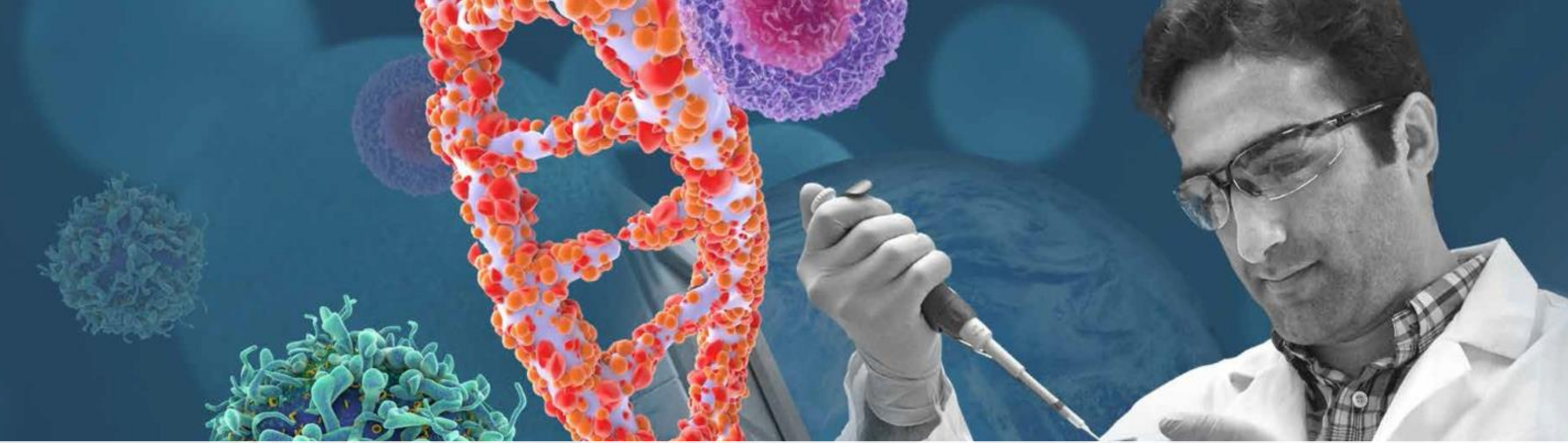

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Image Processing Challenges for Continuous Tilt Tomography

Erik Franken, PhD

About me (Erik Franken)

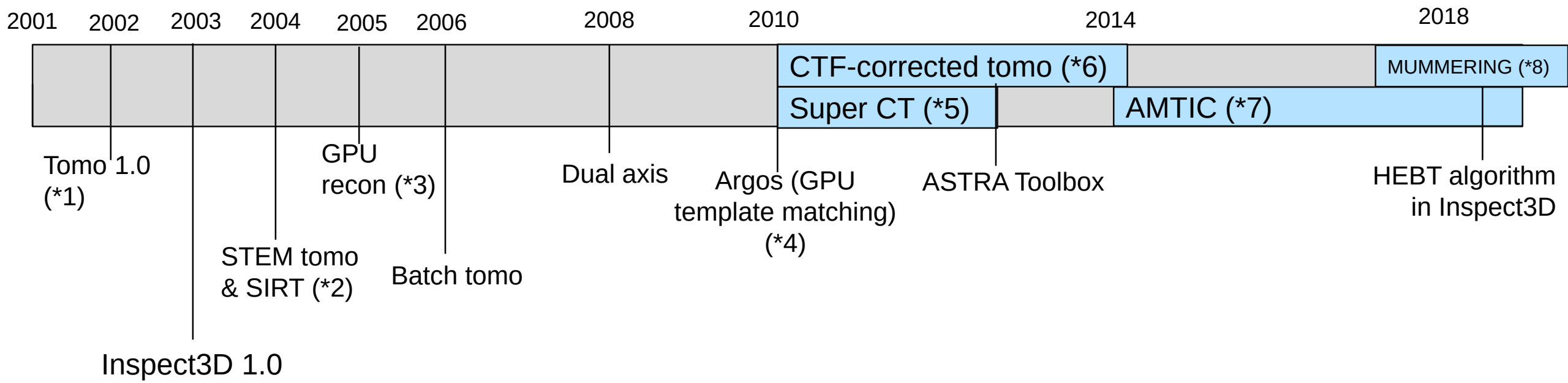
- 2004 : MSc, Electrical Engineering, TU Eindhoven, The Netherlands
- 2008 : PhD, Biomedical Engineering, TU Eindhoven, The Netherlands
- Since 2009: Scientist at FEI Company / Thermo Fisher Scientific
  - R&D, *Advanced Technology* group, subgroup *Algorithms*
  - Working on
    - Tomography: data acquisition and reconstruction methods
    - SPA: data processing algorithms
    - TEM automation: a.o. AutoCTF

Outline

- Introduction
  - Tomography activities in Thermo Fisher
  - Continuous tilt tomography (CTT): towards high throughput tomography
- Continuous tilt tomography activities
  - Results from scientific community
  - CTT holder calibration
  - CTT reconstruction pipelines
  - What's next?
- Concluding remarks

Introduction

History of Tomography activities FEI / Thermo Fisher



Notes:

(*1) Based on OpenTomo Bram Koster (Utrecht) + Martinsried

(*2) Collaboration with Paul Midgley / Matt Weyland (Cambridge)

(*3) Collaboration with Mercury Computer Systems

(*4) Based on Martinsried work. Collaboration with Lebbink (Utrecht), Faas (LUMC), TU/Eindhoven

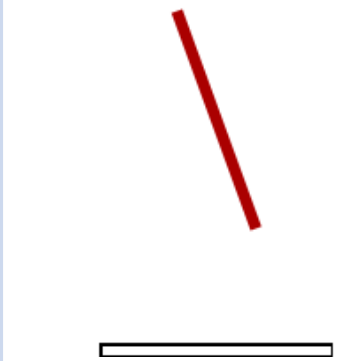
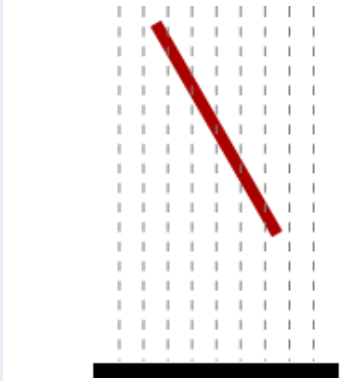
(*5) Collaboration with Antwerp University

(*6) Collaboration with TU Delft and LUMC

(*7) Collaboration with TU Delft and CWI Amsterdam

(*8) Collaboration with Antwerp University and CWI Amsterdam

Vision: high throughput tomography

Method	Animation	Speed
“Traditional” TEM tomography: • Tilt in steps of ~1-2 degrees in start/stop mode.		• Typically takes ~1 hour per tilt series
Continuous Tilt Tomography (CTT) • Continuous sweep from min to max tilt angle • Readout camera frames as fast as possible Thermo Fisher patent US9147551B2 (Priority date 2013-06-06)		• Target ≤ 1 min

Main technical challenges of CTT

- Stage mechanics
  - **Vibrations**: high resolution is lost completely
  - **Runout**: loss of object of interest, high resolution loss
- Dose-sensitive samples
  - **Non-optimal dose distribution**: ‘best’ images (least accumulated radiation damage) are at high tilt
- Data processing
  - **Alignment** on very noisy images is difficult.
  - Reconstructions on large number of images is **time-consuming**

Continuous tilt tomography activities

CTT in the scientific community

SCIENTIFIC REPORTS

OPEN

Rapid low dose electron tomography using a direct electron detection camera

Received: 24 June 2015
Accepted: 02 September 2015
Published: 05 October 2015

Vadim Migunov[1], Henning Ryll[2], Xiaodong Zhuge[3], Martin Simson[4], Lothar Strüder[2,5], K. Joost Batenburg[3,6,7], Lothar Houben[1] & Rafal E. Dunin-Borkowski[1]

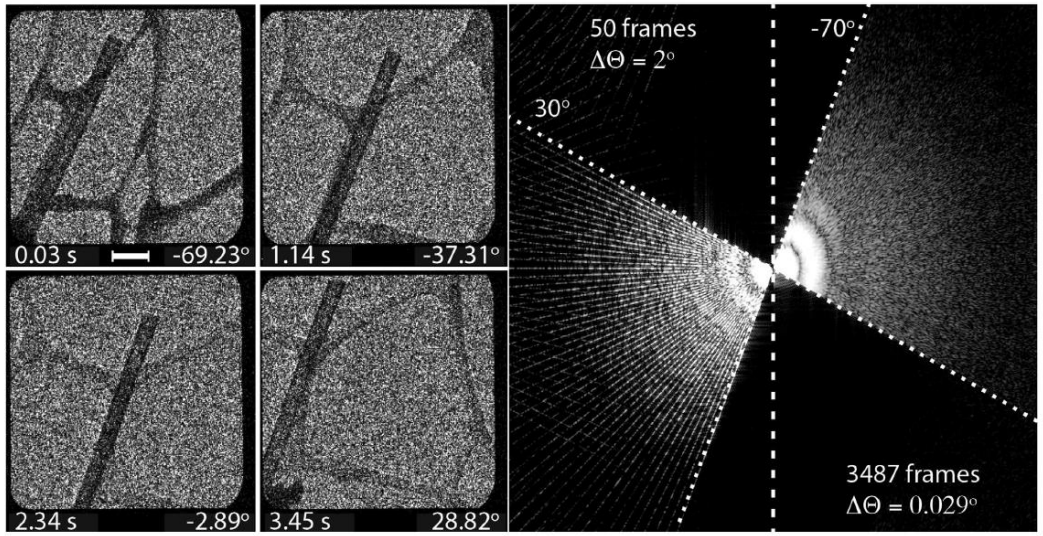


Figure 1. Continuous tilt series acquisition of a $(LaCeS)_{1.2}CrS_2$ nanotube on a lacey C support.

Journal of Microscopy | RMS

Themed Issue Paper

Fast '*Operando*' electron nanotomography

L. ROIBAN, S. LI, M. AOUINE, A. TUEL, D. FARRUSSENG, T. EPICIER

First published: 10 April 2017 | https://doi.org/10.1111/jmi.12557 | Cited by: 1

CSH Cold Spring Harbor Laboratory

bioRχiv

THE PREPRINT SERVER FOR BIOLOGY

New Results

Rapid Tilt-Series Acquisition for Electron Cryotomography

Georges Chreifi, Songye Chen, Lauren Ann Metskas, Mohammed Kaplan, Grant J. Jensen

doi: https://doi.org/10.1101/454587

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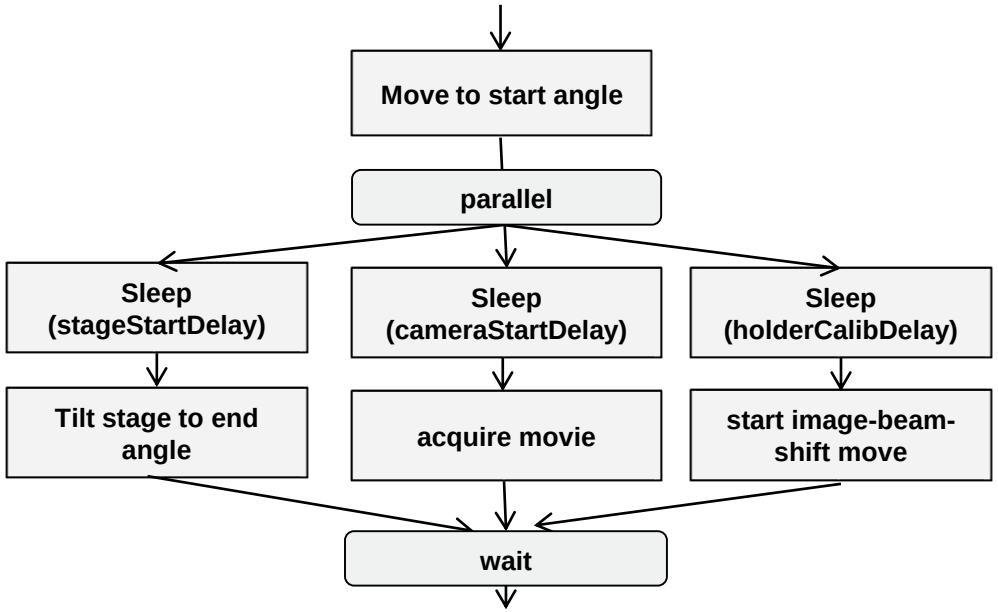
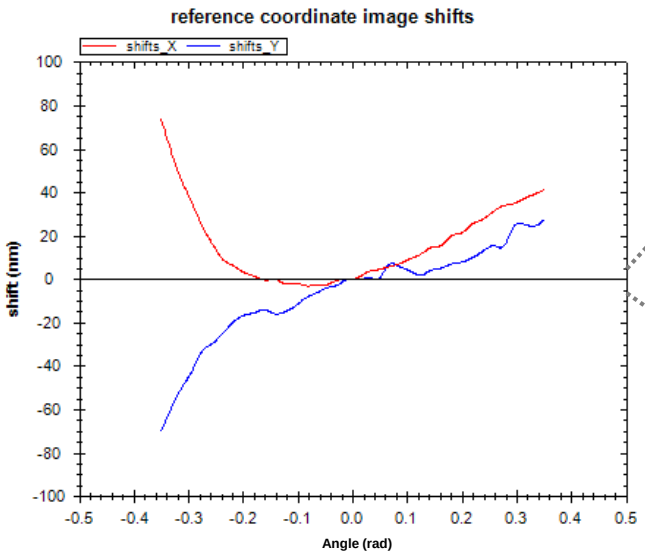
CTT data acquisition experiments @ Thermo Fisher

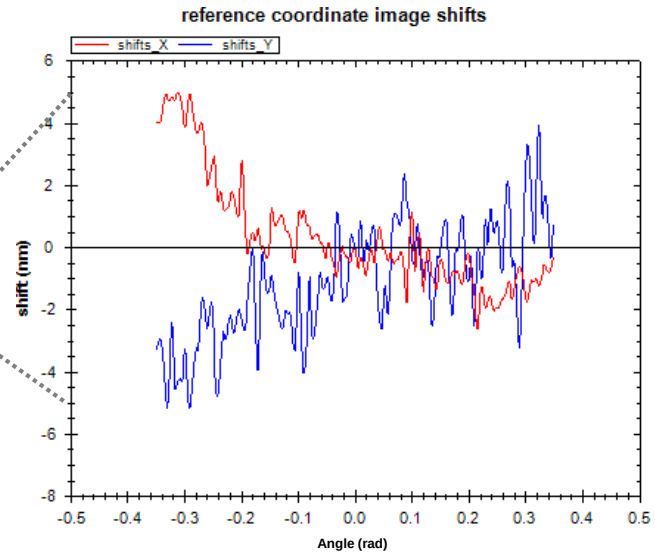
New: CTT holder calibration. Compensate for reproducible sample runout by image-beam-shift



No active compensation



Enabled active compensation



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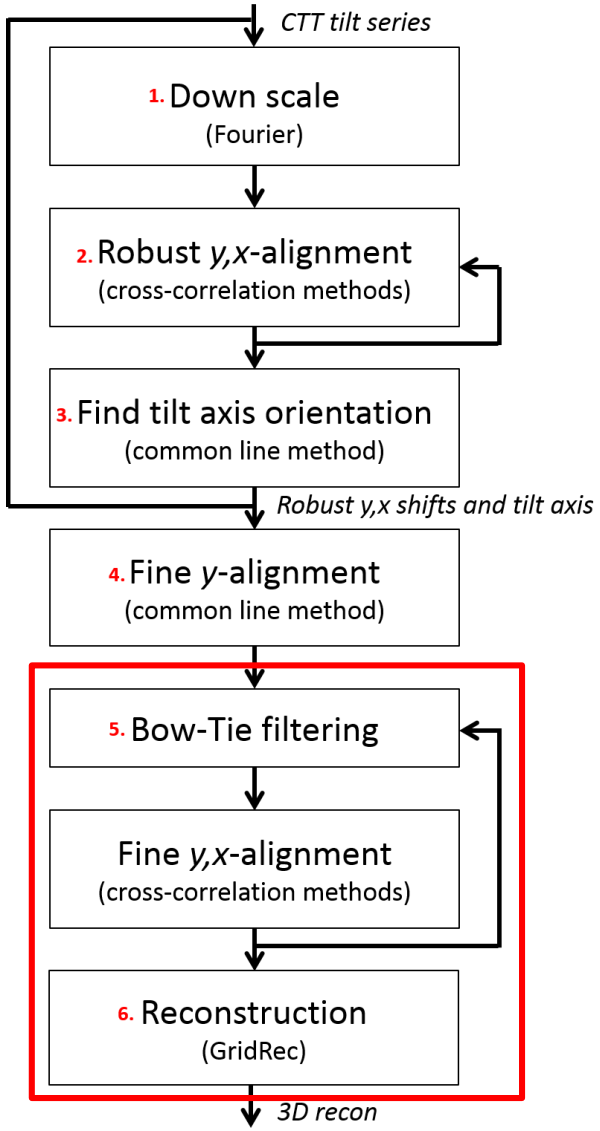
Preliminary CTT Alignment-Reconstruction pipeline

Requirements:

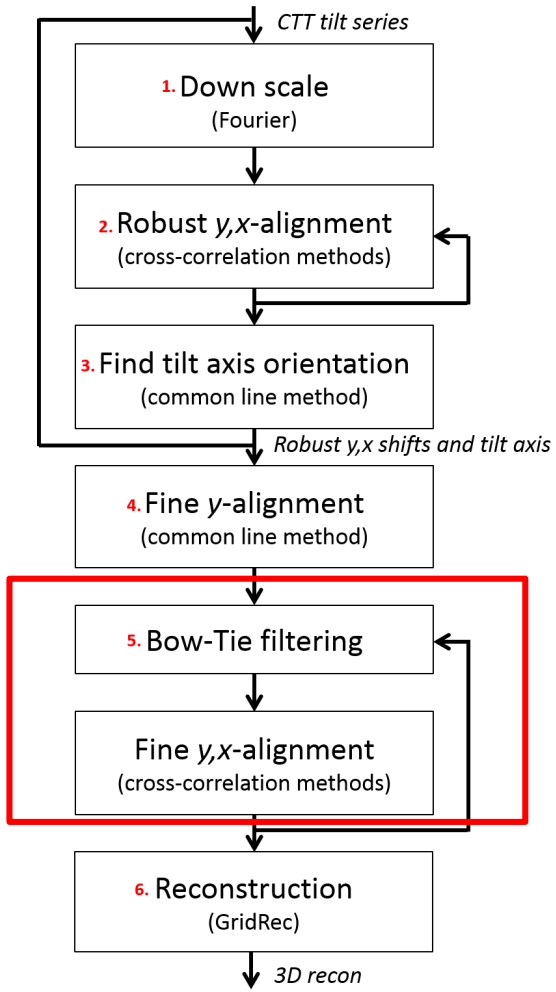
- Meant as ‘live previewing’ reconstruction
- Suitable for cryo-conditions
- No use of markers

Result:

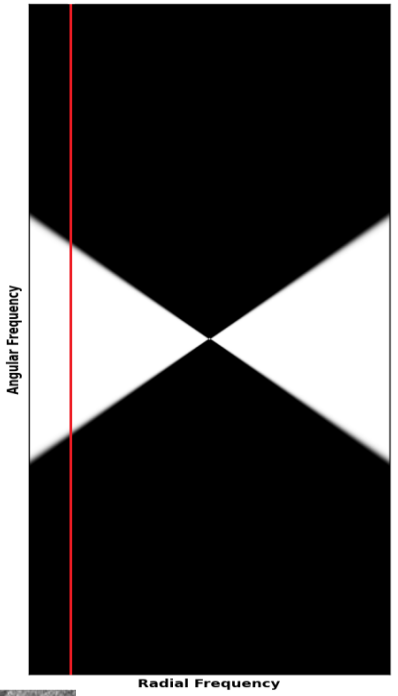
- Proof of concept pipeline & implementation (python/C++)
- Some tricks to speedup
  - Iterative multiscale alignment
  - Bow-tie filtering to mimic project-reconstruct cycle efficiently
  - GridRec Fourier based reconstruction
- No CTF correction yet

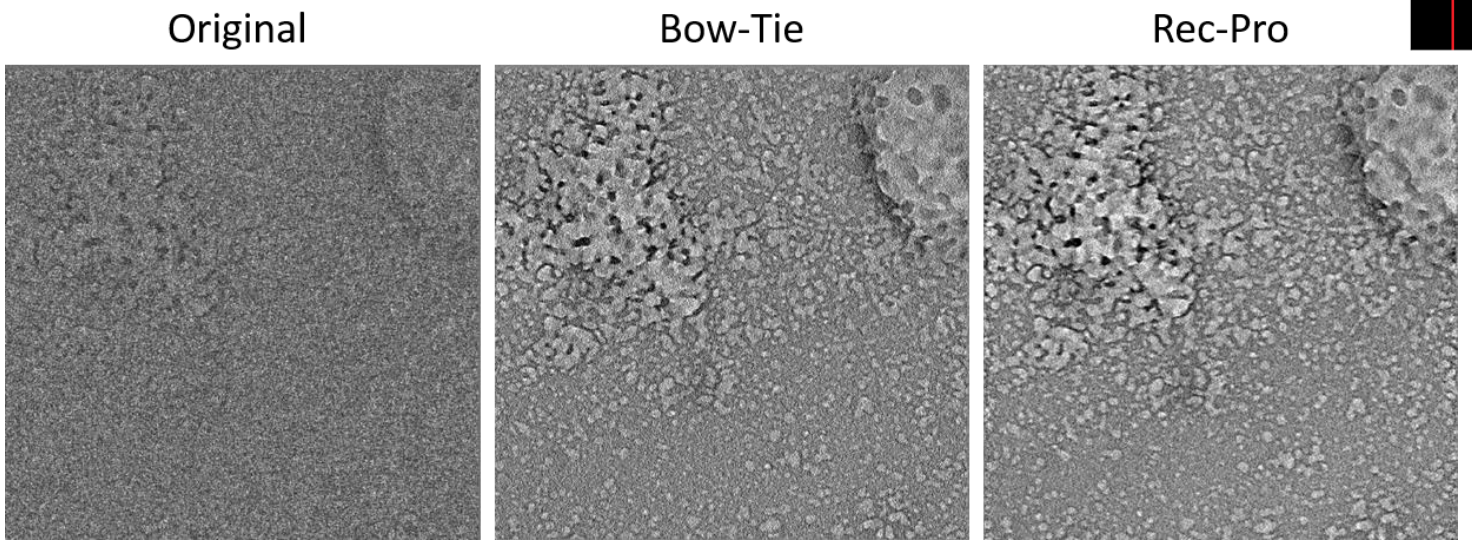


Alignment Reconstruction Pipeline: bow-tie filtering



- Mimicking the process of projection matching by directly filtering the tilt series





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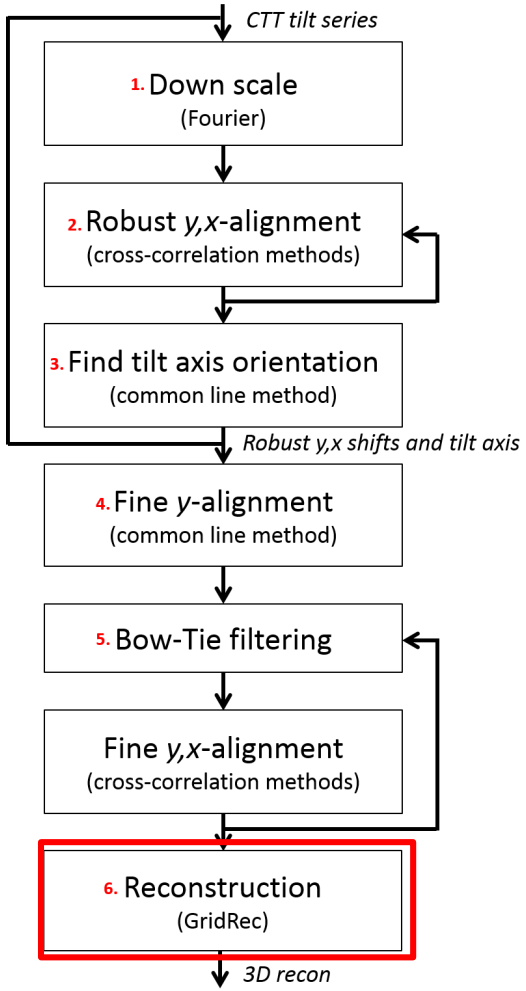
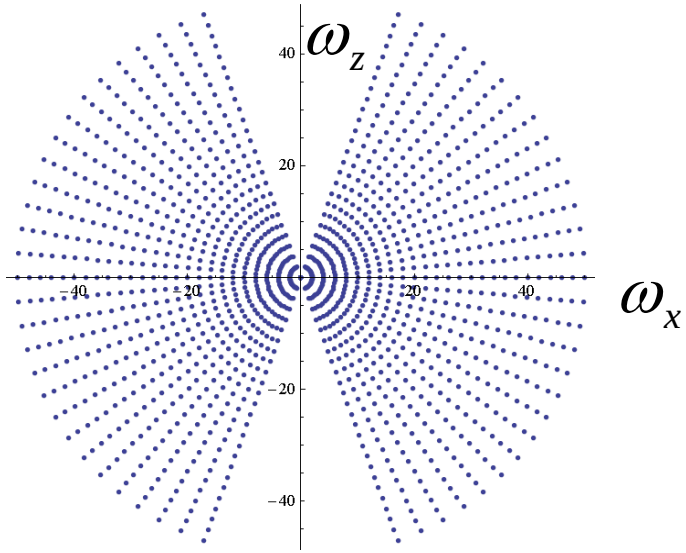
Alignment Reconstruction Pipeline: GridRec



- Complexity of weighted back projection techniques: $O(\Theta XYZ)$
- FFT reconstruction techniques: $O(\Theta XY)+O(XYZ\,\log(X))$

  → More efficient if $\Theta \gg \log(X)$
- We use *GridRec*

  Marone, F., & Stampanoni, M. (2012). Regridding reconstruction algorithm for real-time tomographic imaging. *Journal of Synchrotron Radiation*, *19*(6), 1029–1037. https://doi.org/10.1107/S0909049512032864



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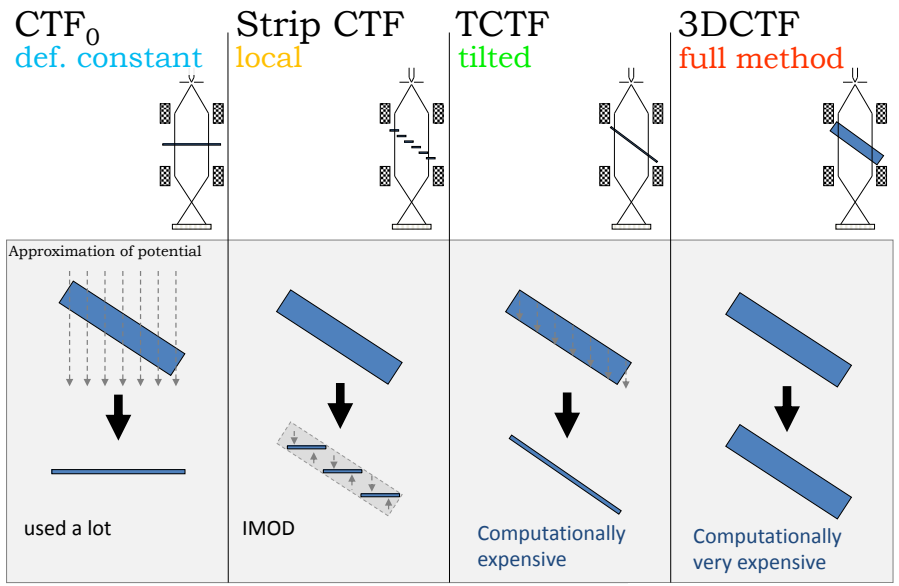
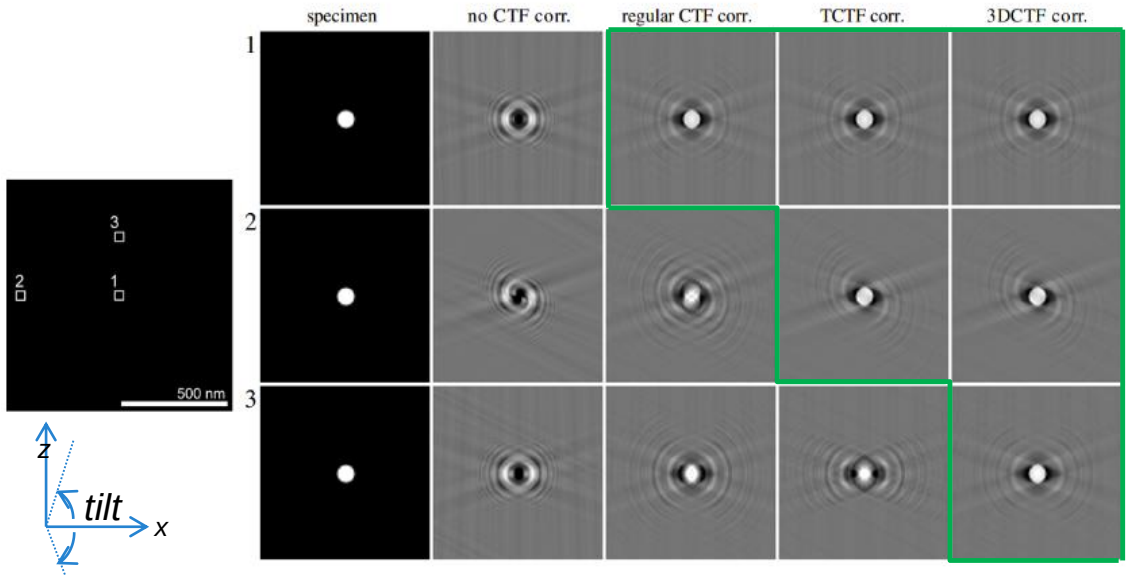
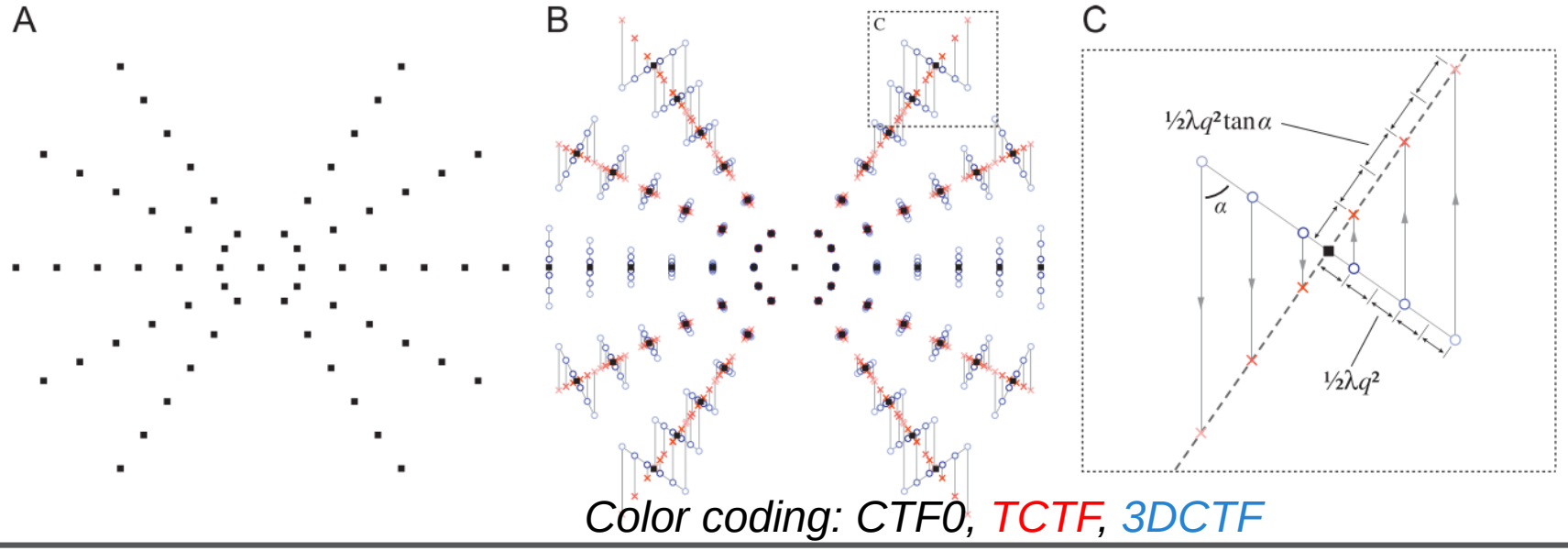
Results from CTF-corrected tomography project 2010-2014: a good fit for CTT?





- Efficient methods for TCTF and 3DCTF forward modelling and correction on tilted samples.
- 3DCTF correction fits directly in Fourier reconstruction method



Color coding: CTF0, TCTF, 3DCTF

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MUMMERING project

Industry challenge	Work Package	ESR project	ESR no.	Host	Secondments	Industry involvement
In situ imaging of industrial processes and reactions at the atomic level 1	Data acquisition, electron and X-ray tomography (WP1) *New modalities, atomic resolution, adaptive acquisition*	Time resolved omni-directional scattering tomography	ESR1	PSI	XNOVO/ CWI/ETH	xnovotech
		Novel developments in high resolution TEM tomography	ESR2	UA	DENSsolutions NanoMEGAS/FEI EO	DENS solutions, FEI, NanoMEGAS
		4D dynamic tomographic acquisition driven by smart image quantification	ESR3	ULUND	Aluinvent/PSI	ALUINVENT
Easily accessible, fast and robust data handling workflow 2	Data management and HPC (WP2) *Robust and automatized*	Analysis pipeline automatization in relation to materials design in 3D	ESR4	UCPH	4Quant/PSI	4Quant
		High Performance Image, Volume, and Movie Analysis	ESR5	UPCH	BSC	BSC
Versatile, fast and scalable reconstruction for gigavoxel volumes 3	3D reconstruction (WP3) *Live reconstruction, missing data and direct inversion from Fourier space*	Ultra-fast 3D reconstruction	ESR6	CWI	FEI EO/PSI/UA	FEI
		3D atomic resolution reconstruction methods	ESR7	UA	FEI EO/EMAT	FEI
		Advanced Algorithms for Data Reconstruction	ESR8	BAM	Vision in X	VISION IN X INDUSTRIAL IMAGING
		Three-dimensional inversion of ptychographic tomography data	ESR9	DTU	XNOVO/ULUND	xnovotech
Unbiased identification and representation for non-expert application 4	Segmentation (WP4) *Trained algorithms, segmentation without reconstruction*	2D/3D multimodal analysis for X-ray security applications	ESR10	AP2K	DTU	ACCENT PRO 2000
		Physical model priors for tomogram segmentation	ESR11	DTU	Tetra Pak/FEI SAS	FEI, Tetra Pak
		Segmentation from projections	ESR12	DTU	FEI SAS	FEI
		Multiscale quantification of damage in composite structures	ESR13	UoM	LM/FEI SAS	FEI, SAERTEX, LM WIND POWER
Extraction of quantitative physical parameters 5	Modelling (WP5) *4D modelling and multiscale*	Reactive transport in porous media: A multi-scale imaging and modelling approach	ESR14	CNRS	Aluinvent/PSI/UA UCPH/Ubx	ALUINVENT
		Multiscale segmentation and modelling of composite materials	ESR15	OCV	DTU	OWENS CORNING

- MUMMERING = **MUltiscale, Multimodal and Multidimensional imaging for EngineeRING**
- Thermo Fisher hosts 6 secondments (‘internships’) of PhD projects.
- 3 projects with secondments in Eindhoven:
  - ESR2 @ EMAT : Fast 4D tomography & multimode tomography
  - ESR6 @ CWI: **Ultra-fast 3D reconstruction for Continuous Tilt Tomography**
  - ESR7 @ UA: 3D Atomic reconstruction methods
- 3 projects with secondments in Bordeaux

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Concluding remarks

Conclusions

- Point of view
  - High throughput tomography is crucial
  - Continuous Tilt Tomography and related schemes are key to accelerate data acquisition
  - Tailored fast reconstruction approaches and automated algorithms are needed
  - These needs are wider than Life Science only

- Open for questions / remarks / suggestions!

- Open to discuss collaborations!

Thank you! Questions?