Combining Simulation and Measurement to Understand Complex Detector Geometries

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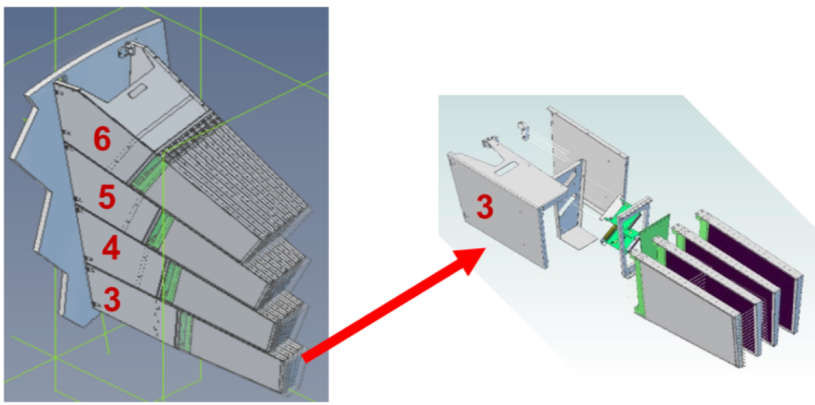
www.europeanspallationsource.se

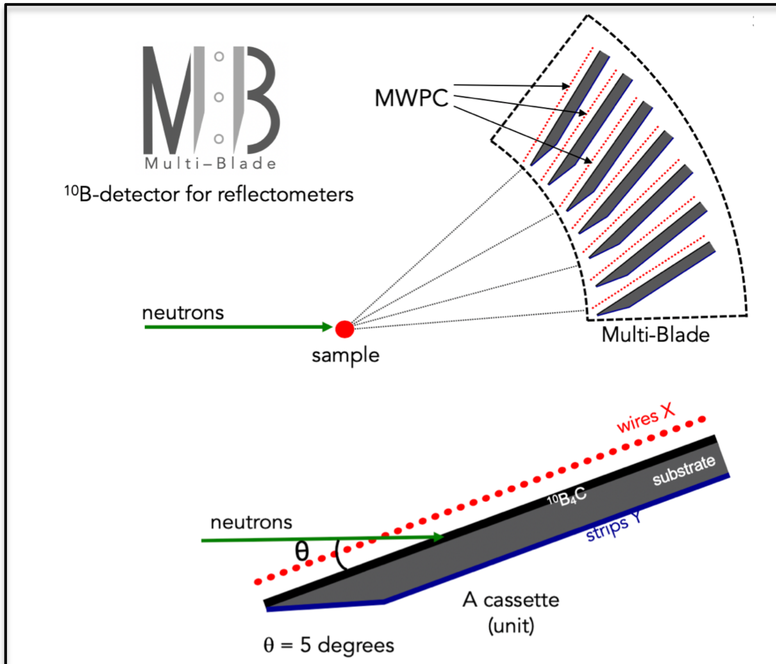
19-10-14

What is the challenge?

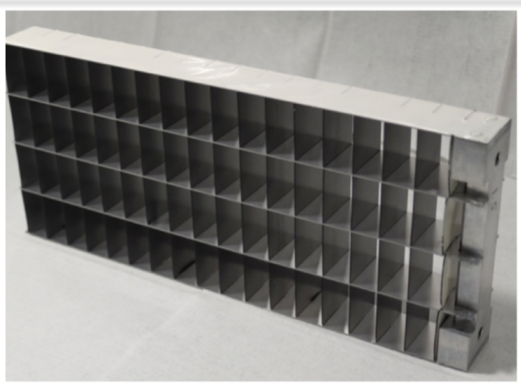
Move away from 3He has led to more complex, volume/voxel, detectors.

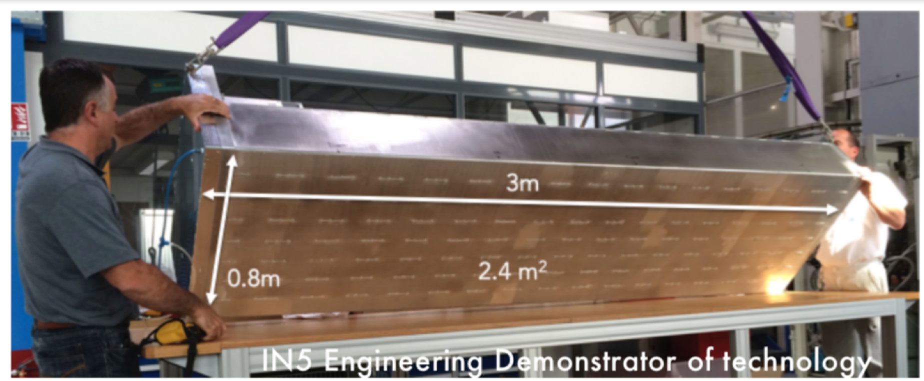


Boron MWPC for diffraction (CDT/FZJ)



Boron Multi-Grid for spectrometers (ESS/ILL)





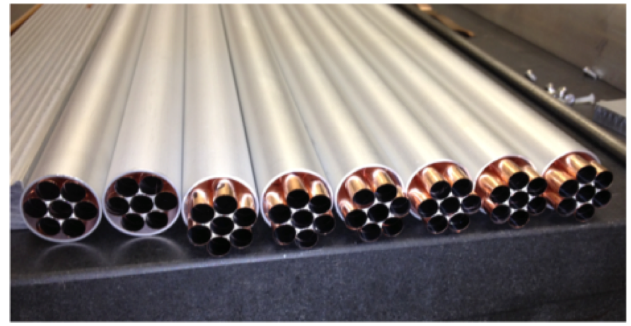
What is the challenge?

Move away from 3He has led to more complex, volume/voxel, detectors.

The LoKI SANS instrument is using Boron Coated Straws (BCS) from Proportional Technologies

To get acceptable efficiency, multiple layers of tubes are needed -> complex geometry & potentially complex corrections

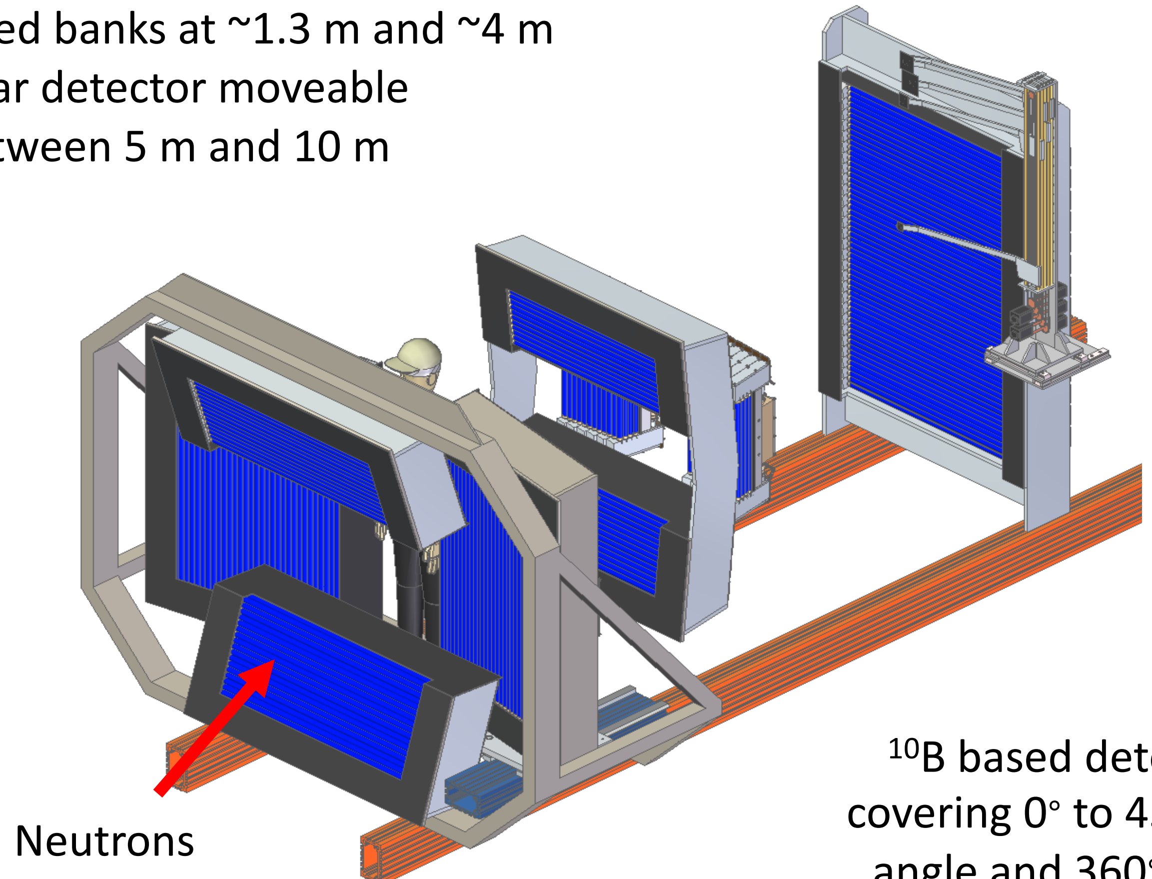
Fundamental simulation studies on these by Milán Klausz – see his poster on Wednesday!



Detector Layout

Large detector array:

- Fixed banks at ~1.3 m and ~4 m
- Rear detector moveable between 5 m and 10 m

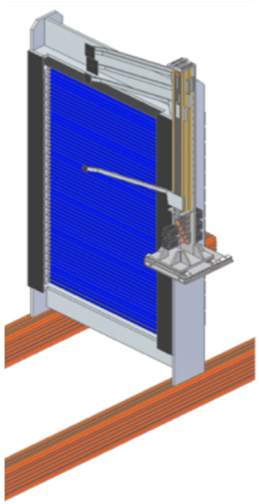


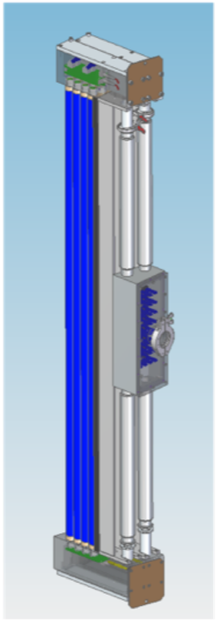
^{10}B based detector system covering 0° to 45° in scattering angle and 360° in azimuthal angle (180° Day 1).

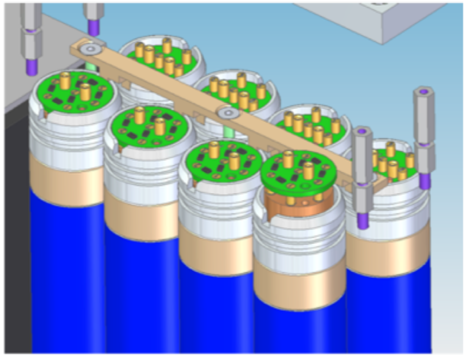
Technology: Boron-Coated Straws
- Proportional Technologies

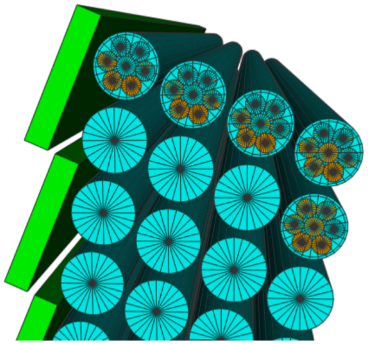
Detector banks have:

- 4 layers of 1” diameter tubes, each containing seven 7 mm diameter straws (in 3 layers, but slightly rotated) = effectively 12 layers.
- 2 columns of four tubes in an “8 pack” sub-module





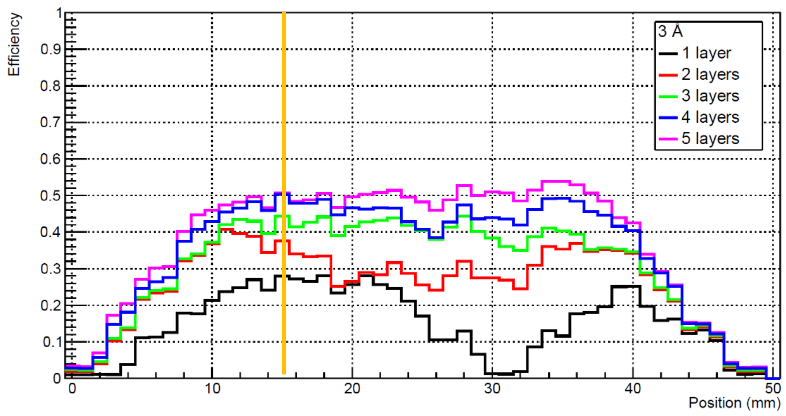


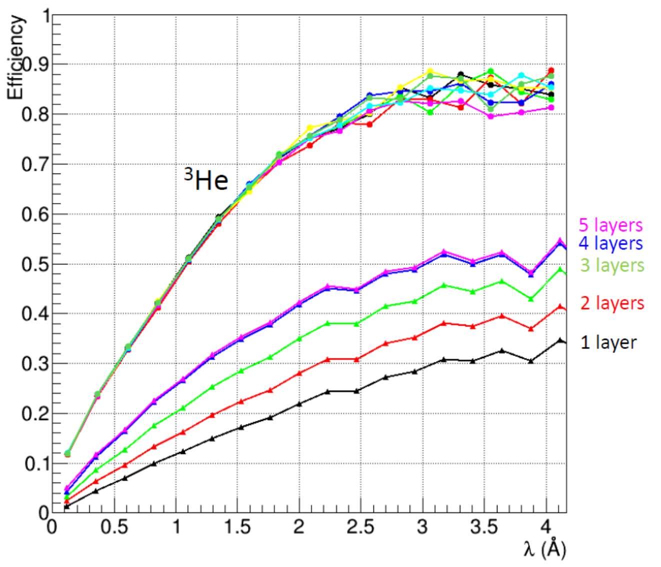


- Horizontal offset 0.4”
- Rotation 20°
- The rotation and the staggering help to have uniform efficiency

Technology: Boron-Coated Straws - Proportional Technologies

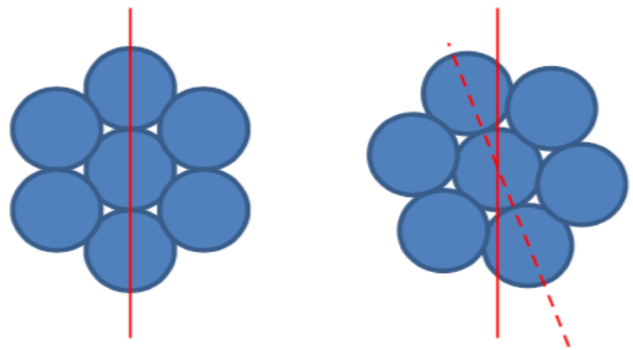
Efficiency vs. Position @ 3 Å

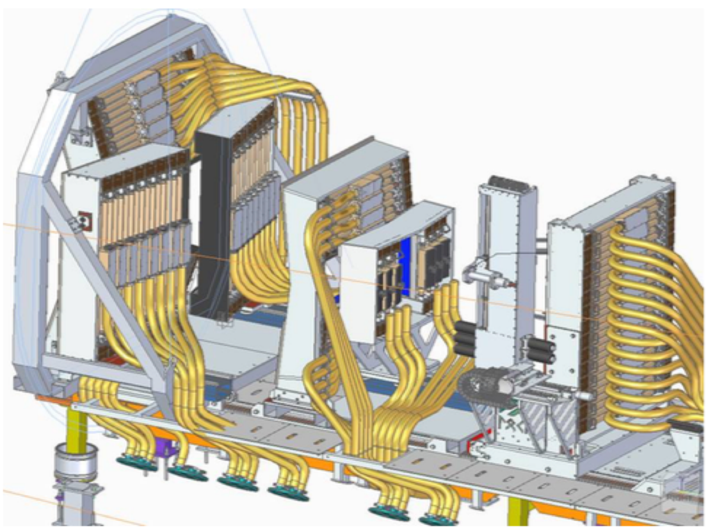


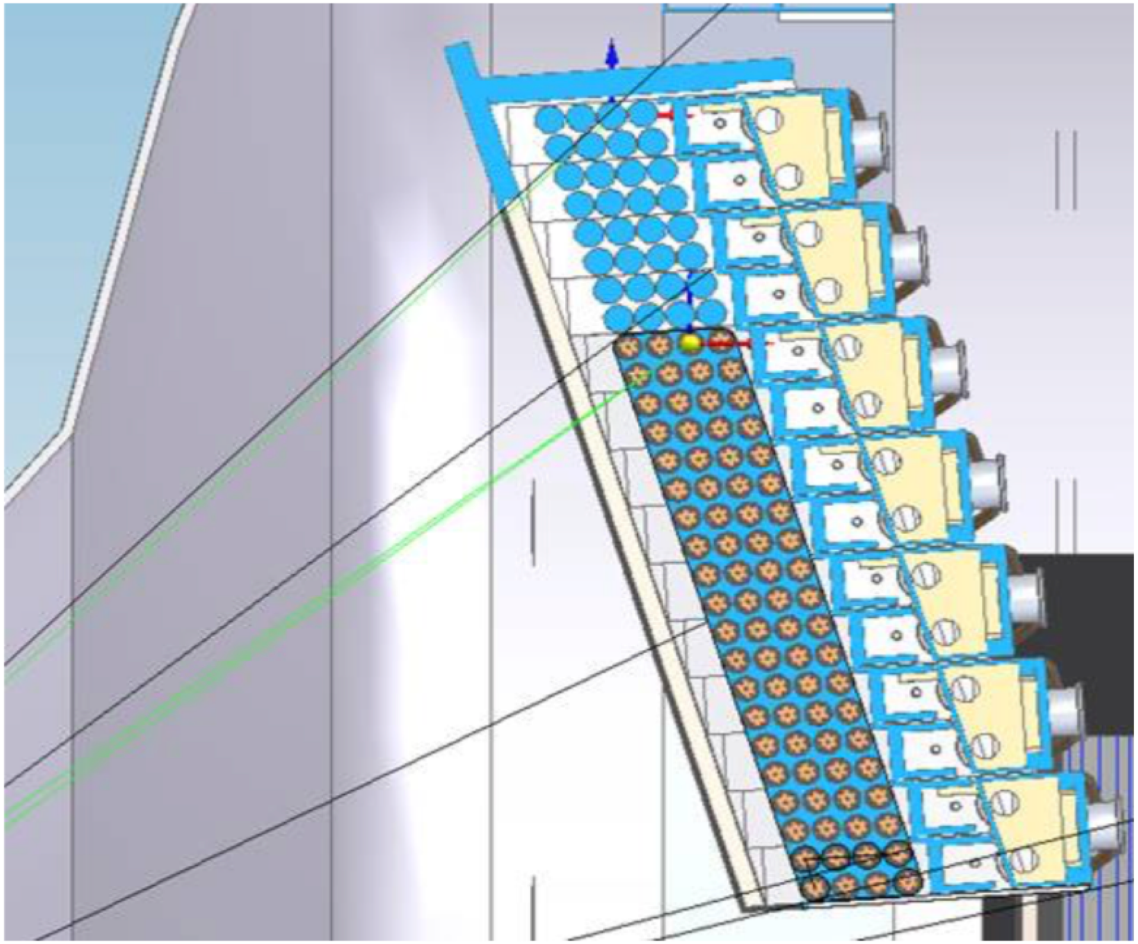


Efficiency: ~50%-60% at LoKI wavelength
Position resolution: FWHM is ~6 mm up to 350 kHz
Rate capability: 15% rate lost at 2.3 MHz

Detector assembly in modules







Detector Simulations

Simulations

McStas simulation of instrument → **Geant4** simulation of full detectors → **Mantid** reduction and analysis of simulated data

Simulate and visualise the expected readout of the real detector modules:

→ Help analyse and debug the early detector tests

→ to develop and test data processing and calibration methods for individual detector panels and, eventually, the full detector array

ESS Detector group framework provides simplified interactions with Geant4 - aim to have public release via GitHub this year. Contact Thomas Kittelmann.

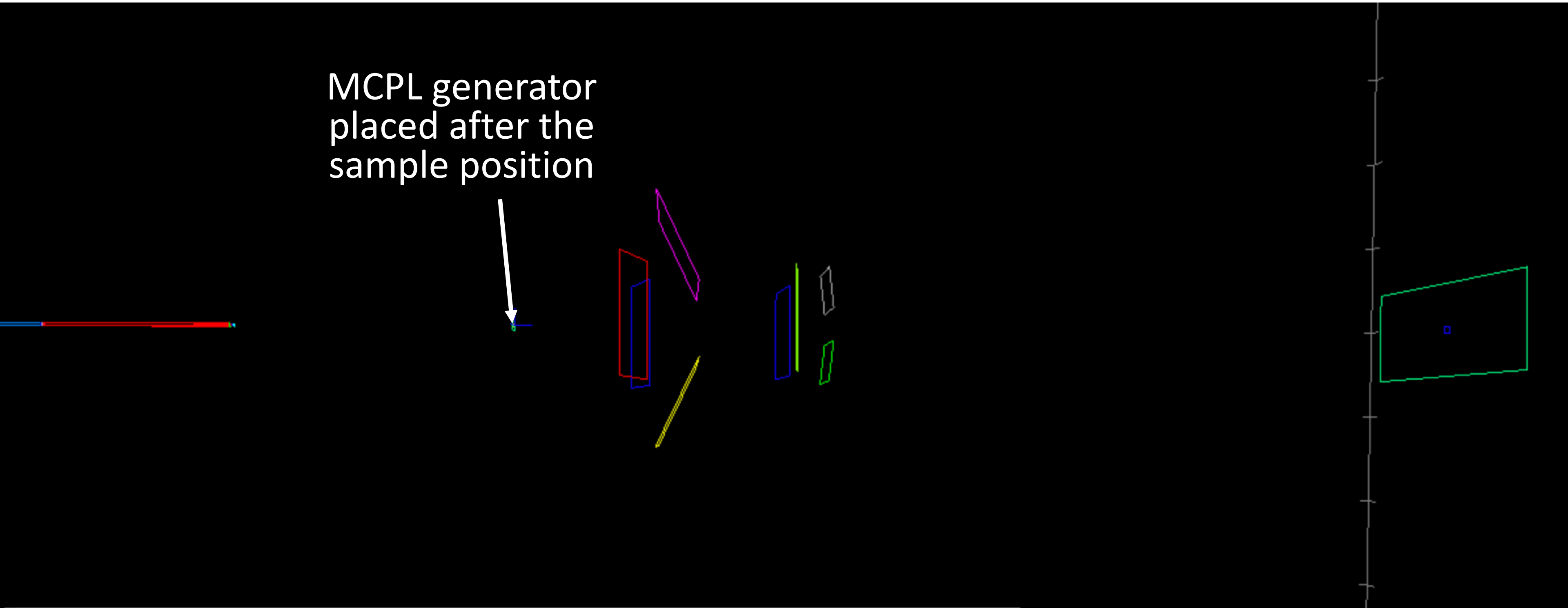
NCrystal extension for thermal neutrons : http://mctools.github.io/ncrystal
MCPL for interchange between MC packages : http://mctools.github.io/mcpl

Simulations

McStas simulation of instrument

Geant4 simulation of full detectors

Mantid reduction and analysis of simulated data



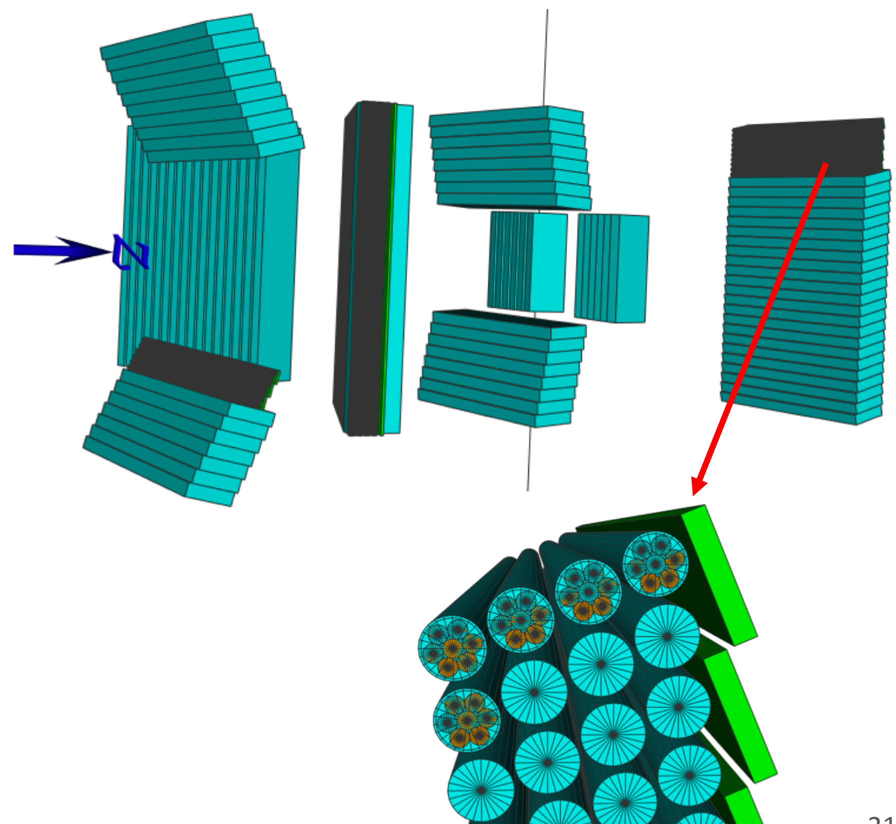

```
COMPONENT mcplout = MCPL_output( filename="McStasOutputGeant.mcpl" )
AT(0,0,0.1) RELATIVE PREVIOUS
```

Simulations

McStas simulation of instrument → **Geant4** simulation of full detectors → **Mantid** reduction and analysis of simulated data

Geant4 is a powerful Monte Carlo simulation toolkit for describing the passage of particles through matter.

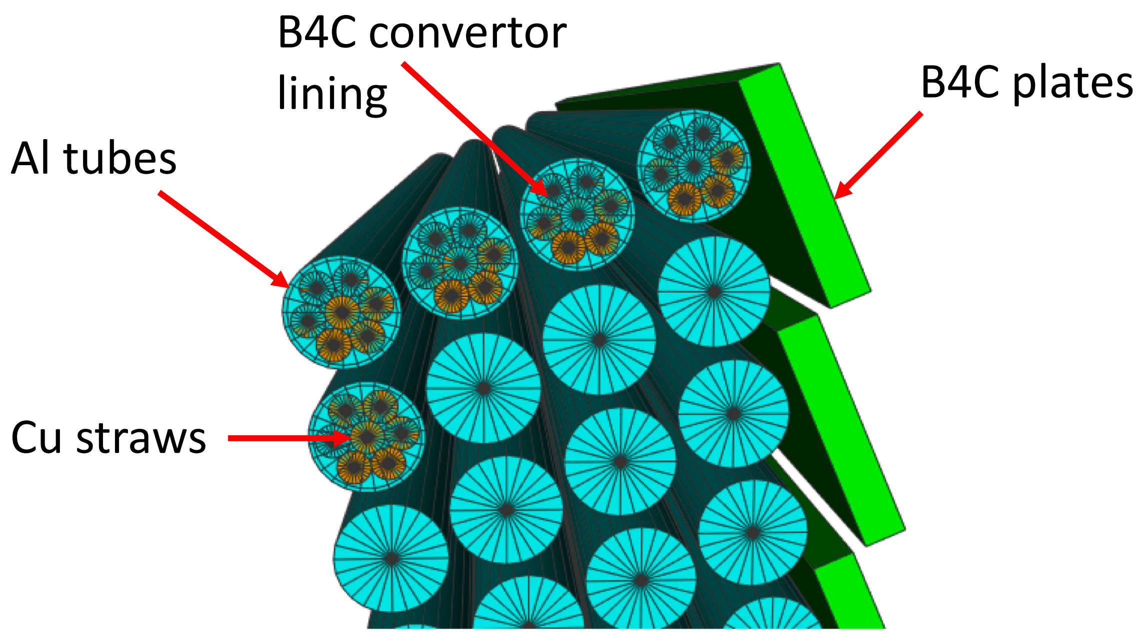
It provides step-based particle simulation in arbitrarily complex geometrical layouts, and with physics modelling capabilities.



Simulations

McStas simulation of instrument → **Geant4** simulation of full detectors → **Mantid** reduction and analysis of simulated data

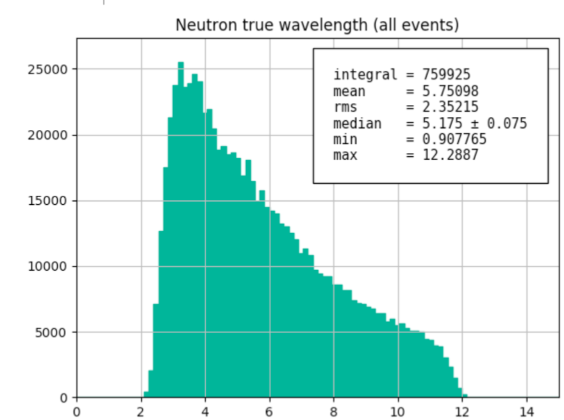
Geometry files describe the dimensions, shapes and components of the detector design

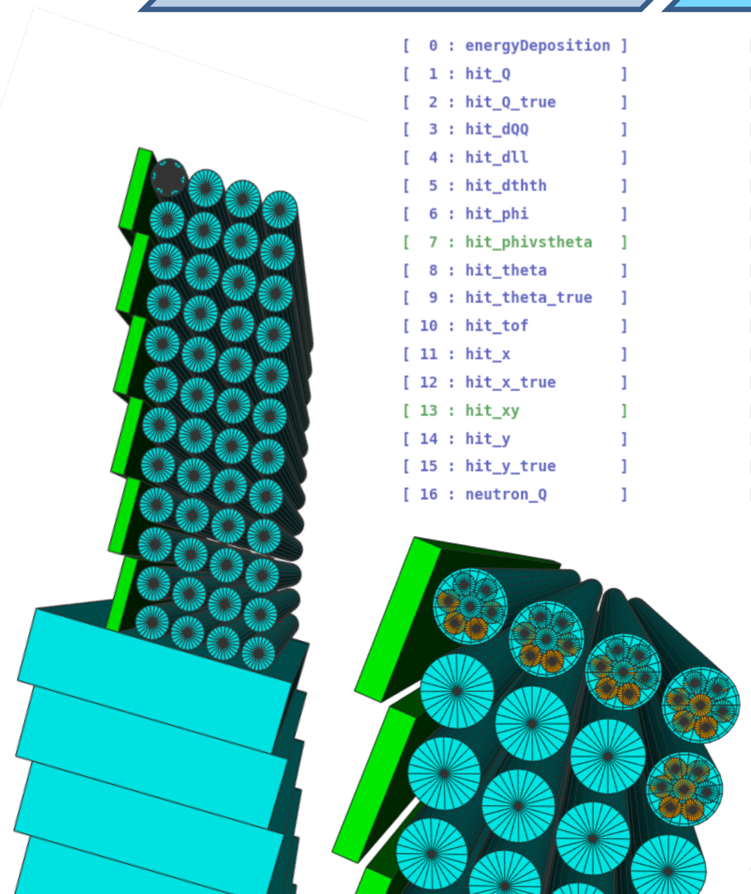


Simulations

McStas simulation of instrument → **Geant4** simulation of full detectors → **Mantid** reduction and analysis of simulated data

```
[  0 : energyDeposition ]     [ 17 : neutron_Q_FP                   ][ 34 : neutron_x          ]
[  1 : hit_Q            ]     [ 18 : neutron_Q_conv                 ][ 35 : neutron_x_FP       ]
[  2 : hit_Q_true       ]     [ 19 : neutron_ekin                   ][ 36 : neutron_x_FP_cut   ]
[  3 : hit_dQQ          ]     [ 20 : neutron_ekin_FP                ][ 37 : neutron_x_conv     ]
[  4 : hit_dll          ]     [ 21 : neutron_ekin_conv              ][ 38 : neutron_x_conv_cut ]
[  5 : hit_dthth        ]     [ 22 : neutron_ekin_eff               ][ 39 : neutron_x_step     ]
[  6 : hit_phi          ]     [ 23 : neutron_lambda                 ][ 40 : neutron_xy         ]
[  7 : hit_phivstheta   ]     [ 24 : neutron_nsegments              ][ 41 : neutron_xy_FP      ]
[  8 : hit_theta        ]     [ 25 : neutron_phi                    ][ 42 : neutron_xy_conv    ]
[  9 : hit_theta_true   ]     [ 26 : neutron_steel                  ][ 43 : neutron_y          ]
[ 10 : hit_tof          ]     [ 27 : neutron_steel_morethanonestep ][ 44 : neutron_y_FP       ]
[ 11 : hit_x            ]     [ 28 : neutron_theta                  ][ 45 : neutron_y_FP_cut   ]
[ 12 : hit_x_true       ]     [ 29 : neutron_theta_FP               ][ 46 : neutron_y_conv     ]
[ 13 : hit_xy           ]     [ 30 : neutron_theta_FP_cut           ][ 47 : neutron_y_conv_cut ]
[ 14 : hit_y            ]     [ 31 : neutron_theta_conv             ][ 48 : neutron_y_step     ]
[ 15 : hit_y_true       ]     [ 32 : neutron_theta_conv_cut         ]
[ 16 : neutron_Q        ]     [ 33 : neutron_tof                    ]
```





Investigate various aspects of the detector performance: efficiency, absorption and the impact of scattering on the measured signal (background effects), multiple scattering effect from the layers of detector panels, λ-dependant transmission of neutrons through the straws

Distribution of Convertor Thickness

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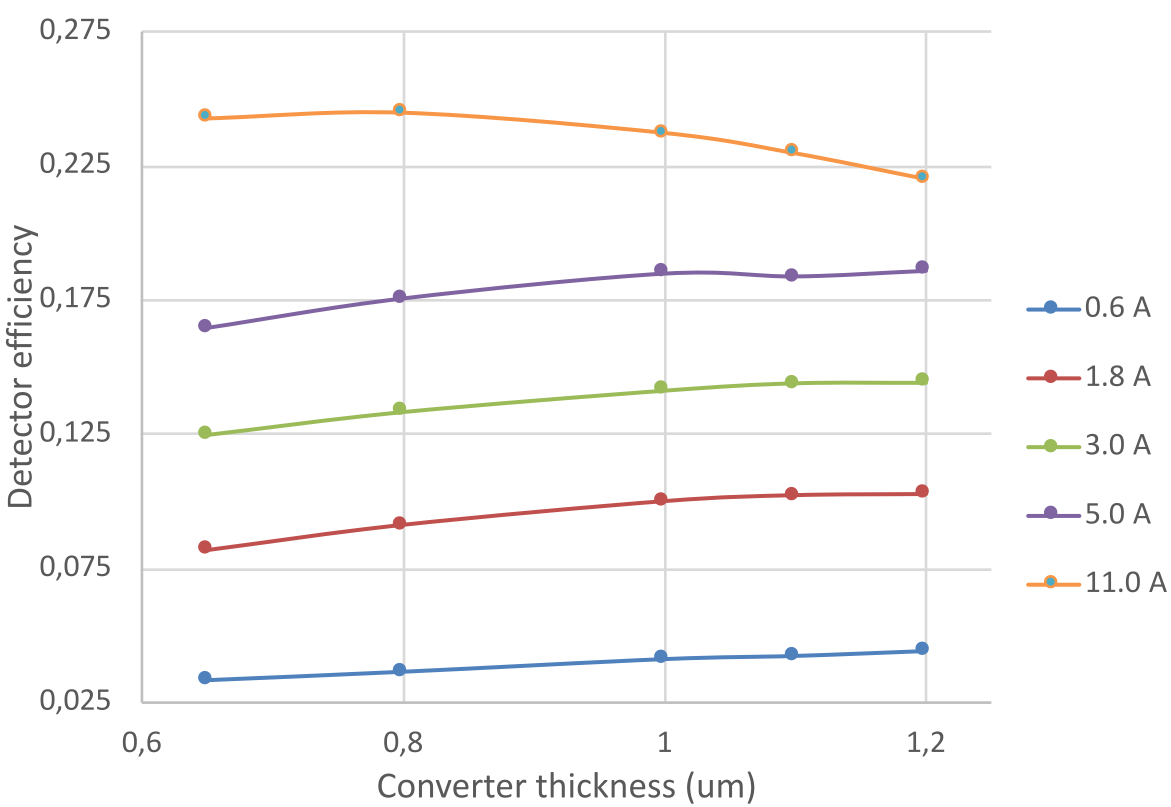
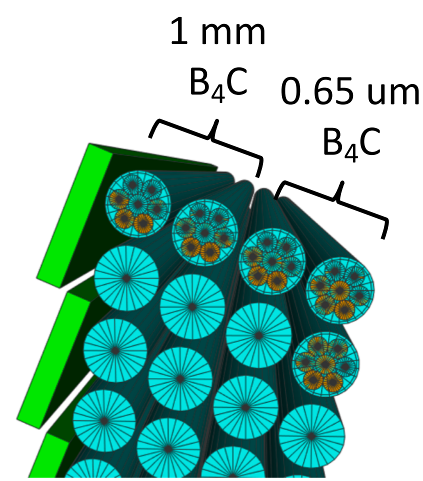
McStas simulation of instrument → **Geant4** simulation of full detectors → **Mantid** reduction and analysis of simulated data





$$E_{det} = E_{con} \cdot DtCR$$

Simulations

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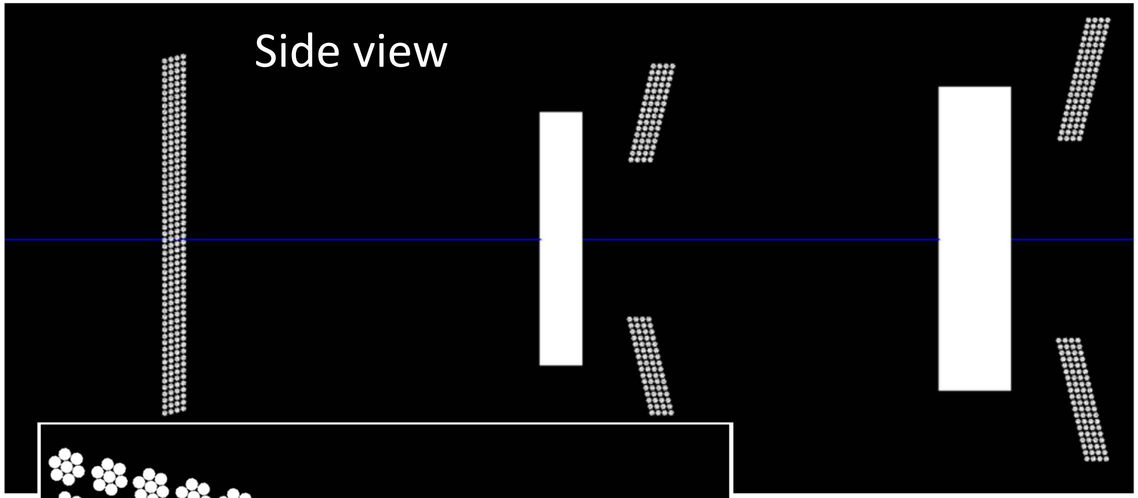
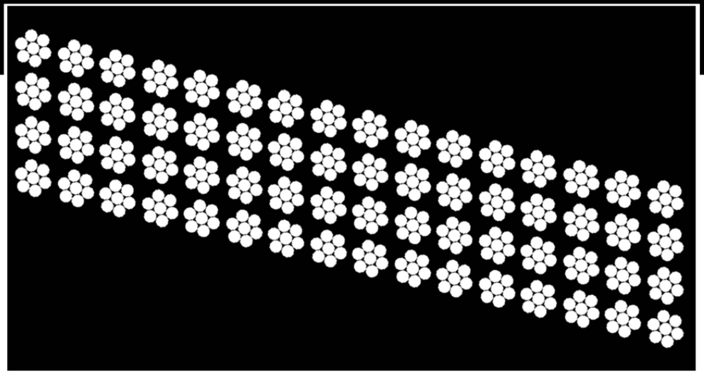
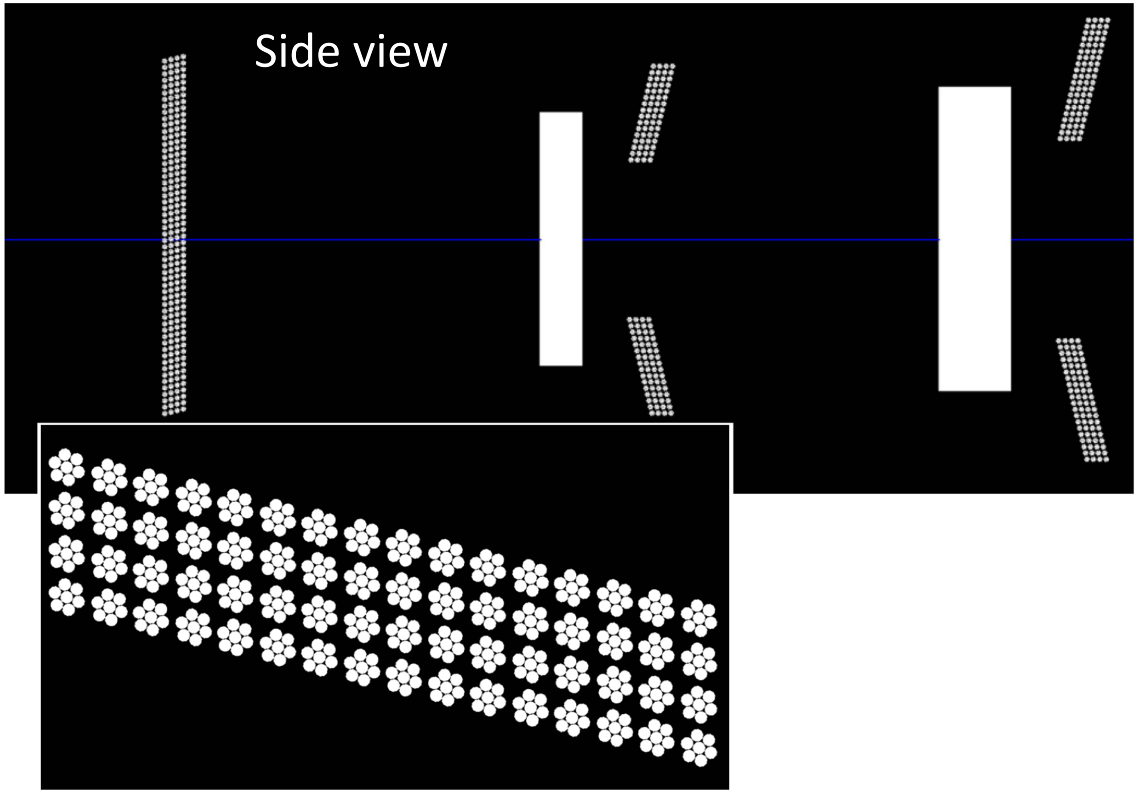


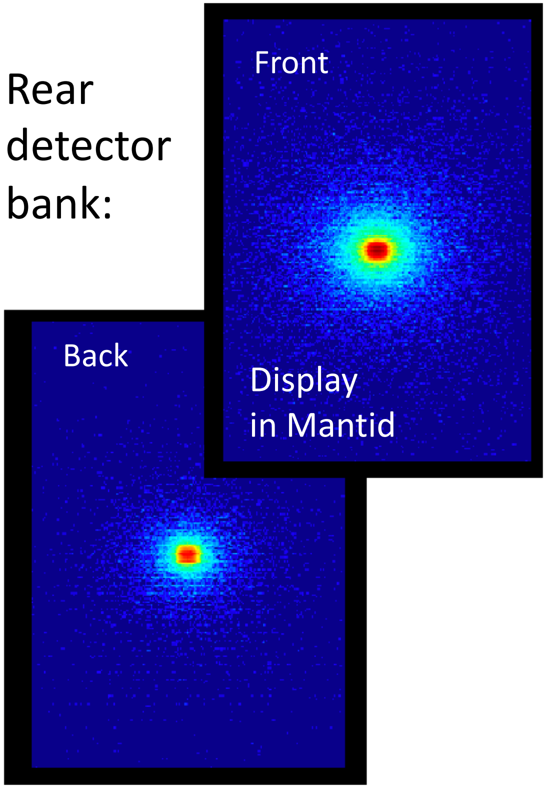


Simulations

McStas simulation of instrument → **Geant4** simulation of full detectors → **Mantid** reduction and analysis of simulated data

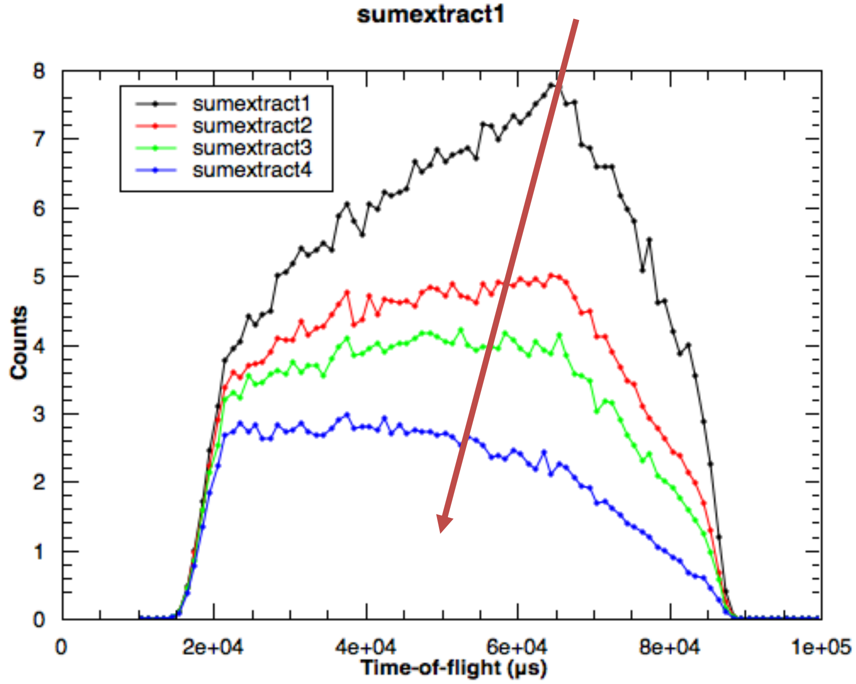


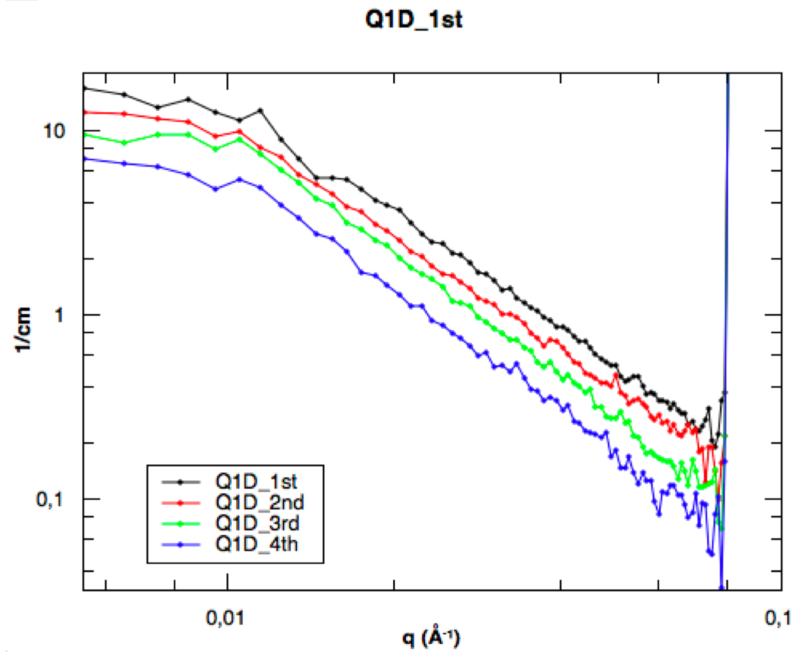
Rear detector bank:



Simulation reduction

Hardening of the neutron spectra





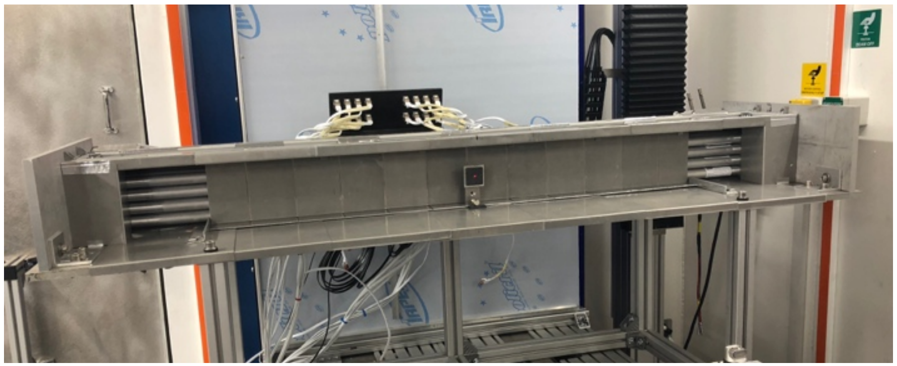
Convert units (to wavelength) → Normalise to monitor → Extract spectrum (e.g. the back detector spectra) → rebin→ Q1D with the appropriate binning (e.g. 0,0.001,0.2)

Mantid Status

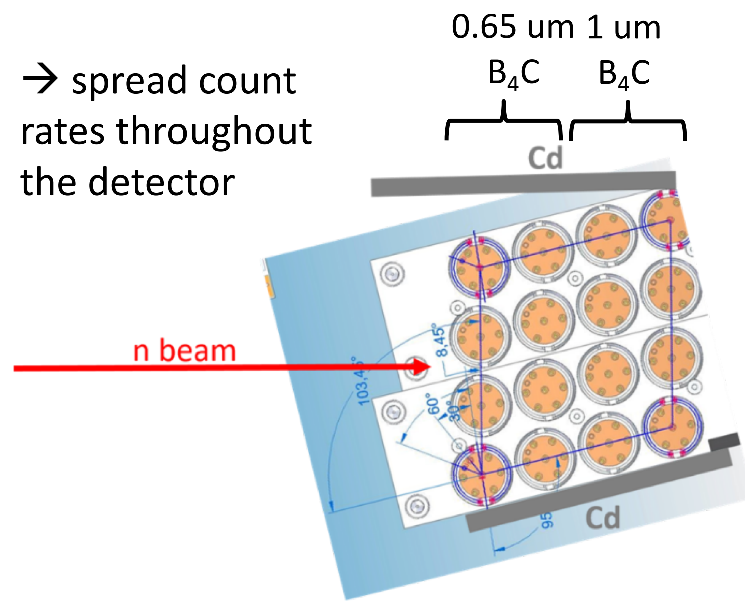
- The Mantid data reduction (DR) team has been closely associated with developments for the LOKI instrument.
- DR have also been assisting in feeding GEANT4 and McStas simulated data into Mantid for early prototyping of data reduction workflows as well as verifying live streaming/reduction.
- So far the DR team have come up with a proof-of-concept which shows that they can cope with data rates of 10e7 for LOKI streaming into Mantid.

Detector Tests

First Tests at ISIS - June 2019



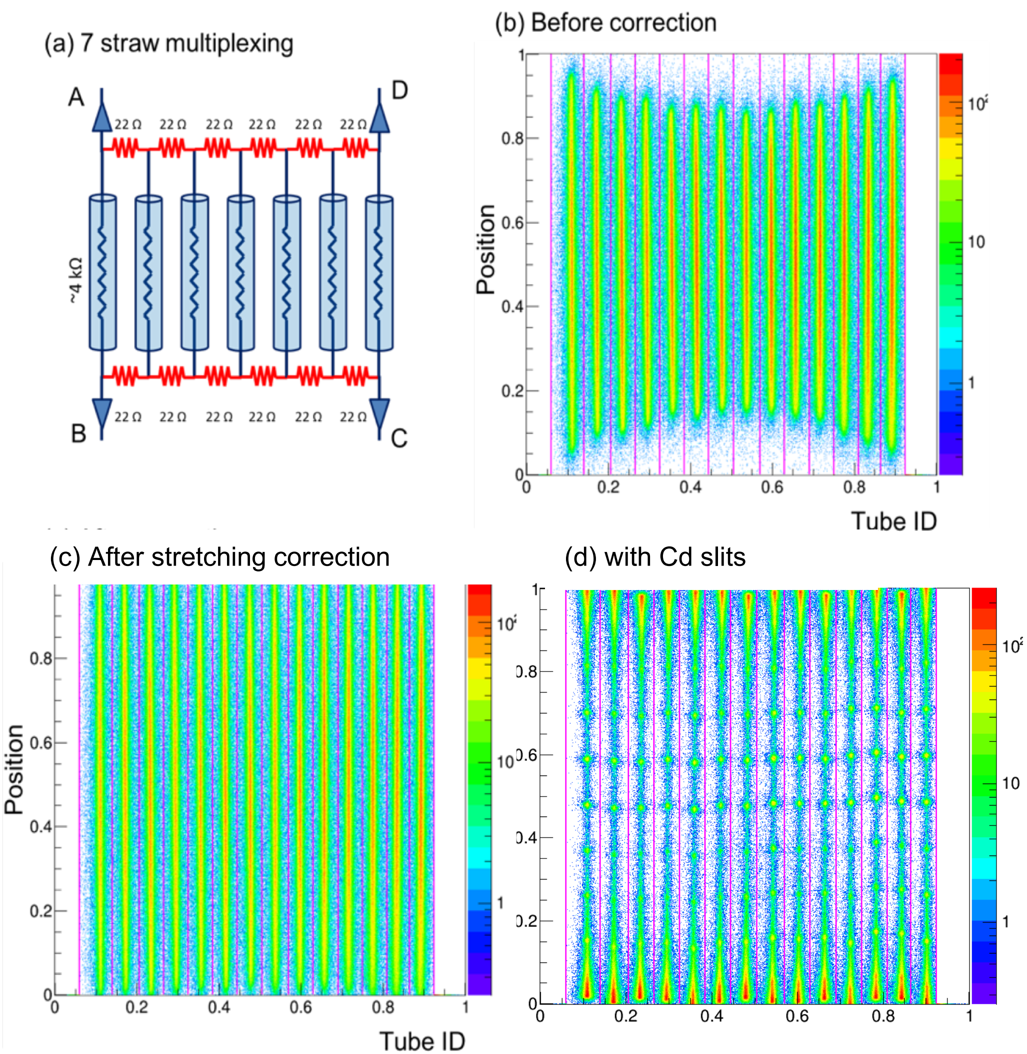
→ spread count rates throughout the detector



Set-up on Larmor:

- 1.5 m long straws (LoKI max. 1.2 m)
- HT=950 V (will be 1150 V)
- ADC in diagnostic/event mode
- Ethernet readout
- Calibration mask for position corrections
- Data corrected and Transformed in histogram mode and loaded in Mantid

Correction for Straw Tube Multiplexing



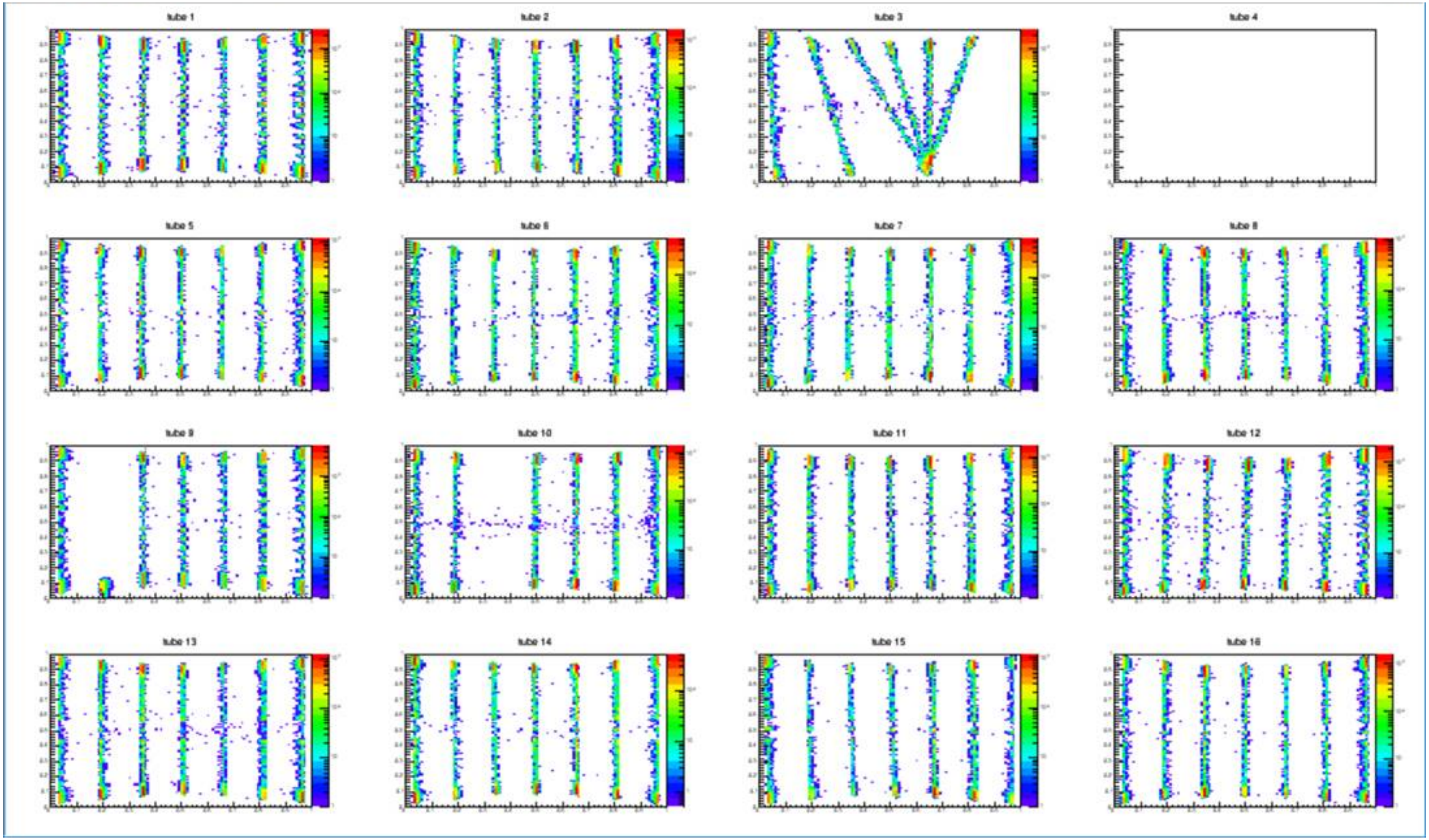
- To reduce the number of signals coming from so many straws
- Resistive chain between both ends of the BCSs
- 7 BCSs in 1 tube are readout by four preamps connected at the corners (A, B, C, and D) of the circuit.
- X axis is used to identify in which BCS a neutron was absorbed
- Y axis is used to calculate where a neutron interacts along the length of the BCS

$$x = \frac{A+B}{A+B+C+D}$$

$$y = \frac{A+D}{A+B+C+D}$$

Readout from Backend Electronics

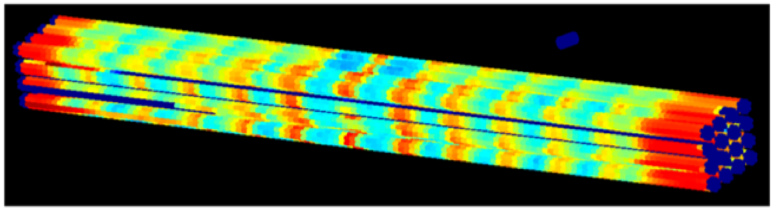
Issues with dead straws



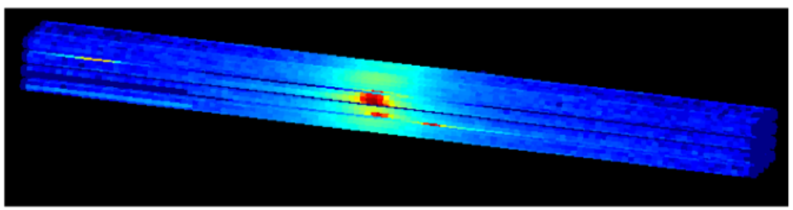
Data Read and Displayed in Mantid

Cd mask, empty beam (with & without beamstop), RTI polymer, SDS powder

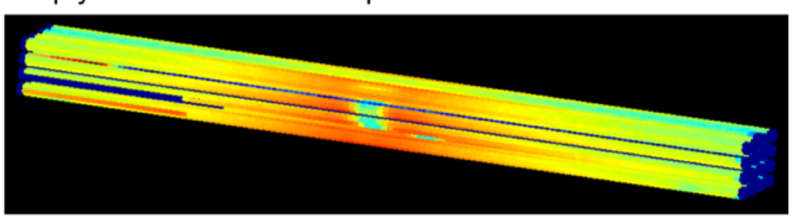
Cd slit mask - 41593



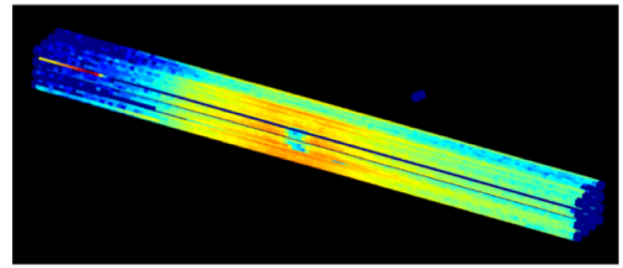
Empty beam with no beam stop - 41603



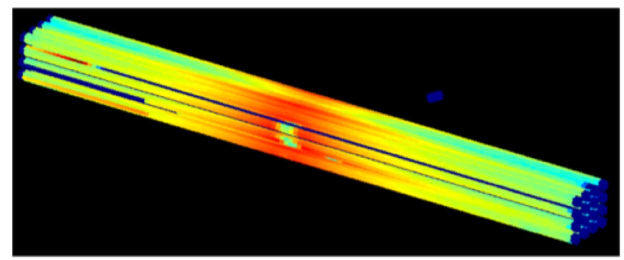
Empty beam with beam stop - 41594



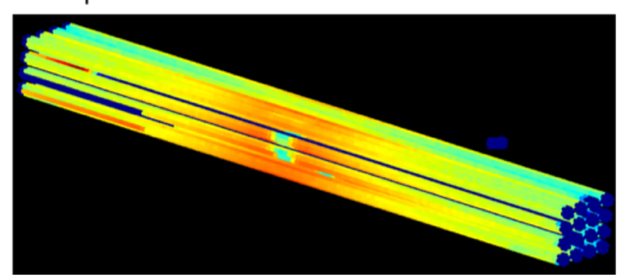
B4C panel on the left side of the detector - 41602



RTI – ISIS polymer blend - 41596



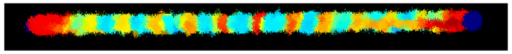
SDS powder - 41600



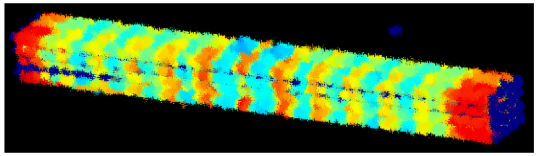
128 pixels along each straw

Straw Cross section

(i) Single tube containing 7 BCSs

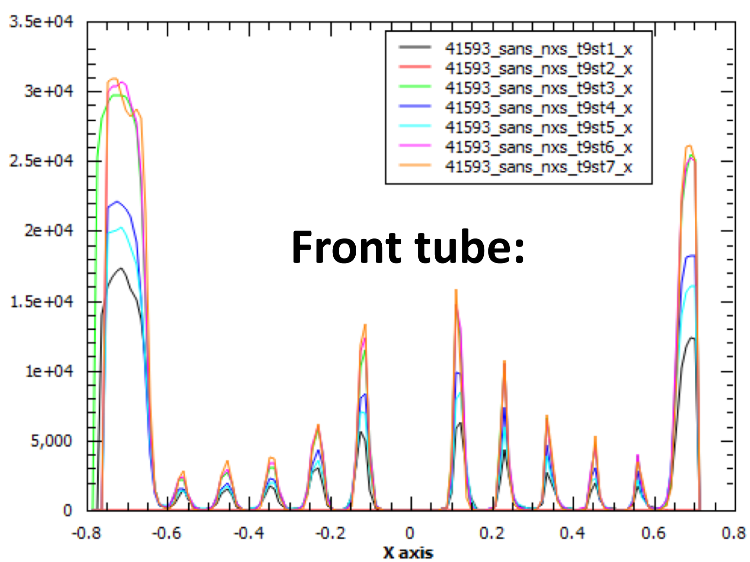


(ii) 16 tubes

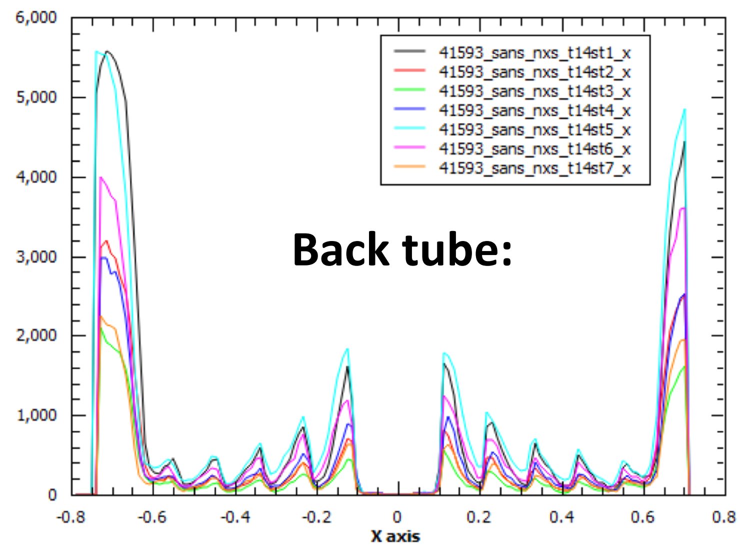


Cd mask:

41593_sans_nxs_t9st1_x masked - except beam centre

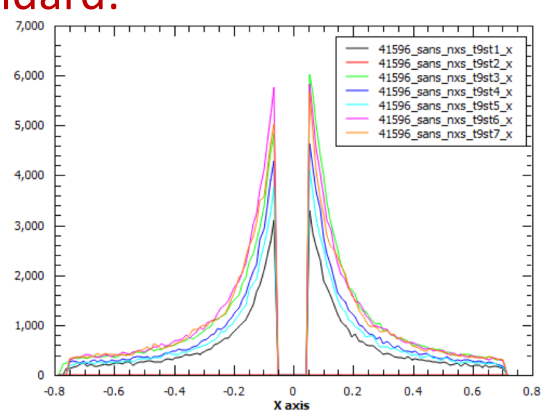


41593_sans_nxs_t14st1_x masked, except beam centre

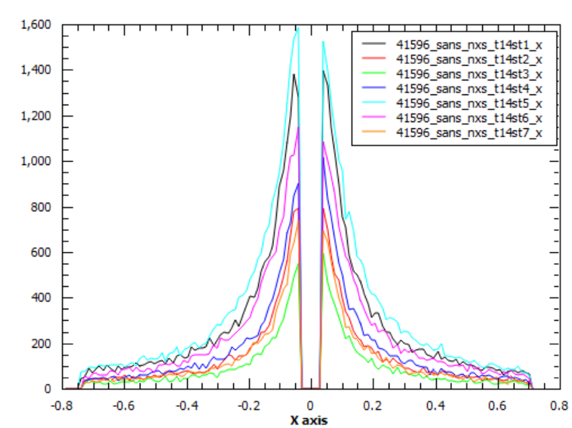


Polymer standard:

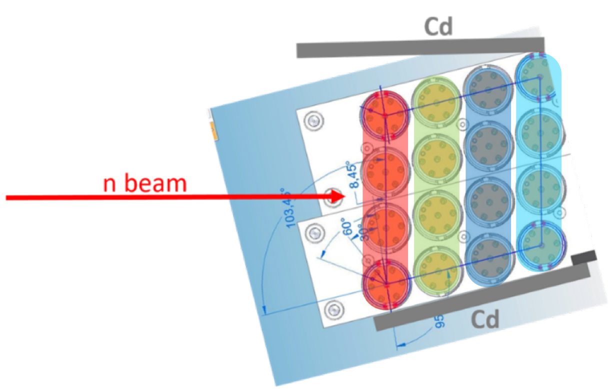
41596_sans_nxs_t9st1_x Masked

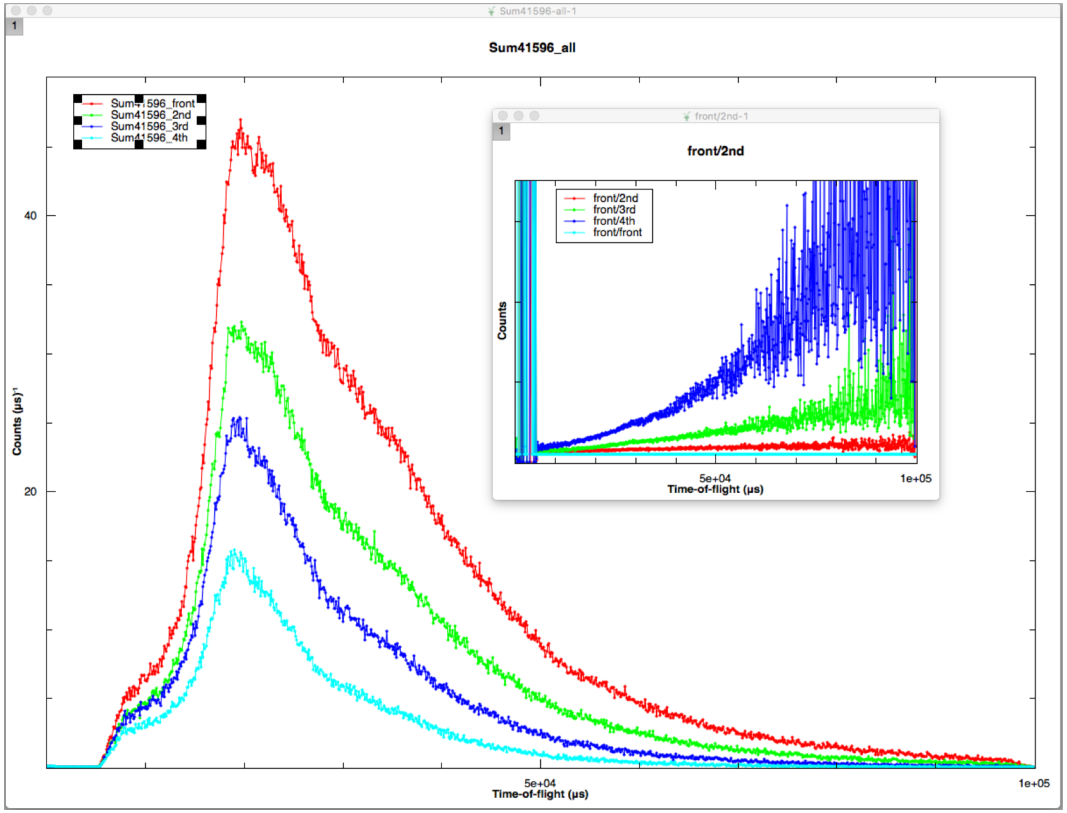


41596_sans_nxs_t14st1_x Masked



Detector Tests





SANS tests and mantid reduction

Reduction using the depreciated ISIS reduction software

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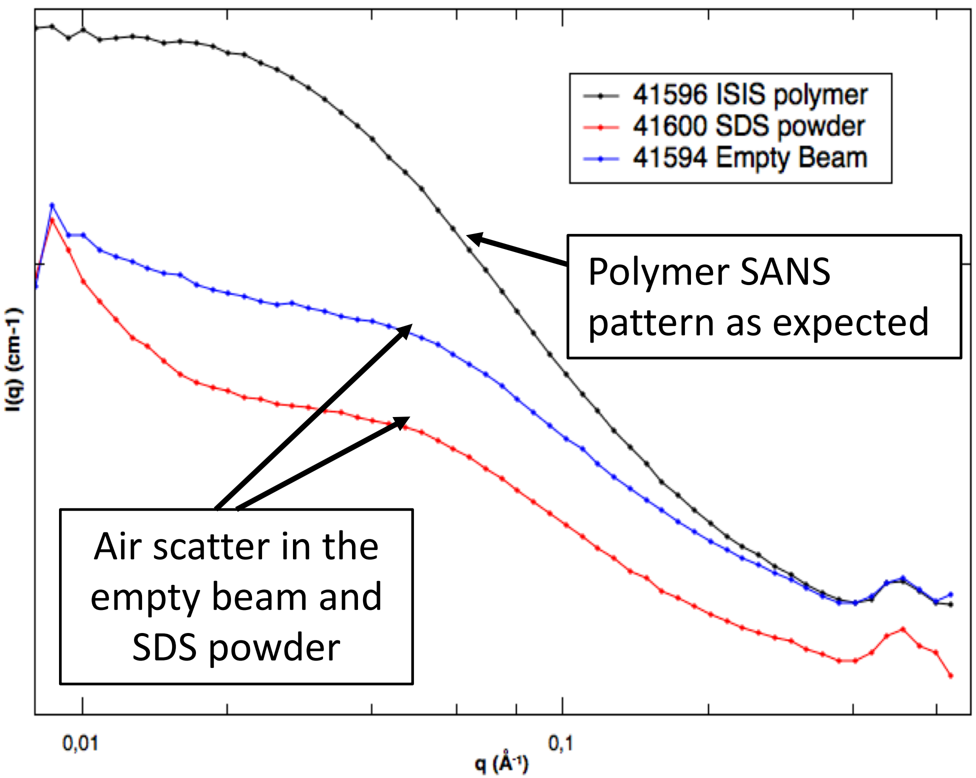
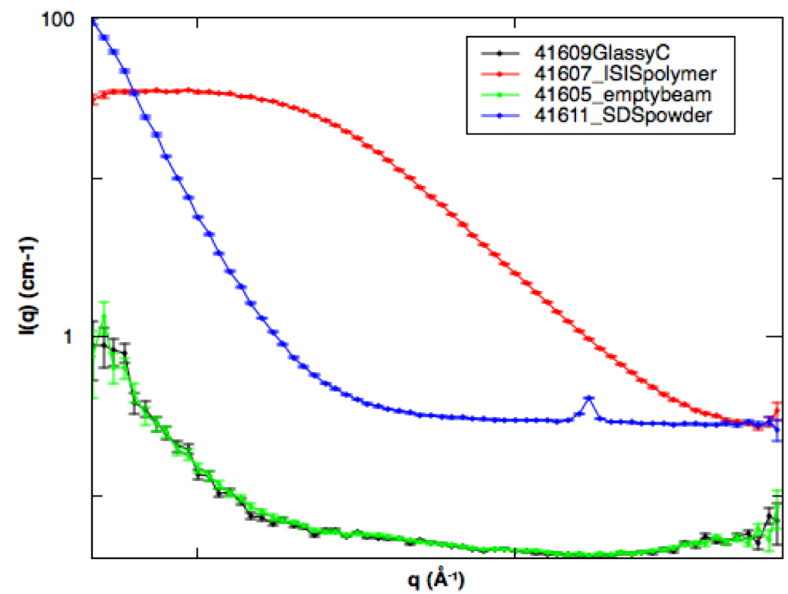
"Reduced" data from the LOKI detectors:



No normalisation or background subtraction

Data from the LARMOR detectors:



RTI polymer standard:

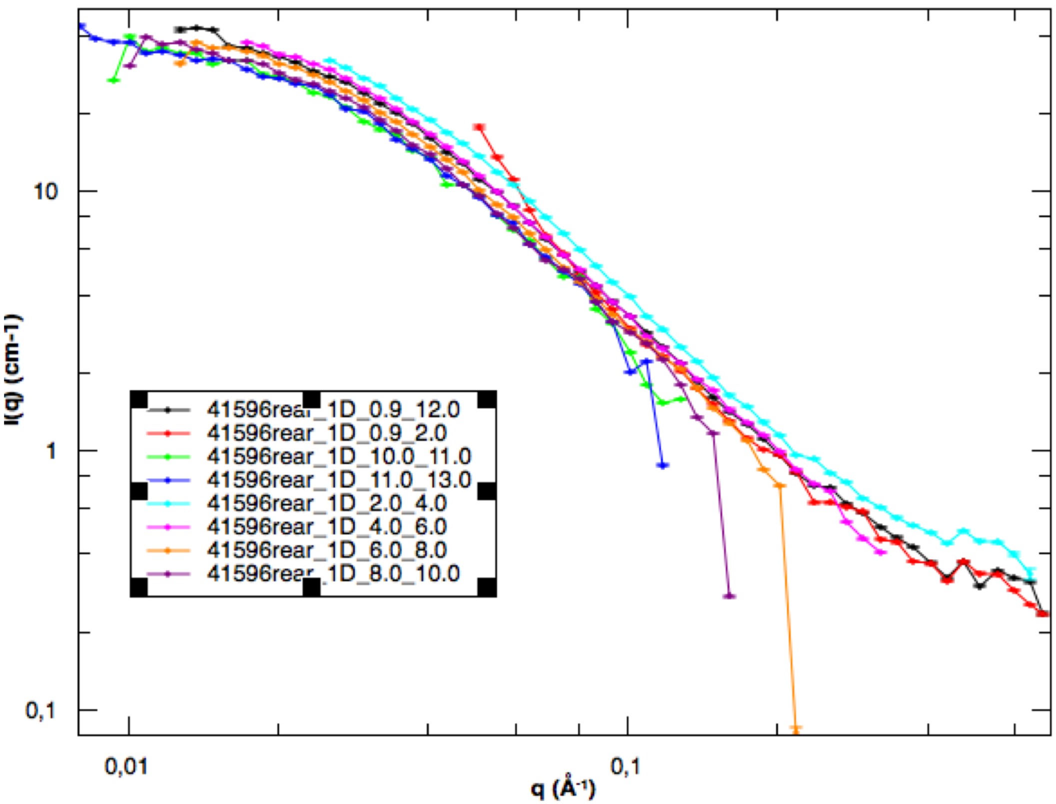
I0 - 55.77

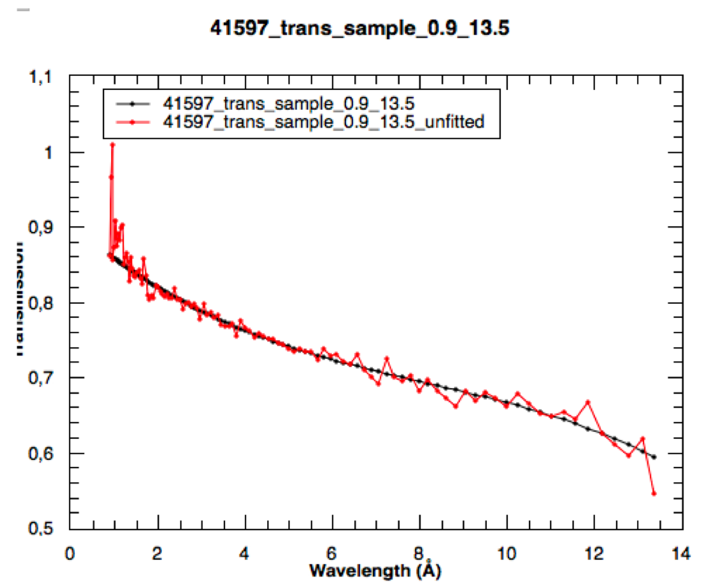
Rg - 60

Pd - 1.02

ISIS Polymer

All four layers of tubes reduced together as a function of wavelength





RTI polymer standard:

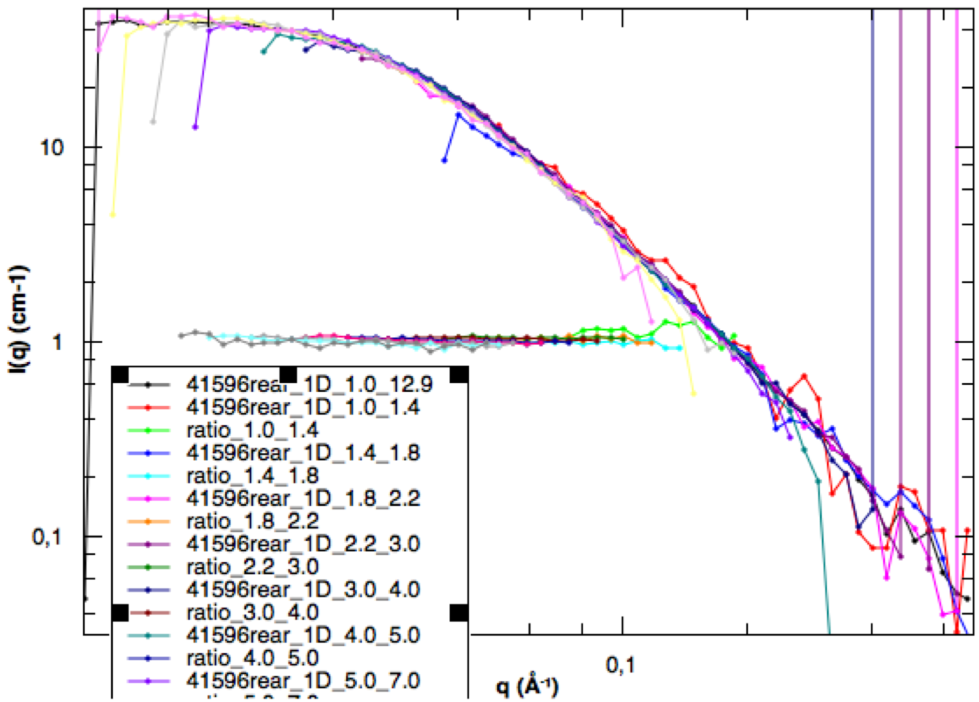
I0 - 55.77

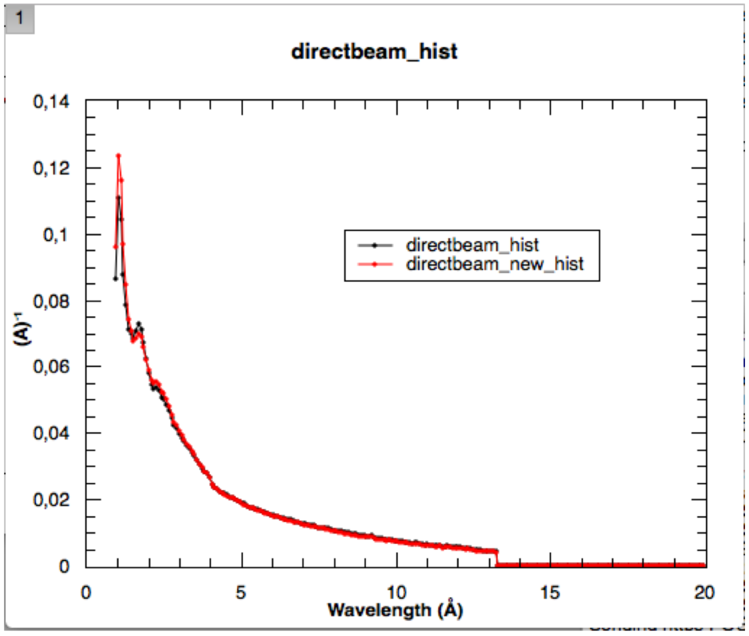
Rg - 60

Pd - 1.02

Direct Beam Function

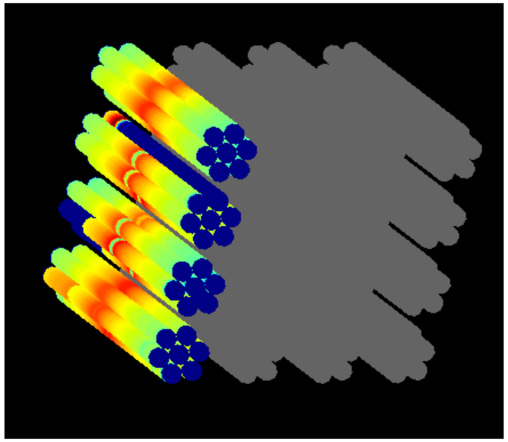
Adjusting for the direct beam….



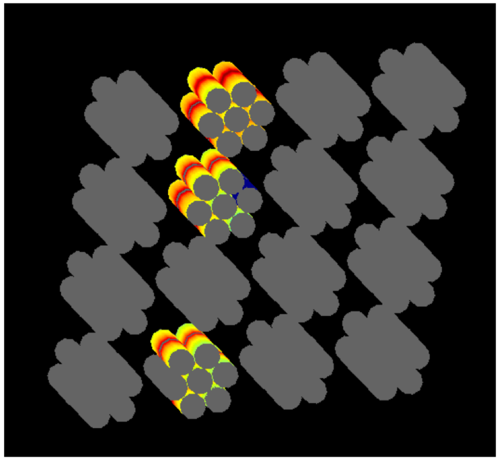


The “direct beam” is the relative efficiency of the main detector compared to the monitor

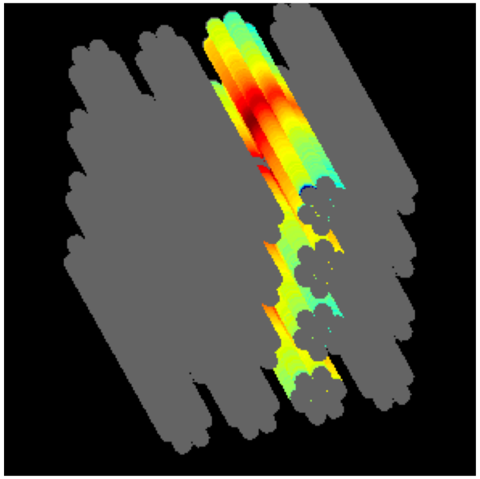
Dissecting the layers



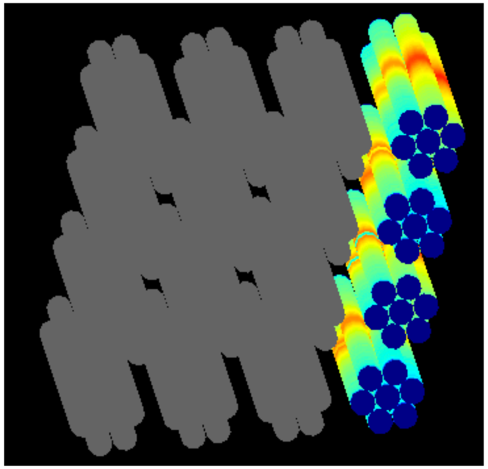
First layer



Second layer



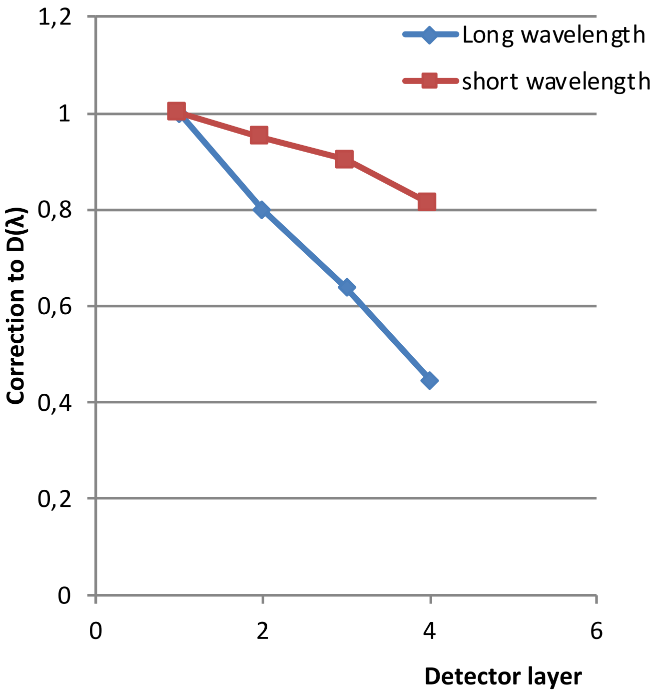
Third layer



Fourth layer

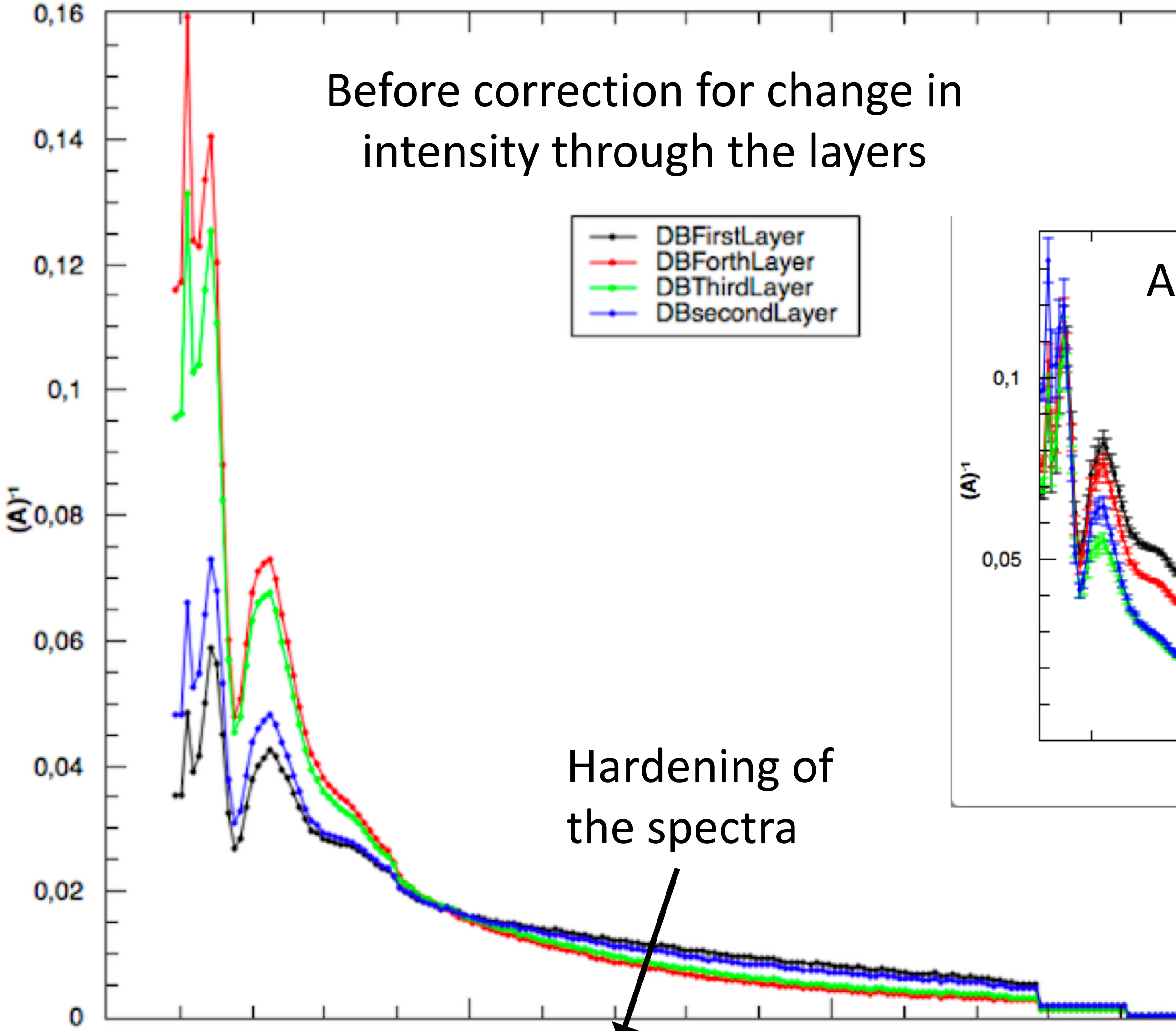
Self-Screening or hardening of the neutron spectra through the 4 (or more) Layers

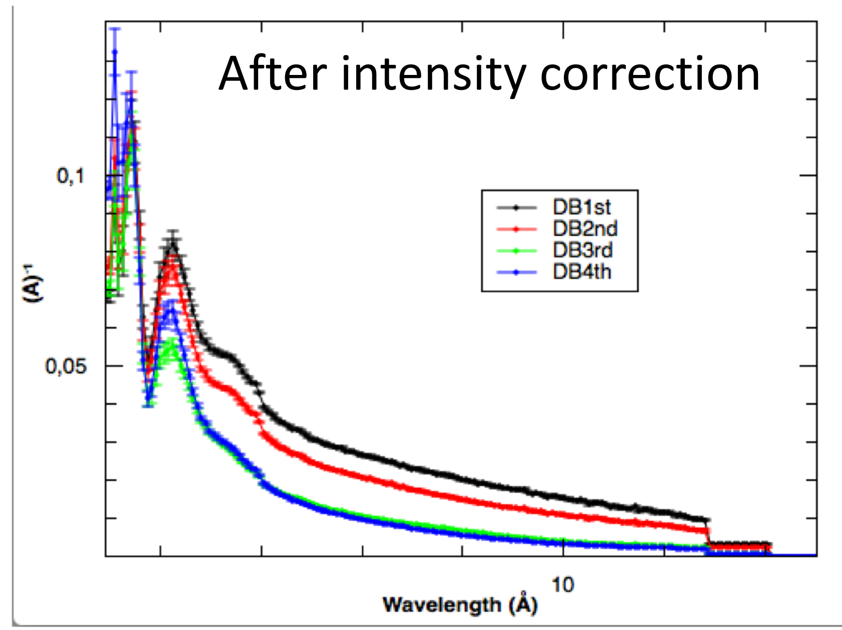
Layer =	1	2	3	4
Long wavelength				
real local efficiency %	**20**	**20**	**30**	**30**
neutrons	**1000**	800	640	448
detected	200	160	192	134.4
effective efficiency %	20	16	19.2	13.44
correction to D(lambda)	1	0.8	0.64	0.448
Short wavelength				
real local efficiency %	**5**	**5**	**10**	**10**
neutrons	**1000**	950	902.5	812.25
detected	50	47.5	90.25	81.225
effective efficiency %	5	4.75	9.025	8.1225
correction to D(lambda)	1	0.95	0.9025	0.81225



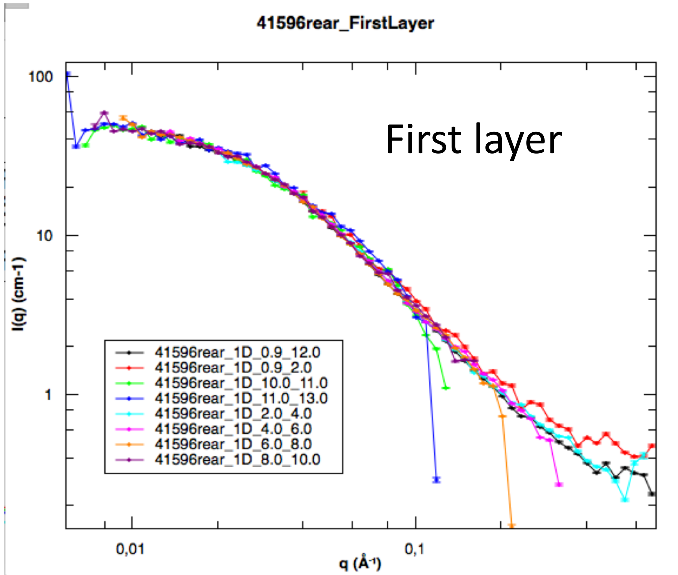
- The shape of D(λ) will have to change as neutrons go deeper into the ~10 layer of straws.
- GEANT simulations will provide initial estimates of this self screening.
- We could split D(λ) into a product of monitor and detector parts,
- or store the relative corrections for say each layer of straws and then final corrections for individual straw.
- Note – the first two layers of tubes have a lower efficiency in order to spread count rates.

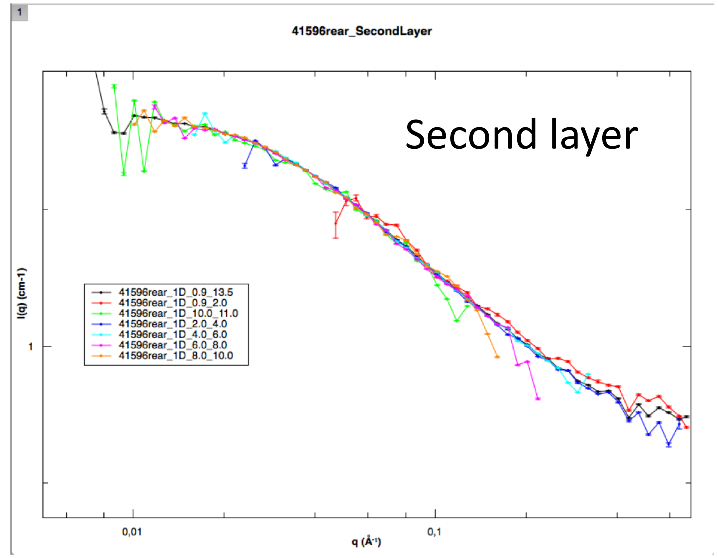
Direct Beam Function Through the Layers

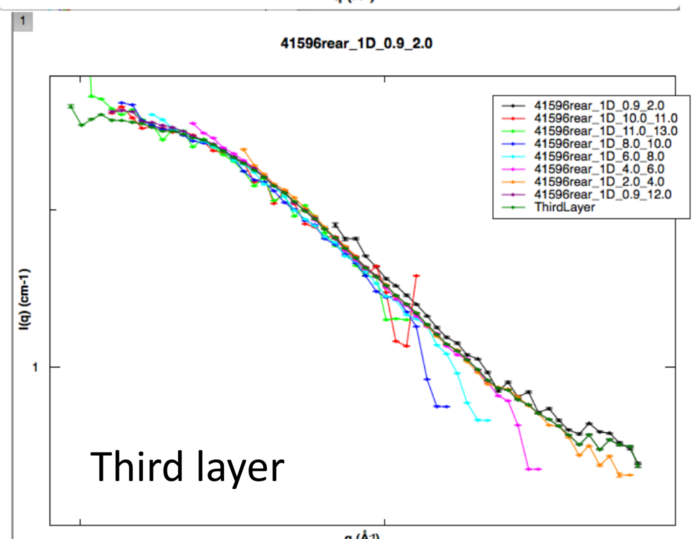


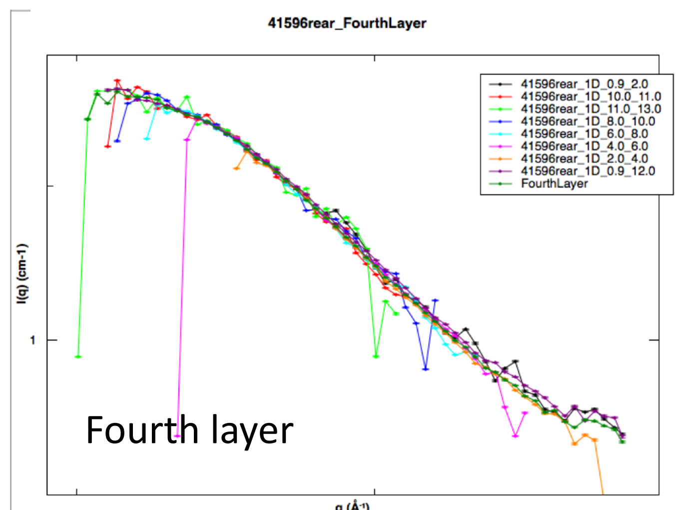


Dissecting the layers

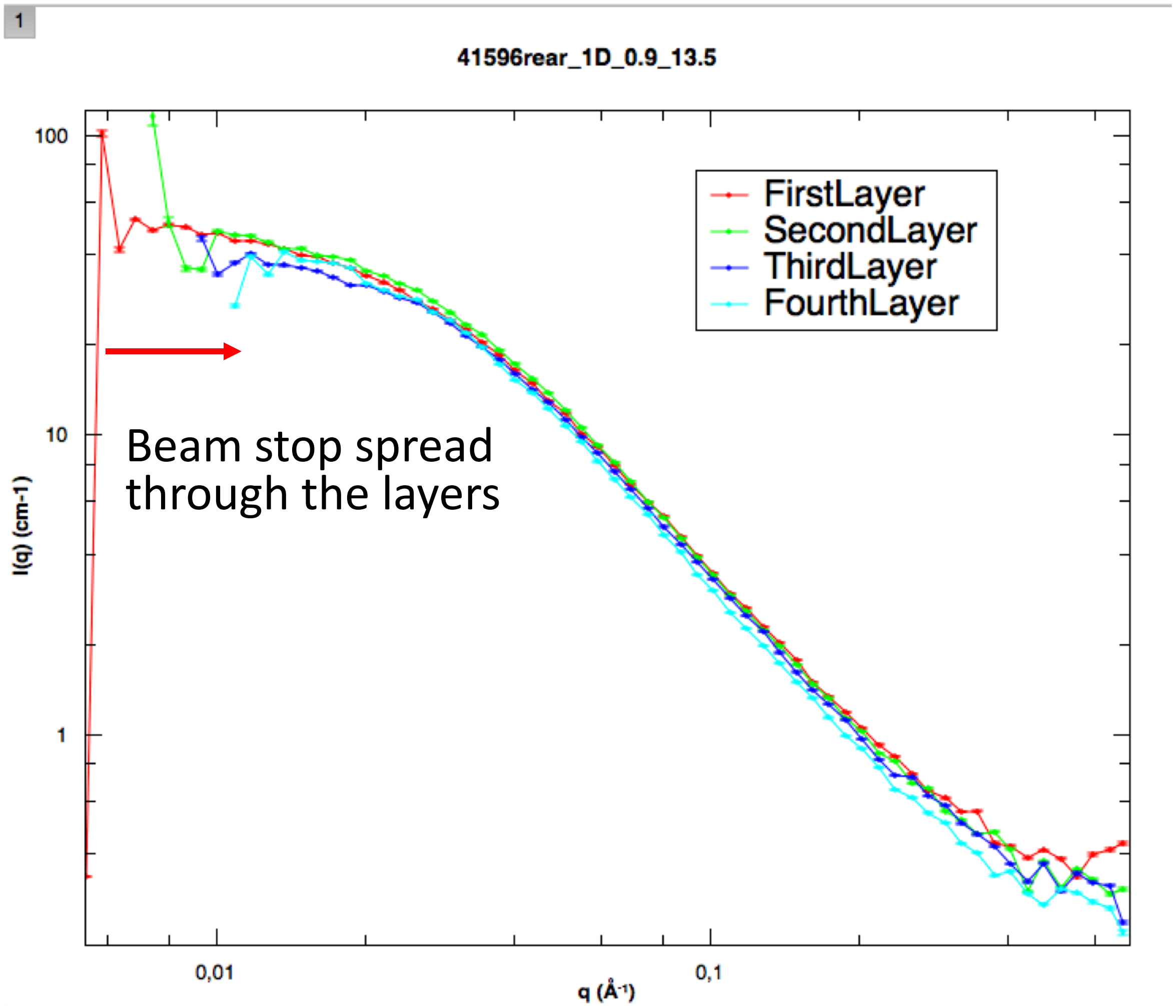








Combined layers



Test conclusions so far …

- useful to refine the technique to quantify the position correction along the tube,
- understand how to handle the parallax due to the use of a 4” deep detector

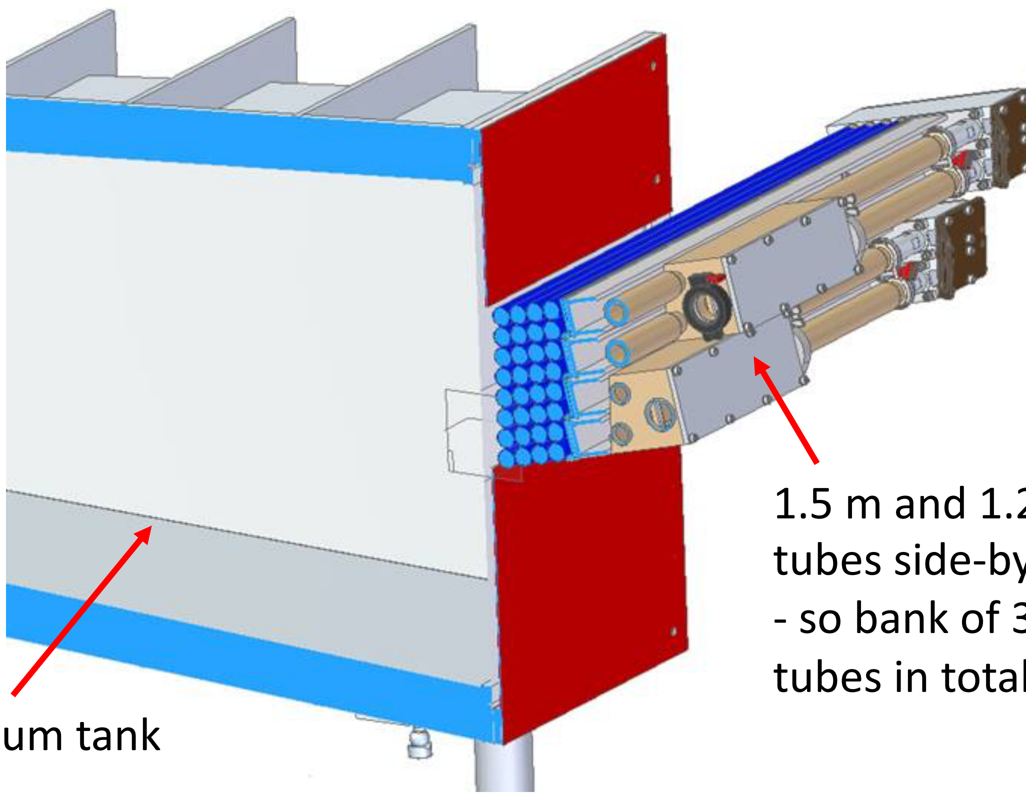
& include the data on Mantid.

- understand how to improve the signal processing,
- and, in particular, guarantee a more uniform position resolution along the length

of the straws.

Future tests and reducing air scatter

Higher voltage of 1050 V so improved resolution of ~ 8mm



1.5 m and 1.2 m tubes side-by-side - so bank of 32 tubes in total

Larmor vacuum tank

Further testing of the backend electronics and data chain from detectors to Mantid

Path to Hot Commissioning

Simulations

- Data for the Mantid *team to test capability for data streaming/reduction*
- Effect of convertor thickness
- Idealised data from the instrument for data processing and reduction
- Bug finding (e.g. selectively turning off tubes, transmission effects)
- Calibrating wide angle detectors which will be difficult for tests at ISIS

Real tests

- Full tests of the detector technology and data chain from detection to reduction software.
- Real data for testing calibration & data processing workflows
- Trouble shooting

Ready for hot commissioning:

1. Data processing workflow from detector to Mantid
2. Calibration plan
3. Data reduction workflow

Challenges… tackling TOF & 3D detectors

Challenges for data processing:

- Detector position calibration

→ We can't simply survey in the pixel positions

→ Need to use surveyed masks in front of the tubes

- *Solid angle corrections:*

→ Issues with parallax in the quite deep detectors

→ …also as detector moves from 5 to 10 m, or changes in the sample position

→ Calibrating wide angle banks (longer pathlengths in samples? And detectors?)

- Relative efficiency of the detectors

→ Self-screening in layers

- *Wavelength calibrations*

Quest for standards:

- Samples which scatter over wide q
- For intensity calibrations