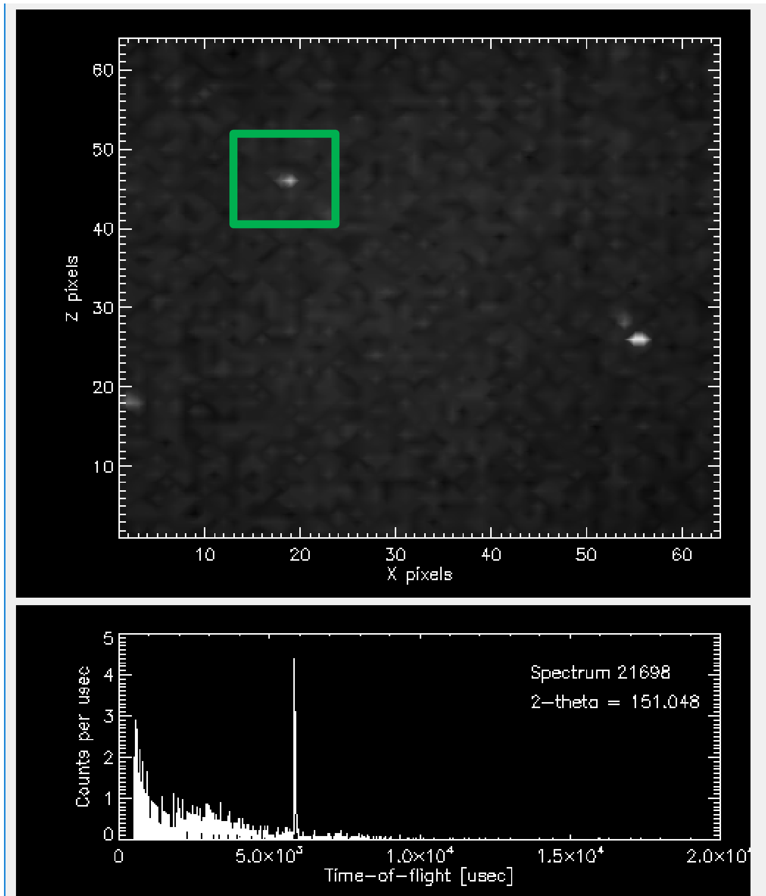




SXD

9,10-Diphenylanthracene

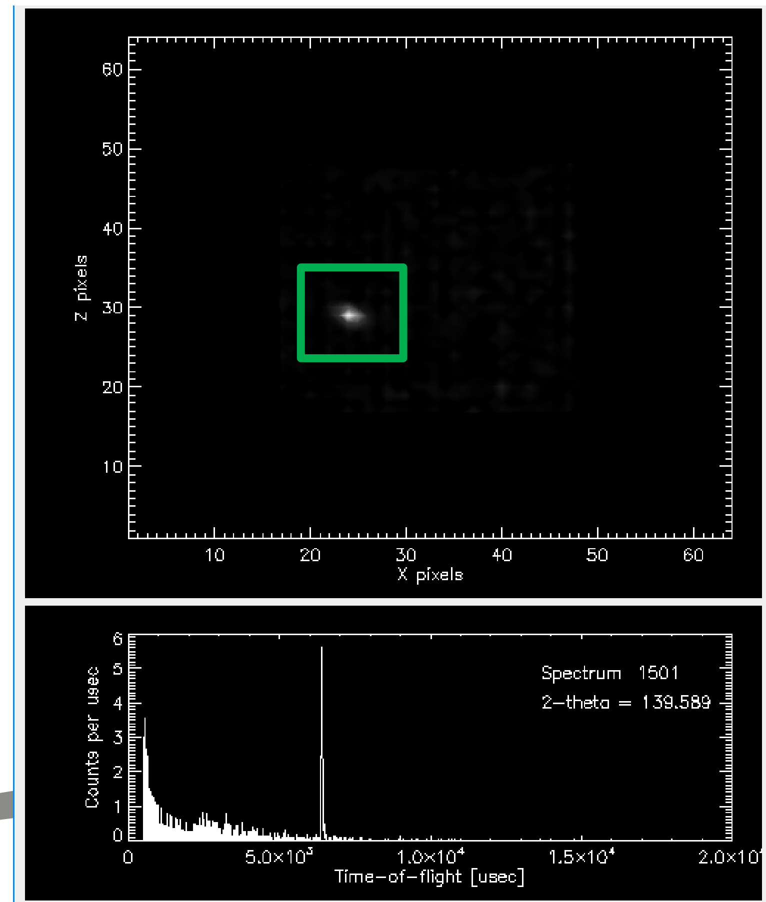
Old detector (Module 6)

3mm x 3mm



WSF detector (Module 1)

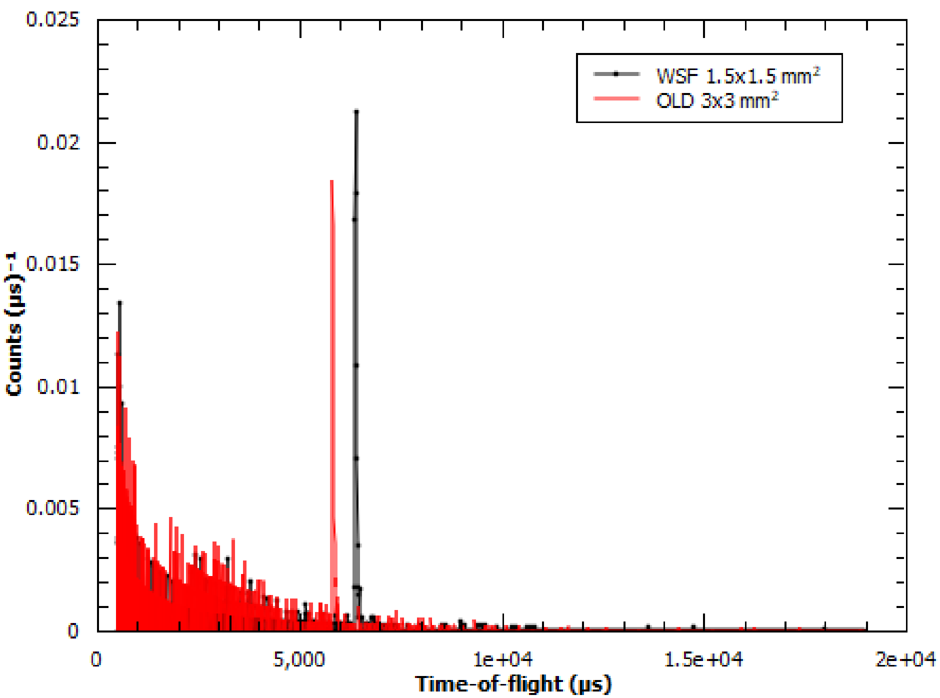
1.5mm x 1.5mm



SXD

9,10-Diphenylanthracene

Raw



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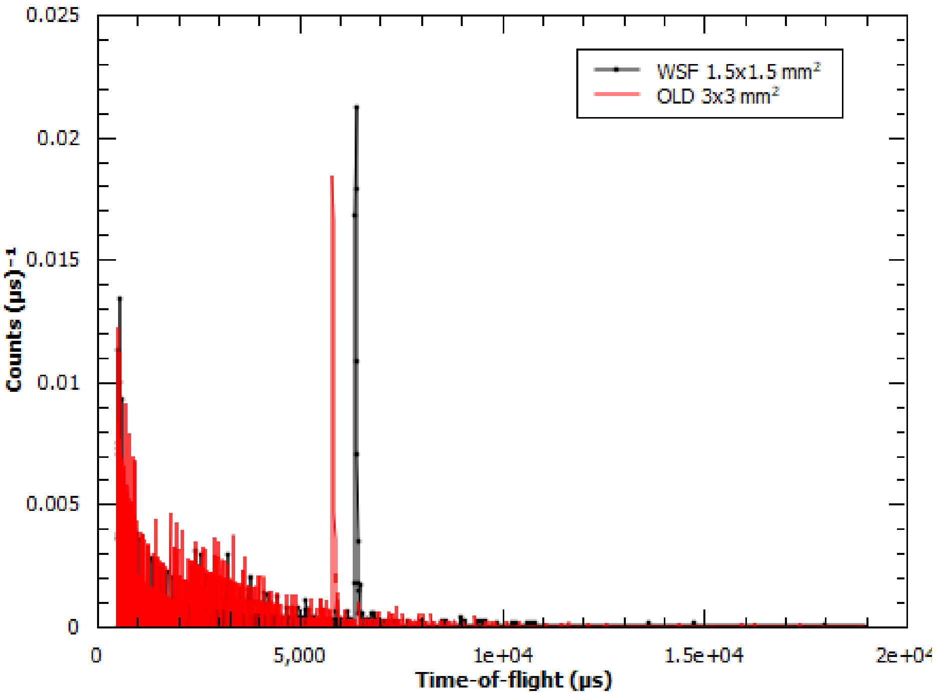
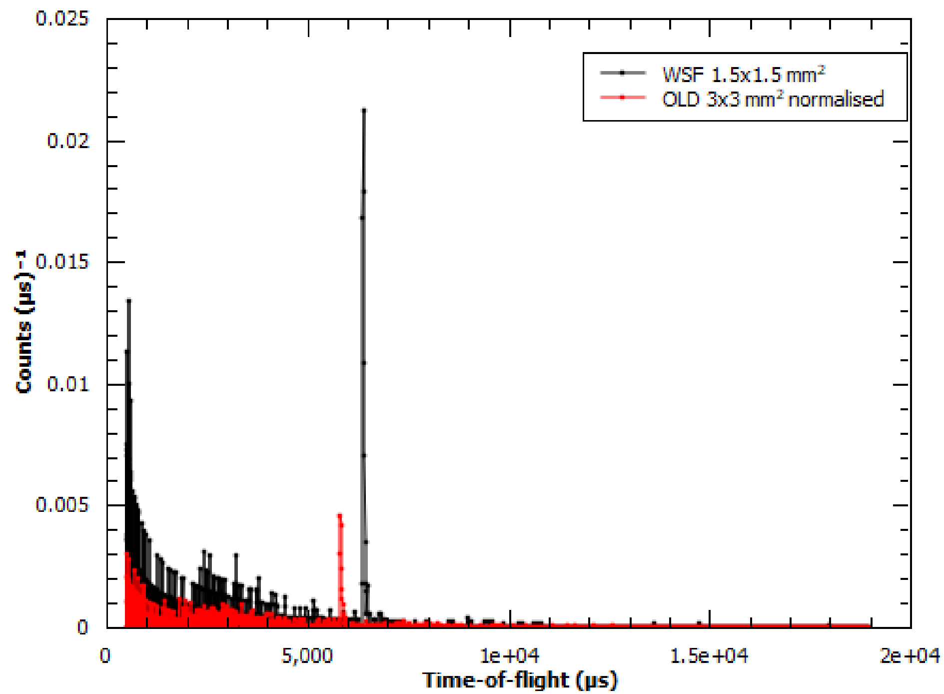
SXD
9,10-Diphenylanthracene

Raw

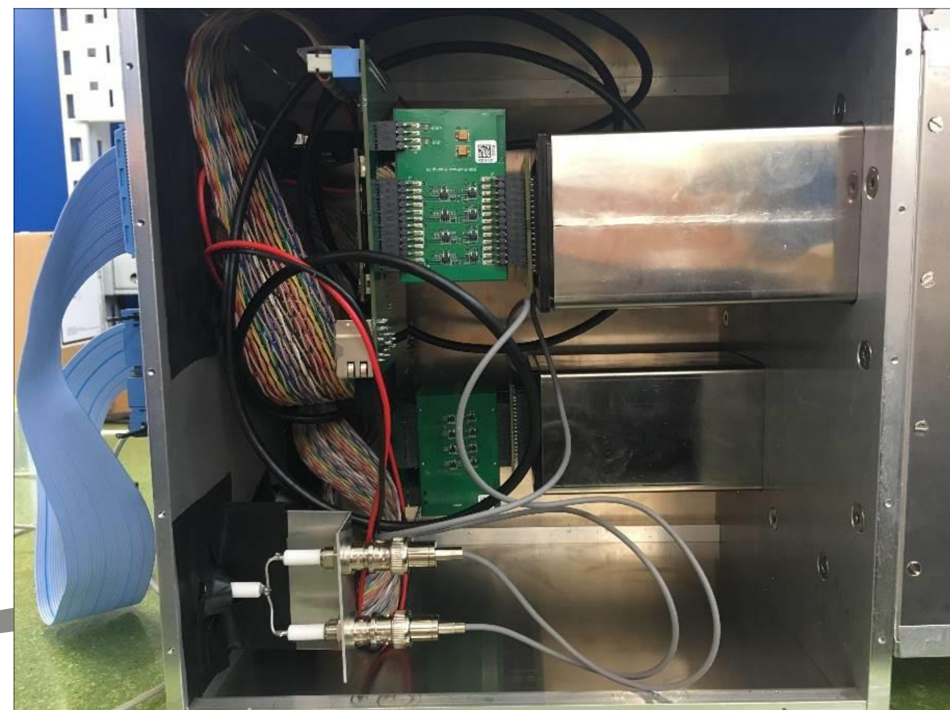


Normalised to pixel area



Full Scale Demonstrator

- 1 mm fibres
- 64 x 64 fibres
- 3 mm pitch
- 2 × 64-channel FPPMTs



Installation on SXD

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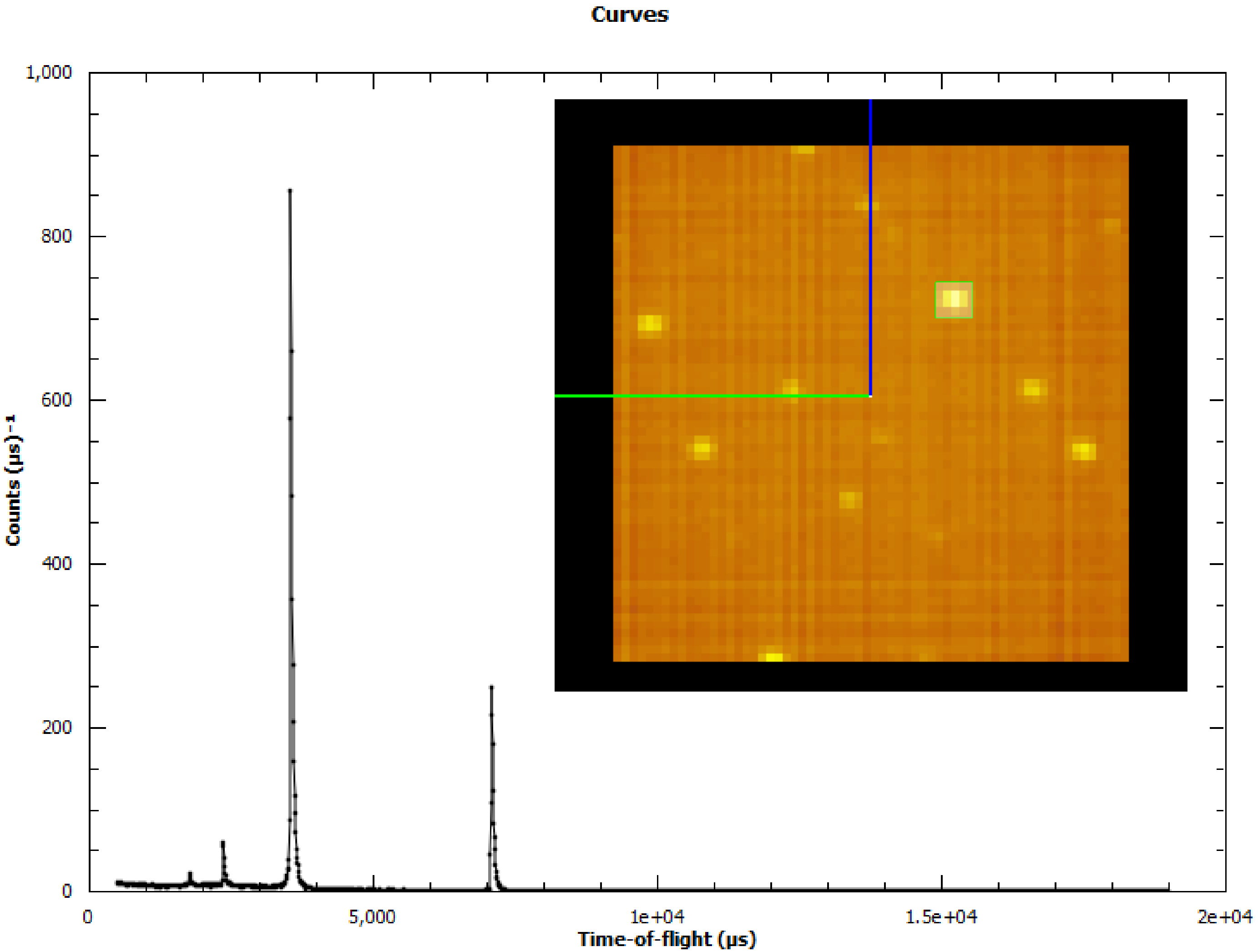
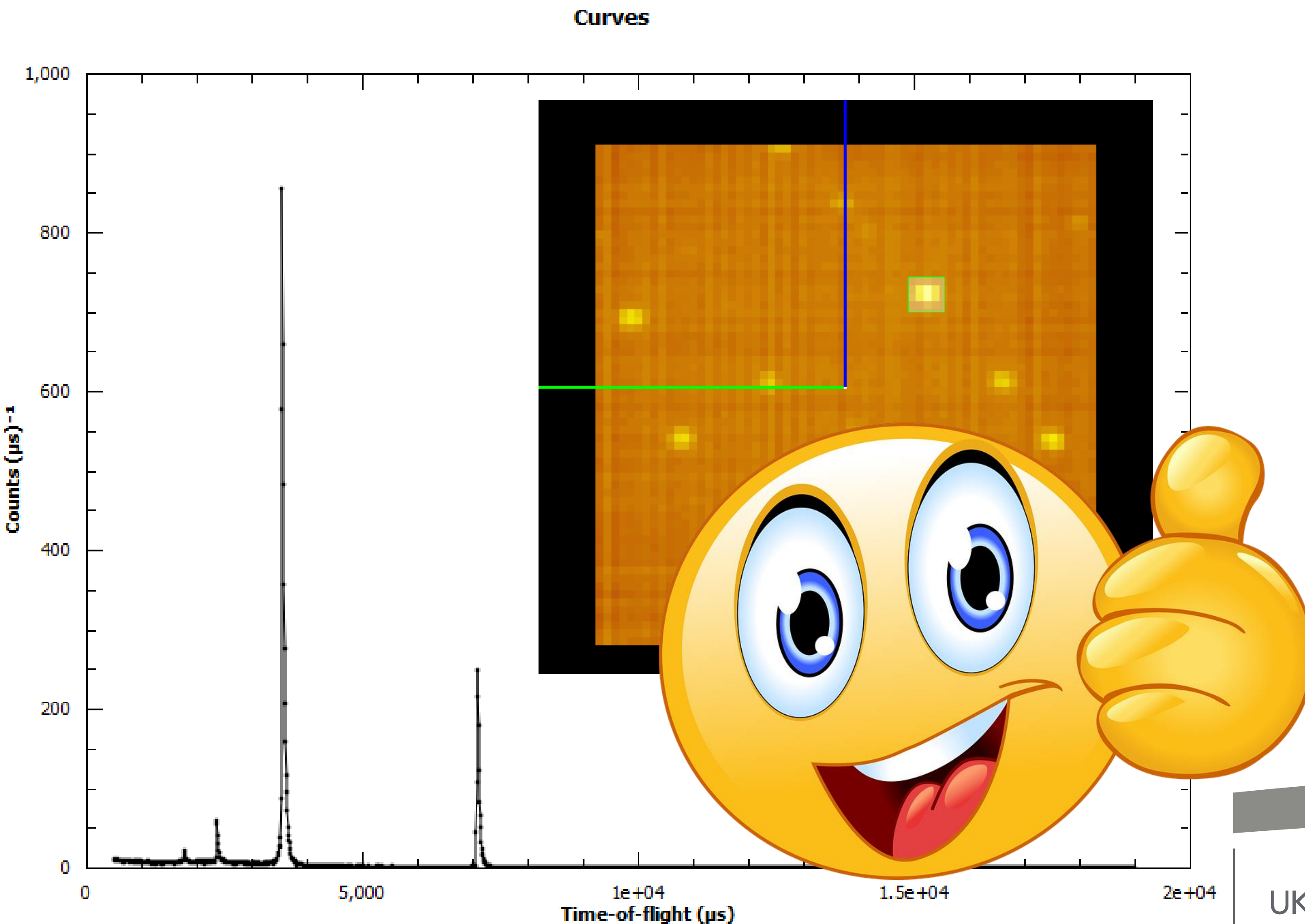
Results
NaCl Sphere



Results

NaCl Sphere



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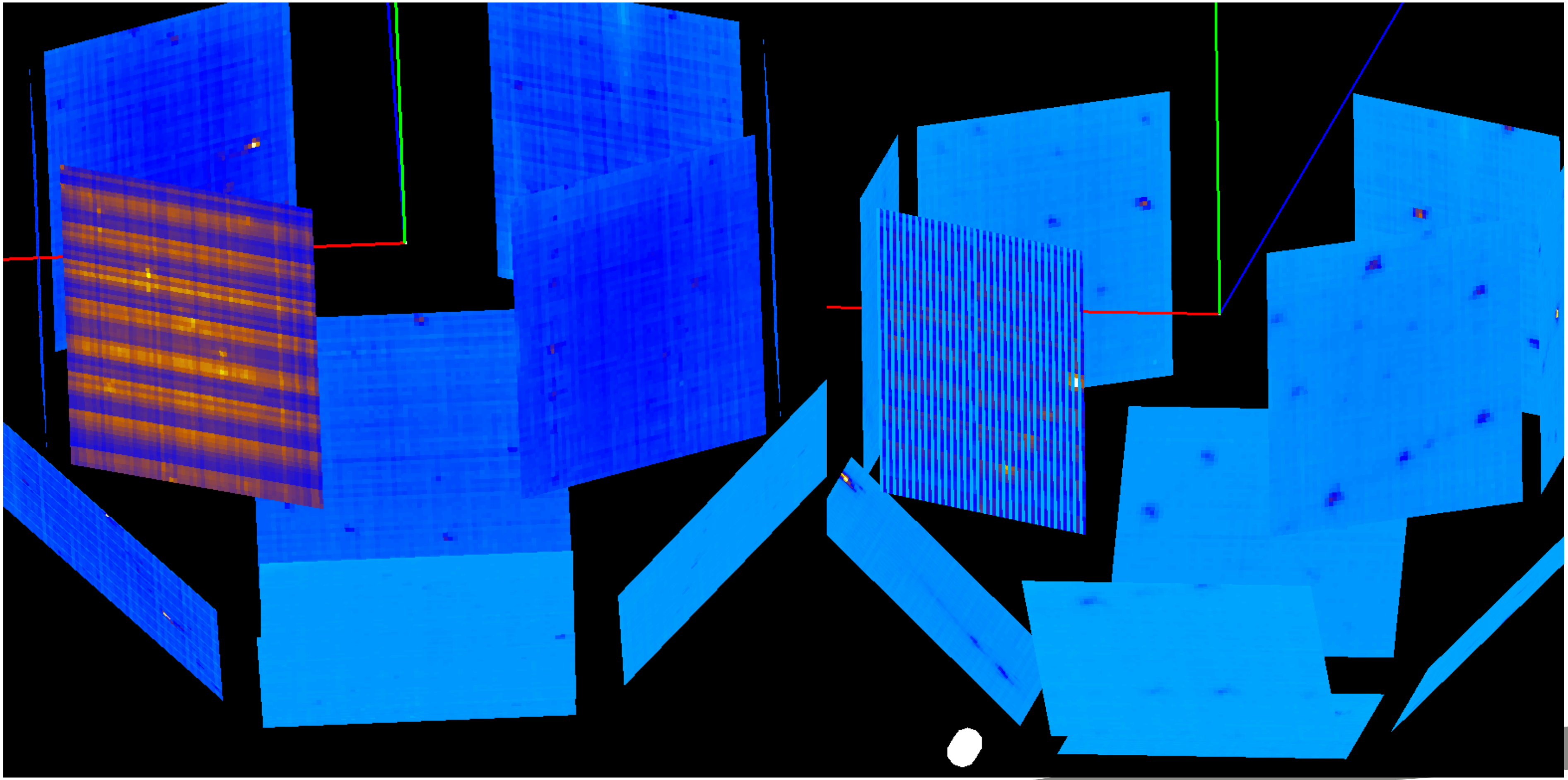
Results

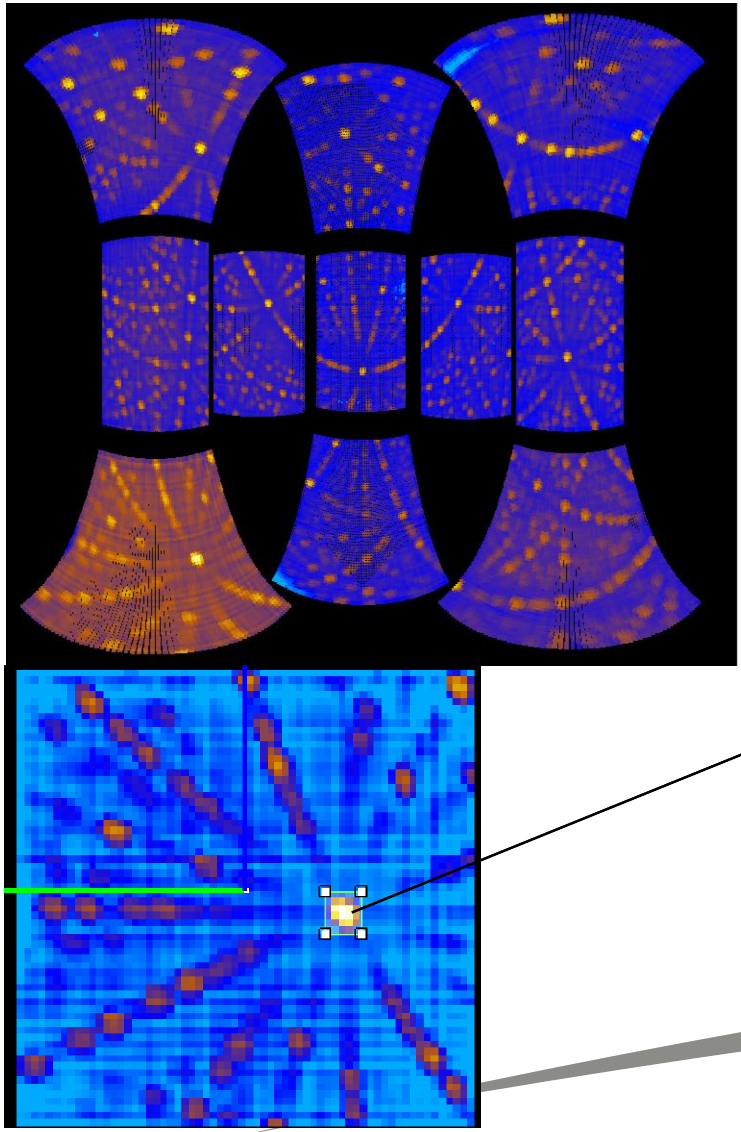
End of cycle

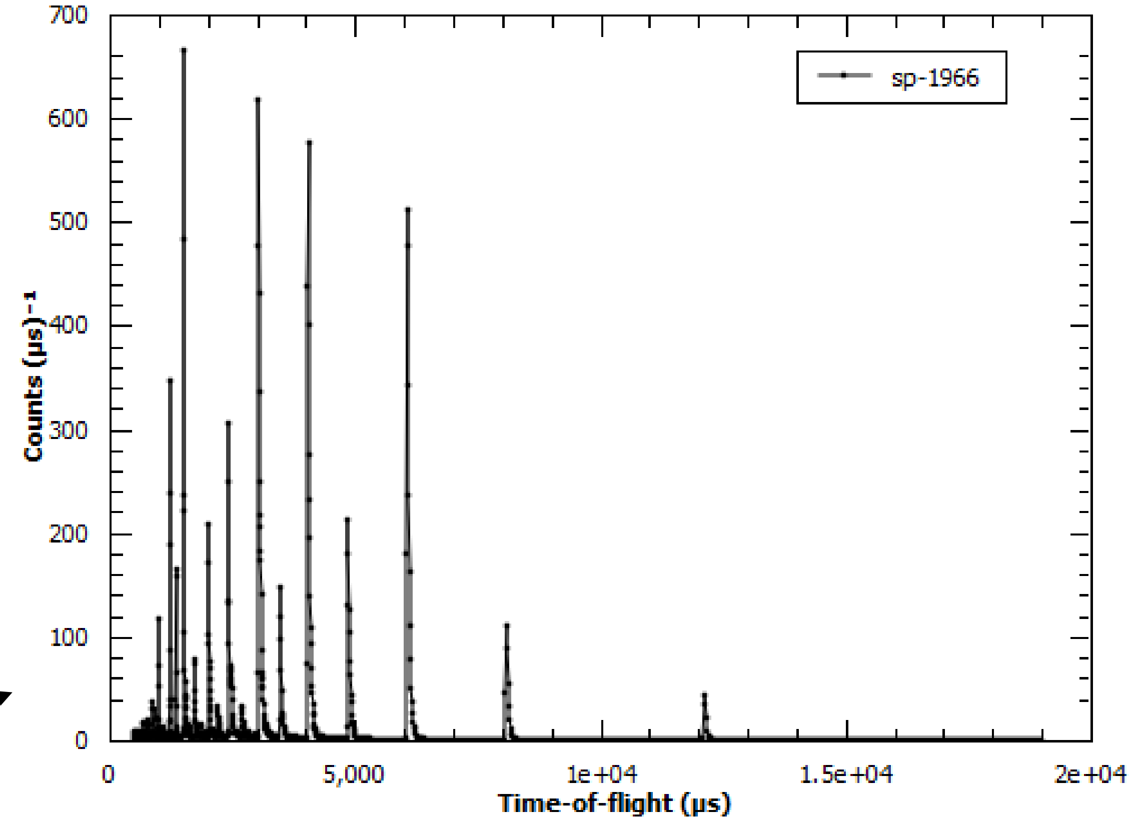


The problem

“Week old” results

HoAgGe at 15K





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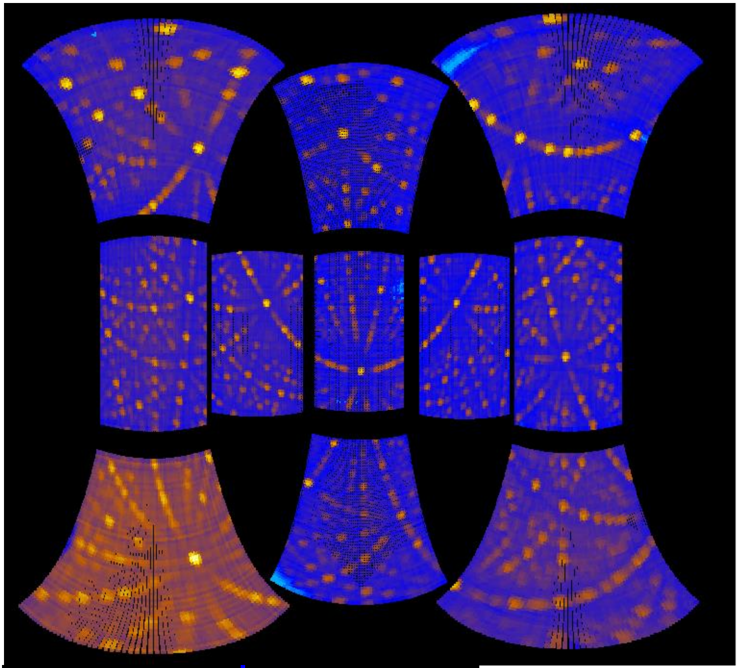
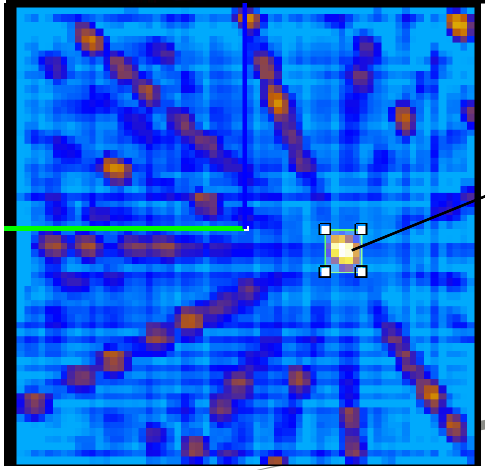
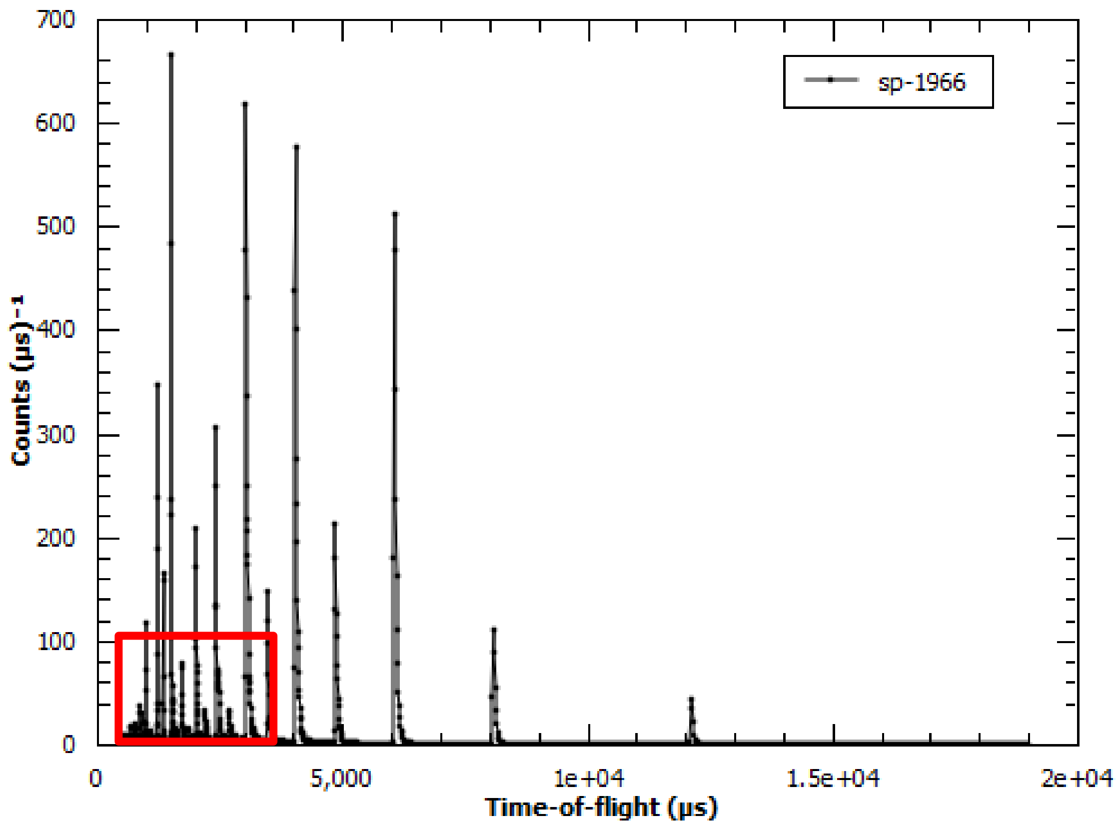
“Week old” results

HoAgGe at 15K







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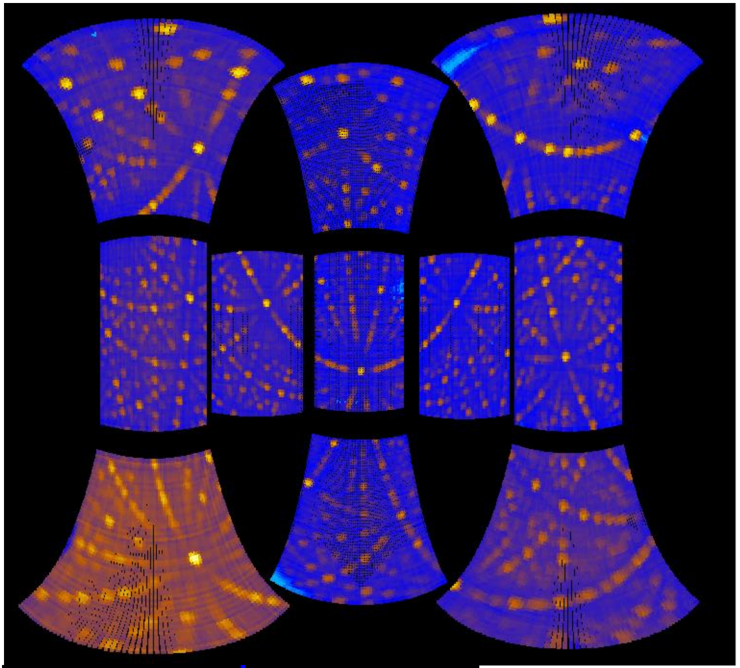
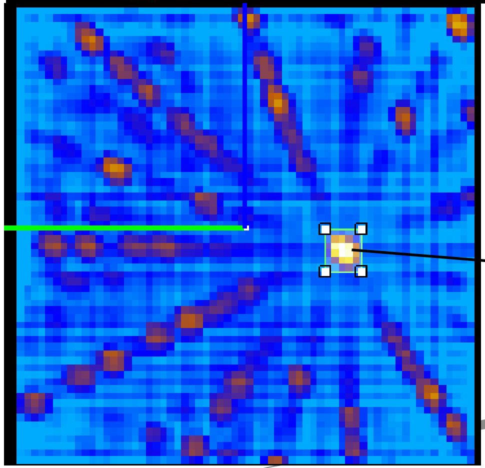
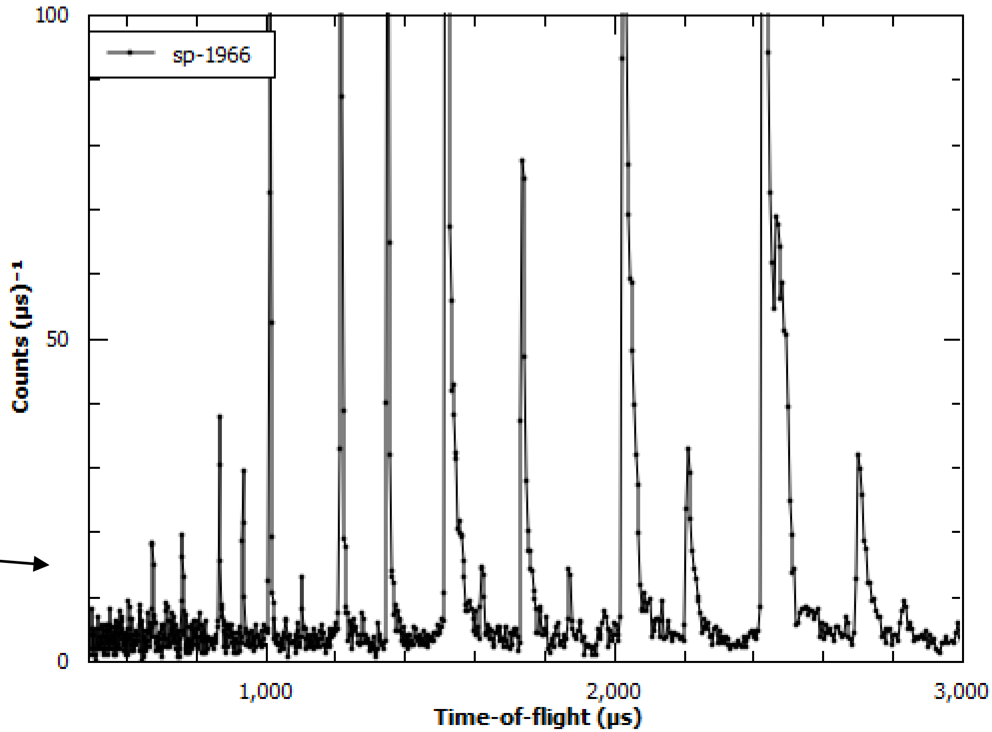




- Clearly distinguish weak peaks
  - Higher order peaks
  - Satellite peak
  - Small crystals
- FWHM = 4 μs



Single crystal diffraction
Detector summary

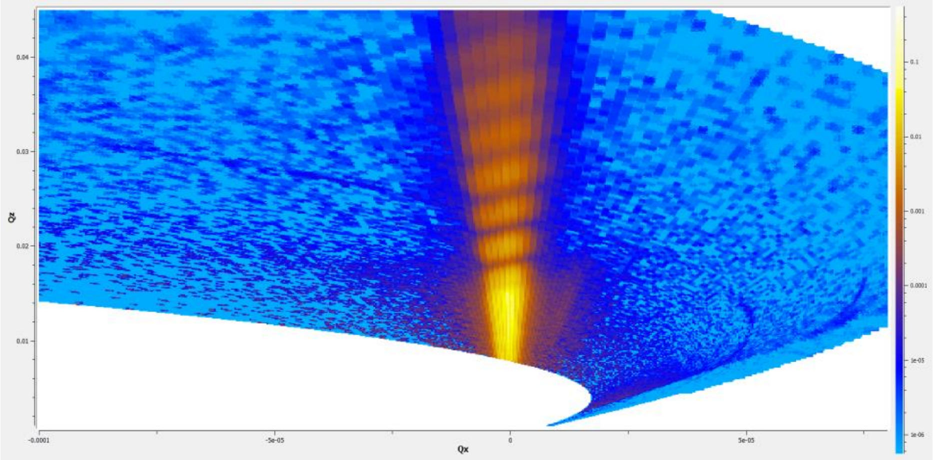
	Current clear fibre detectors (2000)	High resolution WLSF detector (2018)	Full size WLSF module
Neutron detection efficiency @ 1.8Å	21%	67%	67%
Pixel size (mm^2)	3 × 3	0.75 × 0.75*	3 × 3 (1.5 × 1.5)*
Active area (mm^2)	192 × 192	48 × 48	192 × 192
Number of fibres	16384	64	128
Weight (kg)	~70	~6	~8

*With position interpolation

- We now have a cost-effective detector solution for significantly improving performance of single crystal diffractometers.
- New single crystal instruments like LMX and upgrades to existing instruments like HRPD are now feasible.

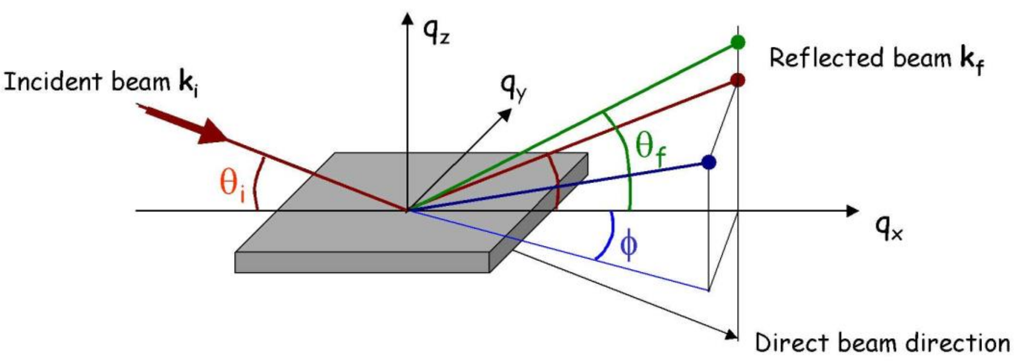
Instrument Development at ISIS

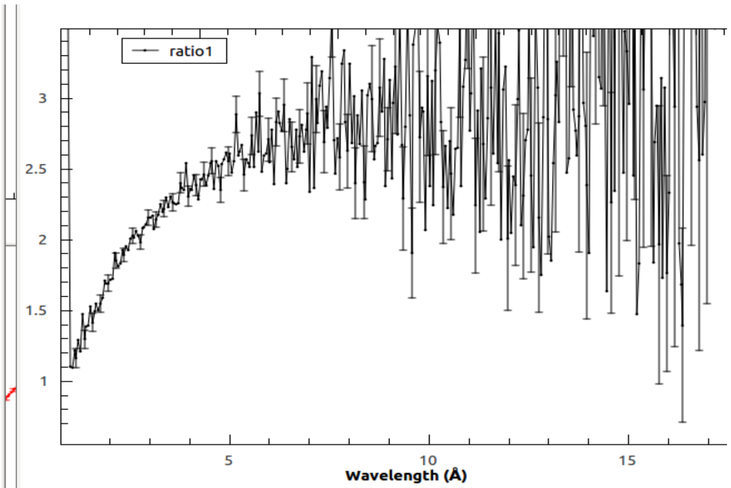
- Single Crystal Diffraction
- Reflectometry
- Powder Diffraction
- SANS/SEMSANS

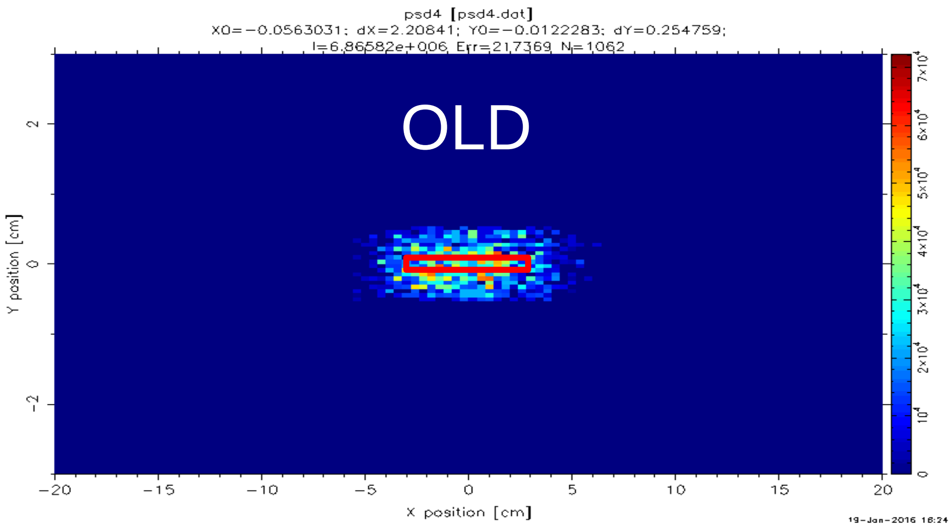


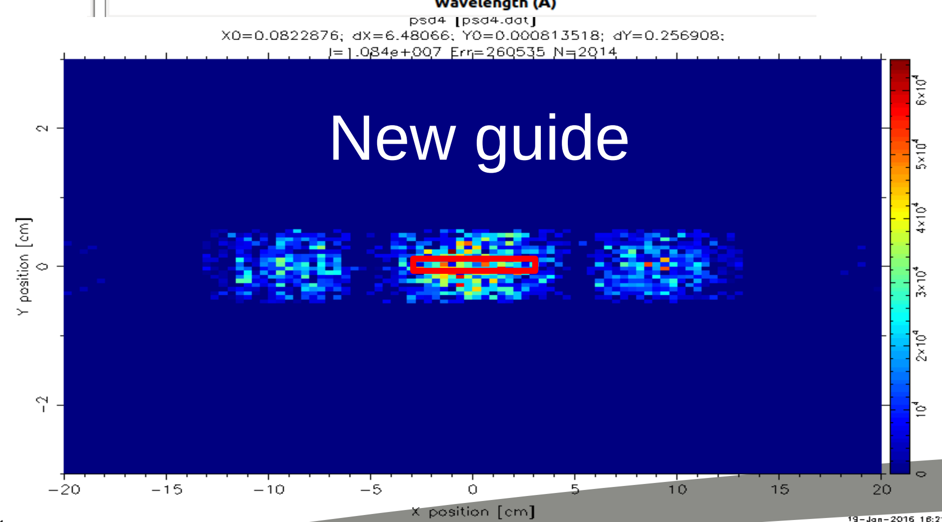
- < 1mm position resolution
- High local rates
  - Direct beam
  - High reflectivity samples
- High global rates (divergent mode)

INTER development









*Becky Welbourn and Max Skoda

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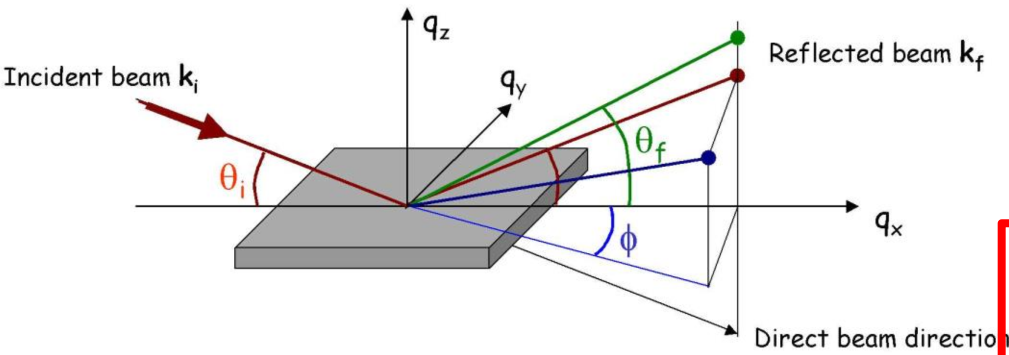
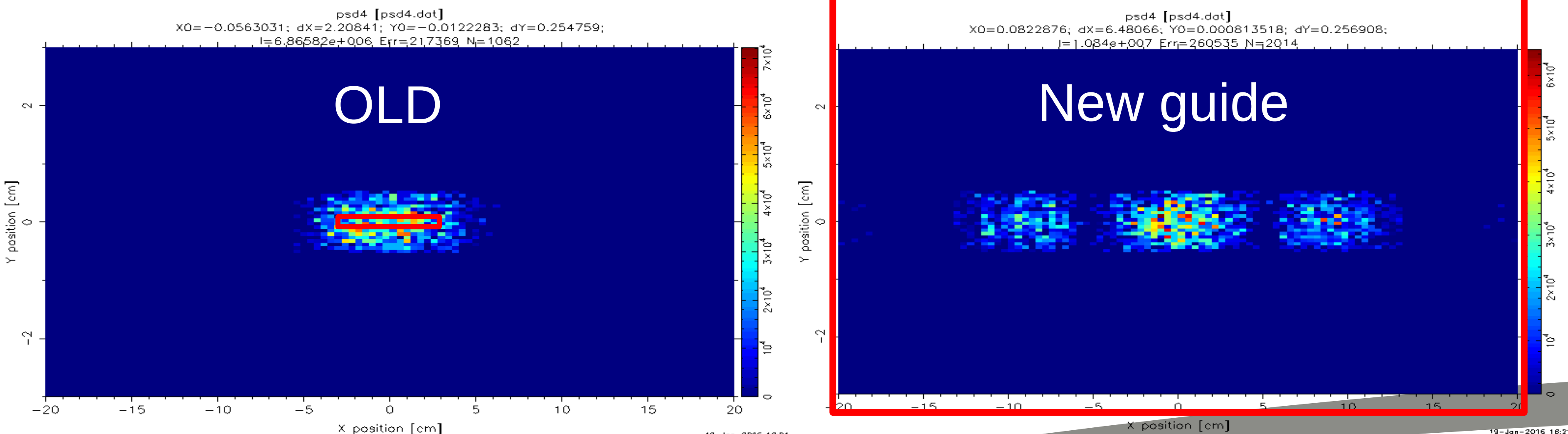
INTER development



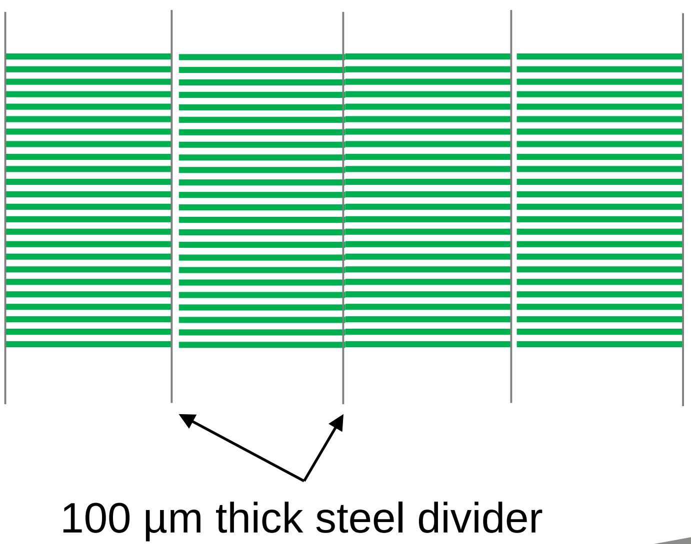


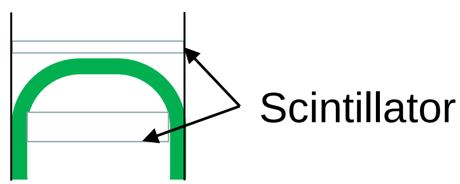
*Becky Welbourn and Max Skoda

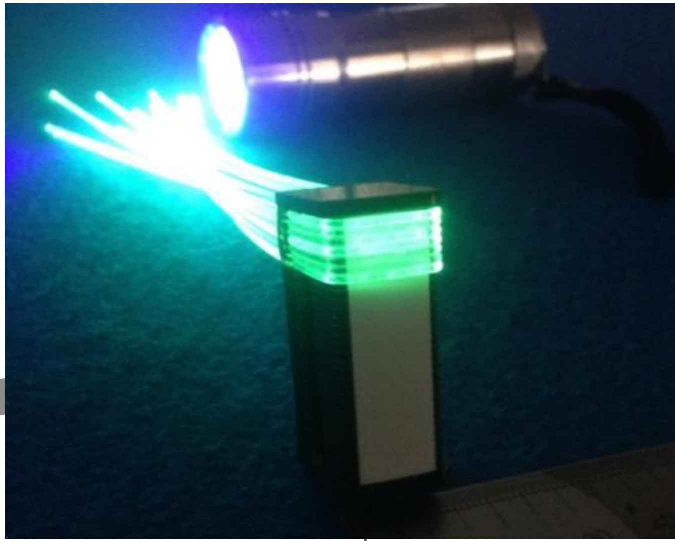
SHARD

Coping with high rates

- Segmented high aspect ratio 2D
- Limits number of possible fibre combinations
- Optically isolated rows for coarse pixilation
- 2.5mm bend radius fibres for close packing



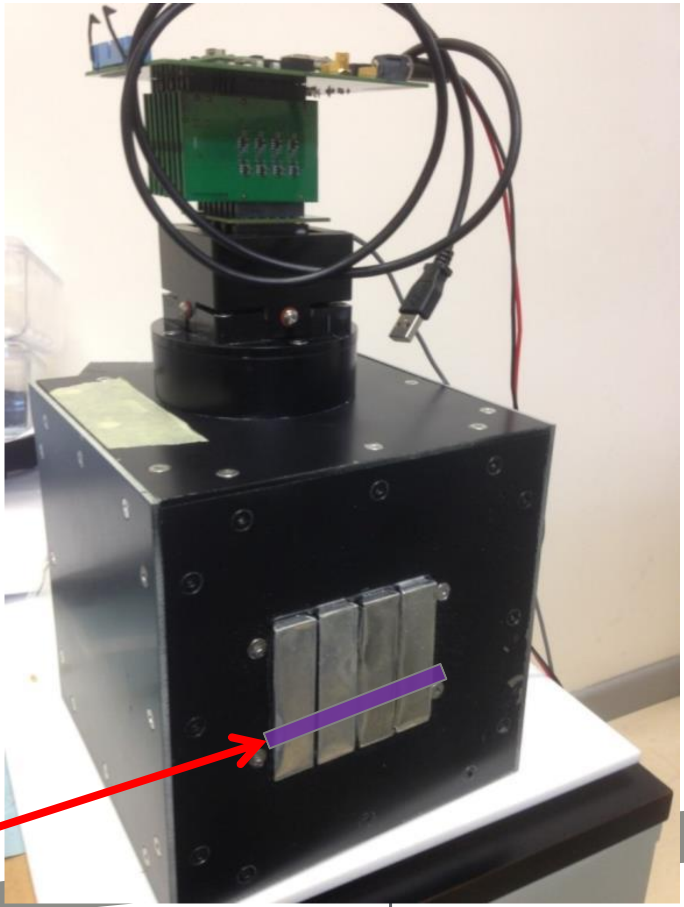




SHARD

Coping with high rates

- 1 mm fibres – 16 mm wide
- 64 fibres vertically
  - 50-100 µm thick dividers between fibres
- Individual segments
  - Optically divided
  - Strips of scintillator front and back
- Walking coincidence fibre code
- Single 64 ch FP-PMT – partitioned FPGA



Neutron beam

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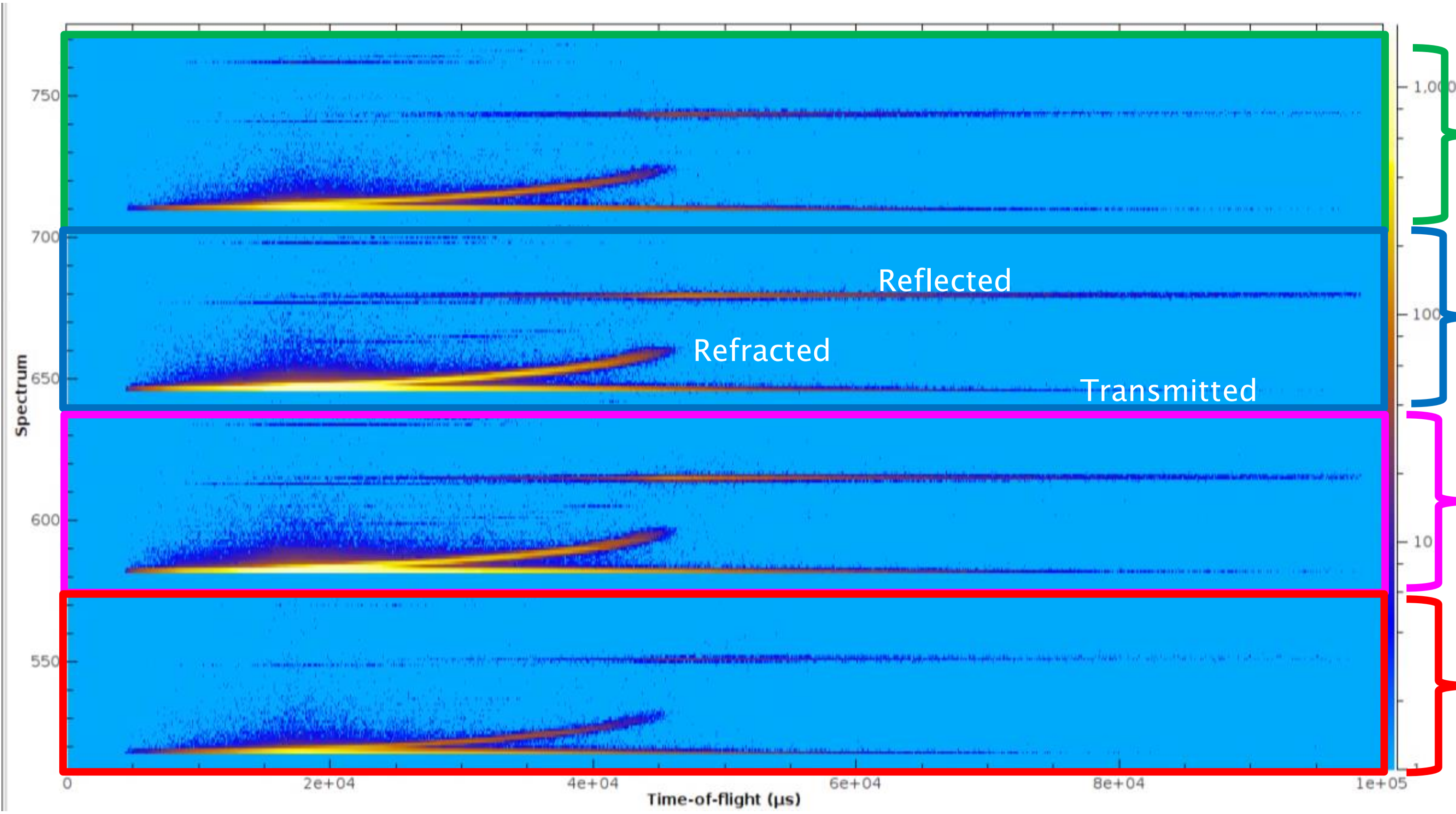
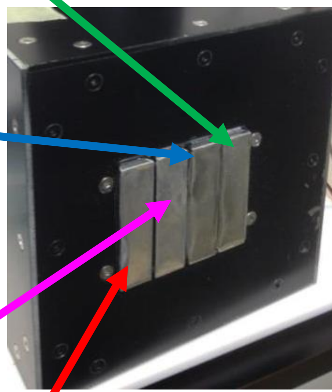
Si reflection at low angle





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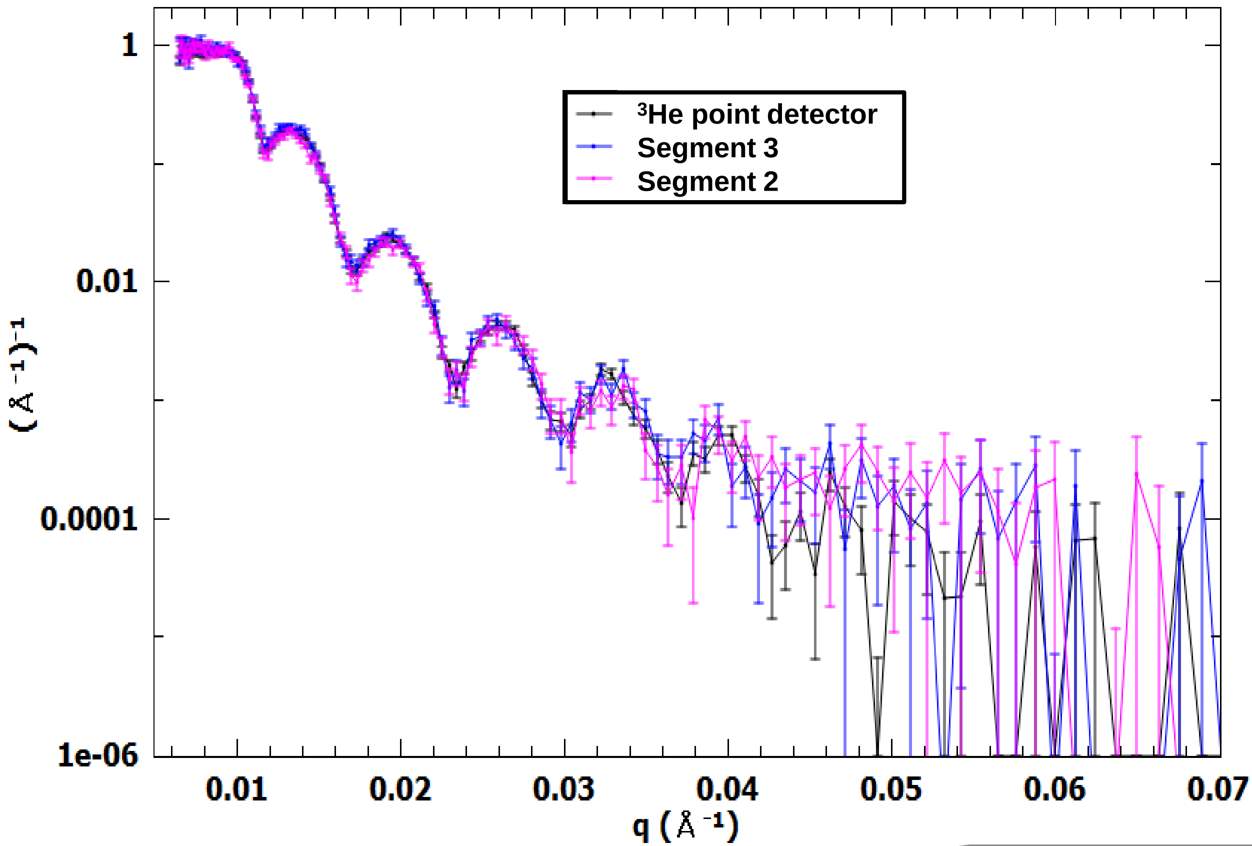
INTER

Polymer on Si

Comparison to ^{3}He tube (40 mm slit)



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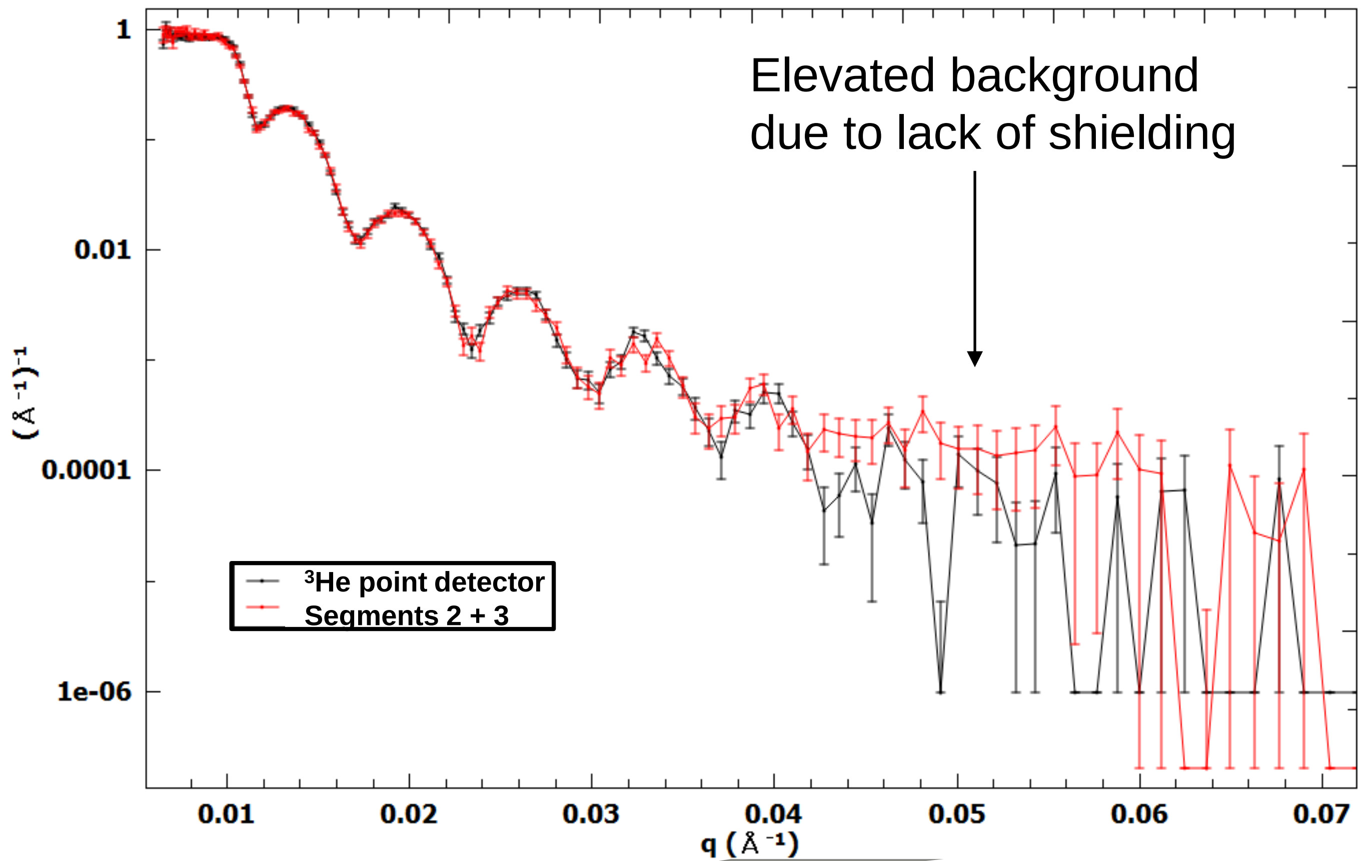

INTER

Polymer on Si

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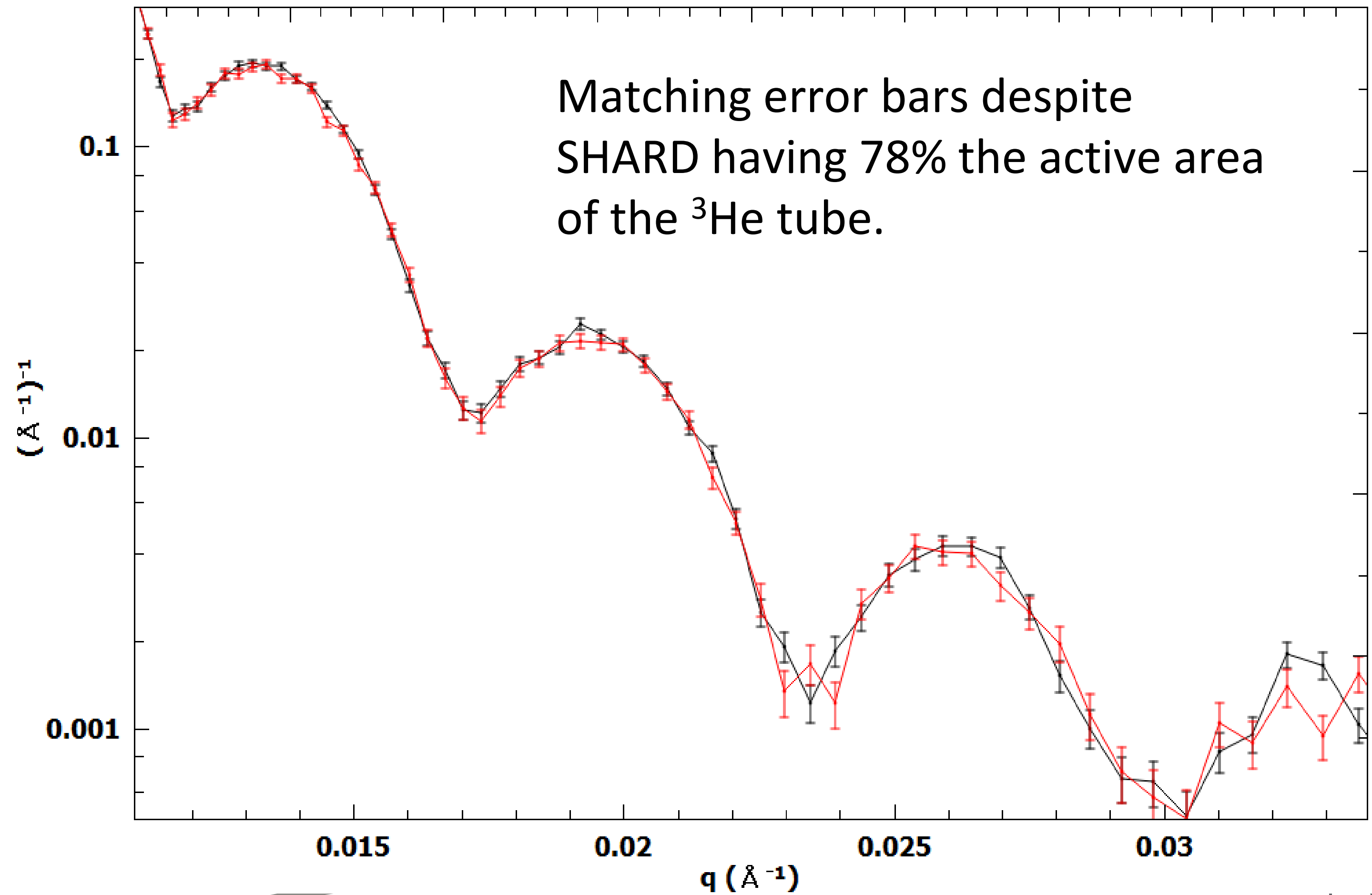
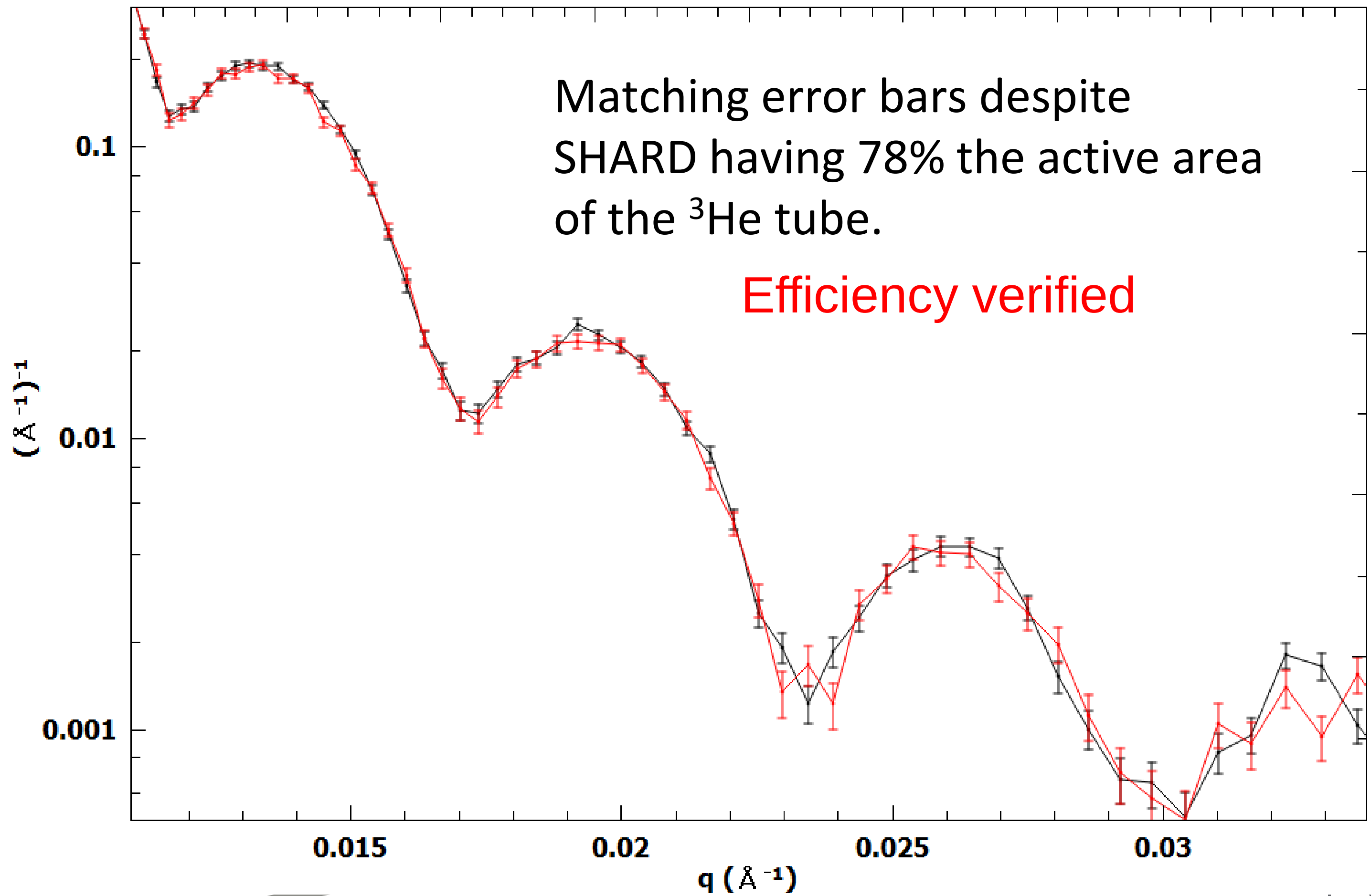


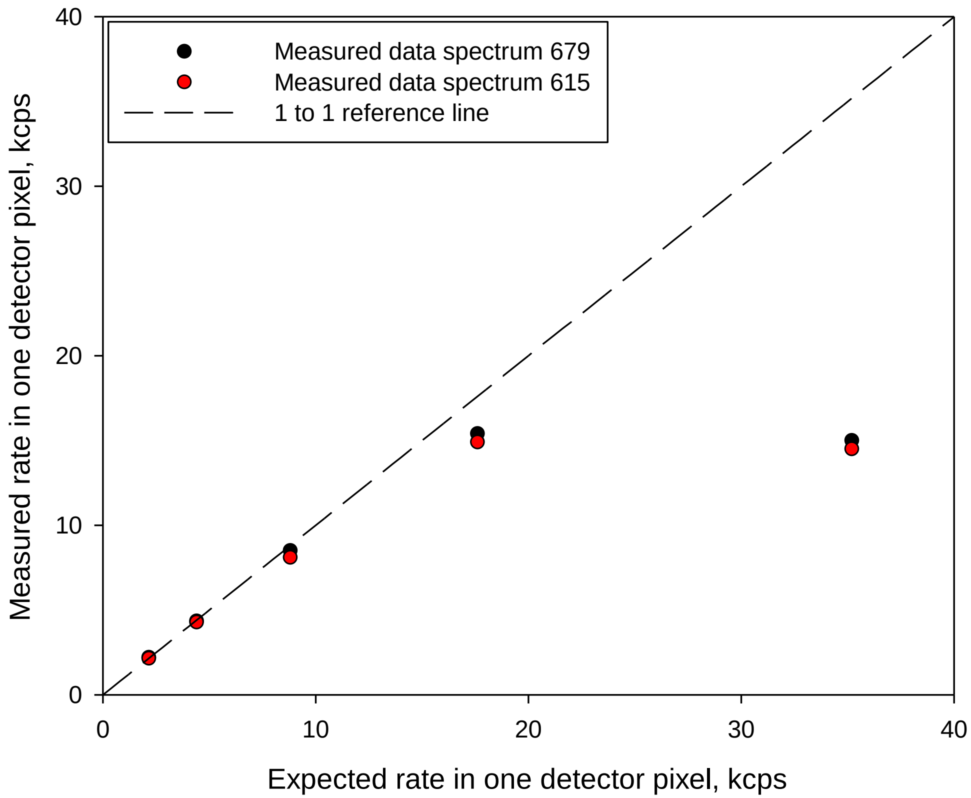
INTER
Polymer on Si
Comparison to ^{3}He tube (40 mm slit)



SHARD

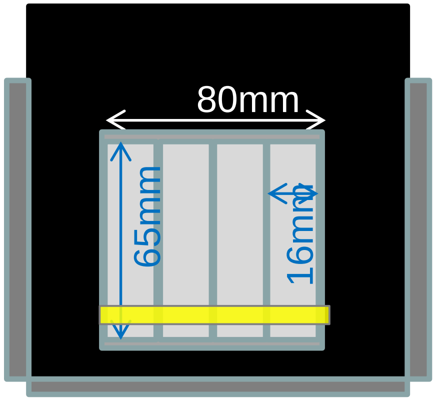
Rates

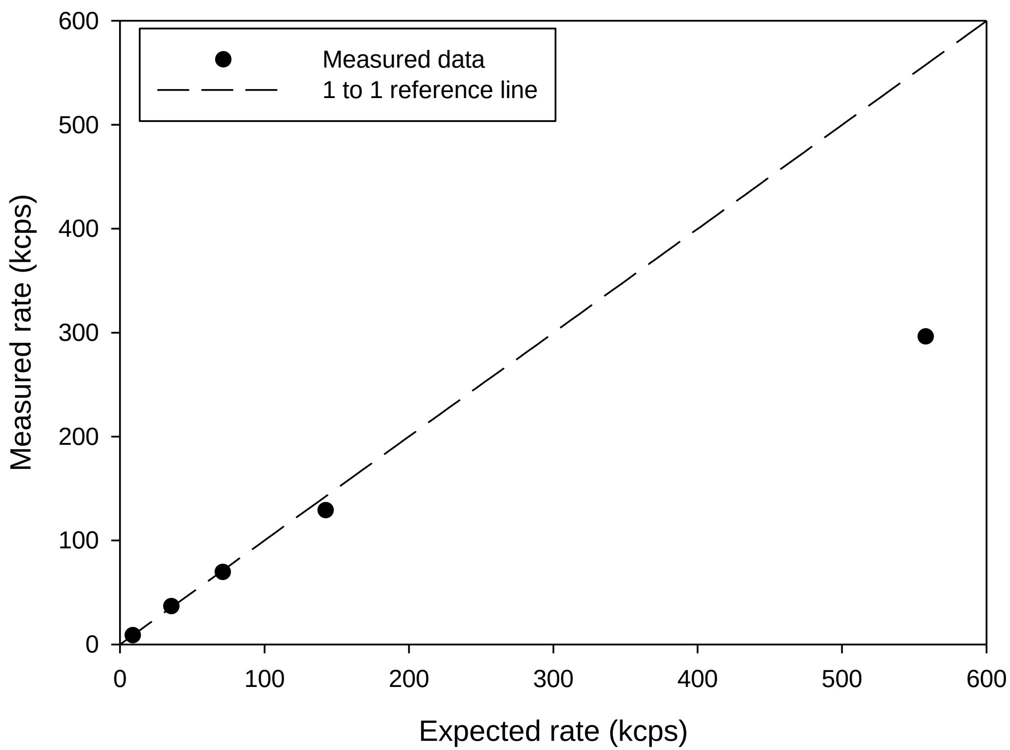
- Local instantaneous peak rates
  - Single pixel peak rates linear until 16 kcps
  - Consistent with other $ZnS:Ag/^{6}LiF$ detectors



SHARD

Rates

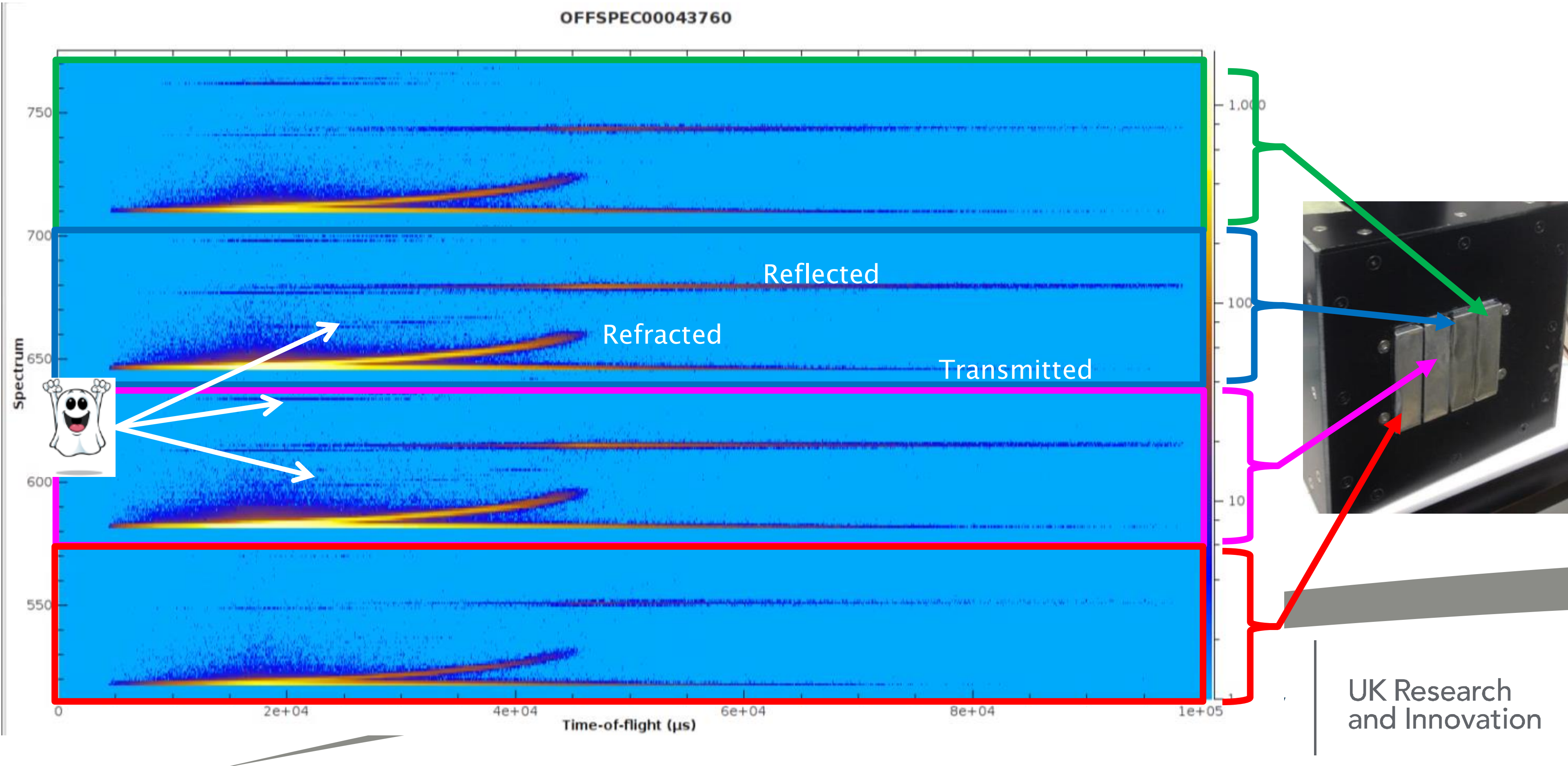




- "Local" (within beam area) instantaneous peak rates
  - Linear until ~160 kcps
- Global (across detector) instantaneous peak rates
  - Limited to 320 kcps

Si reflection at low angle

- Rate dependent neutron misplacement (ghosting)
  - Due to fibre coding and scintillator afterglow



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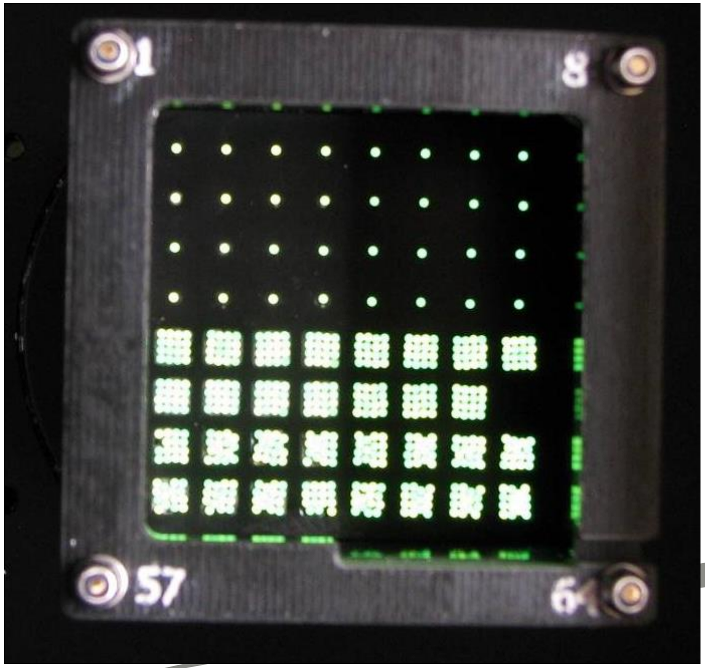
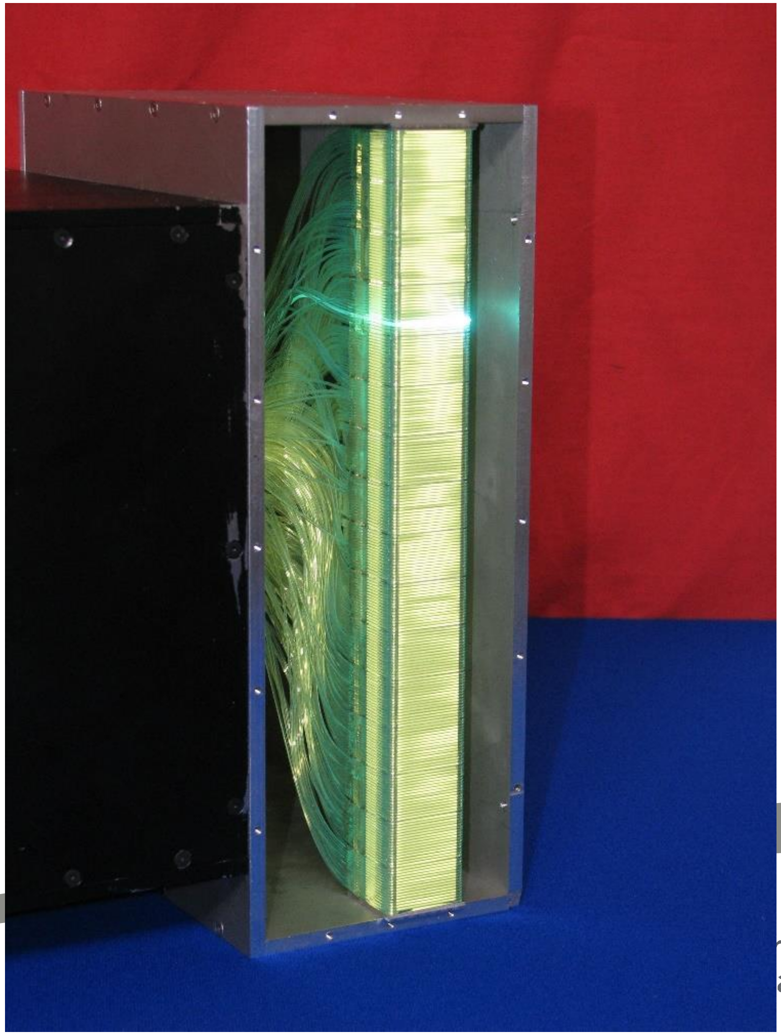
New hybrid fibre coding option

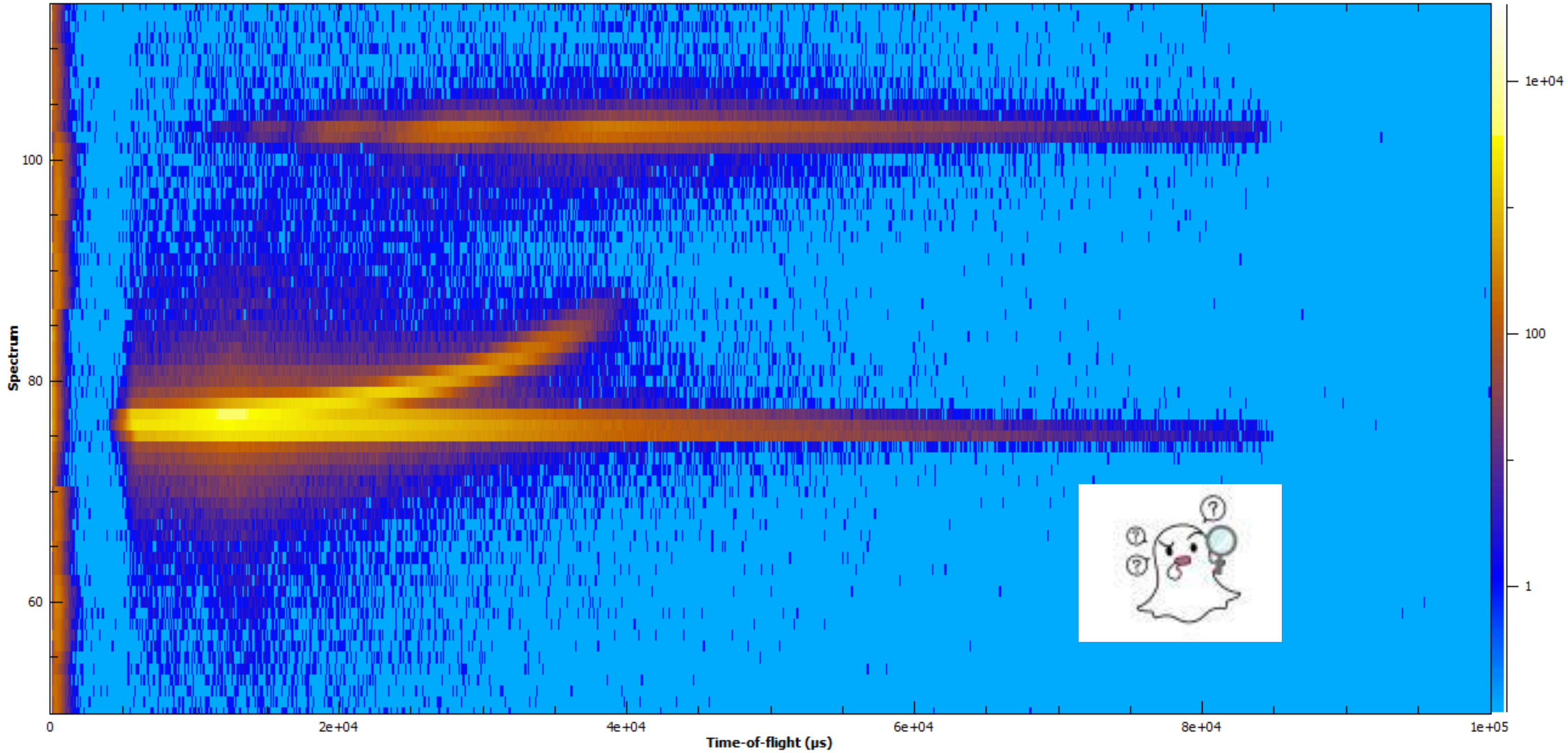
- Optimise rate capability in a specified region
- Eliminates ghosting
- Keeps detector cost-effective





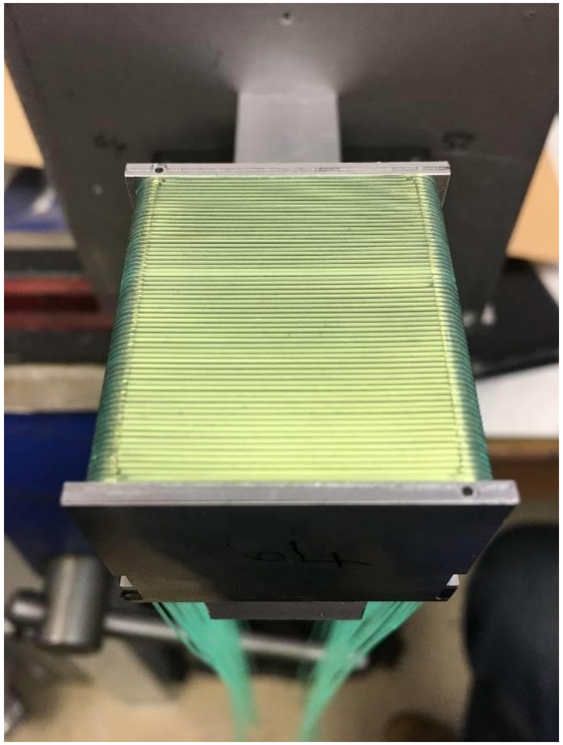
New hybrid fibre coding option

- Ghosting eliminated!



Sub-mm resolution?

- 0.5 mm fibres
  - 0.6 mm pitch
  - 30 mm wide
- 64 fibres vertically
- 100 µm thick dividers between fibres
- Strips of scintillator front and back
- Non-repeating walking coincidence fibre code
- Single 64 ch FP-PMT

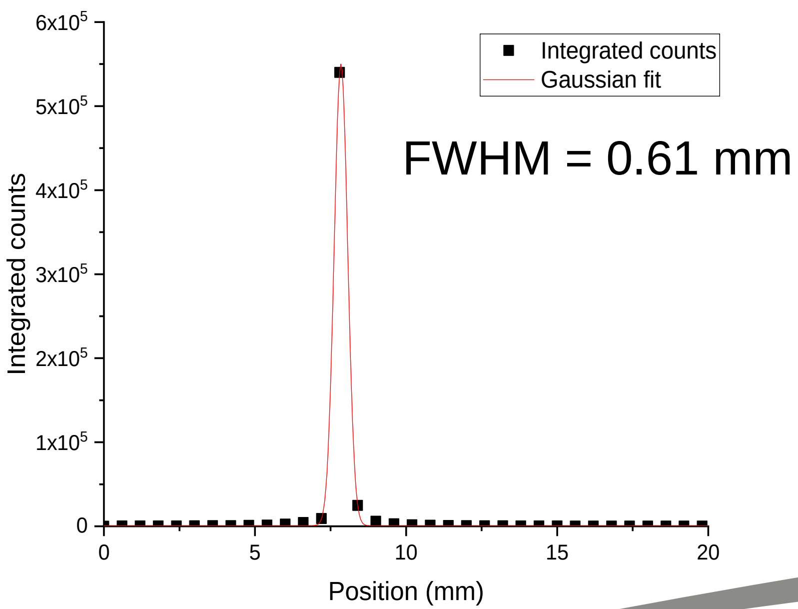


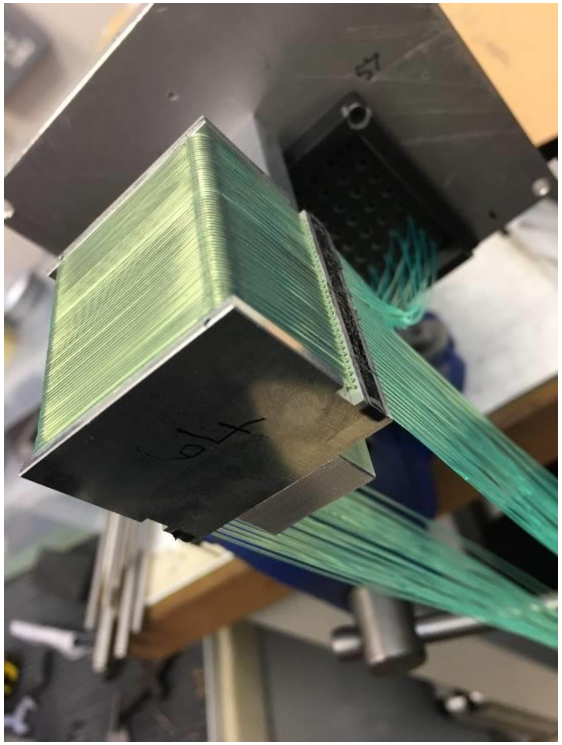
Fibre	PMT A	PMT B
1	1	33
2	2	33
3	2	34
4	3	34
5	3	35
6	4	35
7	4	36
8	5	36

Currently installed and in use on INTER

Sub-mm resolution?

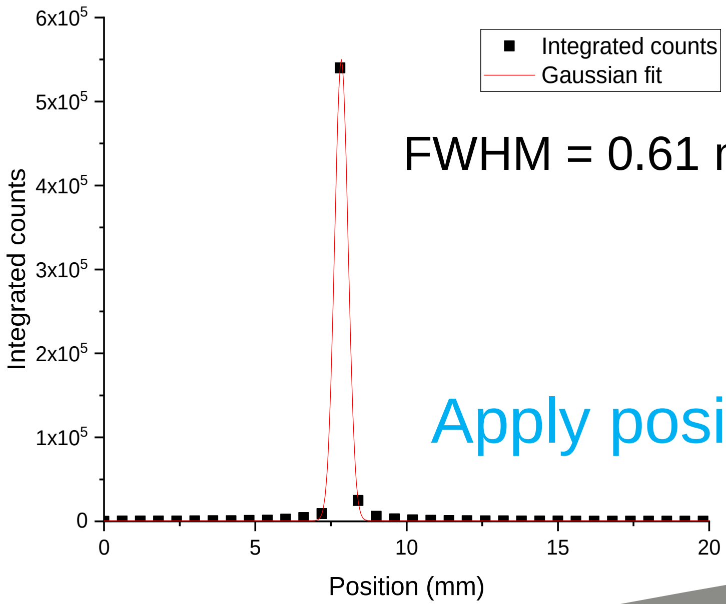
- 200 µm slit close to the detector
  - ~250 µm with divergence
- Integrate over time-of-flight



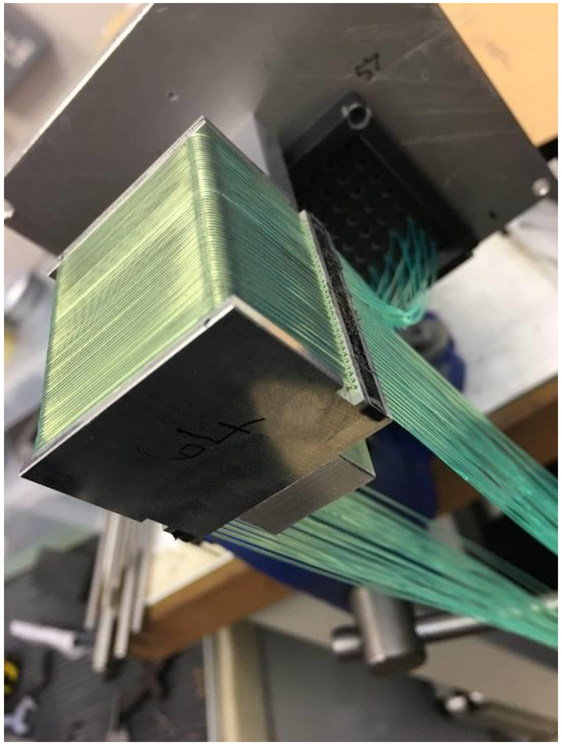


Sub-mm resolution!

- 200 μm slit close to the detector
  - ~250 μm with divergence
- Integrate over time-of-flight



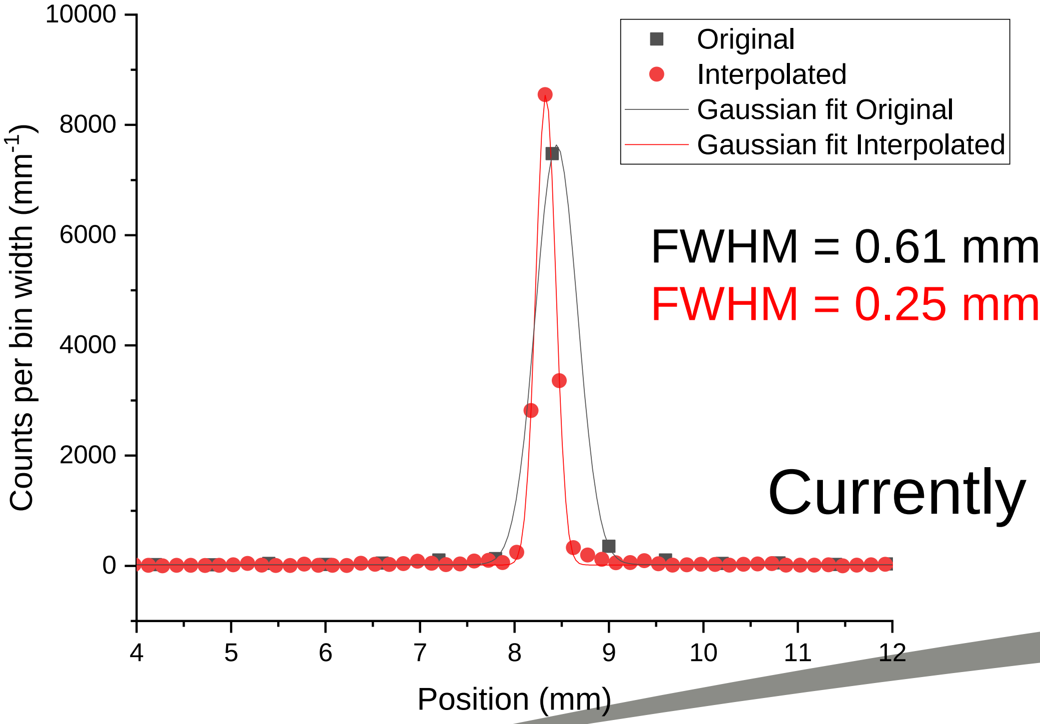
FWHM = 0.61 mm

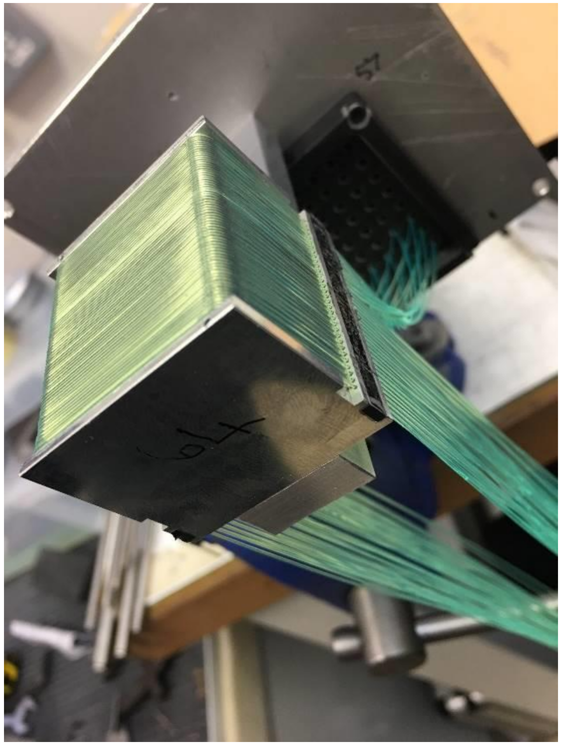


Apply position reconstruction algorithm?

Sub-mm resolution!

- 200 µm slit close to the detector
  - ~250 µm with divergence
- Integrate over time-of-flight



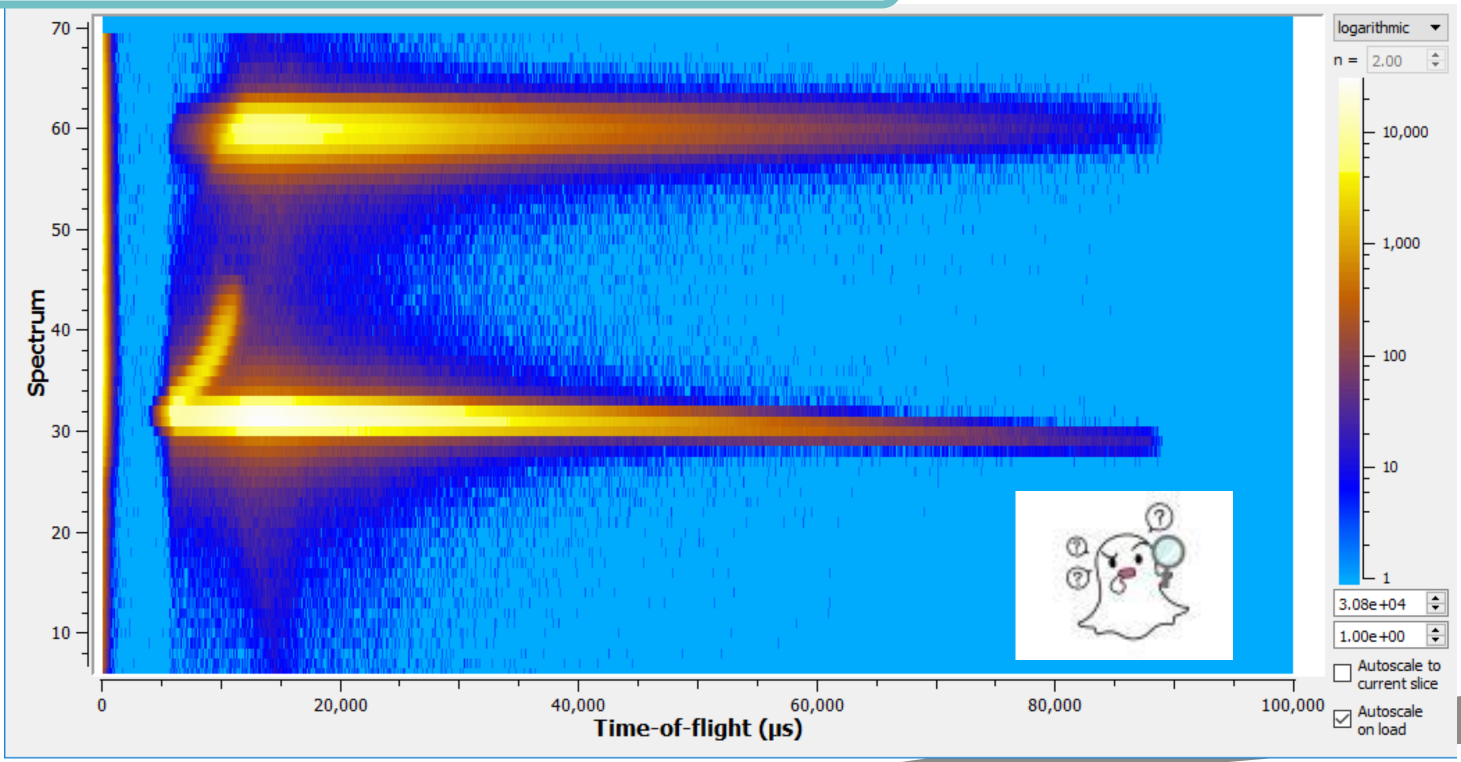


Currently post-processing only

Sub-mm resolution on INTER

Al_2O_3 block

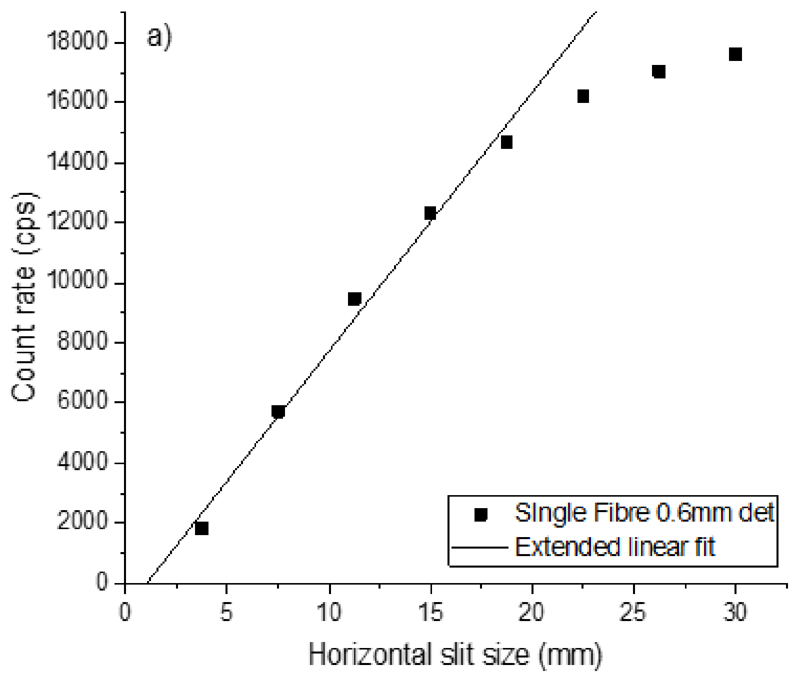
- Walking coincidence does not have ghosting!

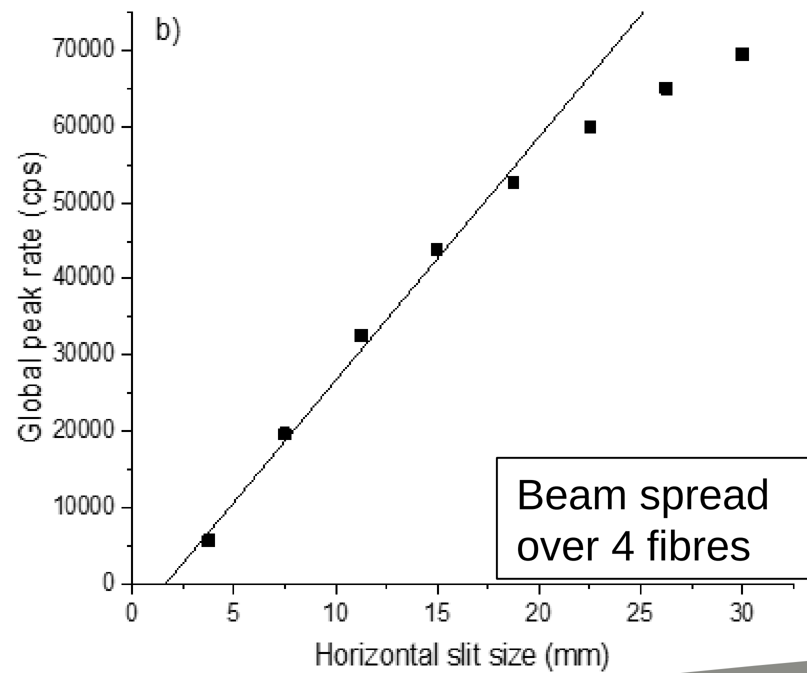


Sub-mm resolution on INTER

Rates

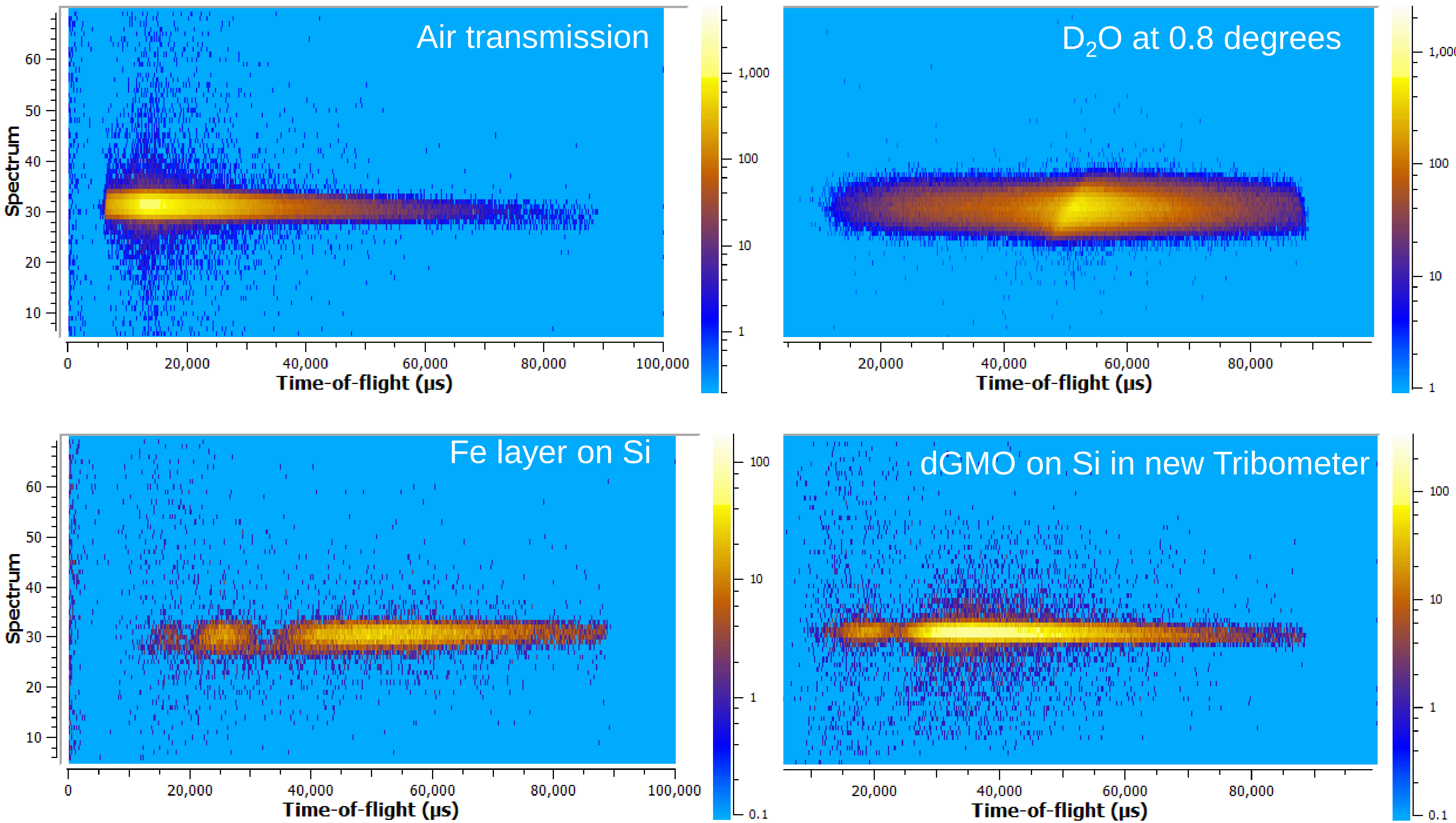
- Rates consistent with other detectors





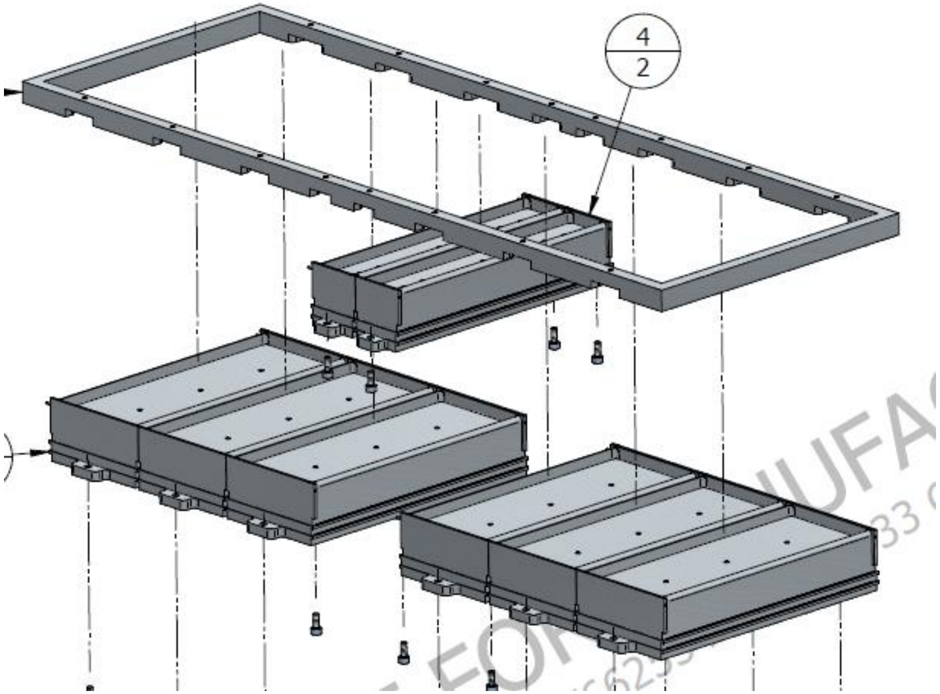
Functioning on INTER

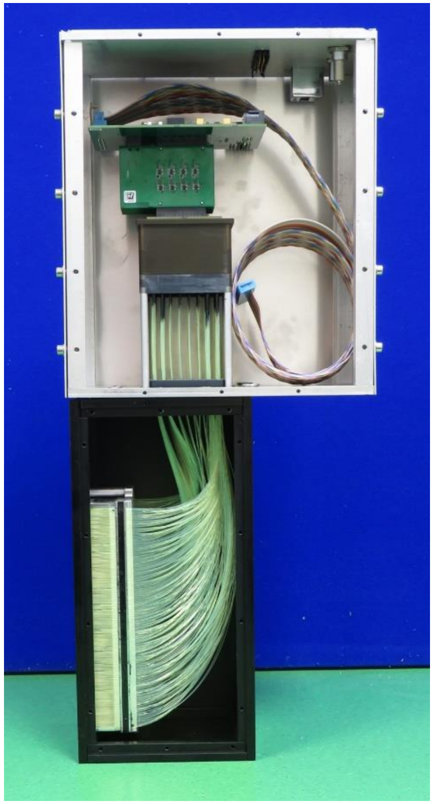
“Day old” data



Reflectometer Summary

INTER detector solution





Reflectometer Summary

Detector	Timing resolution	Position Resolution	Local instantaneous peak rate capability	Issues
SHARD	< 5 µs	1.1 mm x 16 mm	1.8 kcps/mm^2	ghosting
Hybrid fibre coded	< 5 µs	1.1 mm x 30 mm	0.5 kcps/mm^2 per segment	Ambiguous event positioning reduces efficiency
Half mm walking coincidence	< 5 µs	0.6 mm x 30 mm 0.25 mm x 30 mm*	1 kcps/mm^2 per segment	None**

*Post processed interpolation **So far

- A segmented approach provides a simple, cost effective solution to increasing rate capability for reflectometers
- Segments can be made in a variety of widths
- Position resolution at least as good as 0.6 mm with high potential to reach 0.25 mm
- An option for high resolution SEMSANS

Instrument → Detector Development at ISIS

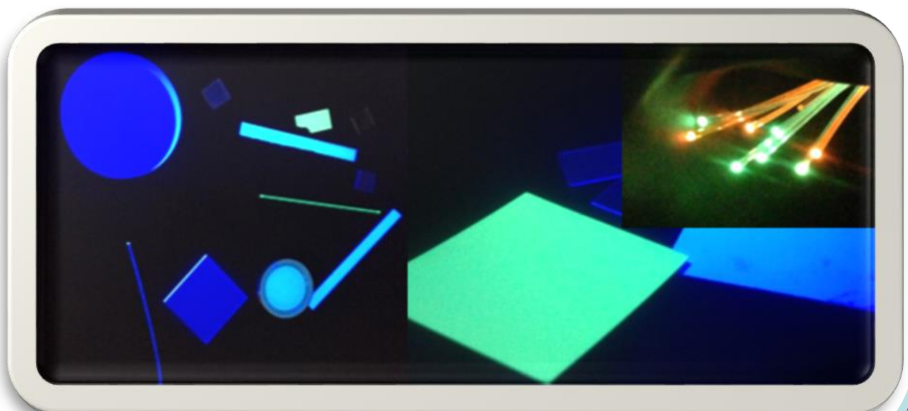
- Single Crystal Diffraction
- Reflectometry
- Powder Diffraction
- SANS/SEMSANS

→

- Position Resolution
- Rate capability
- Scalability
- Cost-effectiveness

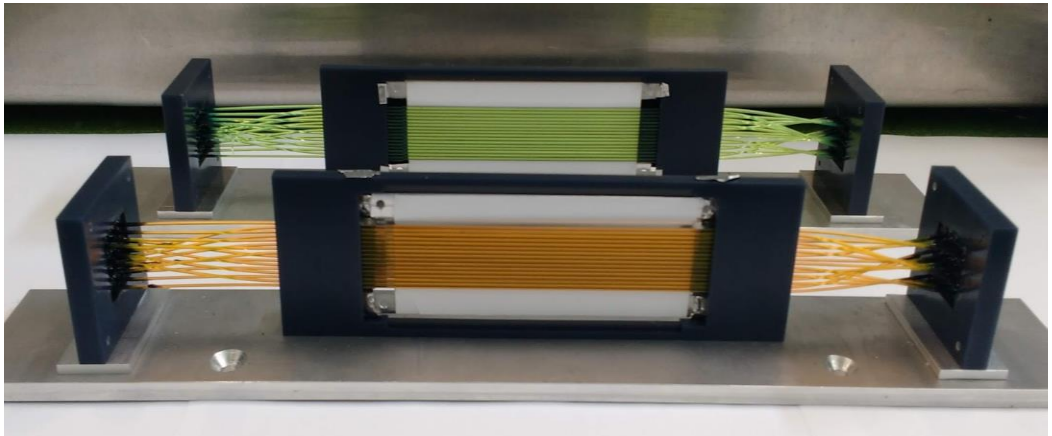
- Further develop working technology

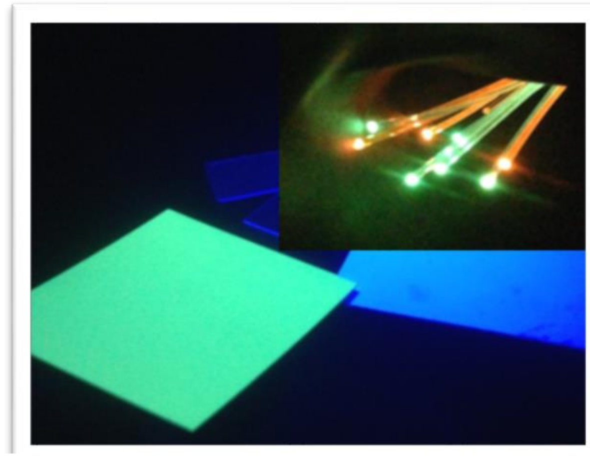
- Investigate novel approaches

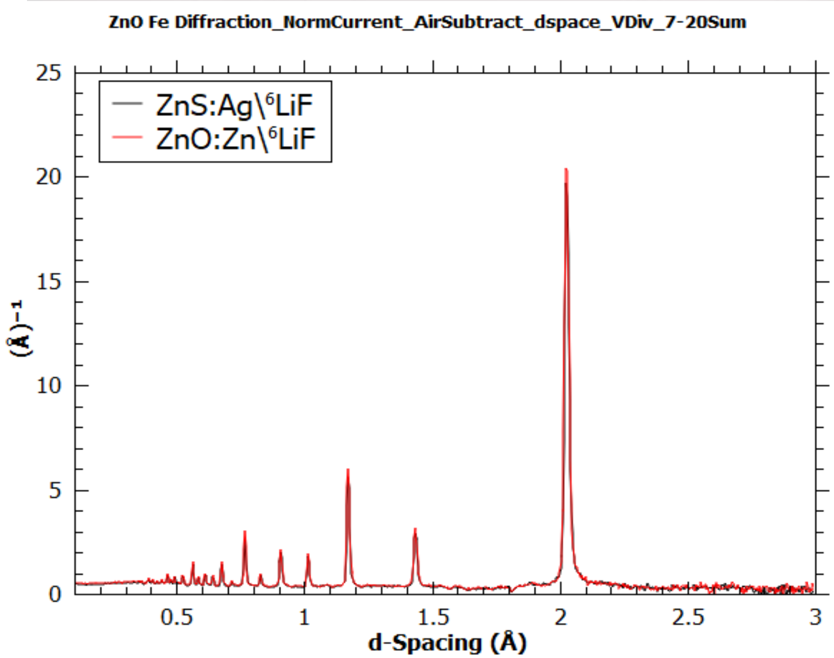


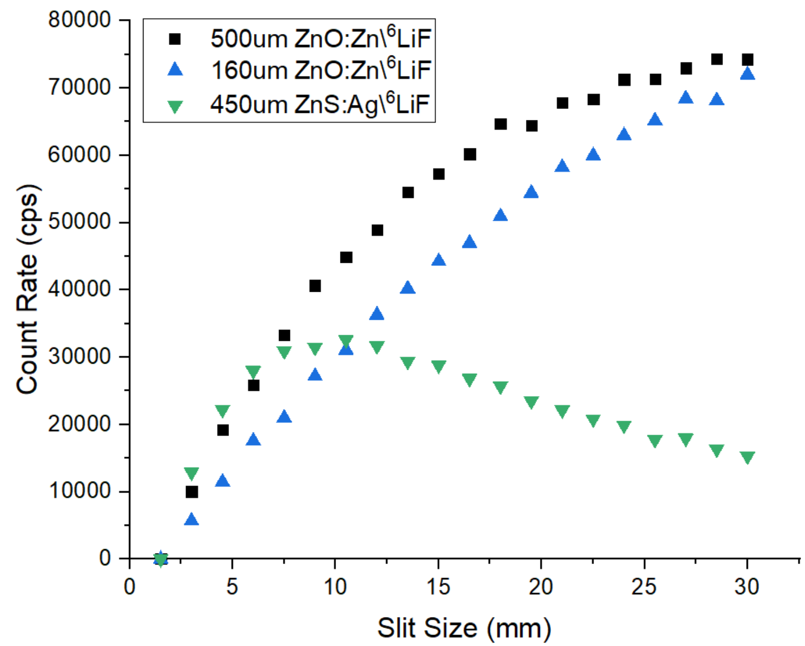
Novel Approaches

Low afterglow ZnO:Zn/^{6}LiF





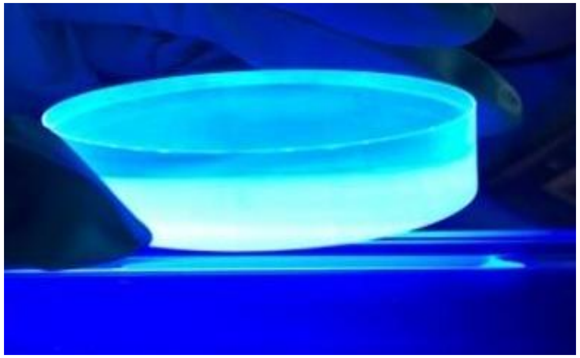


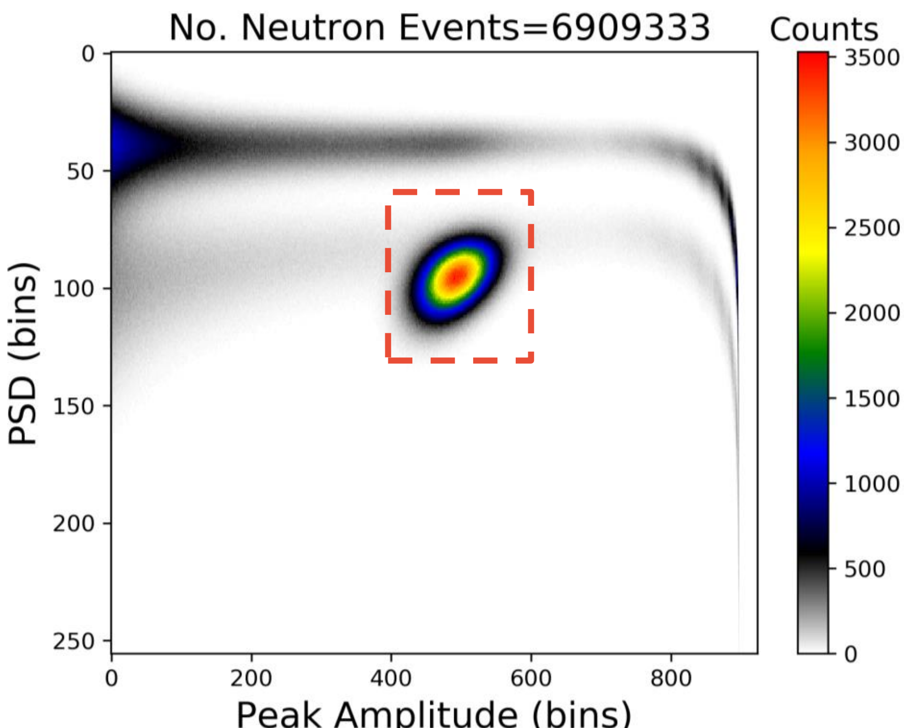


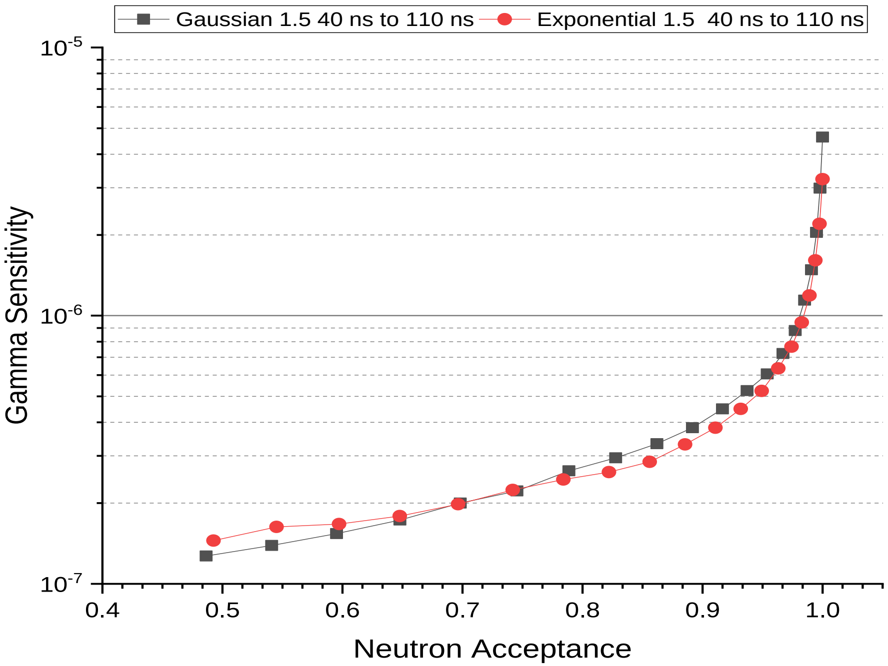
Novel Approaches

Li-Plastic

Sion Richards Talk in IEEE







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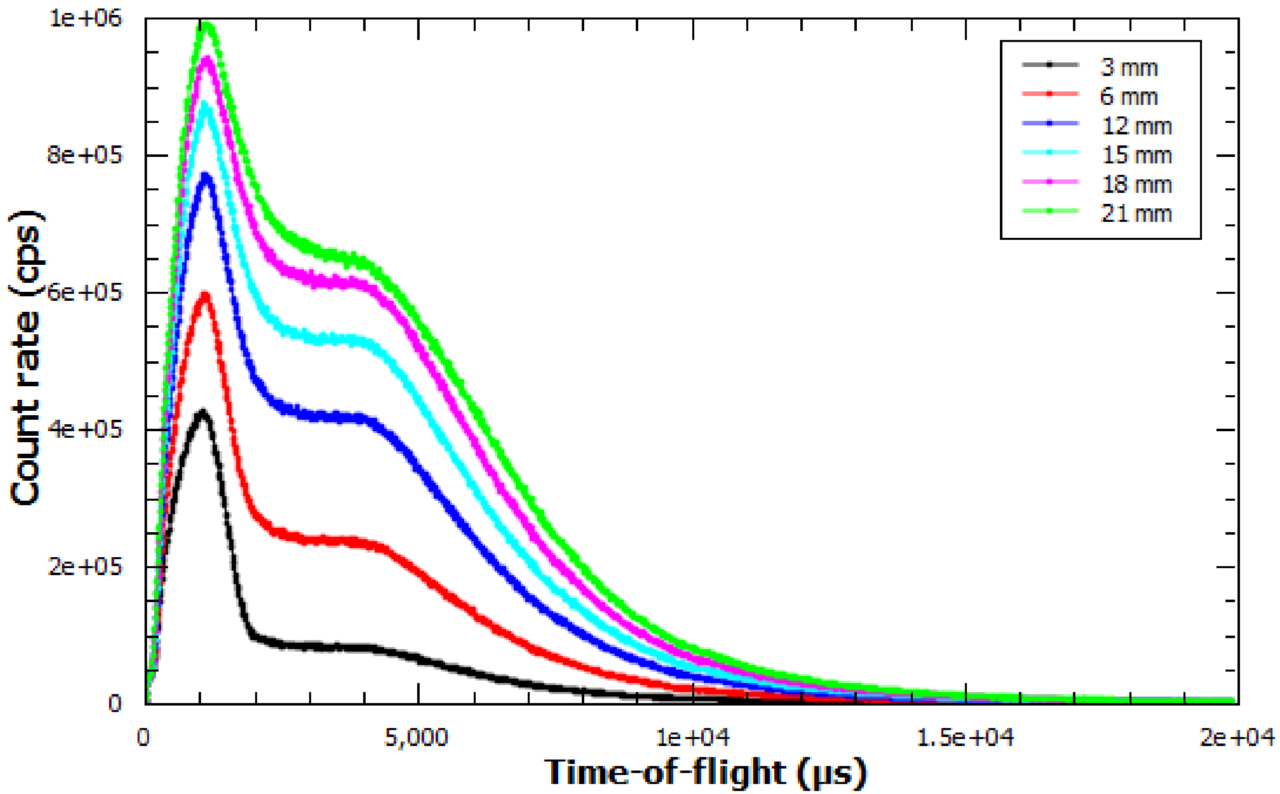
Novel Approaches

Li-Plastic

Sion Richards Talk in IEEE



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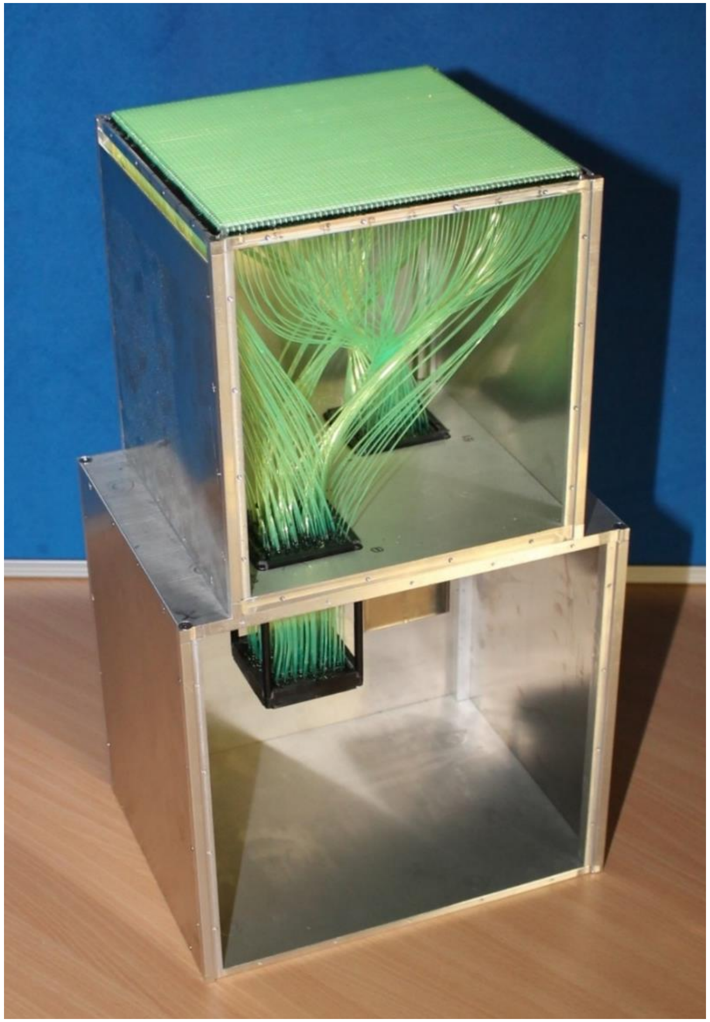
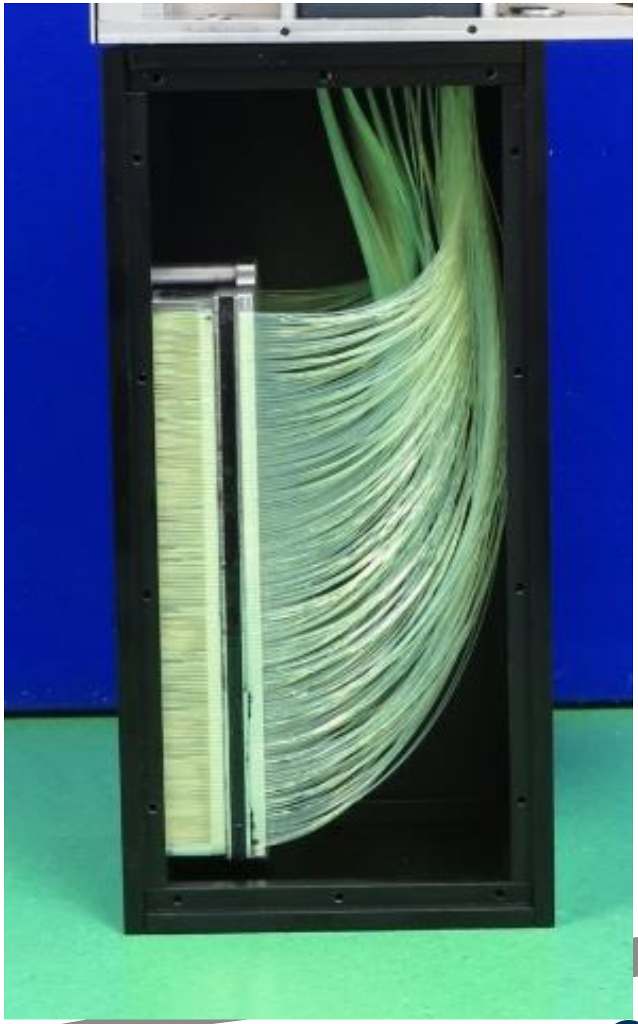
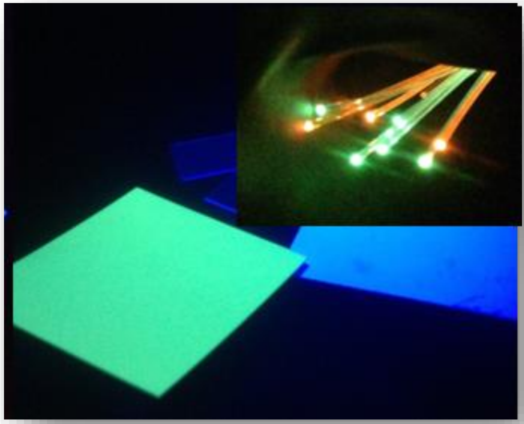
Summary

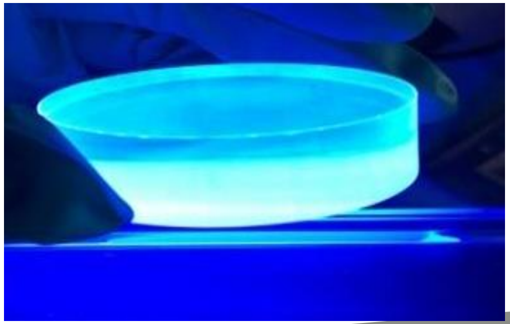
- ZnS:Ag/^{6}LiF – WSF detectors continue to be developed and used for many techniques at ISIS.
- Now have cost-effective solutions capable of handling the required count rates for
  - high resolution single crystal diffraction and
  - high resolution reflectometry.
- Novel approaches to solving the inevitable challenge of very high count rates are progressing and showing promise.

Thank You!









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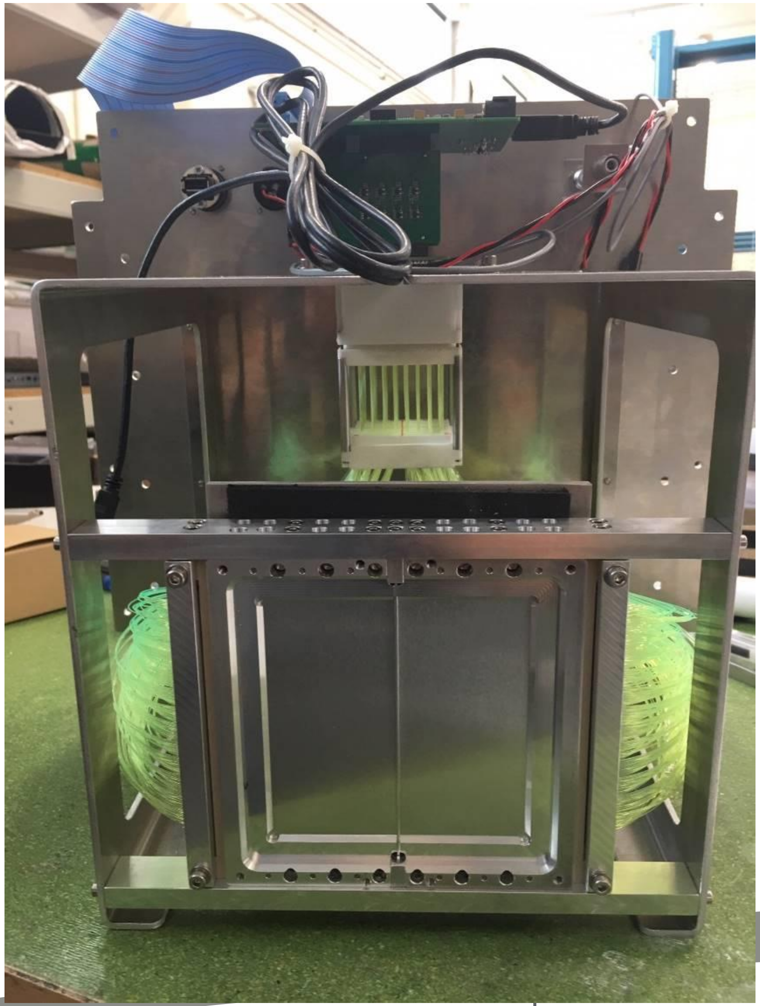
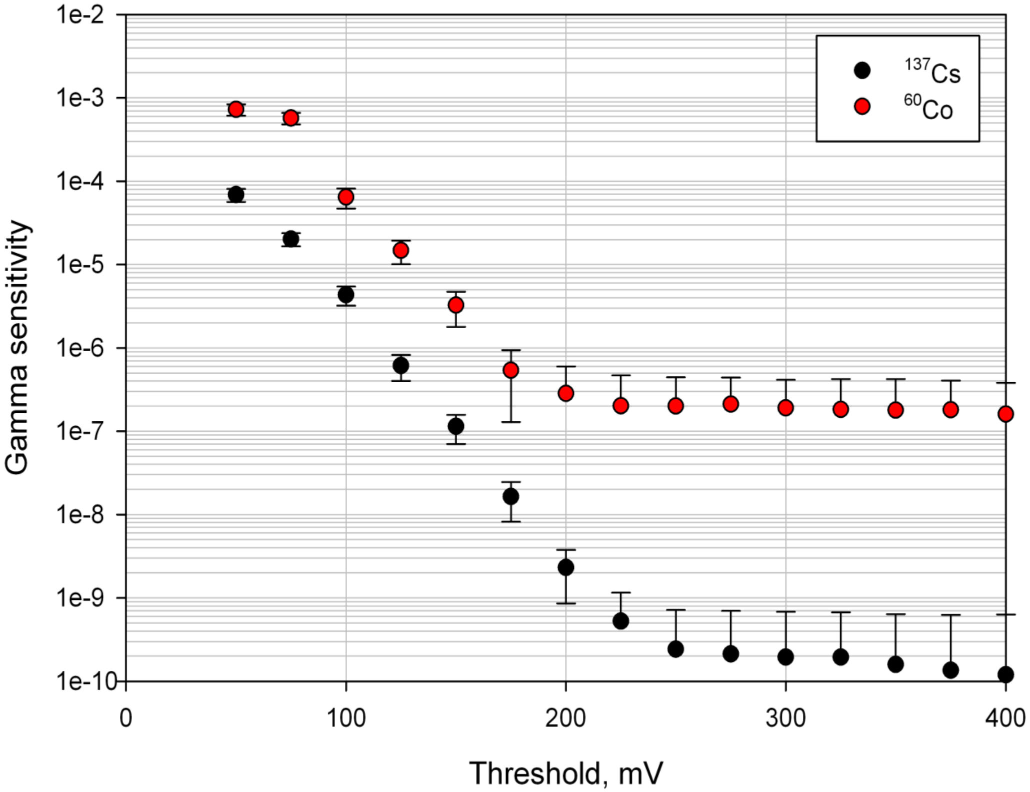
Delft reflectometer detector

- 0.5 mm fibres
  - 0.55 mm pitch
- Single 64-ch PMT
  - 200 Fibres
  - Walking coincidence code

Fibre	PMT A	PMT B
1	1	33
2	2	33
3	2	34
4	3	34
5	3	35
6	4	35
7	4	36
8	5	36



Gamma (only) Sensitivity



Mass attenuation coefficients:

$$\mu/\rho = (\sigma_{pe} + \sigma_{coh} + \sigma_{inc} + \sigma_{pair})/uA$$

μ/ρ (0.66 MeV) for ZnS
~ 7.54×10^{-2} cm^2/g
0.7% attenuation in 0.9mm ZnS

μ/ρ (1.22 MeV) for ZnS
~ 5.52×10^{-2} cm^2/g
0.5% attenuation in 0.9mm ZnS

At the 200 mV operating threshold:

- Sensitivity to ^{137}Cs gamma ~3×10^{-9}
- Sensitivity to ^{60}Co gamma ~3×10^{-7}

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