The ESS Test Beam Line V20
Highlights and lessons learned after 4.5 years

Peter M. Kadletz
Oliver Löhmann
Robin Woracek

Neutron Instrument Division

Overview of V20

Motivation

EUROPEAN SPALLATION SOURCE

HZB Helmholtz Zentrum Berlin

ESS operated the Testbeamline at Helmholtz Zentrum Berlin 2015-2019

- Experimental test case for “Long pulse”-instrumentation with FLEXIBLE SETUP
- Develop/establish procedures and data reduction
- Green field site: Testing and integration of components
- Choppers provided the **ESS pulse structure** (14Hz, 2.86ms)
- Optional **pulse shaping choppers** provided Wavelength Frame Multiplication (WFM)

Main modes of operation

Simple Pulsed mode
2 double choppers
(low resolution)

WFM mode
2 double choppers
4 single disc choppers
(high resolution)

Timeline of V20

Operations: April 2015 – December 2020

Design, Construction and Cold Commissioning

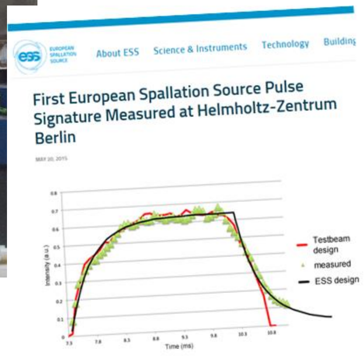
- German contribution as part of the design update phase of the ESS project
- Poster at IKON 1

2011-2013

2013/14

BER2 maintenance

No operation



2015

Start of Operations

- 17 users
- 1 ESS Instrument Scientist stationed at HZB.
- **Hot Commissioning**
- 1st SEMSANS experiment (TUD)

2016

Start of Scientific Program and establish Collaborations

- 36 users
- Integration of **TOF-PSD** (Denex) in collaboration with HZG
- **1st implementation of NICOS (DMSC)**
- 2nd WFM diffraction experiment
- 2nd and 3rd SEMSANS experiment (TUD)
- **WFM stitching** script implemented in MANTID (DMSC)
- TOF grating interferometry (PSI, UCB)
- Fuel Cell: Water vs Ice (PSI)
- Meetings with ESS technical groups

2017

Component testing, method development and scientific experiments

- 71 users
- Fermi Chopper characterization (FZJ)
- Series of TOF imaging experiments using user furnace (DTU, PSI, HZB, BAM)
- Detector tests (HZG,Toshiba)
- **ICS hardware deployed** (ICS, DMSC)

2018

Establish as the ESS Integration Platform

- 62 Users
- 3rd WFM diffraction experiment: successful structure refinement (FZJ, LLB,)
- Test and use of TOF imaging camera (GP2) by ISIS (RAL, PSI, TUM)
- **ESS motion system deployed** (for 12 of 25 axis)
- 2nd Instrument Scientist starts
- Detector tests (HZG)
- **1st Time-Referenced Data Acquisition demonstrated** for WFM diffraction (DMSC, ICS)

2019

Method development and scientific experiments using ESS-like integration

- 92 users
- Test of beam monitors for ESS
- Post-doc (Flexi-Probe, TUD) stationed at V20
- **WFM reflectometry in 'full ESS integration**' (TUD, DMSC, ICS)
- Detector tests for BEER, DREAM, CSPEC, ODIN
- SANS in 'full ESS integration' utilizing SE

2020

Decommissioning

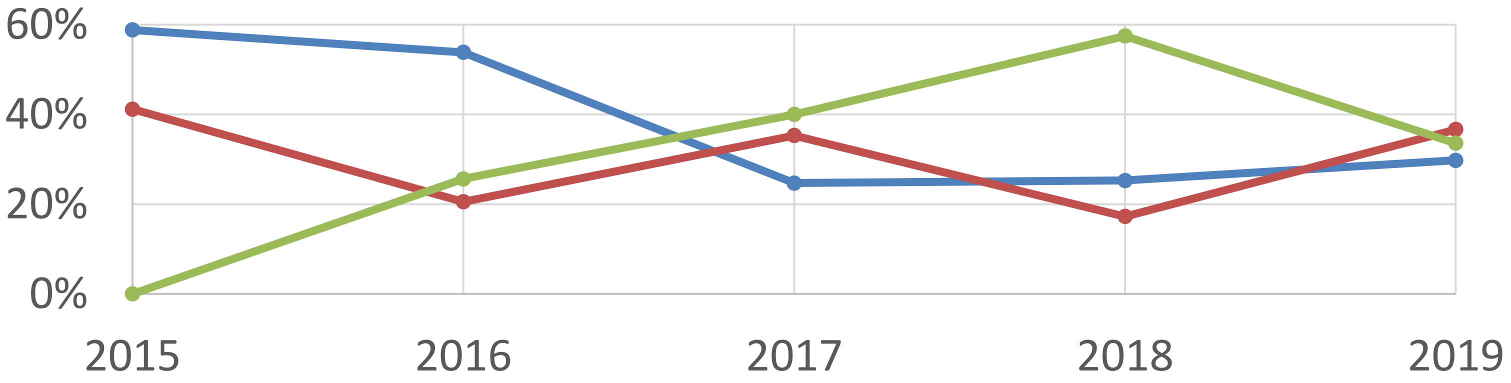
- IKON 18
- 2 people at HZB until June
- Data analysis in continued collaboration
- **Final Report in preparation**

User Statictics of V20

Main purpose by users (multiple possible)

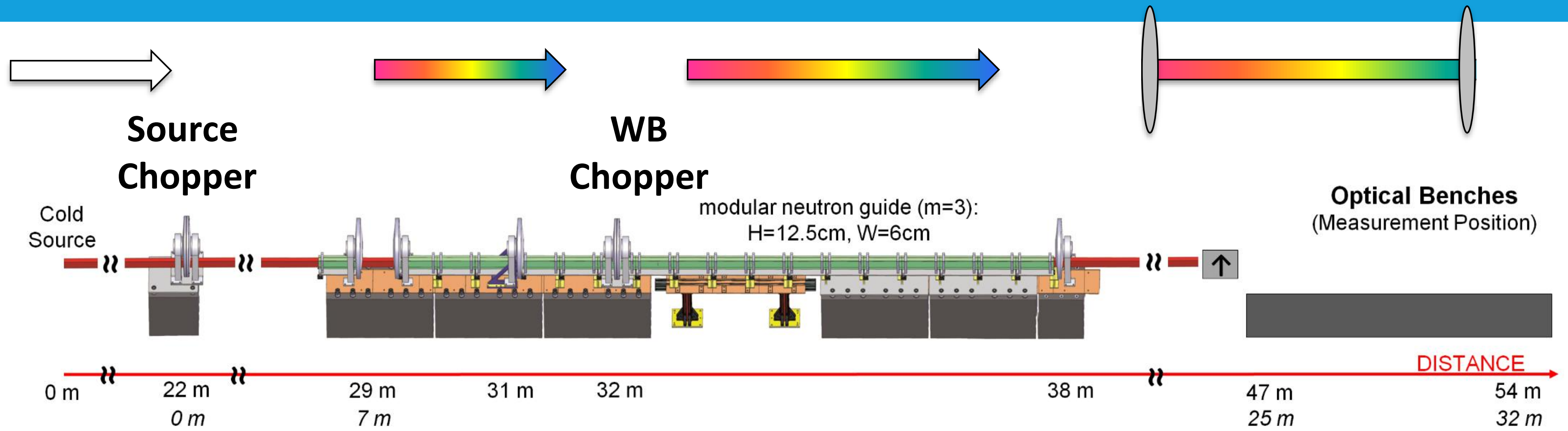
	2015	2016	2017	2018	2019	TOTAL
Users	17	36	71	62	92	**278** (*120 returning, 158 unique*)
Available beam days	32	175	149	151	173	**680**
Used beam days	32	152	112	118	173	**587**

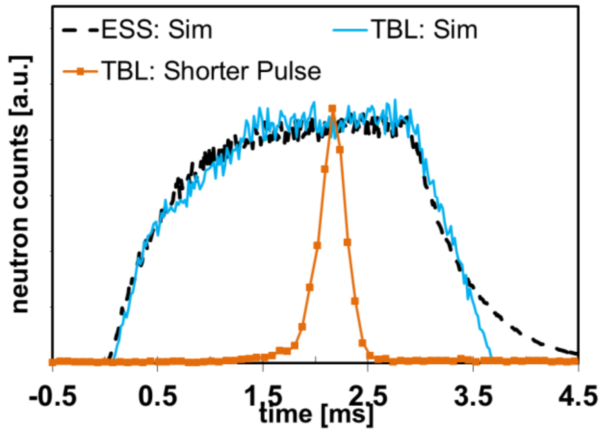
	2015	2016	2017	2018	2019	
Method development	10	21	21	22	40	**114**
Component testing	7	8	30	15	48	**108**
Integration	0	10	34	50	44	**138**



Overview of V20

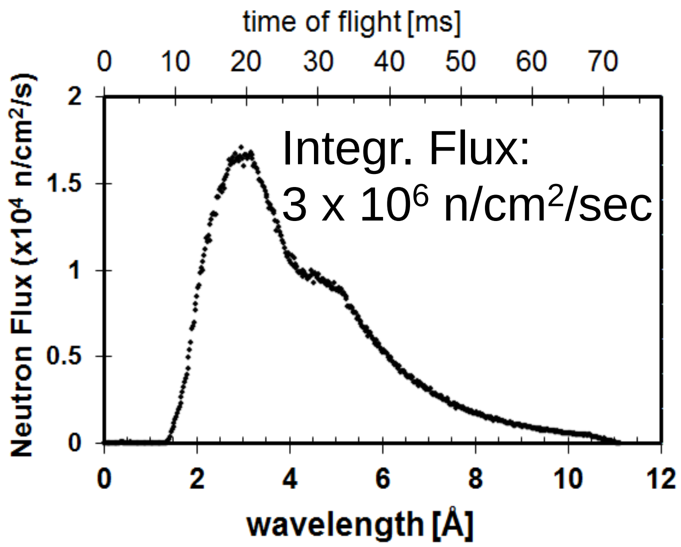
The chopper system





Flexibility!

→ *Vitess & McStas model available*



Repetition: variable

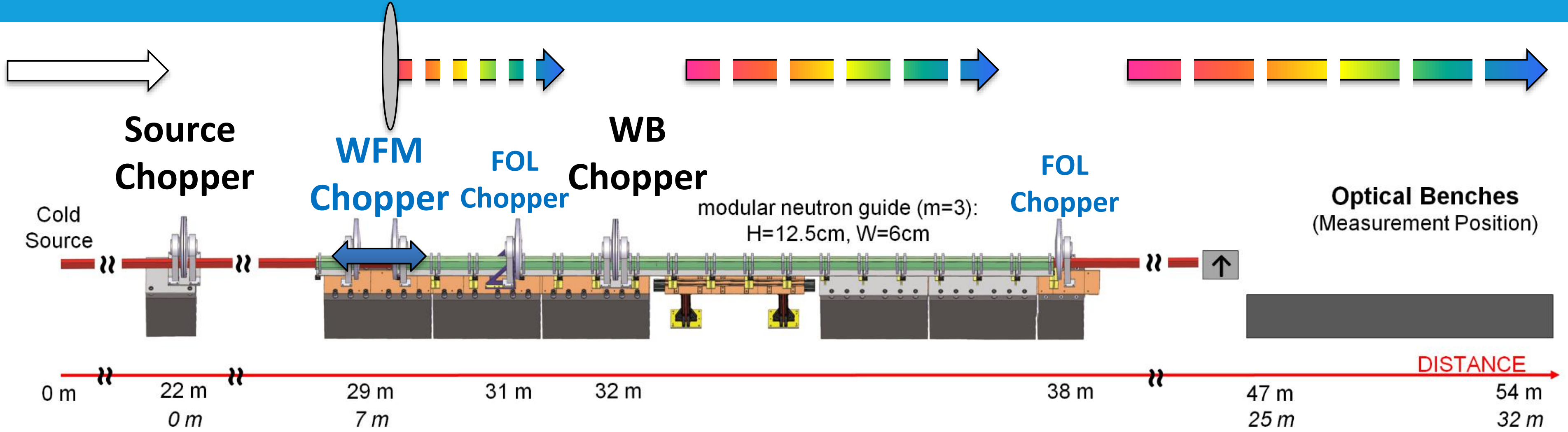
Wavelength resolutions: 4%-23%

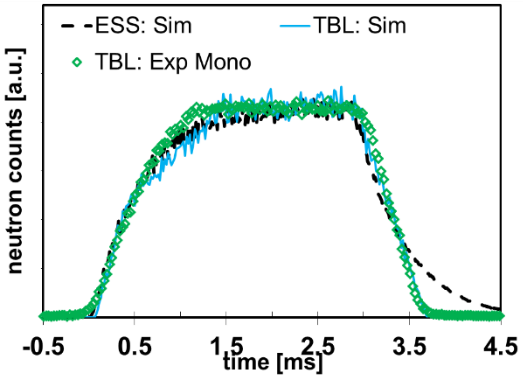
0.7%-3%

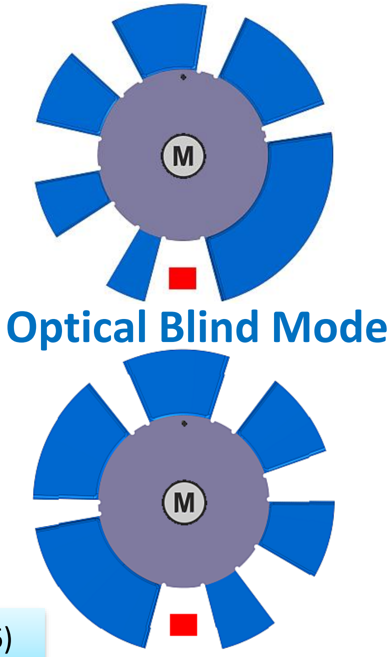
Strobl et al. NIMA 705 (2013); Woracek et al. NIMA 839 (2016)

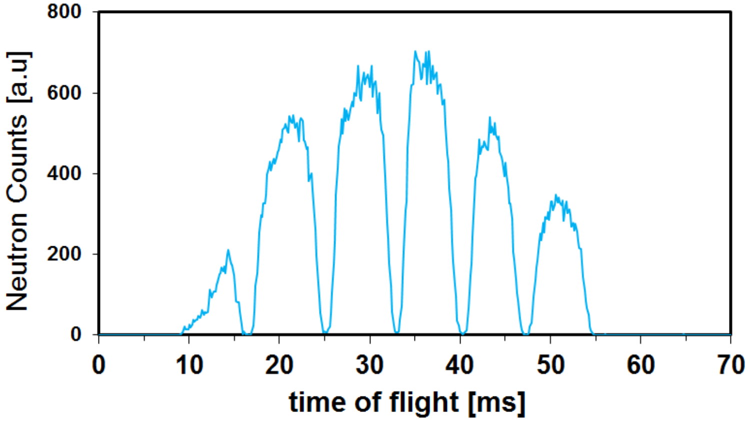
Overview of V20

The chopper system







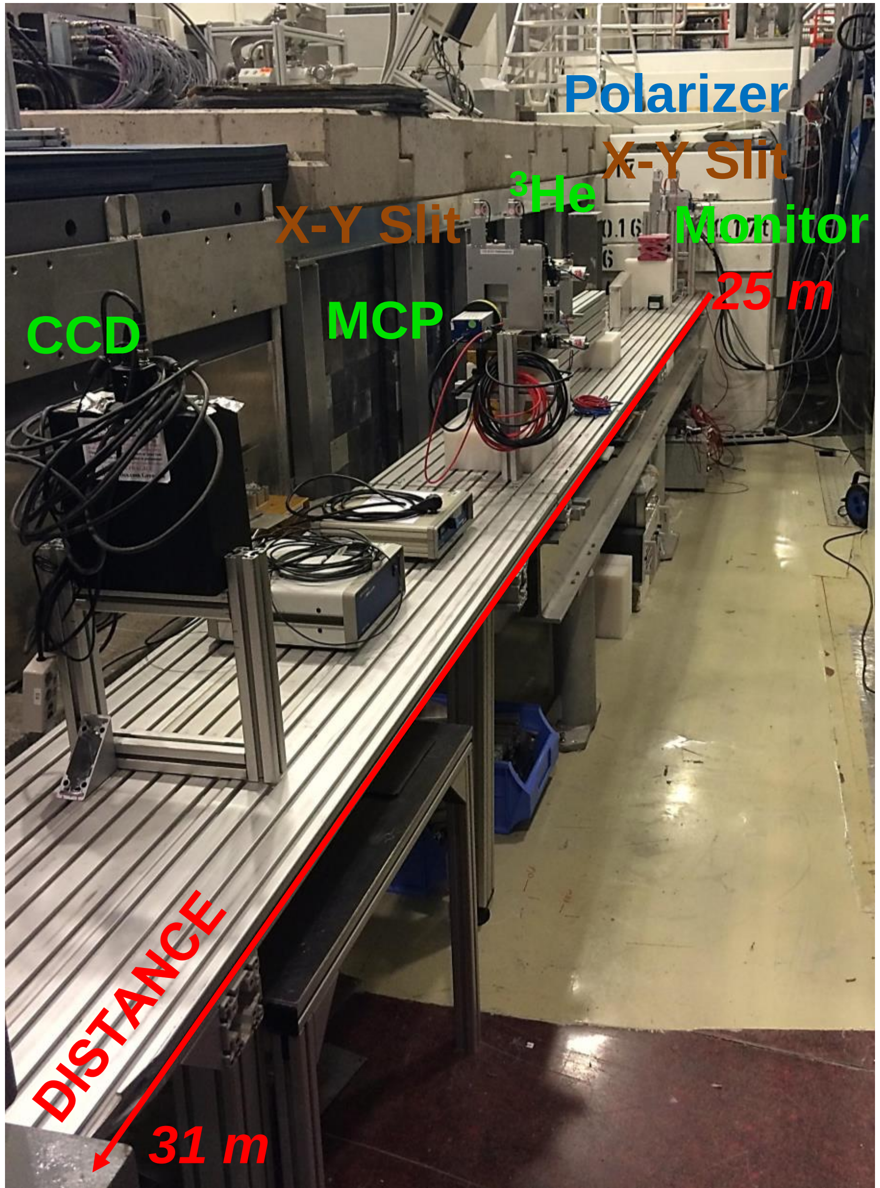


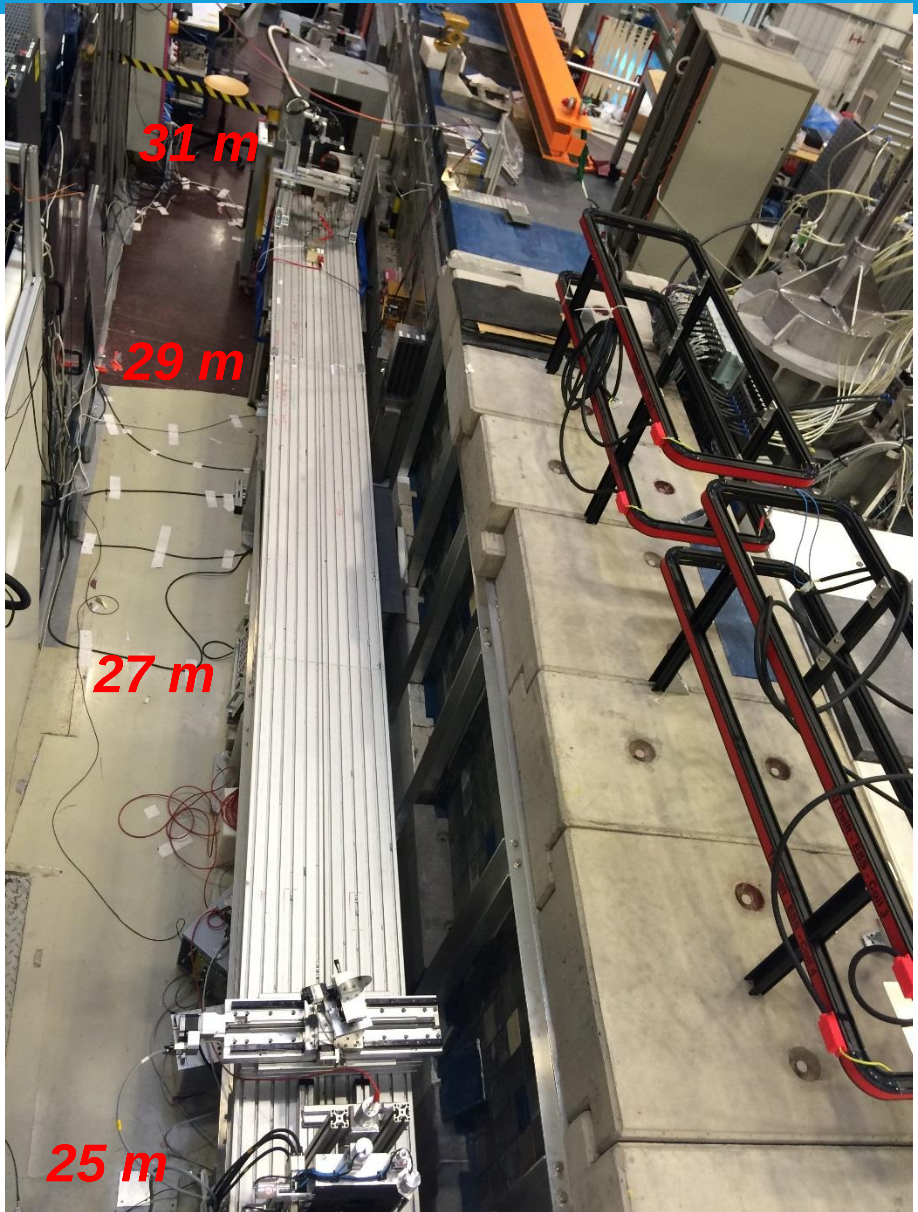
Tunable (but constant)
Wavelength resolutions: 0.5%-2%

Strobl et al. NIMA 705 (2013); Woracek et al. NIMA 839 (2016)

Overview of V20

Layout





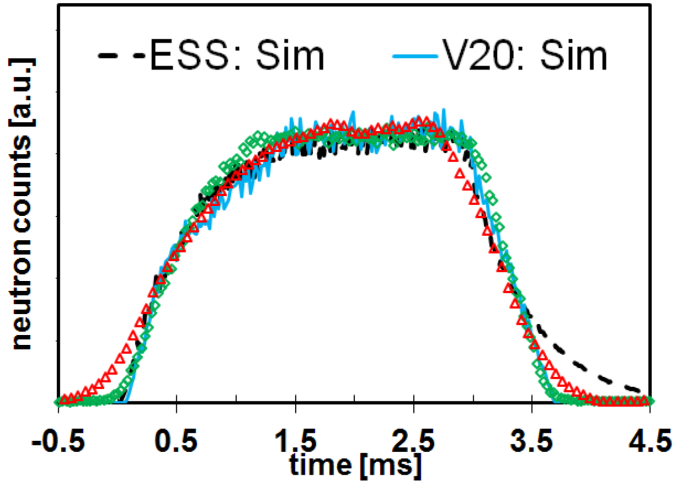
Hot Commissioning in 2015

Verification of chopper system: source pulse and WFM

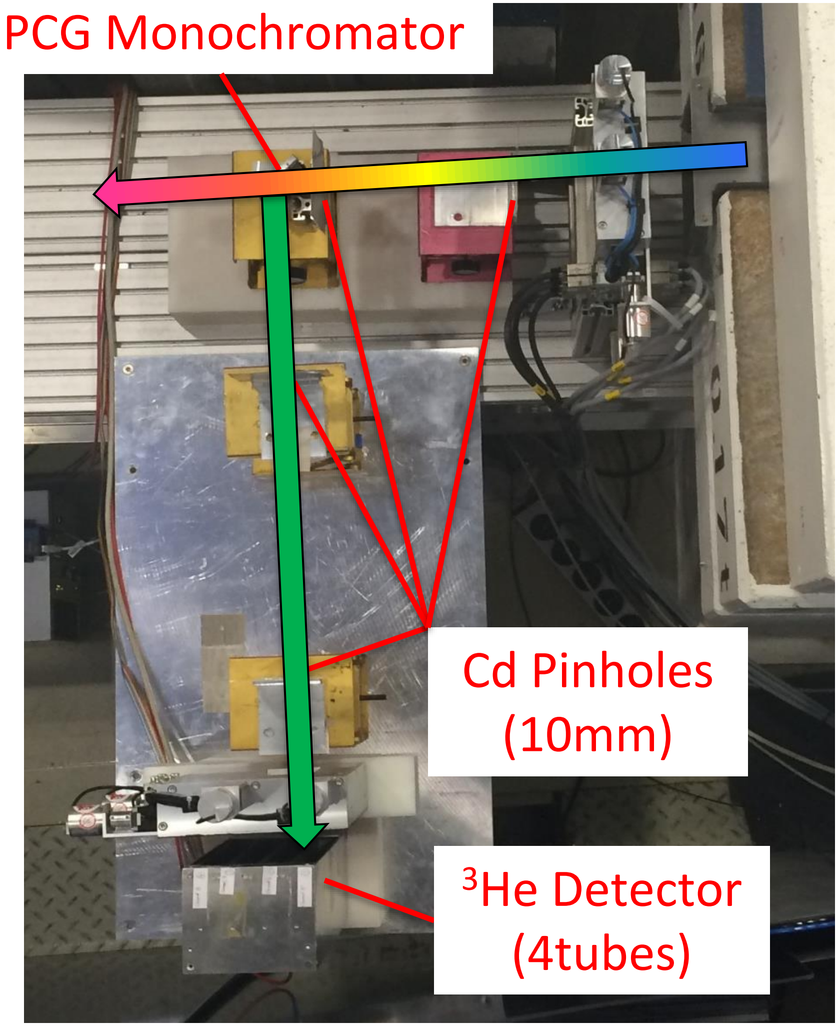
- Source Pulse shape by diffraction (monochromator and detector at 90°)
- Source Pulse shape by “pinhole time of flight” using choppers

About ESS   Science & Instruments   Technology   Building

First European Spallation Source Pulse Signature Measured at Helmholtz-Zentrum Berlin



ESS long-pulse structure replicated at HZB. The ESS test beamline will provide real-world conditions for ESS and its partners to test engineering and scientific concepts in the development of instruments and their associated neutron



Woracek et al. NIMA 839 (2016)

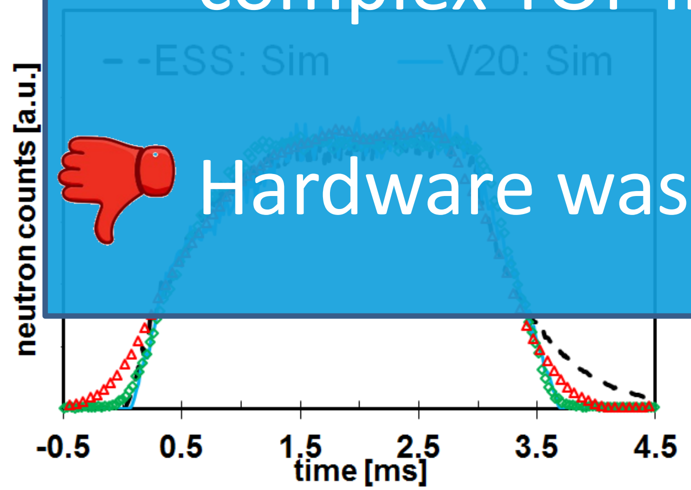
Hot Commissioning in 2015

Verification of chopper system: source pulse and WFM

- Source Pulse shape by diffraction (monochromator and detector at 90°)
- Source Pulse shape by “pinhole time of flight” using choppers

About ESS   Science & Instruments   Technology   Building

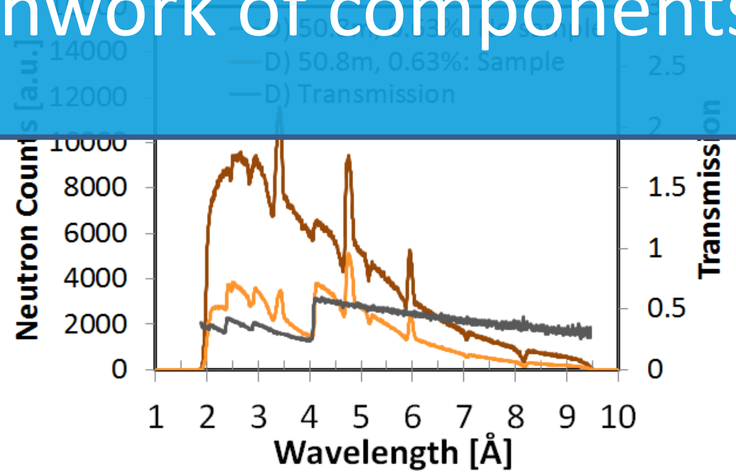
Fir... Sig... Be...

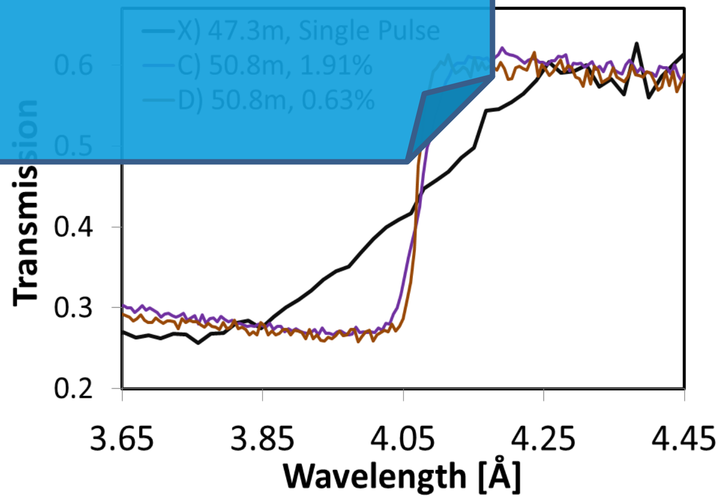


ESS long-pulse structure replicated at HZB. The ESS test beamline will provide real-world conditions for ESS and its partners to test engineering and scientific concepts in the development of instruments and their associated neutron

👍 Hands-on experience of operating and commissioning a complex TOF instrument

👎 Hardware was a patchwork of components

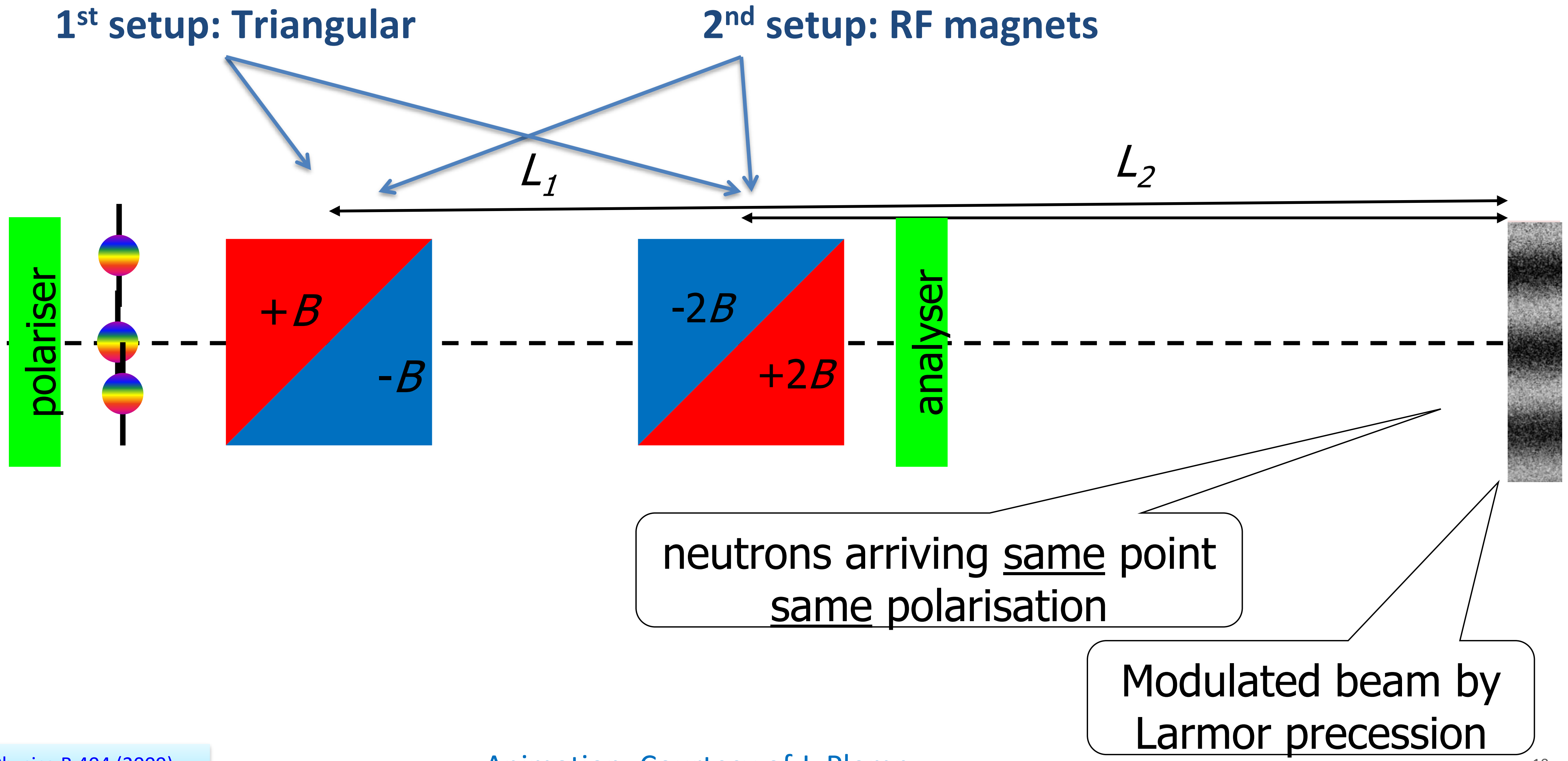




Woracek et al. NIMA 839 (2016)

Method development: Exploiting the long pulse

Spin Echo Modulated Small Angle Neutron Scattering (SEMSANS)



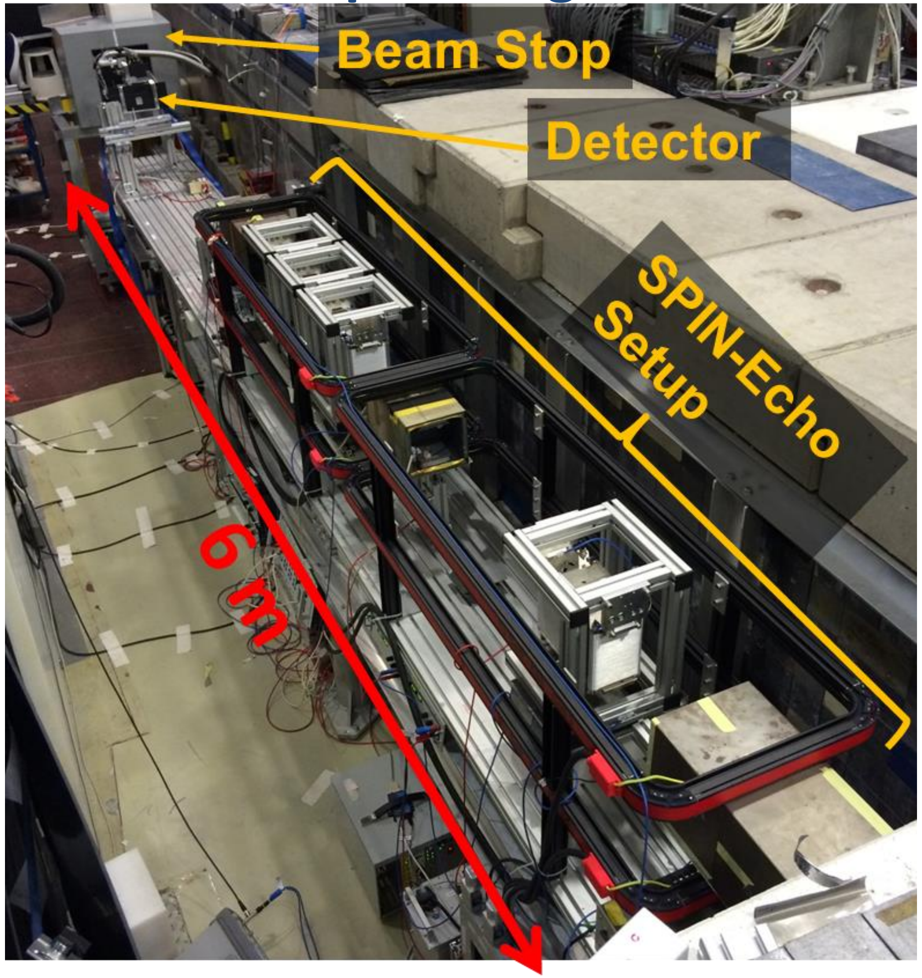
Bouwman et al. Physica B 404 (2009)

Animation: Courtesy of J. Plomp

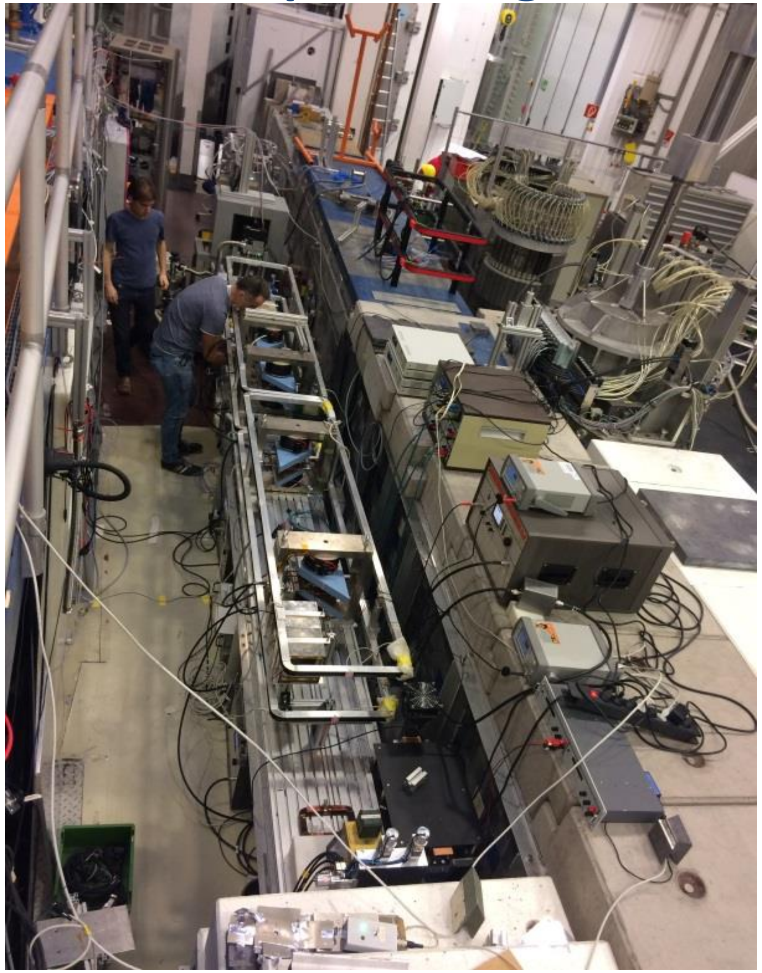
Method development: Exploiting the long pulse

Spin Echo Modulated Small Angle Neutron Scattering (SEMSANS)

1st setup: Triangular



2nd setup: RF magnets

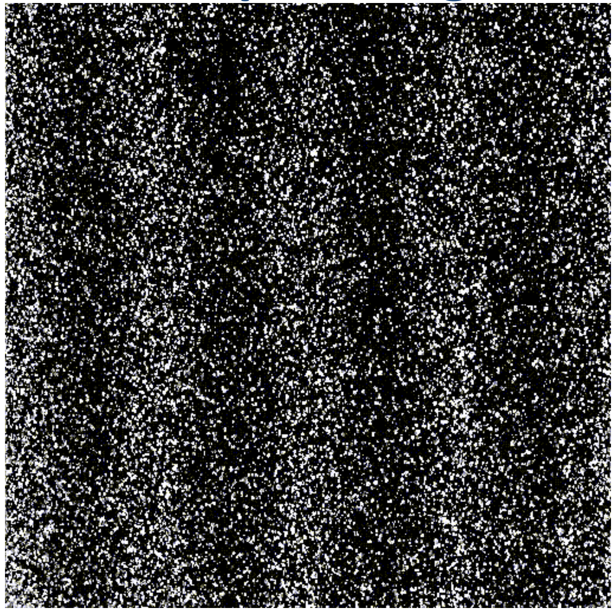


TU Delft: J. Plomp, A. Kusmin, M. Thijs; PSI: M. Strobl, R. Harti

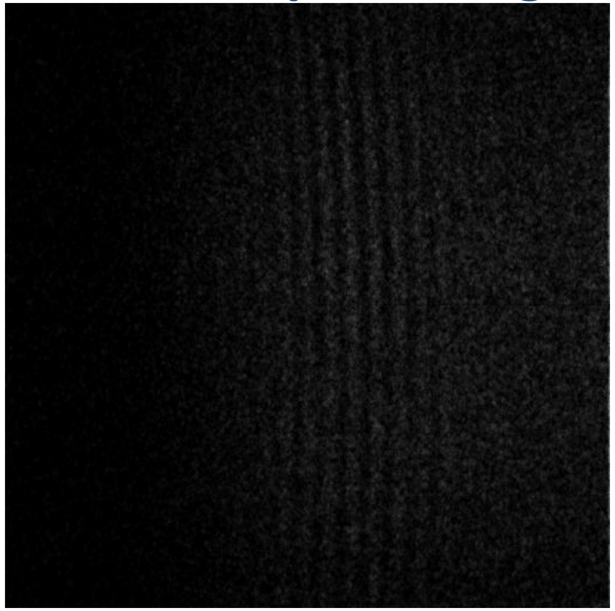
Method development: Exploiting the long pulse

Spin Echo Modulated Small Angle Neutron Scattering (SEMSANS)

1st setup: Triangular



2nd setup: RF magnets



Modulation periods: $\zeta = \pi \tan \theta_0 / (c\lambda (B_2 - B_1))$

- limited by the maximum field we could reach
- limited by the detector resolution

SE lengths: $\delta^{SE} = c\lambda^2 L_s (B_2 - B_1)/(\pi \tan \theta_0) = \lambda L_s / \zeta$

- S-D distance large (50-100cm) to get ~10-**150nm**
- S-D of 20cm is reasonable to get **~400nm** (at 6Å)

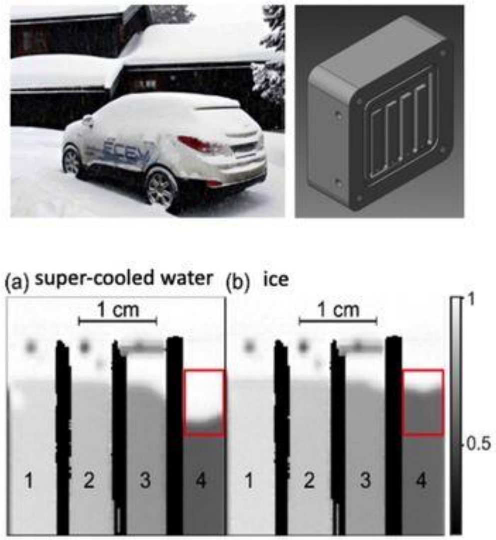
TU Delft: J. Plomp, A. Kusmin, M. Thijs; PSI: M. Strobl, R. Harti

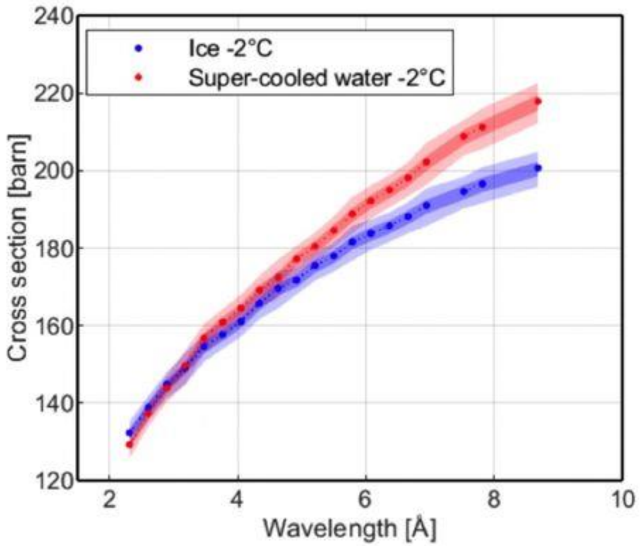
Method development: Exploiting the long pulse

Application to energy research

- Exploiting synergies of long pulse (high intensity) and WFM (high resolution)

Distinction of liquid (super-cooled) water and ice using neutron imaging





- Long pulse: Kinetic studies to distinguish between *liquid water, super-cooled water and ice in fuel cells*
- WFM: reference data for calibration and modelling

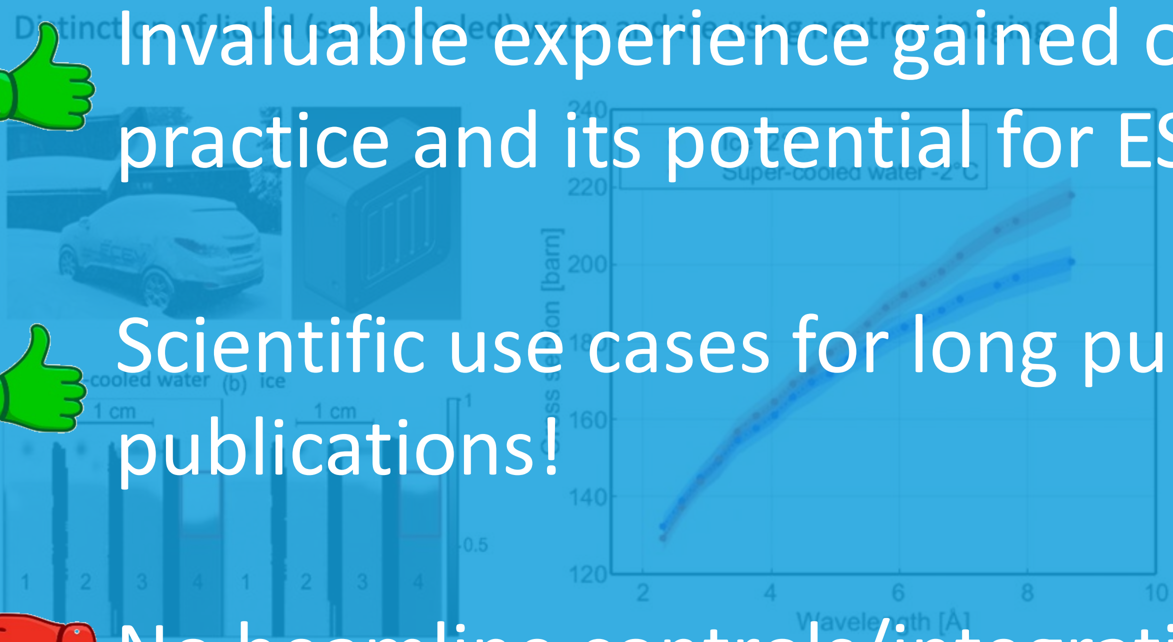
Siegwart et al. Review of Scientific Instruments, 90 (2019)

Method development: Exploiting the long pulse

Application to energy research

EUROPEAN SPALLATION SOURCE

- Exploiting synergies of long pulse (high intensity) and WFM (high resolution)



- Invaluable experience gained on how to use SEMSANS in practice and its potential for ESS
- Scientific use cases for long pulse and WFM & successful journal publications!
- No beamline controls/integration support at that time

- Long pulse: Kinetic studies to distinguish between *liquid water, super-cooled water and ice in fuel cells*
- WFM: reference data for calibration and modelling

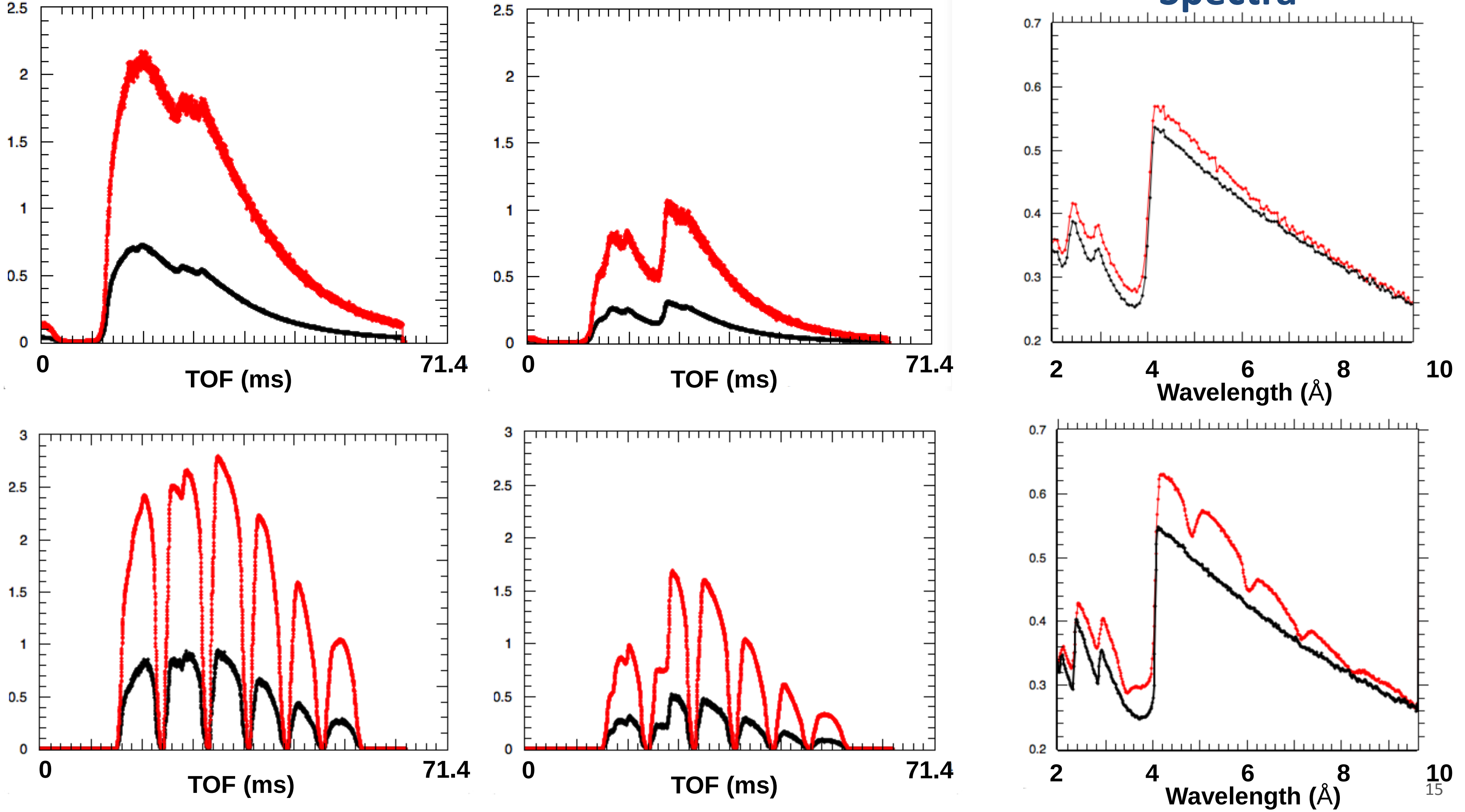
[Siegwart et al. Review of Scientific Instruments, 90 (2019)]

Wavelength Frame Multiplication (WFM) in Practice

Example: Detecting pile-up in a simple transmission Setup

Source	Intensity (a.u.)
Source Pulse Choppers	100
	40
WFM Choppers	100
	40

Open Beam Spectra | **BCC Iron Spectra** | **Resulting Transmission Spectra**



Data processing: O. Arnold (DMSC)

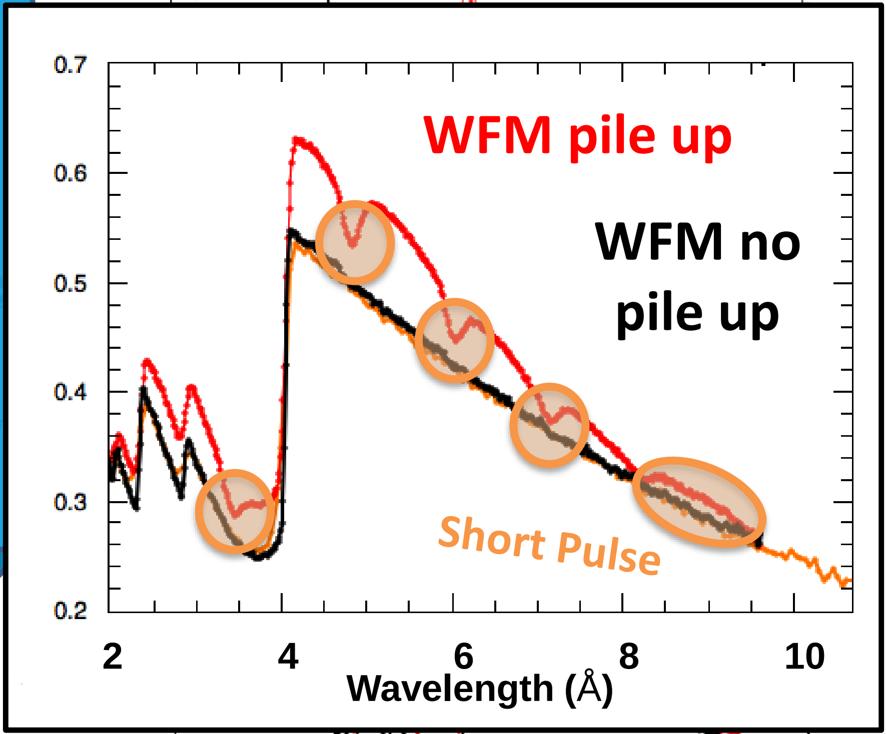
Wavelength Frame Multiplication (WFM) in Practice

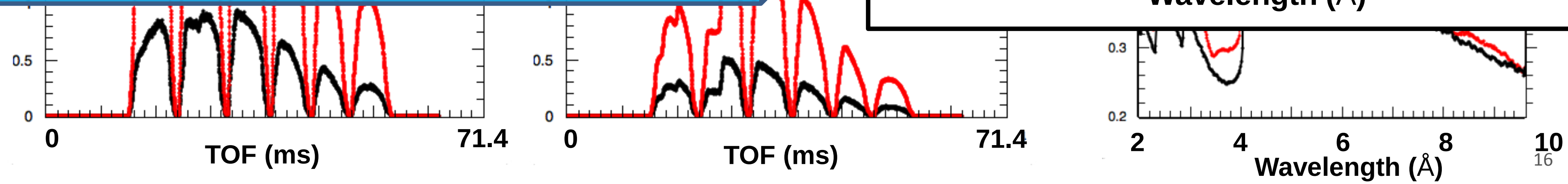
Example: Detecting pile-up in a simple transmission Setup

EUROPEAN SPALLATION SOURCE

Resulting Transmission Spectra

- Invaluable lessons learned about WFM data reduction ('stitching') and possible artefacts. Collaboration with DMSC!
- WFM generally works and scripts developed for different configurations (Imaging, Diffraction, Reflectometry).
- More work needed for commissioning and operating instruments at ESS.

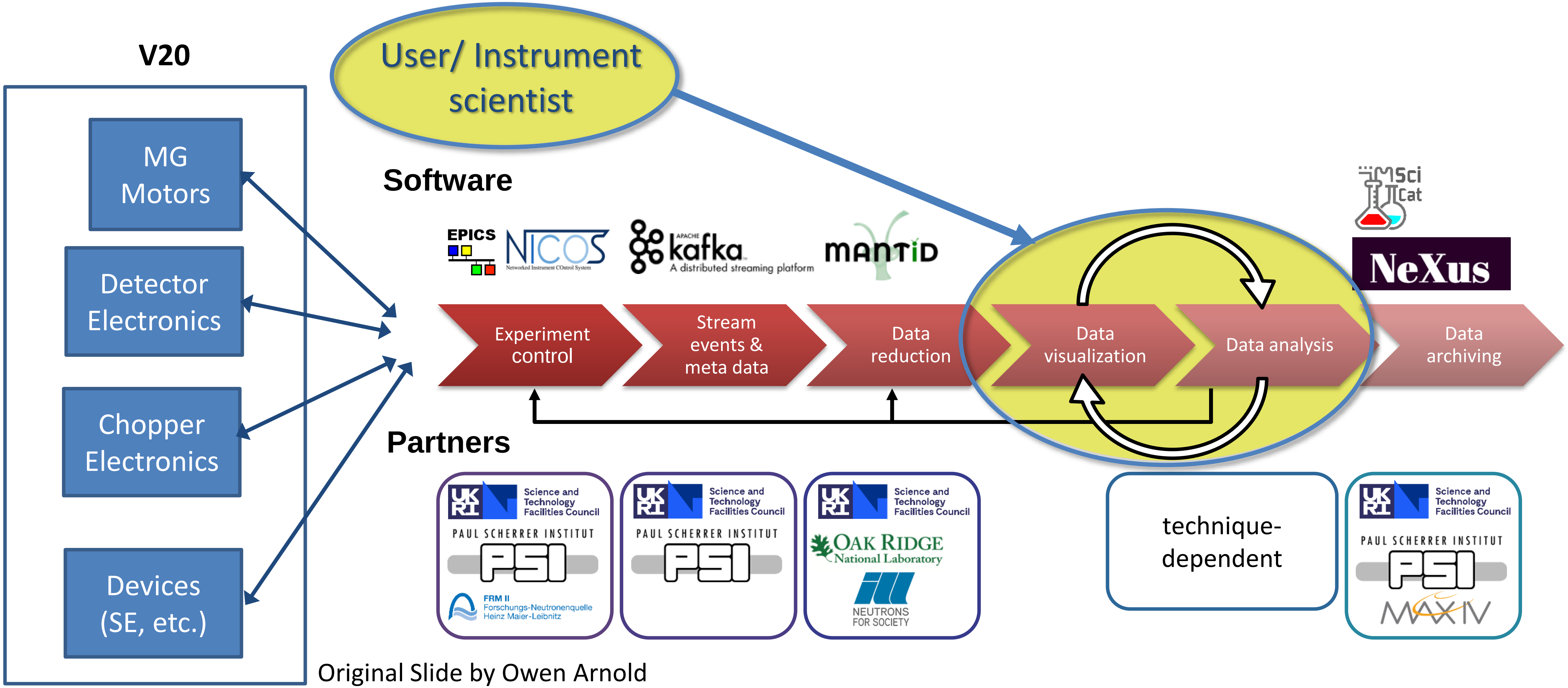




Data processing: O. Arnold (DMSC)

V20 as the ESS integration platform

Workflows and practical experiences



Original Slide by Owen Arnold

V20 as the ESS integration platform

Workflows and practical experiences

EUROPEAN SPALLATION SOURCE

Experiences as V20 instrument scientist:

- Sometimes unclear workflow if a problem occurs:
  - ➢ Writing a Jira ticket (too slow during a measurement)
  - ➢ Where is the error?
  - ➢ Who is responsible for solution? DMSC, MCAG, BCG, ICS, …?
- Integration of custom/user equipment sometimes challenging:

Working with DMSC (BCT/ECDC) over a sustained period has been beneficial for all parties!

Original Slide by Owen Arnold

WFM powder diffraction

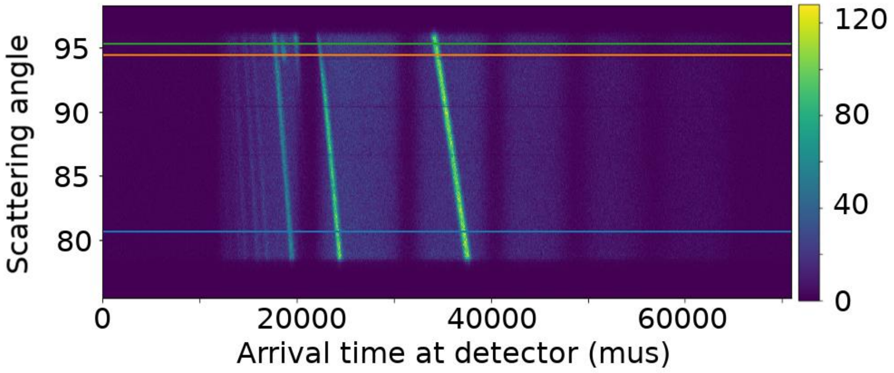
4th time: Now in event mode (Dec 2018)

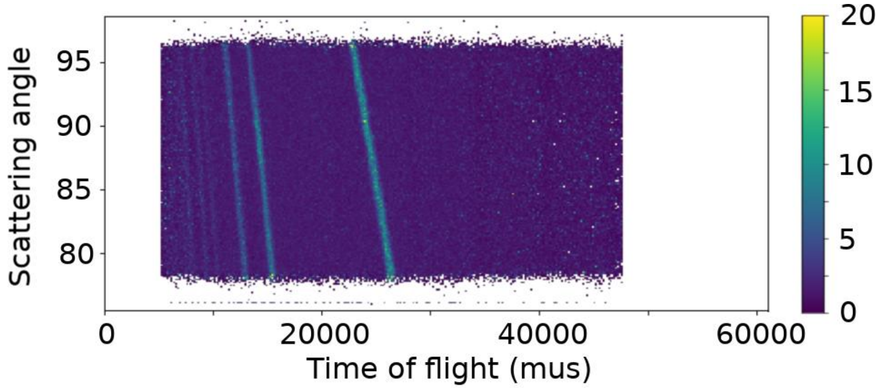
Example diffractograms of Si: reduced ‘stitched’ data yield a continuous diffractogram (2θ vs. TOF): ready for Rietveld refinement.

	As-recorded Data		Stitched Data

Event Data

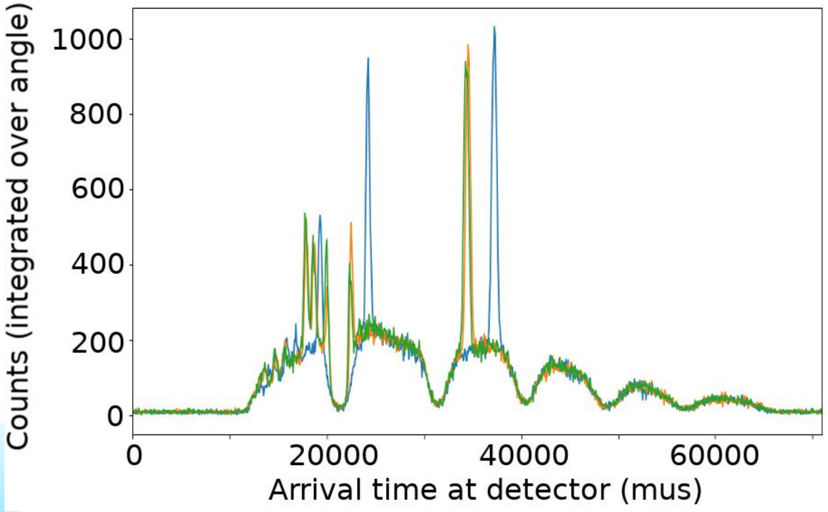
Scattering angle vs.
TOF vs.
Neutron counts



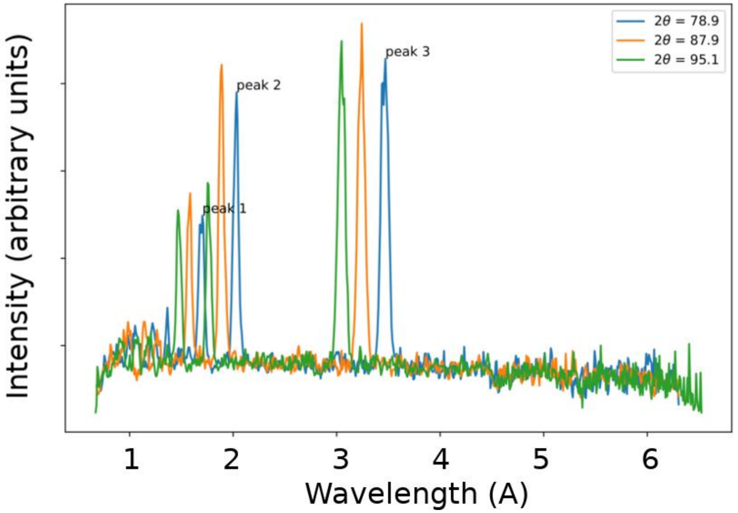


Data Processing

Scattering angle vs.
TOF vs.
Neutron counts



slices at three 2θ angles



Intital PSD detector setup:
G. Nowak (HZG), T. Wilpert (HZB)

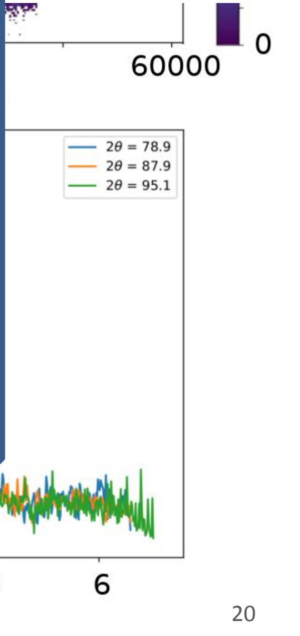
WFM powder diffraction

4^{th} time: Now in event mode (Dec 2018)

Example diffractograms of Si: reduced ‘stitched’ ready for Rietveld refinement.

Main contributors in alphabetical order:
Afonso Mukai
Gregor Nowak
Irina Stefanescu
Jonas Nilsson
Maria Romedahl
Markus Olsson
Matt Clarke
Matthew D Jones
Michael Hart
Neil Vaytet
Nicklas Holmberg
Owen Arnold
Peter Kadletz
Robin Woracek
Steven Alcock
Torben Nielsen
Wayne Lewis
Will Smith
(Some of them helped in preparations or remotely, the group photo is from the peak of the attendance at the instrument.)
Additional thanks go to LU and HZB for lending us equipment.

- Time referenced DAQ successfully implemented. Excellent collaborative effort.
- WFM data reduction demonstrated based on this data (DMSC)
- WFM diffraction data analysis ‘only’ demonstrated on histogrammed data so far (LLB: F. Porcher, FZJ: M. Feygenson)

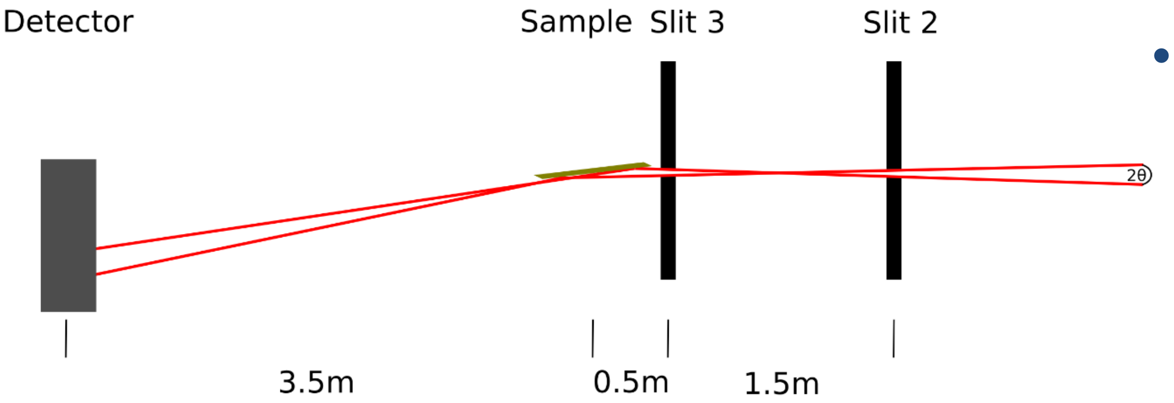


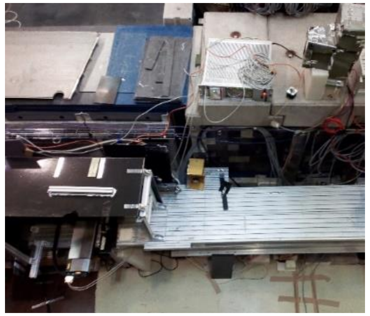
WFM Reflectometry

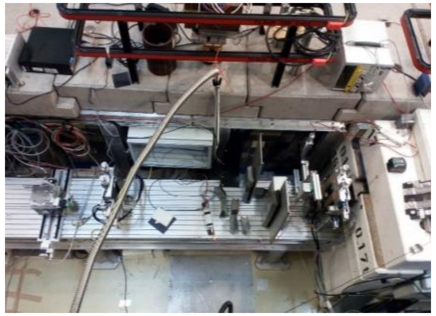
And more integration (April 2019)

Demonstrate WFM concept

- Vertical setup
- Two well-known samples

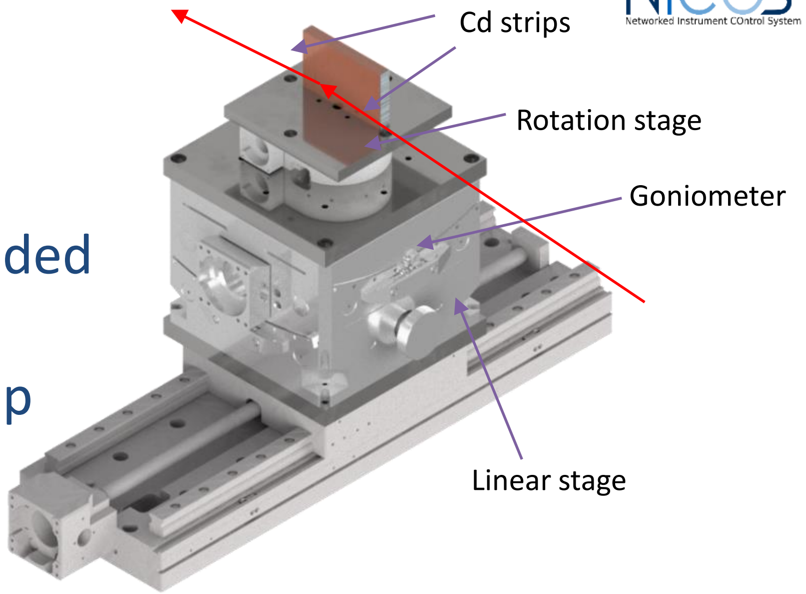


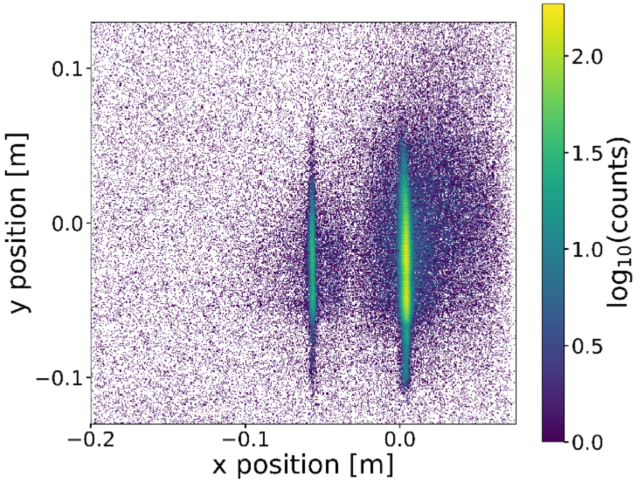


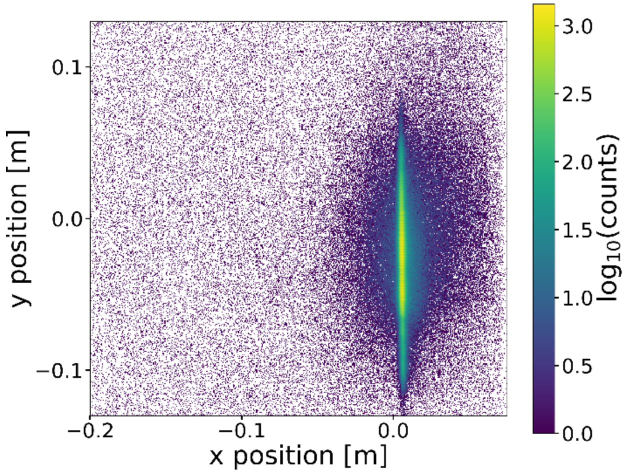


Vertical integration:

- EPICS (Motion, SE)
- Event mode DAQ
- NICOS
- Live-request of needed software tools for alignment and setup





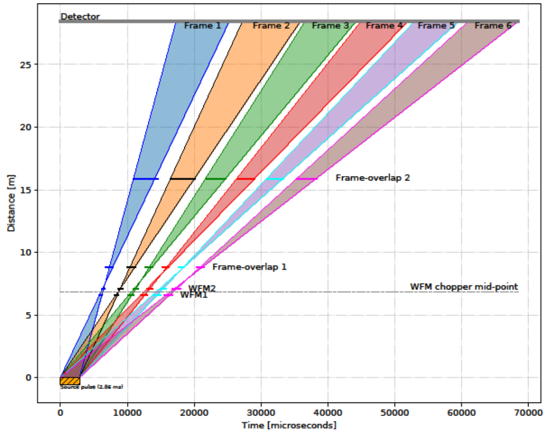


Lohmann et al. in preparation

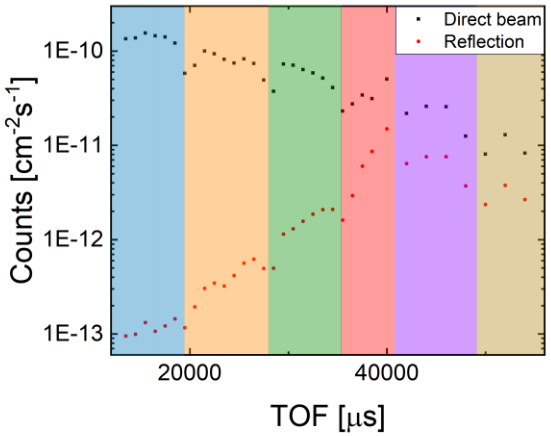
WFM Reflectometry

And more integration (April 2019)

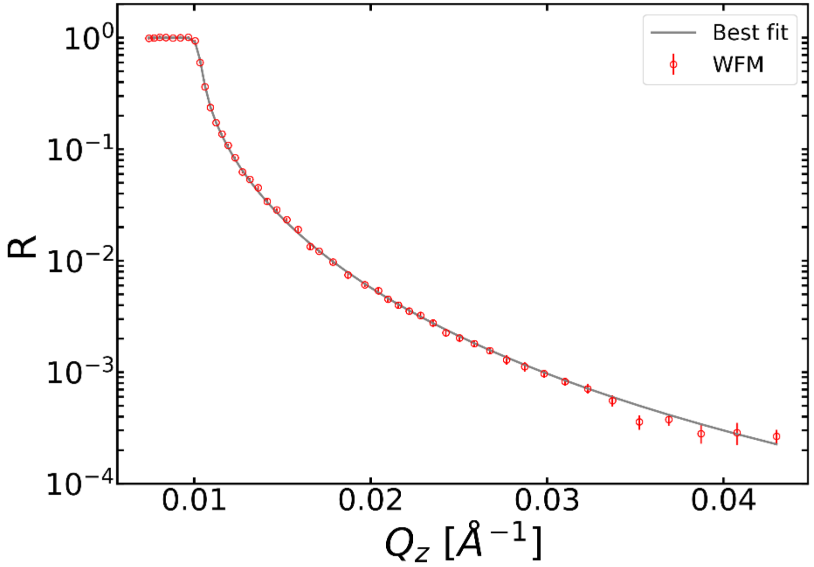
TOF diagram and 'stitching'



https://github.com/nvaytet/tofdiagrams

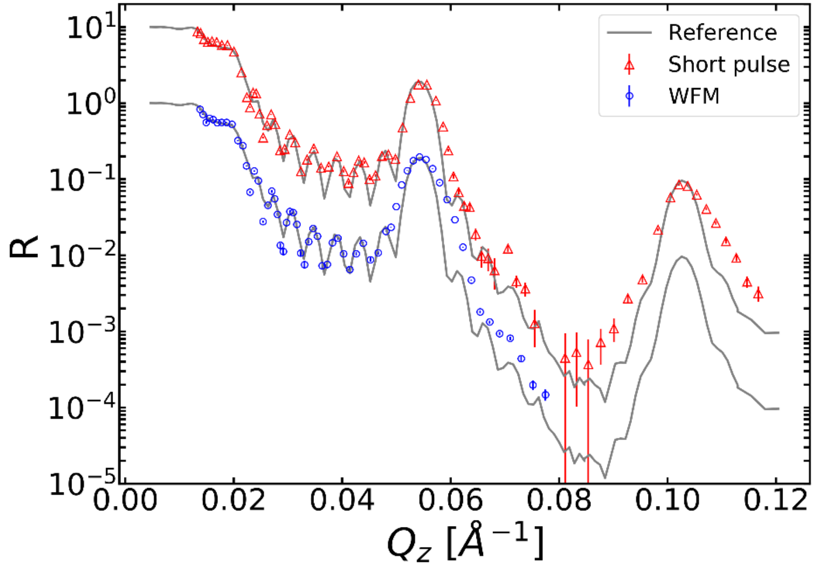


Bare Si block



Super mirror

Glass/(5nm Si + 10 nm $Fe_{90}Co_{10})_{10}$/ 5nm Si



- Sub-frames visible in the raw data, but no stitching artifacts in the final data

Lohmann et al. in preparation

Data reduction in close collaboration with DMSC: N. Vaytet, O. Arnold

WFM Reflectometry

And more integration (April 2019)

TOF diagram and 'stitching'

Bare Si block

Super mirror

Glass/(5nm Si + 10 nm $Fe_{90}Co_{10}$)$_{10}$/ 5nm Si

https://github.com/nvaytet/tofdiagrams

- Reflectivity data reproducible using WFM and Short Pulse.
- Vertical integration fully demonstrated from neutron detection to fitted result!
- Experimental errors due to misalignment only revealed after data analysis: Identified the need for improved software tools!

Sub-frames visible in the raw data, but no stitching artifacts in the final data

Mantid

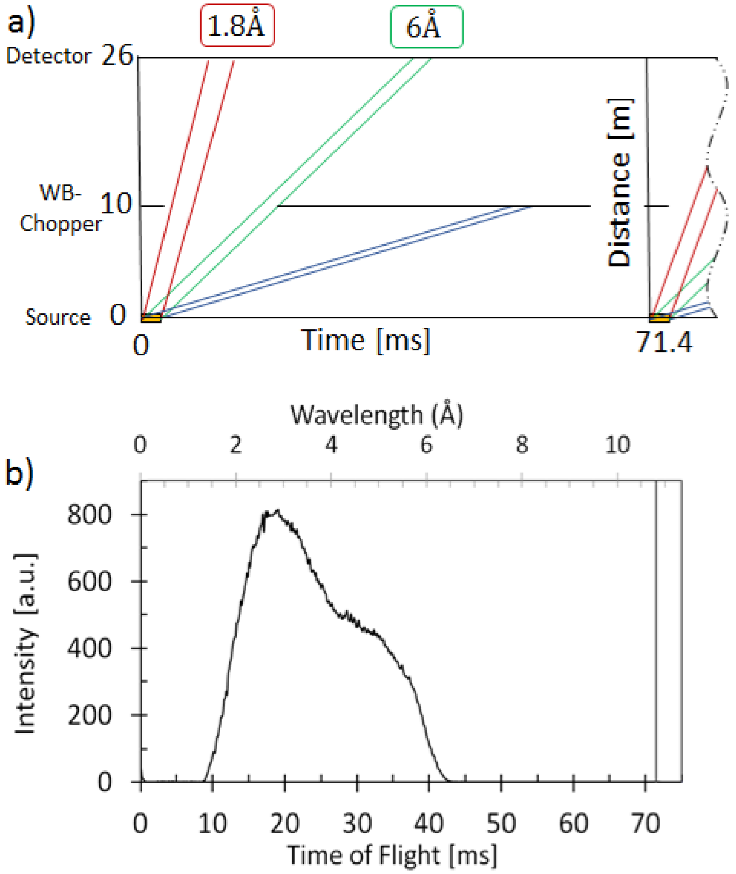
Lohmann et al. in preparation

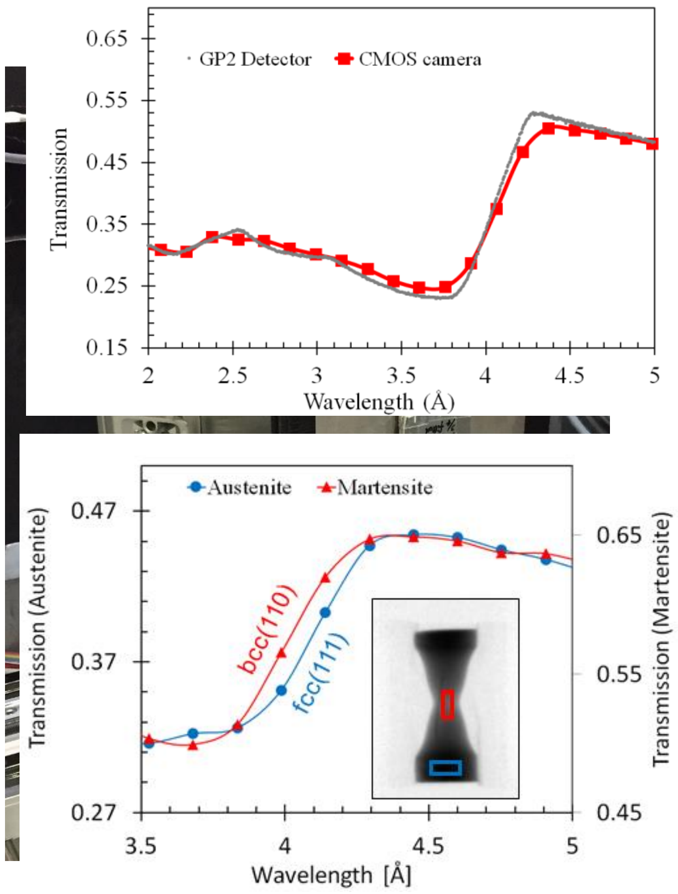
Data reduction in close collaboration with DMSC: N. Vaytet, O. Arnold

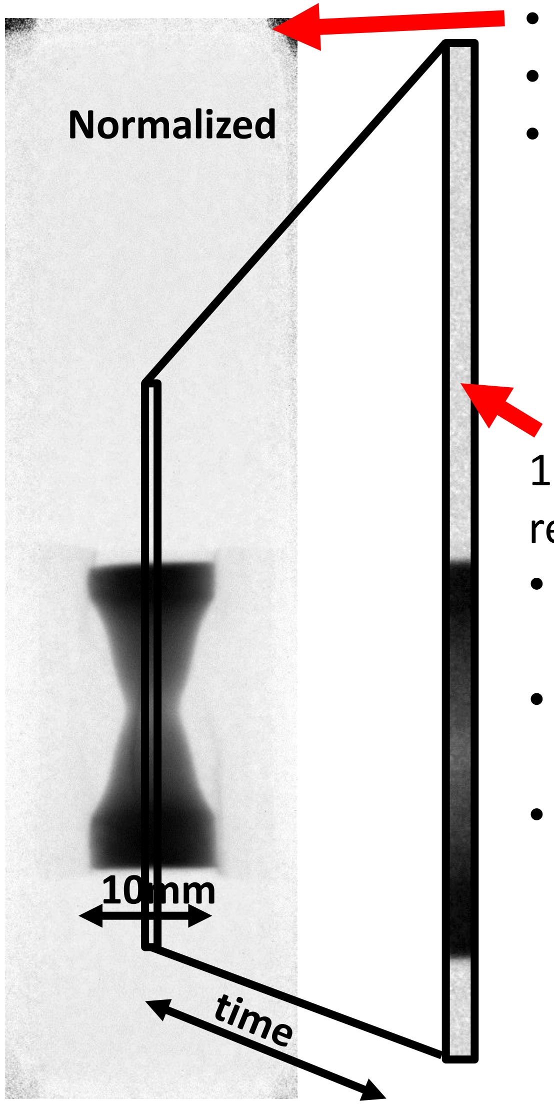
V20 as 'playground': ToF imaging detector prototype

Scintillator CMOS-camera detector

- Demonstrated CMOS camera to be suitable for TOF applications (by Bragg edge imaging)







- Slowly acquired
- complete FoV
- (100 x 5 sec exposure time)

1KHz continuous readout

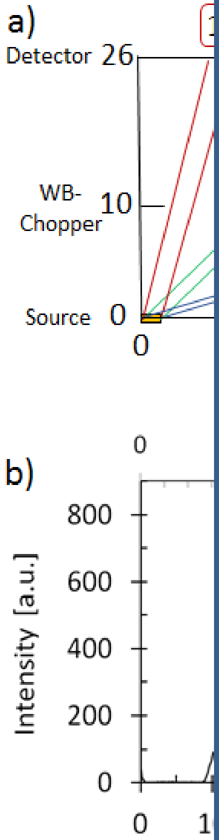
- Fast acquired stripe of the image
- 32 pixel wide equal to 1.1 mm
- 100,000 x 0.001 sec exposure time

Woracek et al. Optics express 27((2019)

V20 as ‘playground’: ToF imaging detector prototype

Scintillator CMOS-camera detector

- Demonstrated CMOS camera to be suitable for TOF applications (by Bragg edge imaging)



V20 also provided opportunity to test new ideas ad-hoc.

Compare devices under same conditions.

Example: Camera detector demonstrated to be suitable for low wavelength resolution ToF imaging (1ms time resolution NOW).

→ potential use at ESS for imaging and commissioning?

Woracek et al. Optics express 27((2019)

Summary

- ✓ V20 enabled testing, integration and development of several technologies that are relevant for ESS before CC+HC.
- ✓ V20 triggered and enabled the development of crucial and time critical software tools:
  - ✓ Major progress and engagement in collaboration with *Experiment Control and Data Curation Team.*
  - ✓ Many technical details addressed, e.g.: non-equidistant time bin for WFM, understand origin of visible artefacts in stitched WFM data, communication challenges for certain components,… .
  - ✓ O. Arnold: “Shared understanding helped DMSC build tools to diagnose problems as well as process experimental data. Neil Vaytet's WFM diagnostic tools and our ever improving WFM treatment procedures are a good testament to this.”
- ✓ Getting things right takes time and effort from all parties: Should not be underestimated!
- ✓ Invaluable experience gained for advanced methods that benefit from long pulse structure.
- ✓ V20 had a positive impact of shaping the future working culture of ESS!
- ✓ Close out report will be prepared. https://confluence.esss.lu.se/display/NID/V20+Test+Beamline+at+HZB

V20, while operated with a minimum budget, was a highly appreciated tool for all users from the beginning. Collaborative effort was key to success!

THANKS TO EVERYONE INVOLVED!

& in-kind:

Timing System and Data Chain:
Hardware: David Brodrick, Nicklas Holmberg, William Smith, John Spager, Faye Chicken, Freddie Akeroyd
ADCs/FPGAs: Steven Alcock, Jonas Nilsson
Grafana/Daqiri: Alfonso Mukai, Martin Shetty
NEXUS files: Matthew Jones, Owen Arnold
Data reduction: Owen Arnold, Matthew Jones, Neil Vaytet, Jonas Nilsson, Lamar Moore, Jack Harper
Coordination: Tobias Richter

Motion Control:
Thomas Gahl
Paul Barron
Markus Larsson
Torsten Bögershausen

Detectors:
Gregor Nowak
Fatima Issa
Jörn Plewka
Christian Jacobsen
Jörg Burmester

NICOS:
Michael Hart
Michael Wedel
Matt Clarke
Michele Brambilla

Host and Local Contact:
Klaus Habicht

Detectors:
Thomas Wilpert

(Technical) Support:
Robby Kischnik
Knut Mäkelein
Peter Granz
Hans-P. Schneider
Sunny Spreu
Nico Grimm
Klaus Kiefer
Dirk Wallacher
Nikolay Kardjilov
Mirko Boin
W. Treimer

V20 installation (2011-2013)
Muhammer Bulat
Tommy Hofman
Markus Strobl

Software:
Lutz Rossa
Ala Al Falahat

User Accomodation:
Heike Gast
Barbara Pfeil

Radiation Protection:
Gregor Bukalis
Rolf Hellhammer
Anja Söte
Kim Ryll-Clavery

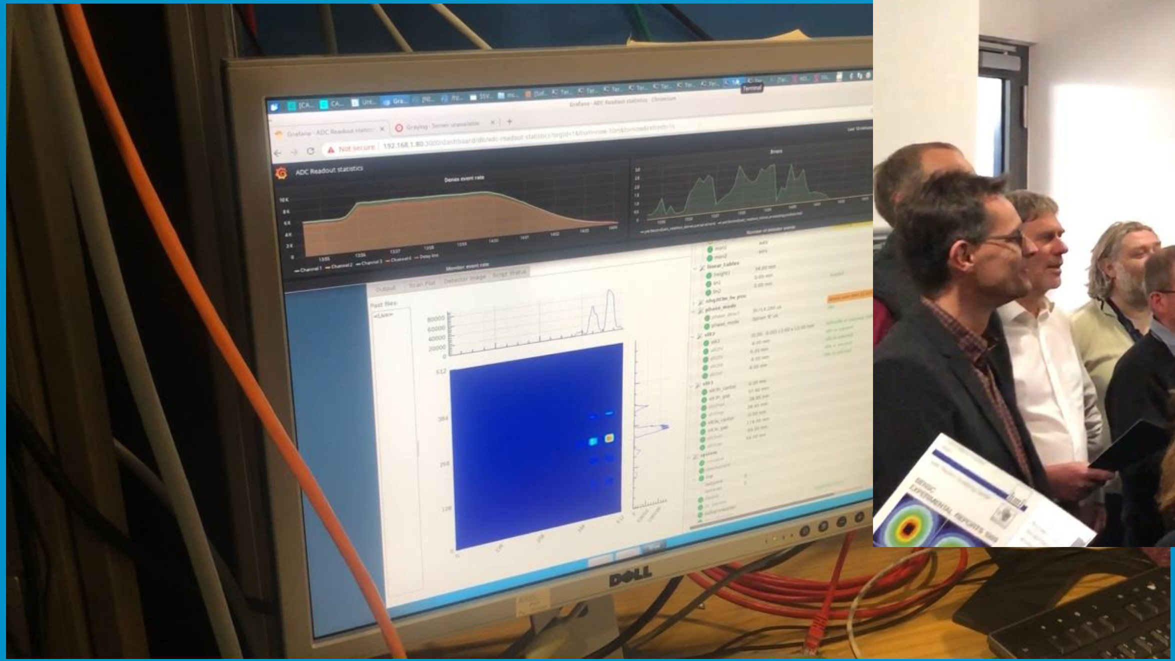
PLUS MANY MORE USERS WHO SUPPORTED V20!

Last not least… Thank you BERII for the neutrons!

EUROPEAN
SPALLATION
SOURCE

Final shutdown of BERII on 11 Dec 2019

MANY THANKS TO HZB Helmholtz Zentrum Berlin
AND THE GREAT STAFF
FOR BEING SUPPORTIVE!



Questions?


V20
Good Bye
Peter Kadletz von der ESS und Lamar Moore von der Neutronenquelle ISIS.
Die beiden Forscher arbeiteten an der Testbeamline, die am BER II für die Europäische Spallationsquelle in Lund eingerichtet wurde.