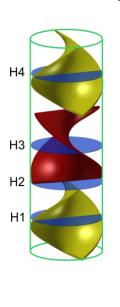
Analysis of hydrodynamic effects using ultrafast X-ray tomography with GPU accelerated data acquisition

André Bieberle Helmholtz-Zentrum Dresden - Rossendorf



Outline

- Motivation
- Ultrafast X-ray CT scanner
- Data processing
 - ✓ Previous
 - ✓ Current
 - ✓ Further strategy
- Further concepts
- Conclusion



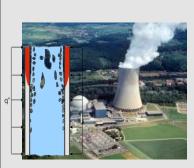


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<u>Motivation</u>

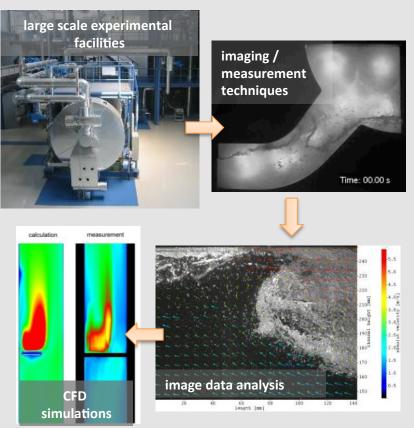
Experimental investigations for chemical engineering,

power engineering, mineral oil processing





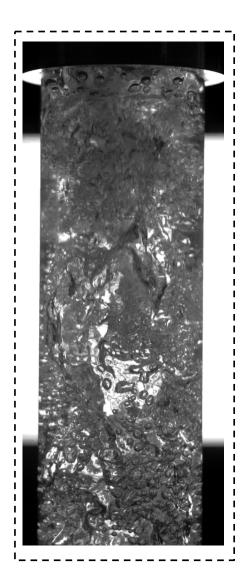
Fluid mechanics and multiphase CFD modeling and simulation





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Motivation



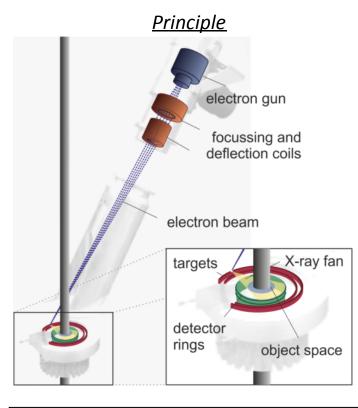
Optimal measurement technique

- high spatial resolution (in 3D)
- high temporal resolution
- non-intrusive measurement
- non-superimposed information
- suitable for opaque systems
- suitable for any geometry (including internals)



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ROFEX - Parameters



frame rate:	up to 8000 s ⁻¹
spatial resolution:	down to 1 mm
acceleration voltage:	150 kV
max. beam power:	10 kW
no. of detector elements:	2 x 288
detector frequency:	1 MHz

<u>Setup</u>



Setup with housing and elevator unit

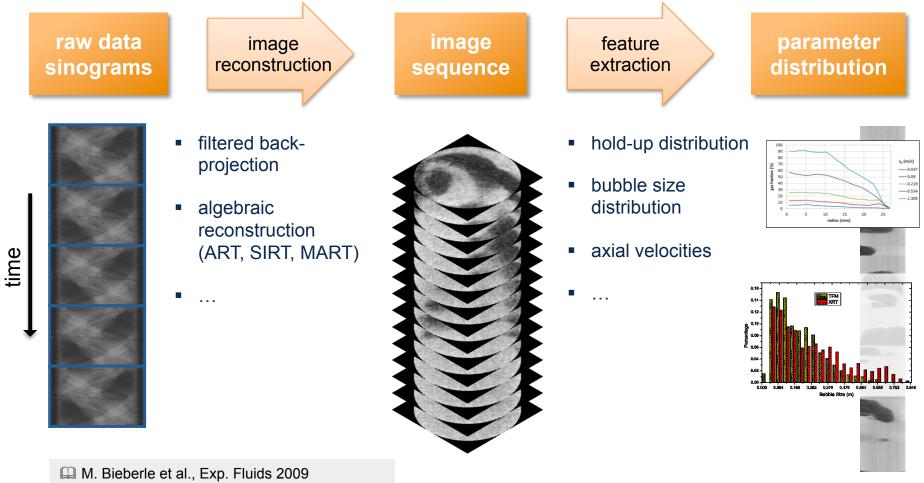


F. Fischer et al., Nucl. Eng. Des. 2010



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<u>ROFEX – Data processing (theory)</u>

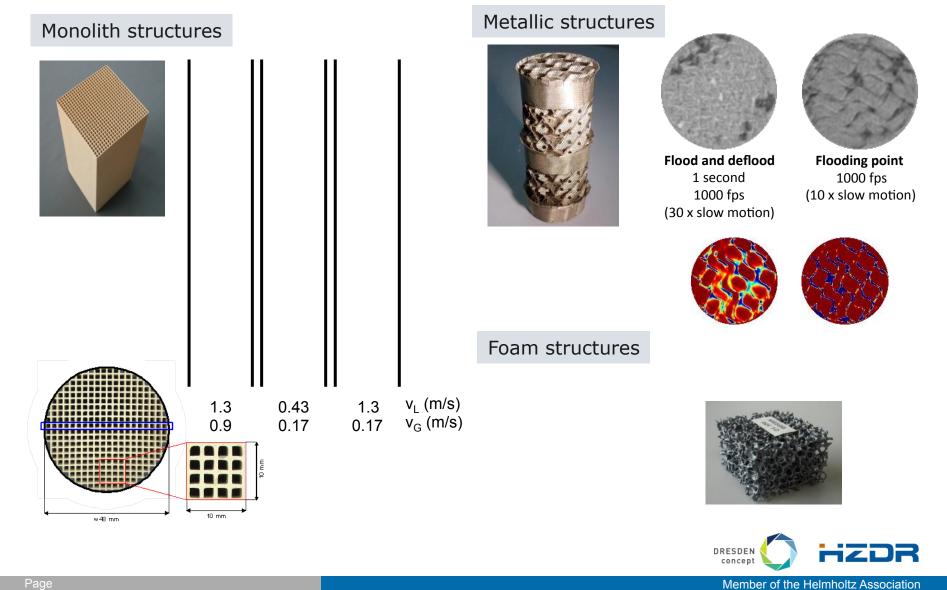


M. Bieberle et al., Philos. T. Roy. Soc. A 2015



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<u>ROFEX – Applications</u>



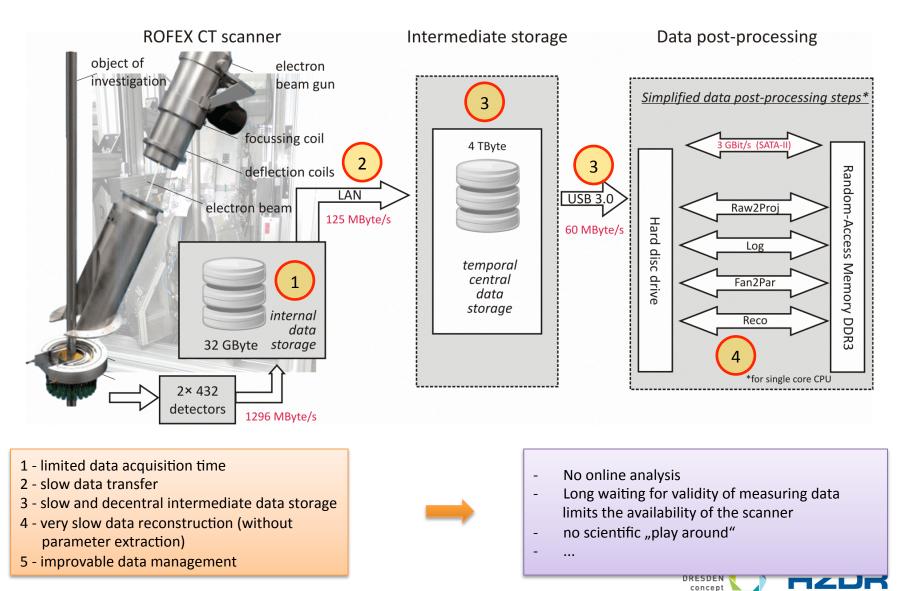
<u>ROFEX – Systems</u>

	time				
	ROFEX-I	ROFEX-III	ROFEX-III+	ROFEX-II	HECToR
Start-up date	2010	2012	2016	2017	2018
Maximal photon energy [keV]	150	150	150	150	998
Measuring planes	2 (8)	2	2	2	2
Measuring diameter [mm]	120	180	160	60	420
Sampling frequency [MHz]	1	1	2	1	2
Data volume [GByte / s]	0.80	1.21	1.97	1.34	??



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Data acquisition & data processing (until 2014)



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Concept for an enhanced data acquisition & processing (2014)

Main problems

Data transfer

Priority 3

- New detector hardware
- Sufficiently fast (& commercially available) data interface

Data processing

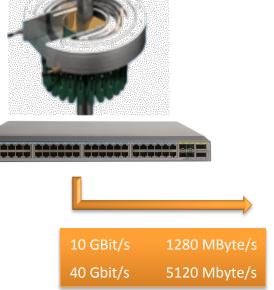
Priority 2

- Enhanced data processing hardware
- Massive data
 processing algorithms

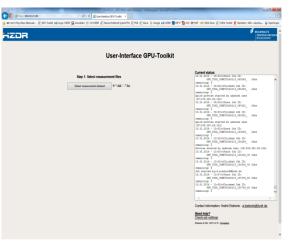
Data management

Priority 1

 Central and web-based data processing and management









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Concept for an enhanced data acquisition & processing (2014)

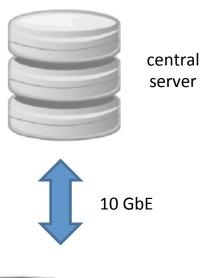
Priority 1 & 2

Basis for data processing





	Advanced performance PC
Processor	Intel Xeon E5-1650 v3 (6 cores / 12 threads)
Processor clock	3.5 GHz / 10 MB (Turbo: 3.8 GHz)
RAM	128 GByte DDR4 / 2133 MHz
HDD	SSD Samsung SATA III 256GB (500 MByte read / 410 MByte write)
Multi-core GPU	2x Tesla K20 (NVIDIA [®] , 4.8 GByte DDR5)
Ethernet interface	2x 10GbE/40GbE (Intel XL710QDA2BLK)
System software	Ubuntu 14.02 LTS (64 Bit)
Developer KIT	NVIDIA NSight / Eclipse
Compiler	GCC 4.8.1 & NVCC
Special libraries	OpenMP, CUDA 7.5







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<u>Concept for an enhanced data acquisition & processing (2014)</u>

Ξ

Priority 1

Processing concept

Requirements

- OS independent
- Uniform software versions
- (Hidden and) central data storage
- Integrated data management



Web based solution

- Homepage as input media (mobile access with Laptops, Smartphones, etc.)
- Job server (collecting all job requests)
- OS behind (Linux) is regardless
- No decentral data transfer
- Comfortable notification via email

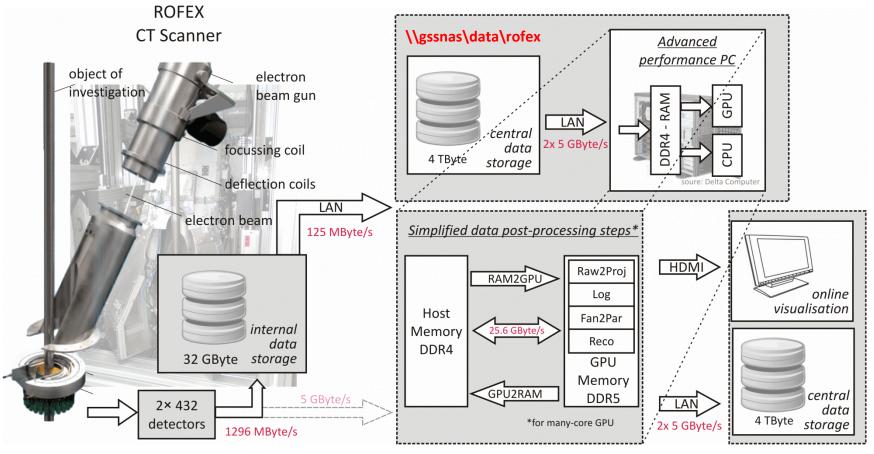
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		Re-select measurement dataset ● *.dat ○ *.fxc		
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Concept for an enhanced data acquisition & processing (2014)

Priority 2



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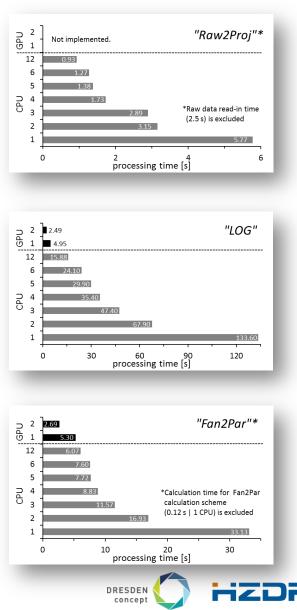
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Enhanced processing – Results - I

Data pre-processing (Raw2Proj, LOG, Fan2Par)



Raw2Proj	\sim
LOG	
Fan2Par	
Reco	2
neco	



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André Bieberle I Institute of Fluid Dynamics I Experimental Thermal Fluid Dynamics I www.hzdr.de

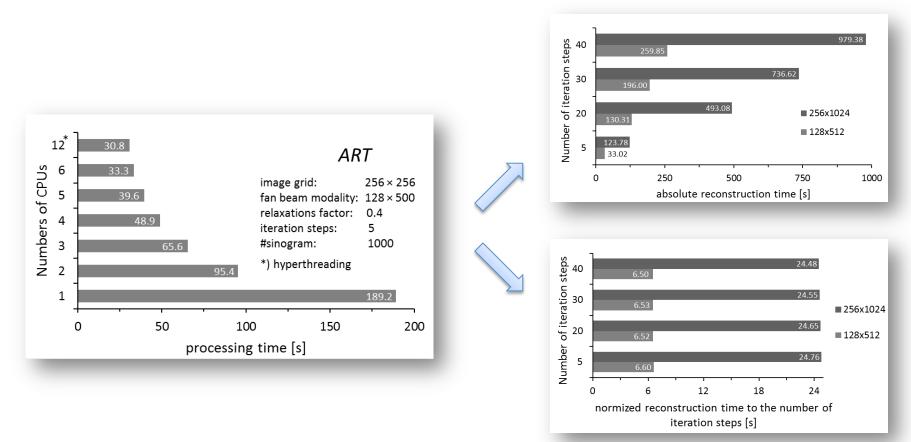
Priority 2

Enhanced processing – Results - II

Data reconstruction

•

(Algebraic Reconstruction Technique)

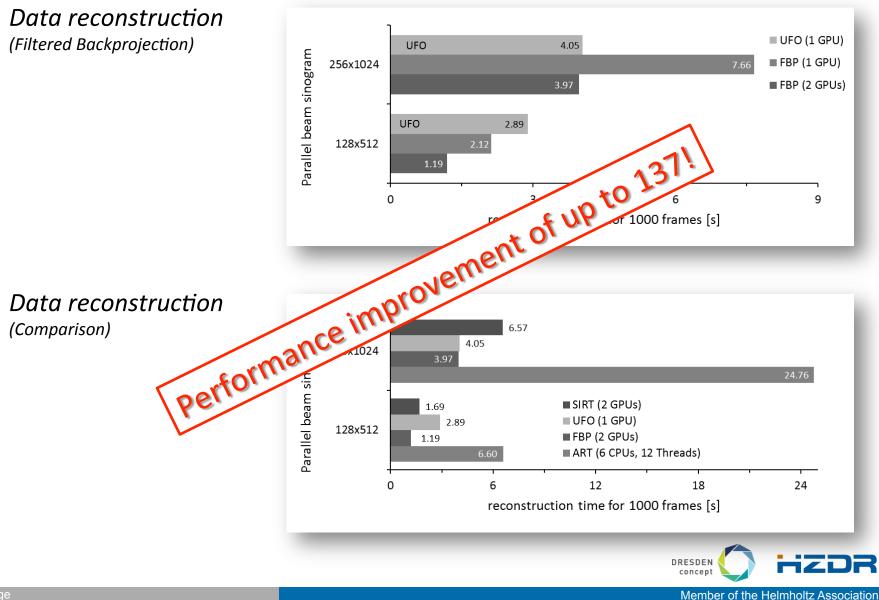




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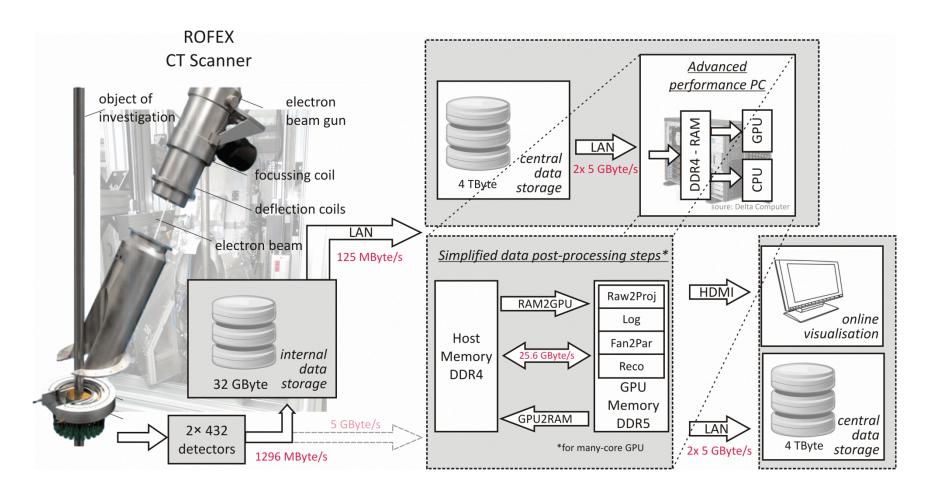
Enhanced processing – Results - III

Priority 2



Further concepts

Priority 3

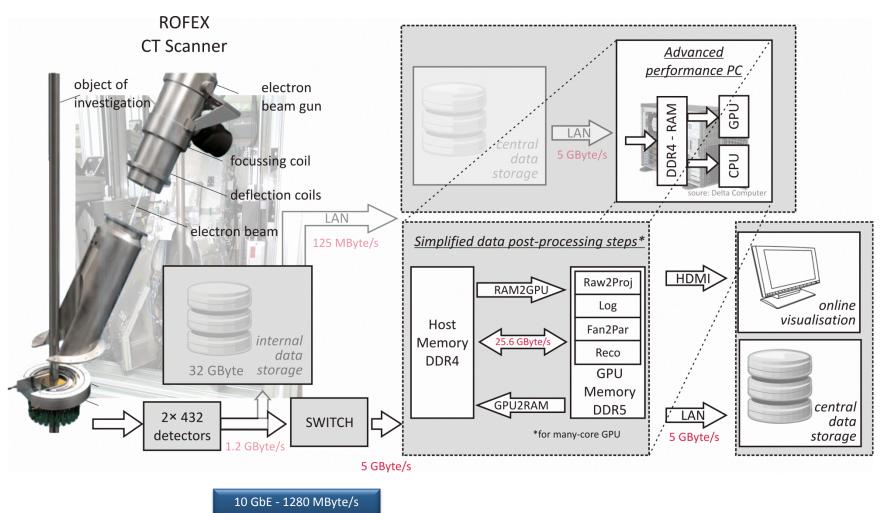




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Further concepts

Priority 3

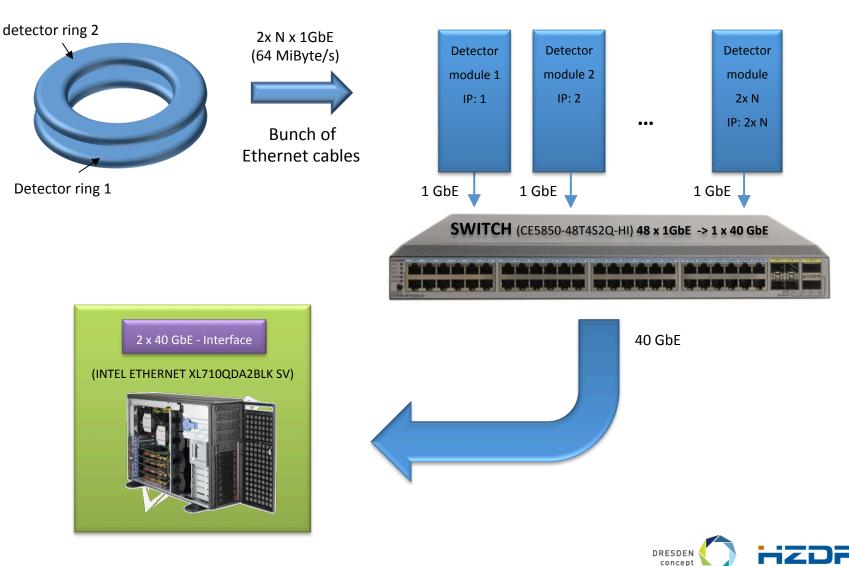


40 GbE - 5120 Mbyte/s



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Further concepts - Hardware

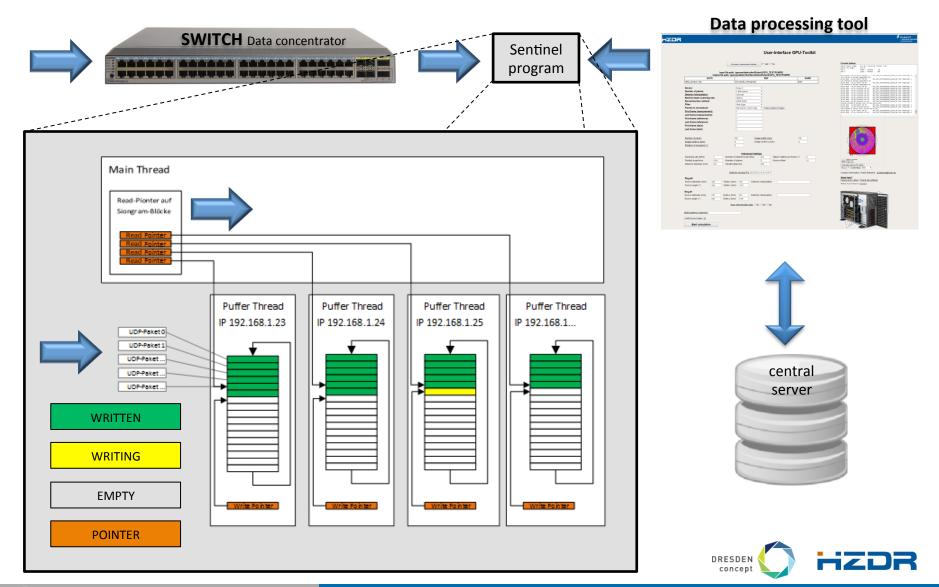


Priority 3

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Further concepts - Software

Priority 3



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<u>Conclusion</u>

- The ultrafast electron beam X-ray CT scanner is very suitable for contact-free multi-phase flow investigations in technical devices. The X-ray CT scanners deliver up to 8,000 frames/s with a spatial resolution of approximately 2 mm.
- Each scanner produces more or less 1 GByte/s of measuring raw data (reconstructed data excluded!). Thus, there is an immense amount of data to be handled.
- A new data processing tool is established that is server-based. Thus, it can be (internally or even externally) used via web browser (OS independent). A job server lists all incoming reconstruction requests. Data is centrally stored (and archived).
- The new data processing tool uses multi core CPU and many core GPU architectures to perform massive data processing. This increases data reconstruction time by a factor of up to 137.
- Because of the strongly reduced data processing time new reconstruction algorithms and other post-processing algorithms (interpolation, image processing, parameter extraction, etc.) can be applied to enhance scientific work.
- A new detector hardware concept is developed and to be installed in the 2nd quarter of 2016. Thus, online analysis will be possible and therefore online process controlling.

<u>Acknowledgment</u>

Students

- Sebastian Vogt (Practical training & Bachelor student)
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- Dominic Windisch (Research assistant)
- Jan Stephan (Student assistant)

Academics

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- Michael Bussmann (HZDR)
- Andreas Kopmann (KIT)
- Peter Kaever (HZDR)
- Guido Juckeland (HZDR / TU Dresden)

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- IT group of HZDR

Thanks for your attention!



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