X-ray Imaging and Coherence
I13 Beamline at Diamond

Christoph Rau

Overview

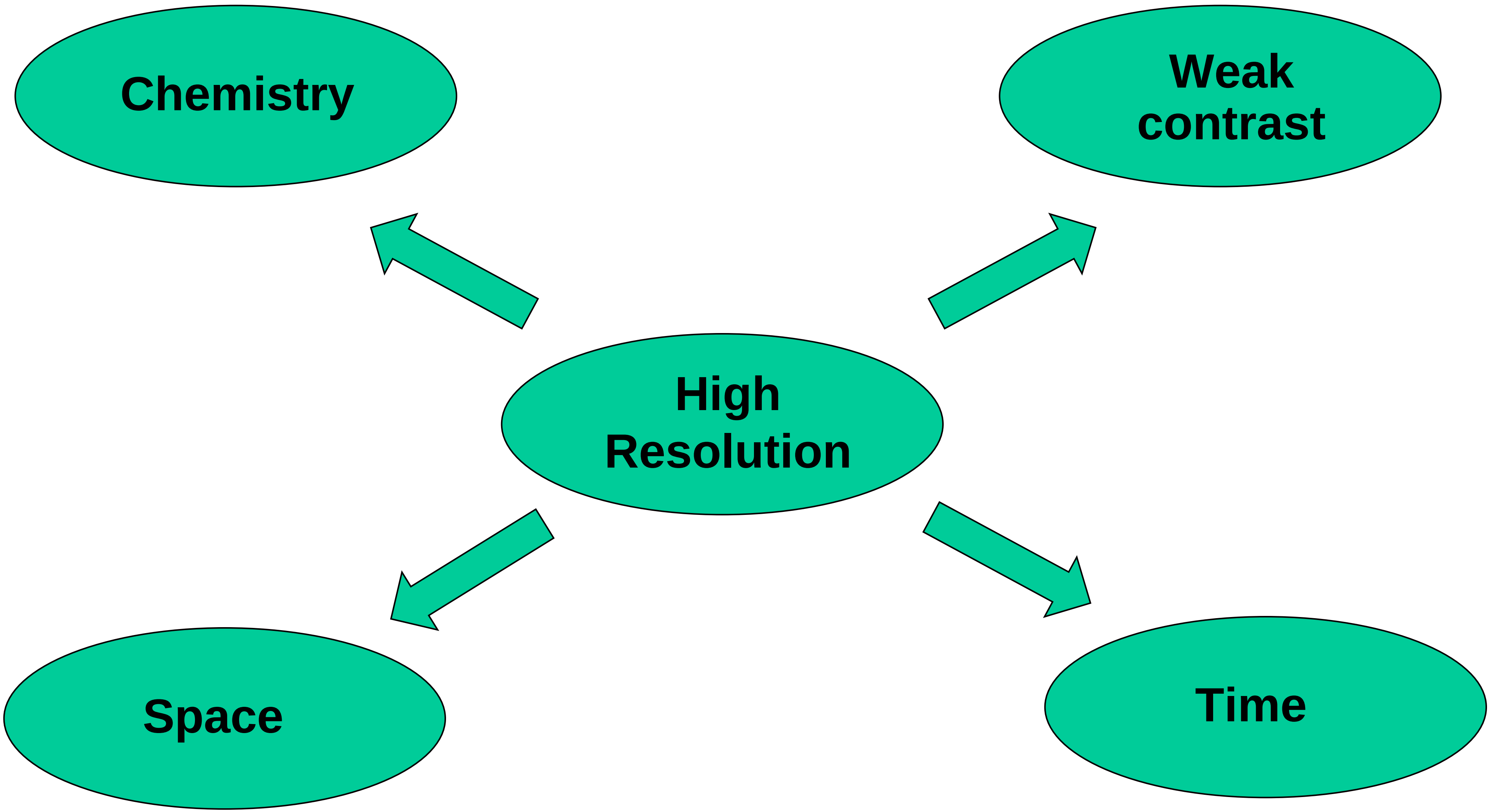
- Introduction
- Instrumentation
- Science
- Diamond II
- Summary

Overview

- High resolution imaging over several lengthscales

- Instrumentation

High Resolution with Synchrotron Radiation



Coherent Imaging: The I13 branches

Imaging

<u>At z=0:</u>

Absorption contrast

<u>Small z:</u>

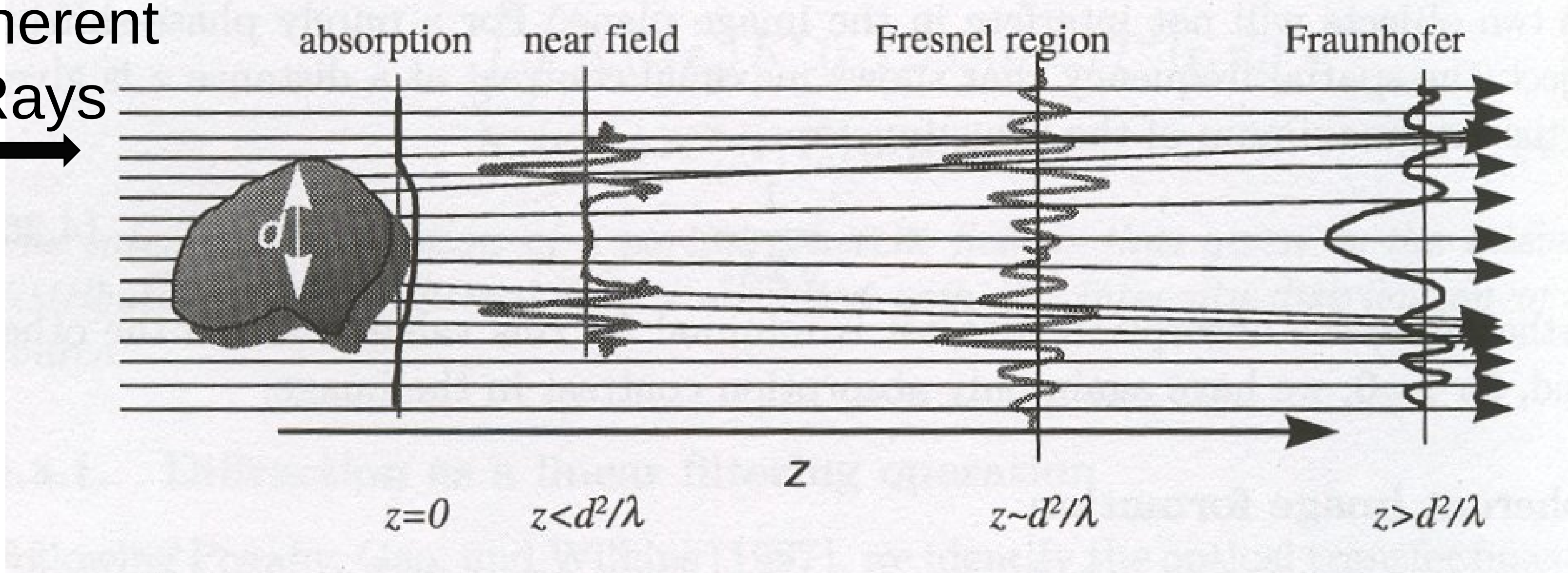
Edge enhancement

Coherence

<u>Far field (large z):</u>

no resemblance to original structure

Coherent X-Rays



Graph: C. Raven, PhD thesis, Shaker Verlag, Aachen

I13 Imaging and Coherence

Imaging with coherent hard X-rays (6-30keV):

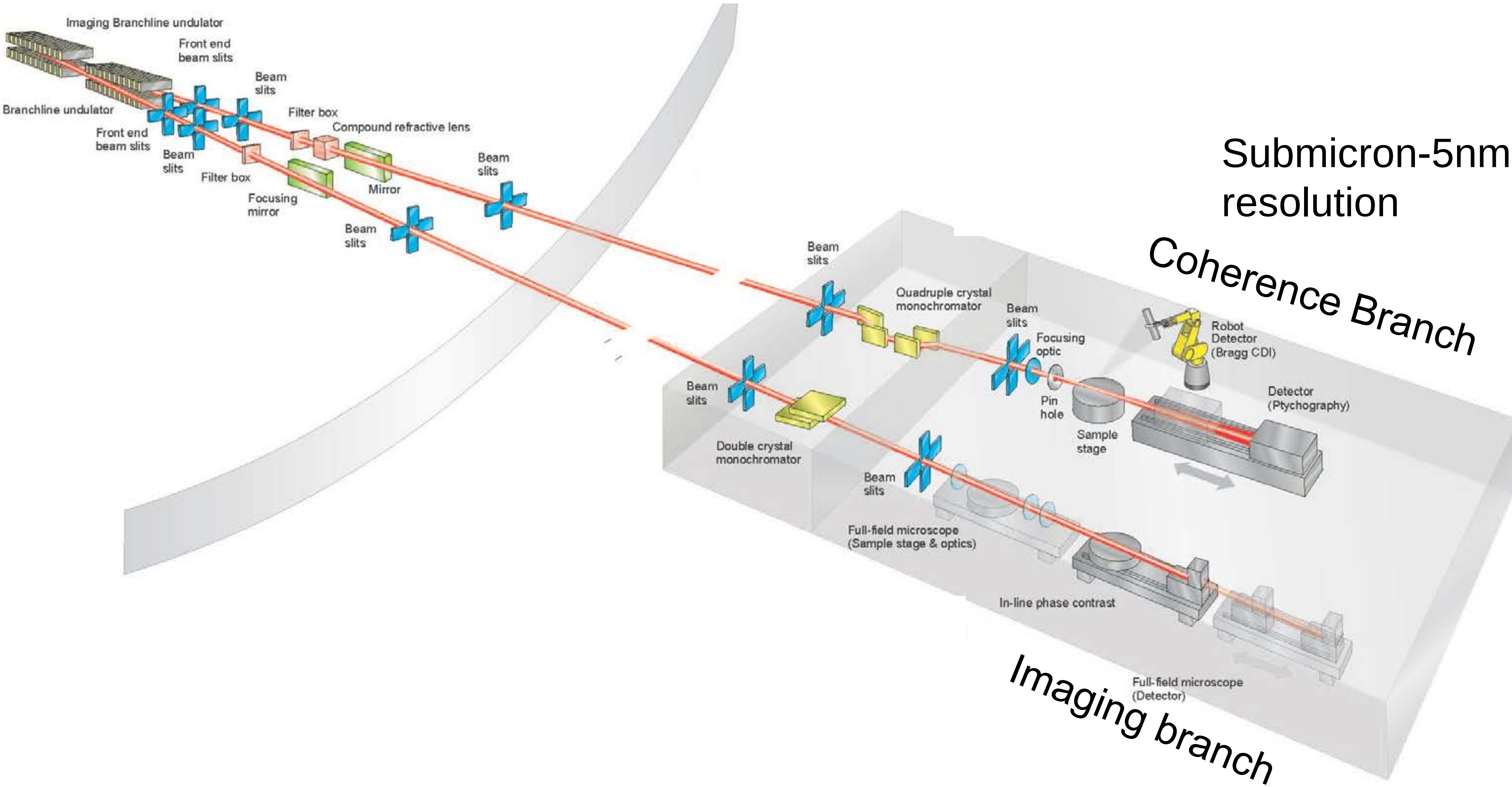
Imaging (real space)

- In-line phase contrast tomography : Resolution ~1µm
- Hard X-ray microscopy: Resolution 50nm

Coherence (reciprocal space)

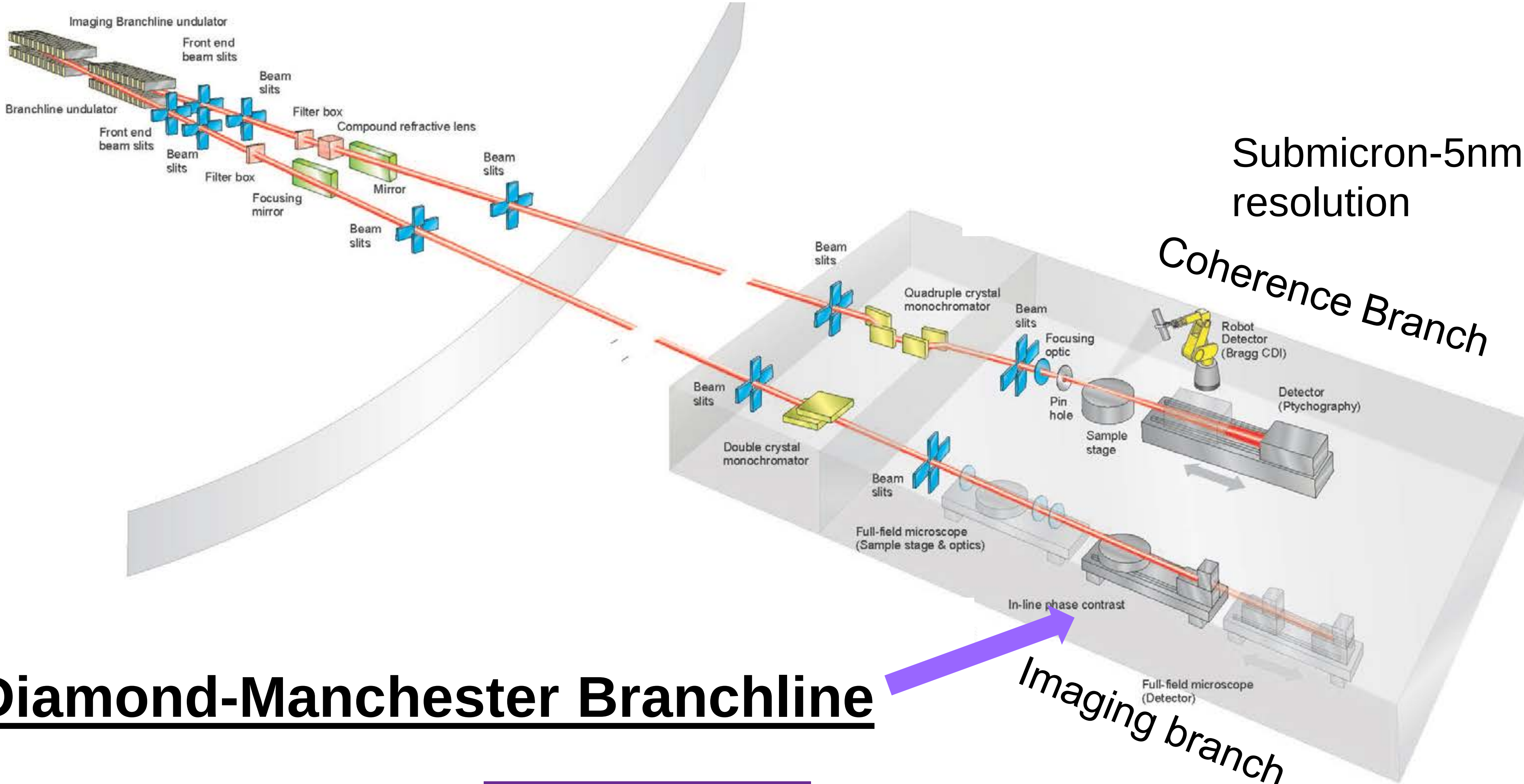
- Coherent Diffraction Imaging: Resolution -> 5nm

Overview Experimental Stations



Micron-50nm resolution

Overview Experimental Stations



Submicron-5nm resolution

Coherence Branch

Imaging branch

Micron-50nm resolution

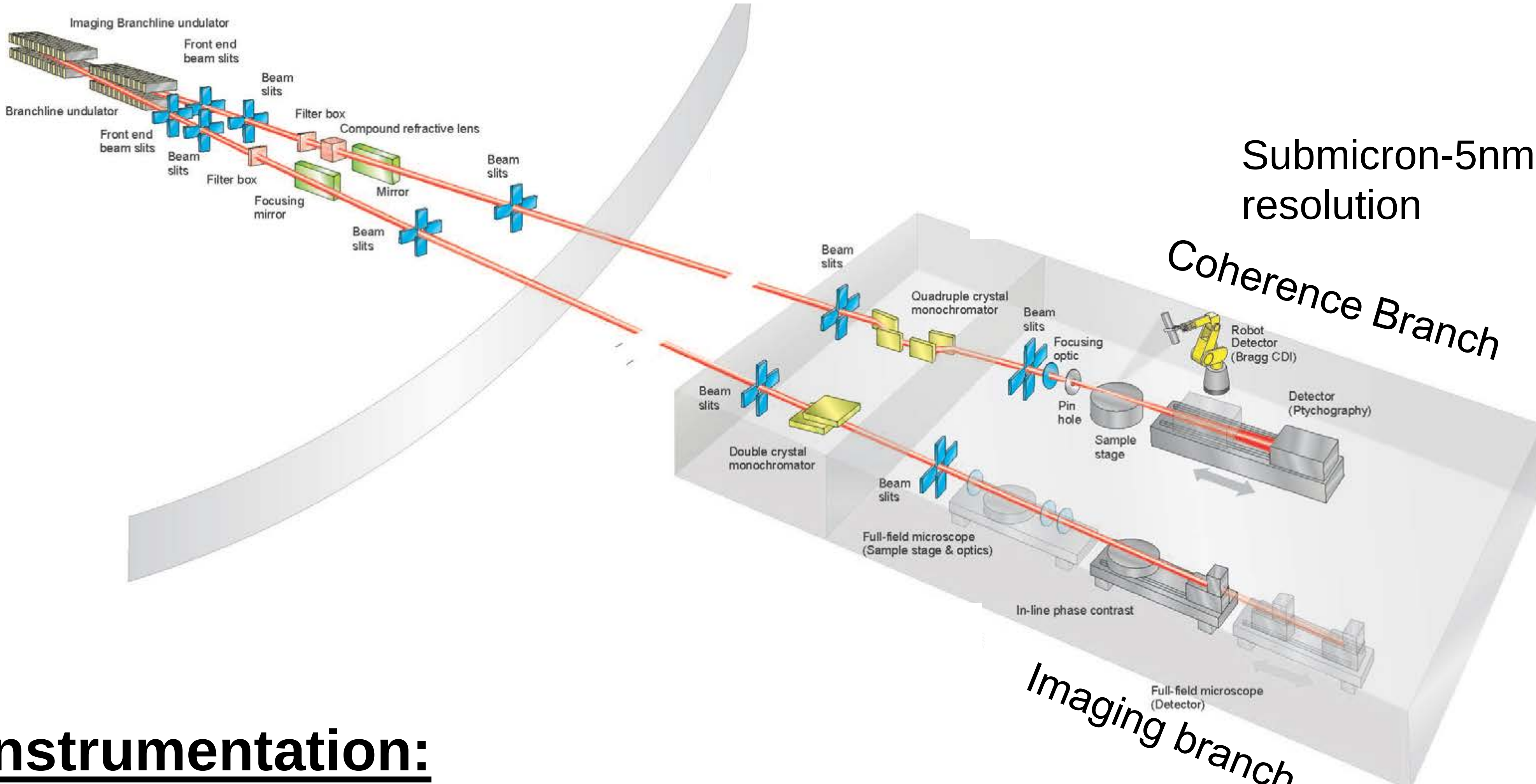
Diamond-Manchester Branchline

diamond

MANCHESTER 1824

The University of Manchester

Overview Experimental Stations



Submicron-5nm
resolution

Coherence Branch

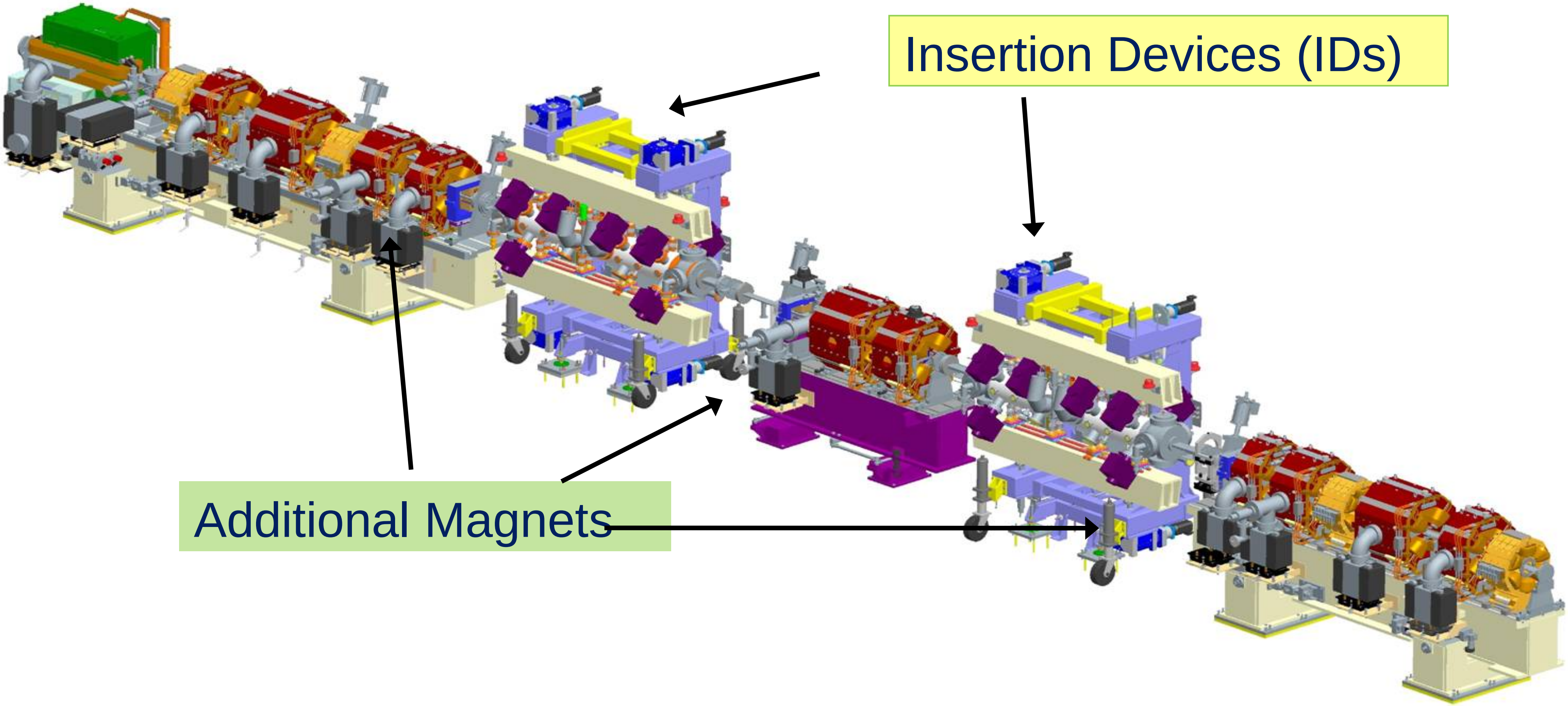
Imaging branch

Micron-50nm
resolution

<u>Instrumentation:</u>

- Source ('mini-beta')
- Optics : Mirror

Mini-Beta



- Increases brilliance
- Changes electron optics in storage ring

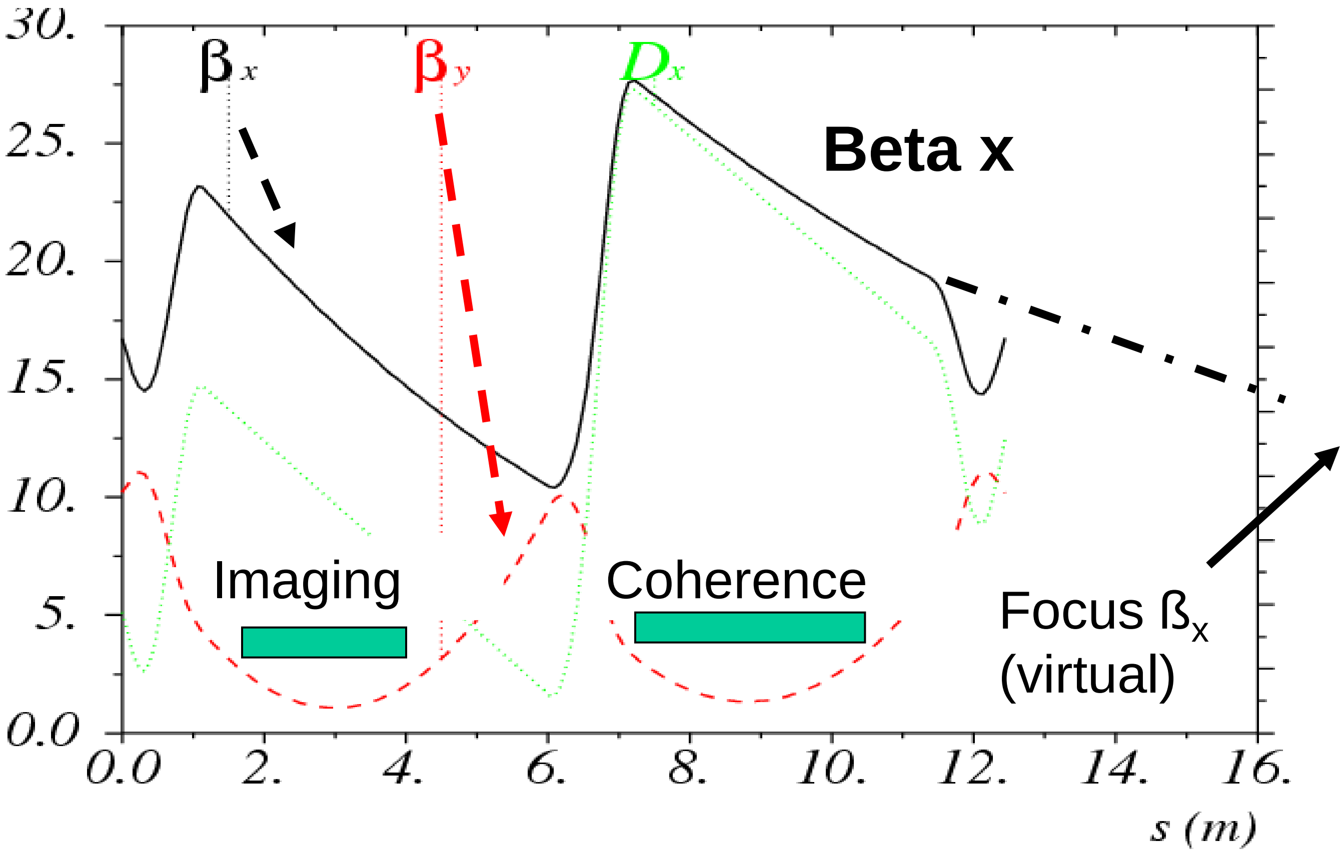
Machine: B. Singh, R. Bartolini, R. Walker

Engineering: N. Hammond, R. Holdsworth, J. Kay

Mini-beta

B. Singh, R. Bartolini, R. Walker

Long straight divided into two ‘mini-beta’

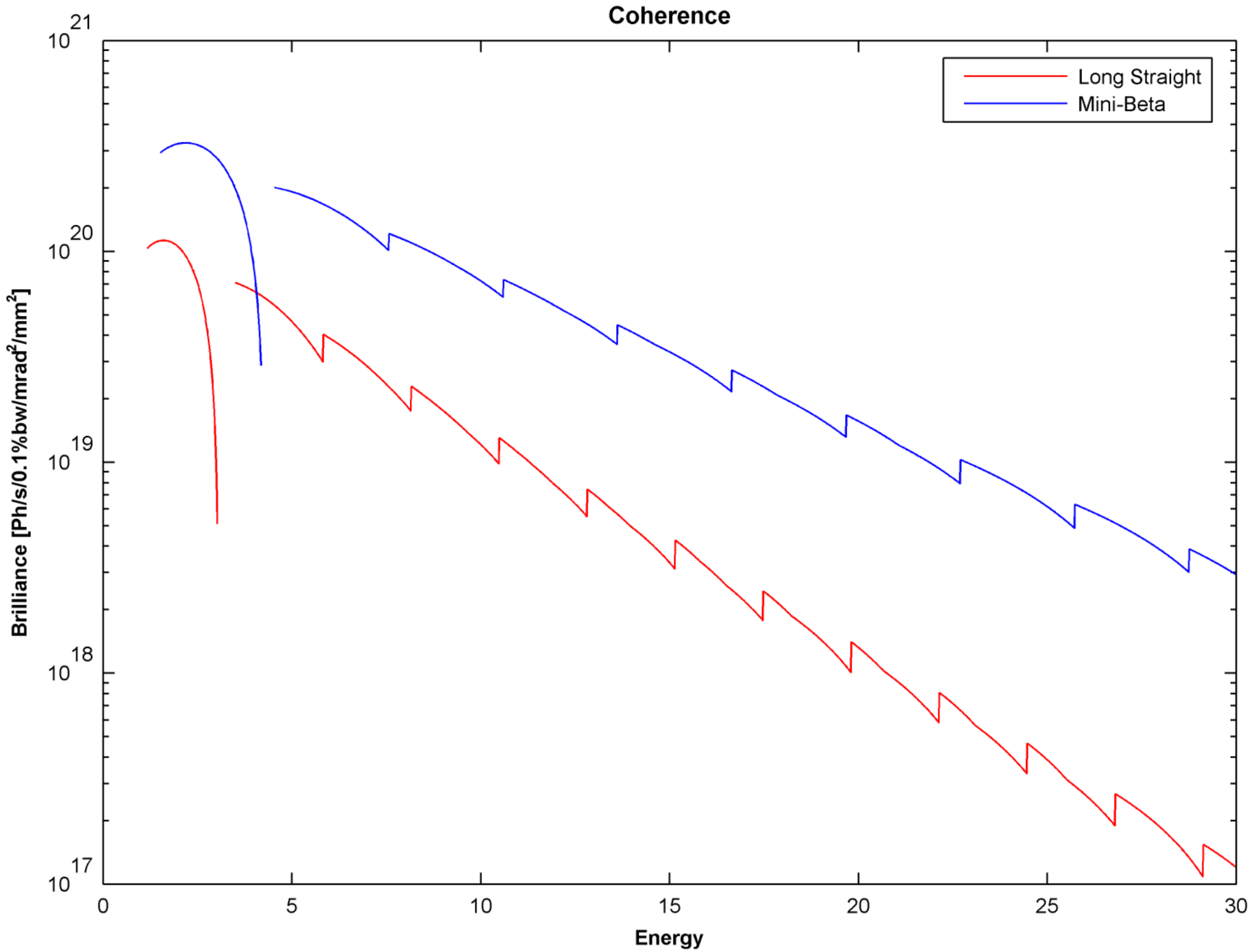


-Small $ß_y$: high brilliance
-Slope $ß_x$: beam focus

Coherence branch: Focus in Front End
‘Access’ to source by Front-end Slits

Motivation Mini-Beta

U20 Undulator long straight (red) and 'Mini-beta' (blue)

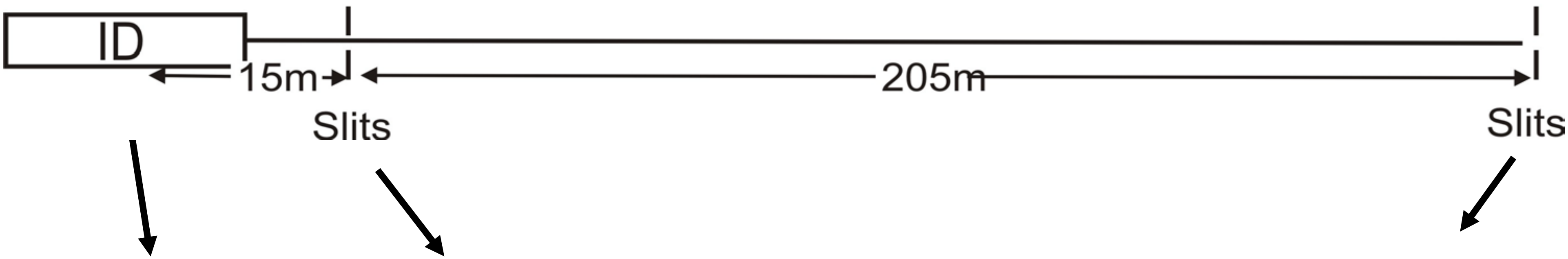


Important increase

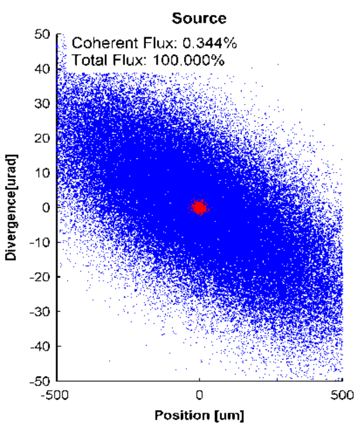
Simulation U. Wagner

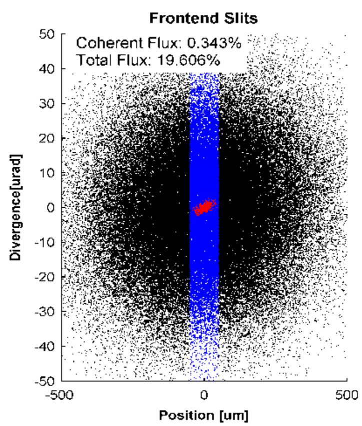
Coherent Fraction

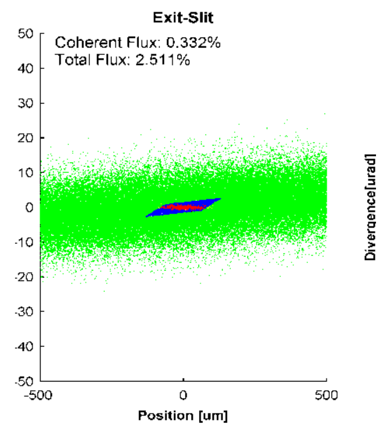
Coherence Branch



Phase-Space Diagram (hor.)







-Slit in front-end defines beam position

-Horizontal clean extraction of coherent fraction

Simulation U. Wagner

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The Branches

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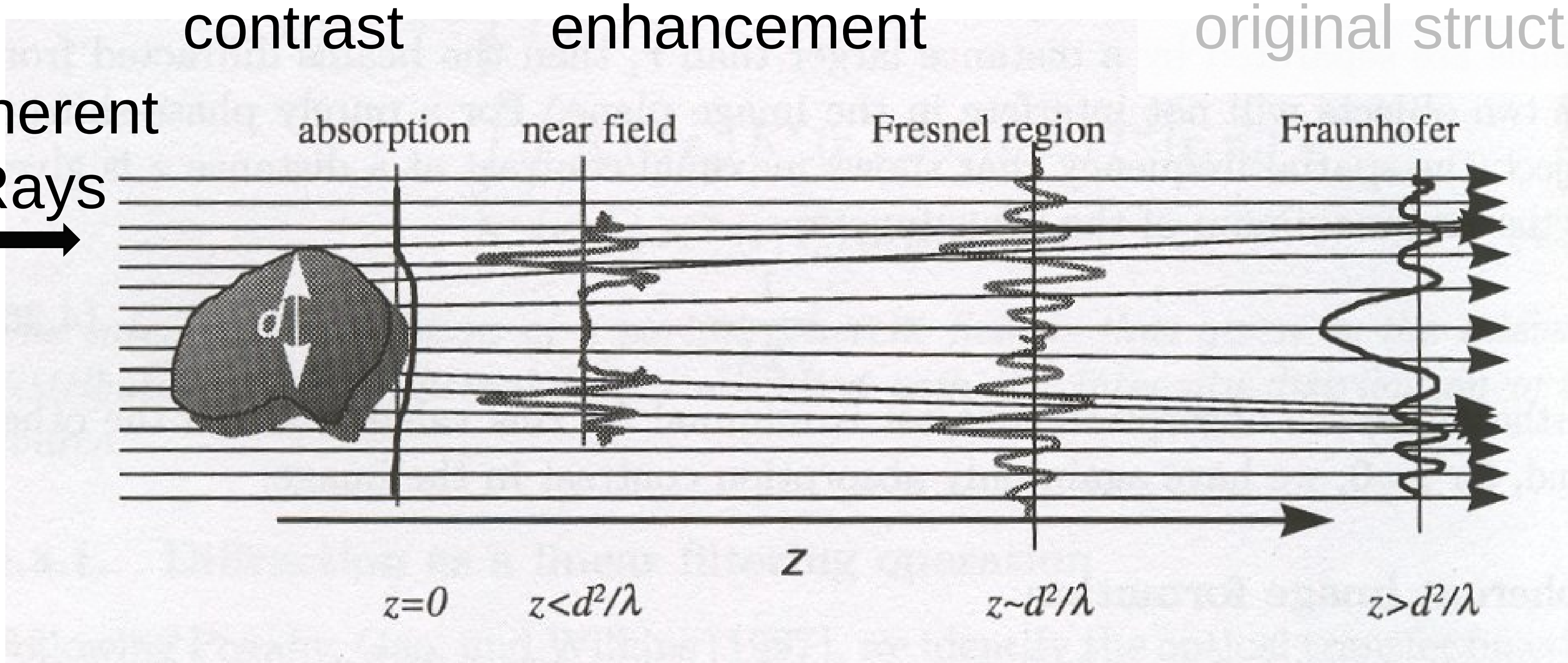
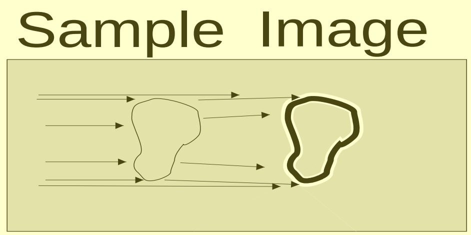
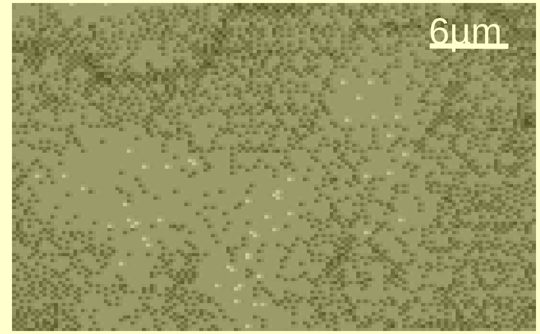


Graph: C. Raven, PhD thesis, Shaker Verlag, Aachen

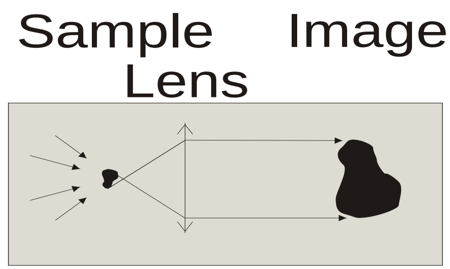
Imaging - Methods

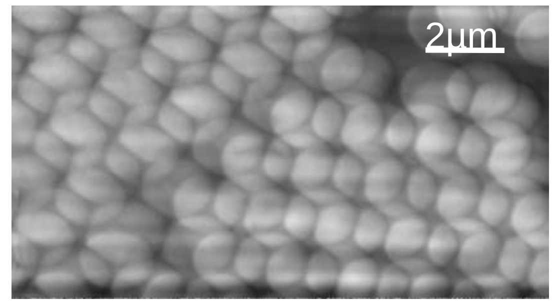
<u>In-line phase contrast</u>
-**µm** resolution
-easy to use
-large field of view





<u>Full-field microscope</u>
- **50nm** resolution
- imaging of phase objects
- combined methods

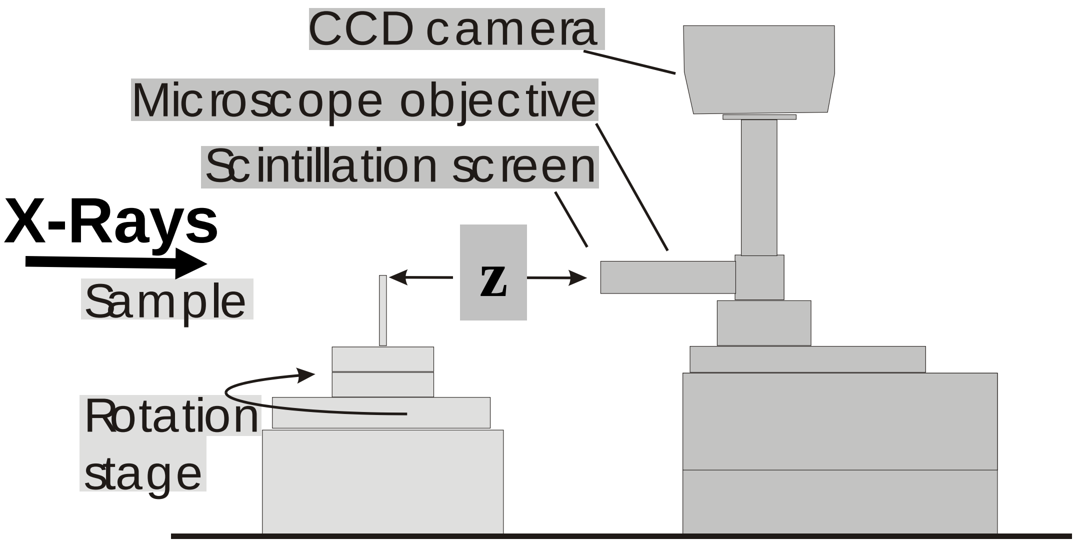


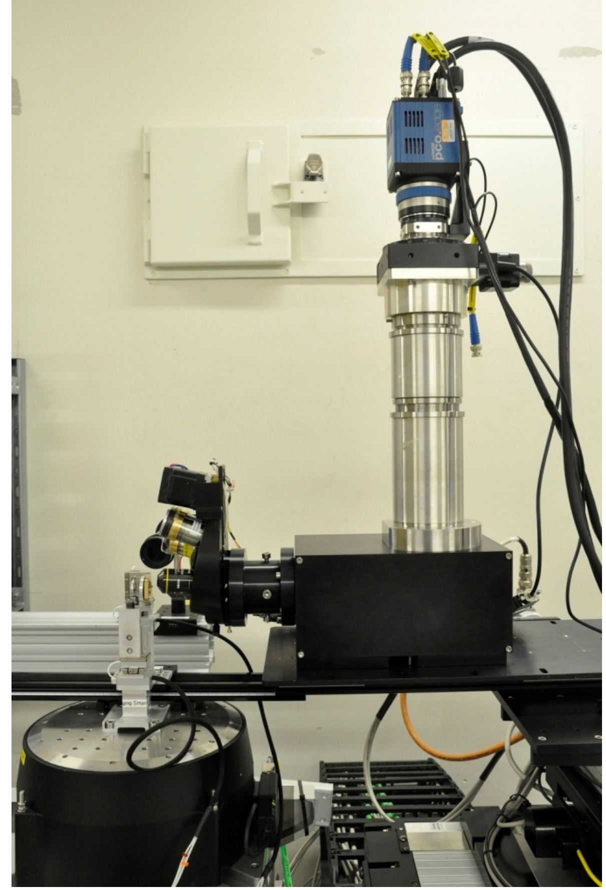


<u>Cone-beam imaging</u>
-**sub-µm** resolution
-dose efficient
-sub-100nm source

Full-field imaging with different spatial resolution

Micro-tomography setup

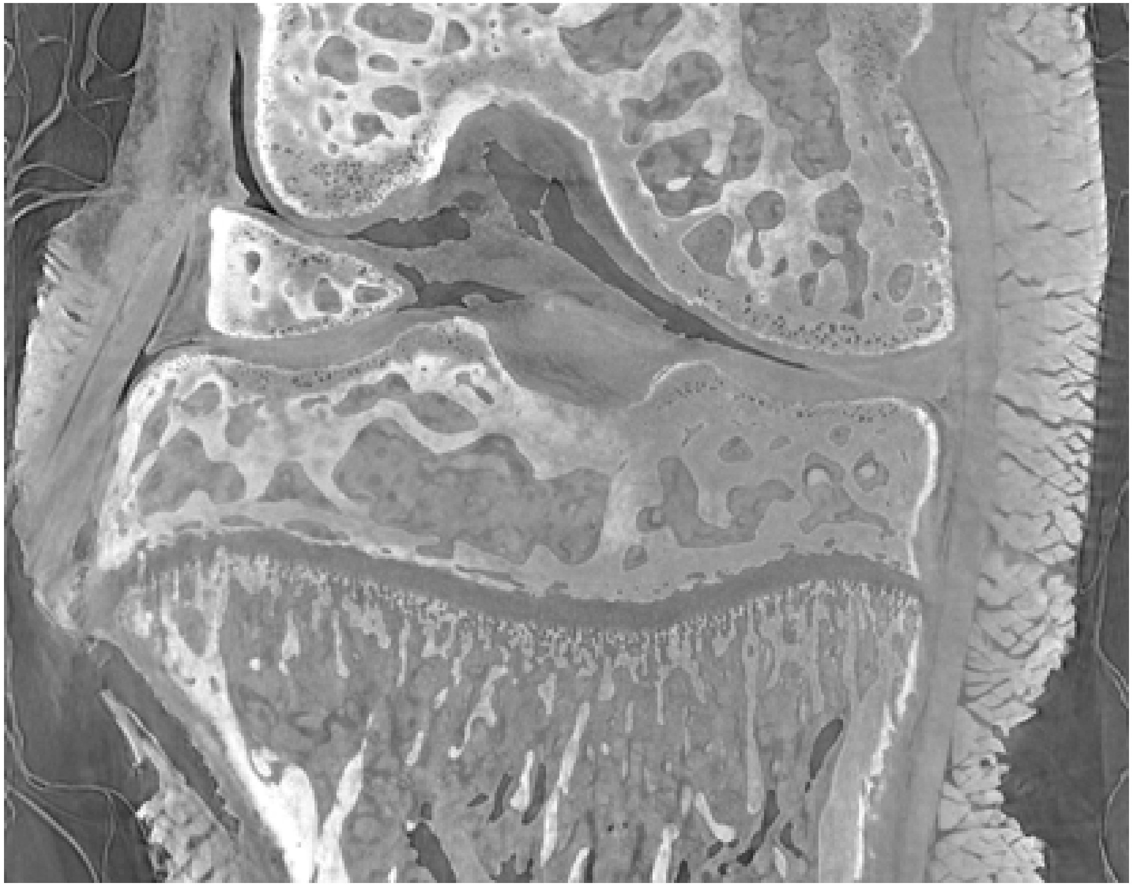




- Detector resolution: **1µm**
- Energy range:6-30keV

- Change contrast with detector sample distance

Weak contrast : In-line phase contrast



Reconstructed slice of mouse knee

Results courtesy K. Maadi

Image processed with support of A. Bodey

- Imaging with In-line phase contrast
- High-fidelity imaging

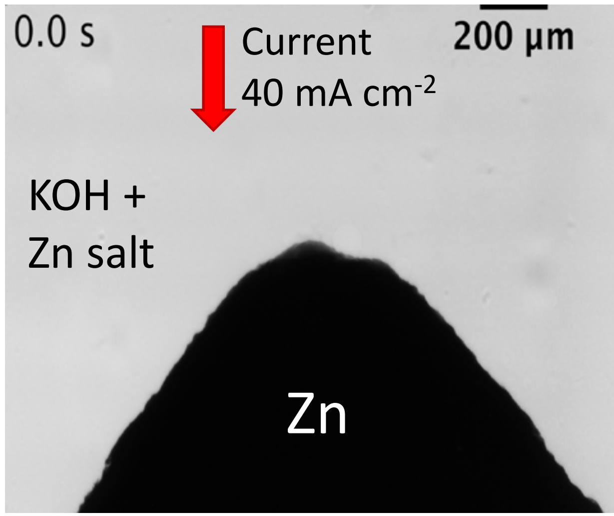
Biology: Bee eyes

Learn about navigation skills of bees (in tropical forest)

- Eyes: Emily Baird, Lund Vision Group

Application

Zinc dendrite electrodeposition



Close-up of 'single' dendrite

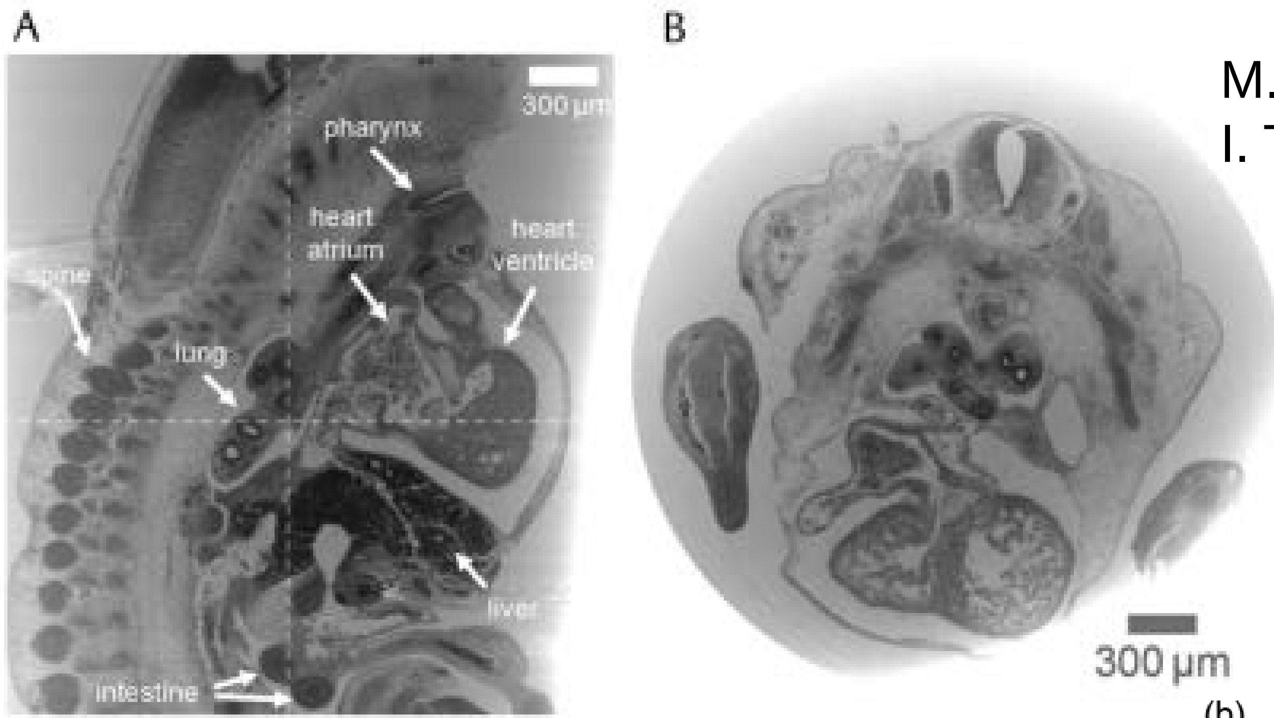
$$Zn(OH)_4^{2-} + 2e^- \rightarrow Zn + 4OH^-$$ "battery charging"

- Clarify dendritic growth problems with rechargeable Zinc-air batteries for transport

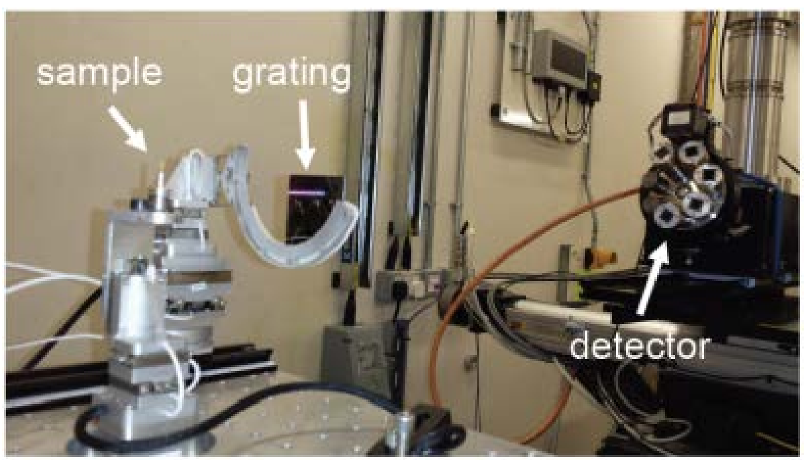
Slide courtesy David Eastwood

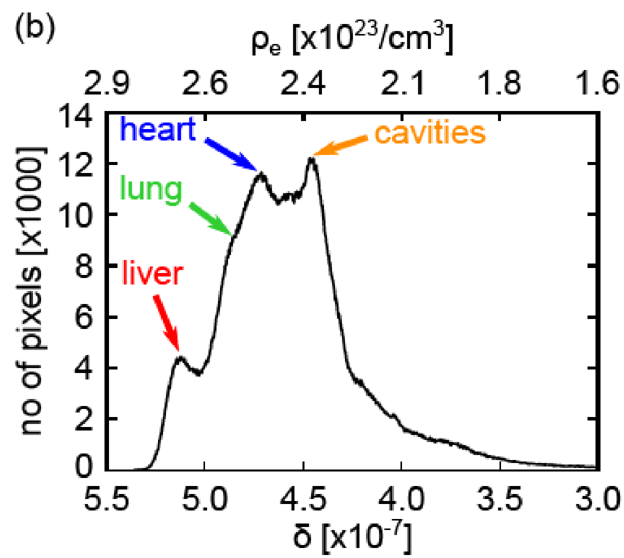
Diamond-Manchester Collaboration
D.S. Eastwood, P.D. Lee (UoM),
V. Yufit, F. Tariq, B. Wu, N.P. Brandon (Imperial)
A. Bodey, C. Rau (Diamond)

Phase-Sensitive Imaging



M.-C. Zdora, I. Zanette
I. Teh, Schneider (Oxford)



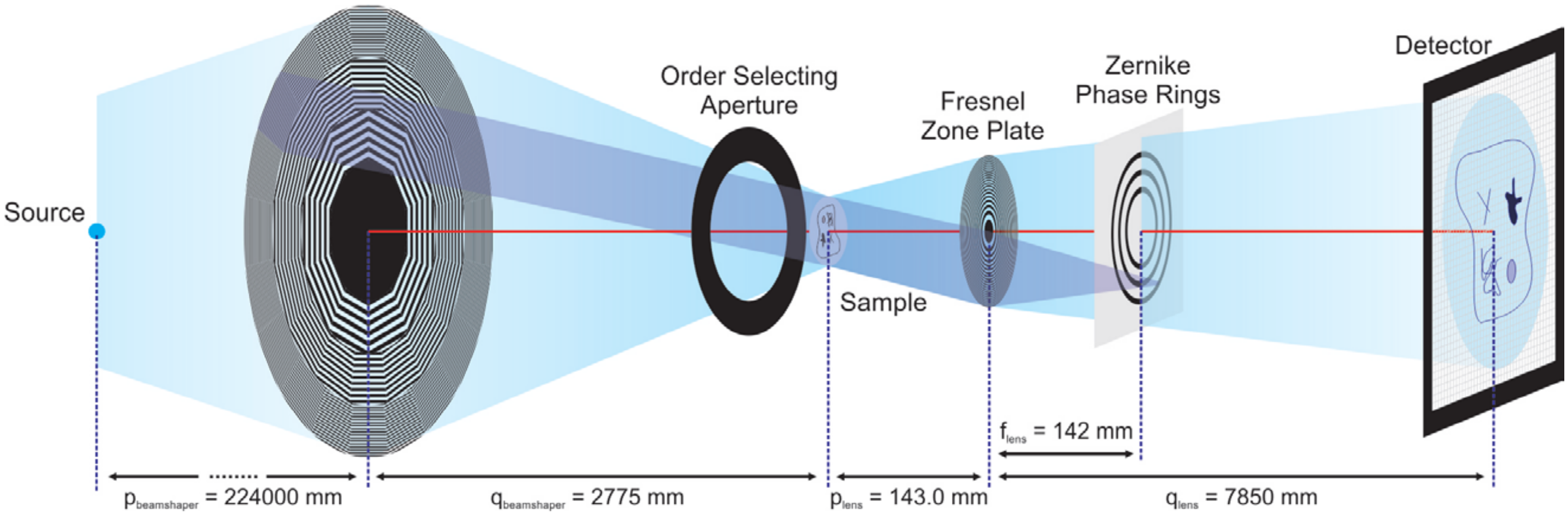


Science

related to

50 nm

Full-field X-ray microscope



Large field of view	~80-100µm^2
Long working distance	>50mm
Resolution	50-100 nm
E= 6-13keV	Zernike PC

t_{exp} some 100msec. -> multilayer mono, detector

Pilot experiments, user operation

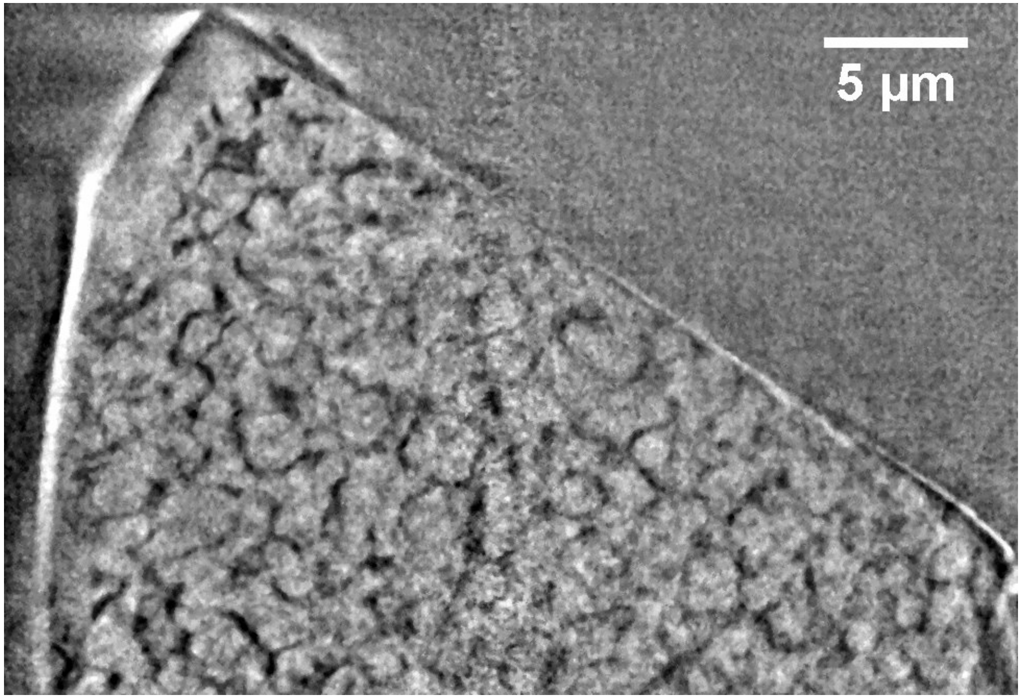
Project: M.Storm, S. Marathe, S. Cipiccia, J. Vila

Collaboration C. David (PSI), F. Doering , J. Bosgra

Graph: J. Vila

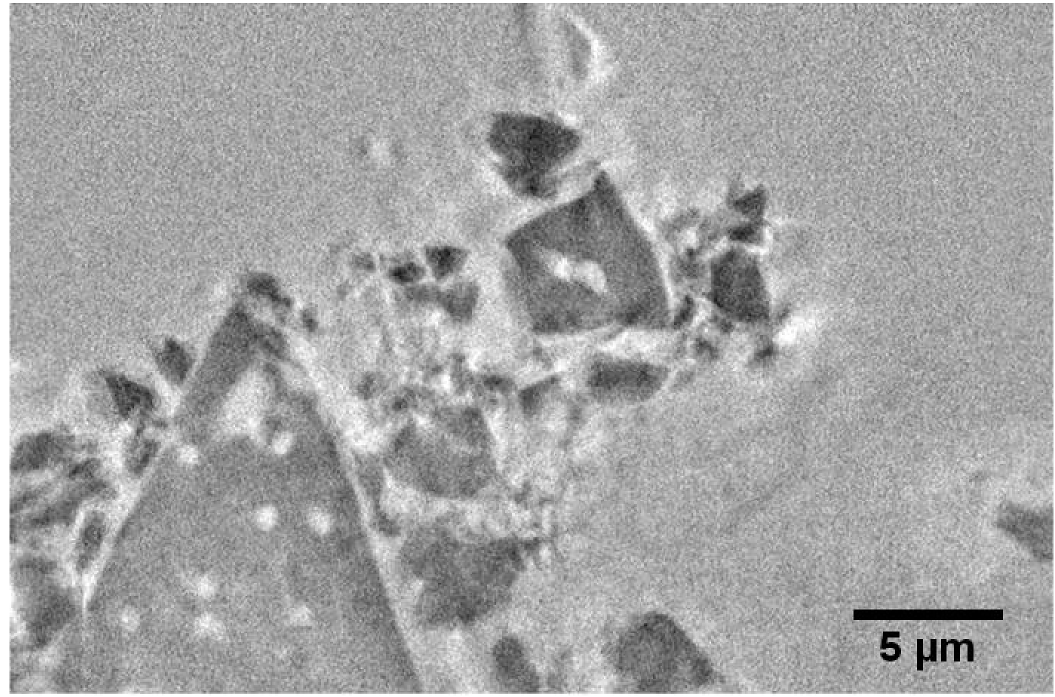
Nano - Tomography

Ni Particle from Solid Oxide Fuel Cell



courtesy of R. Bradley

Coir-based Supercapacitor Fibre



courtesy of D. Eastwood

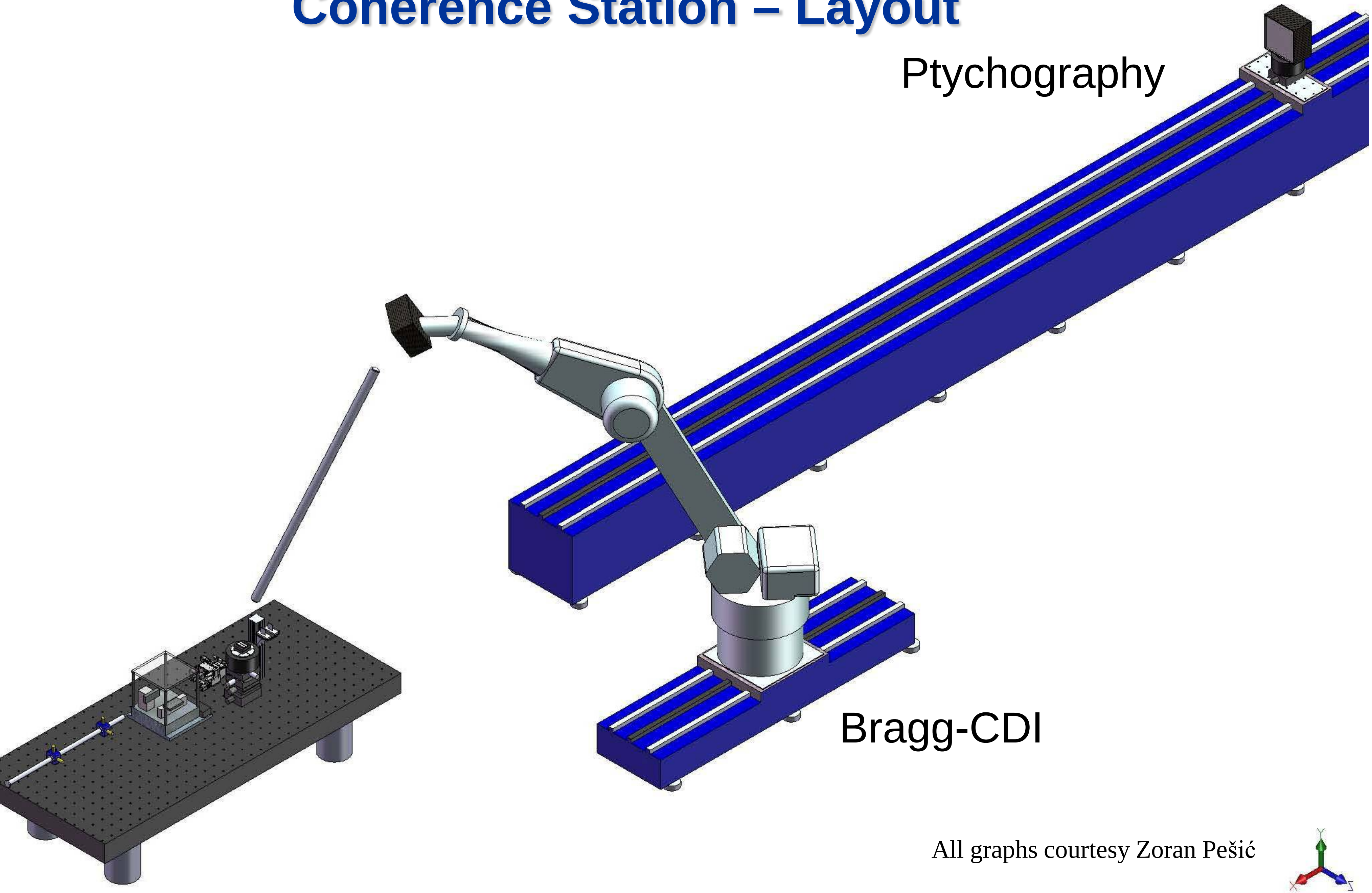
Image courtesy J. Vila coll. C. David/J. Bosgra

Science

related to

5 nm

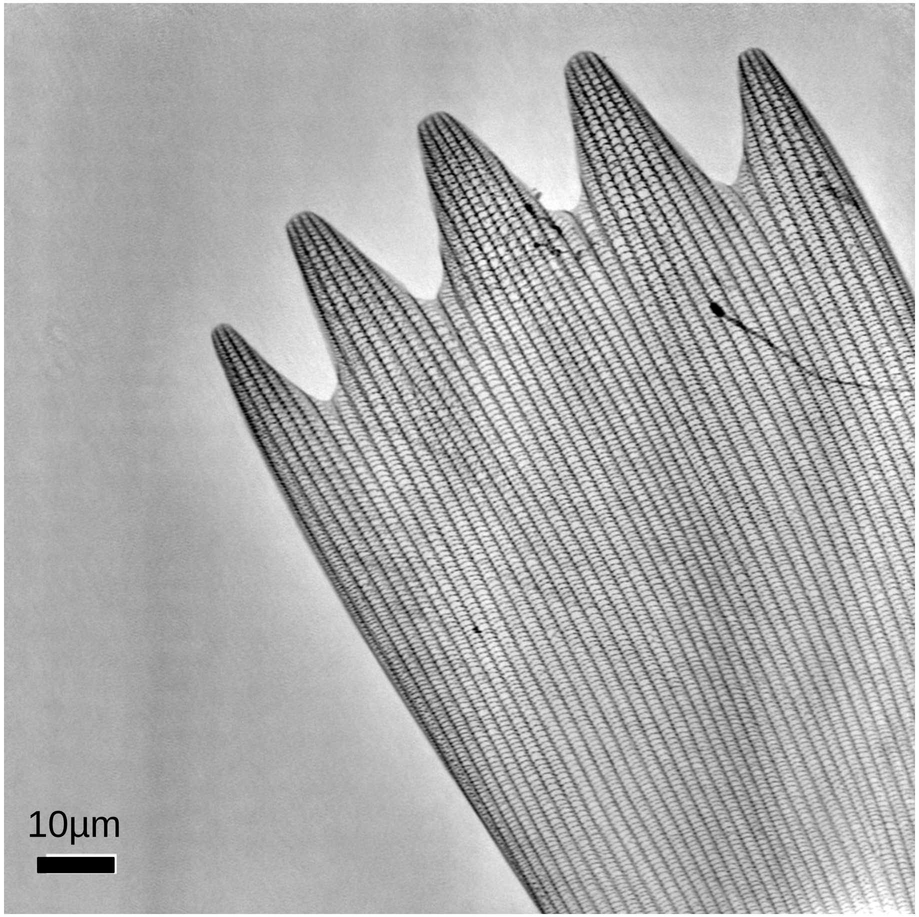
Coherence Station – Layout



All graphs courtesy Zoran Pešić

Coherence Branch: Ptychography

Butterfly wing



Experiment team P. Thibault, image Darren Batey

Ptychography:
Resolution beyond Detector and X-ray optics

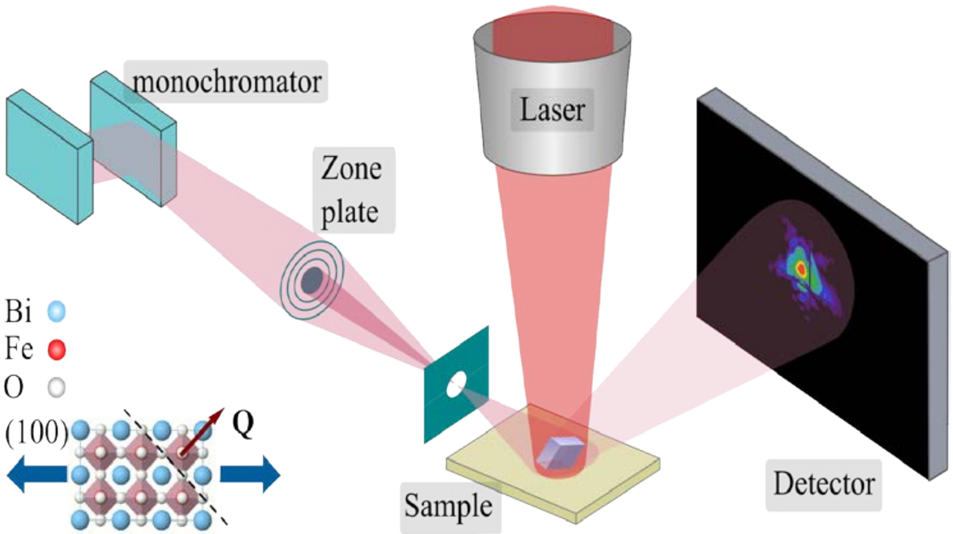
Resolution
Potentially ~5nm
Currently ~30nm

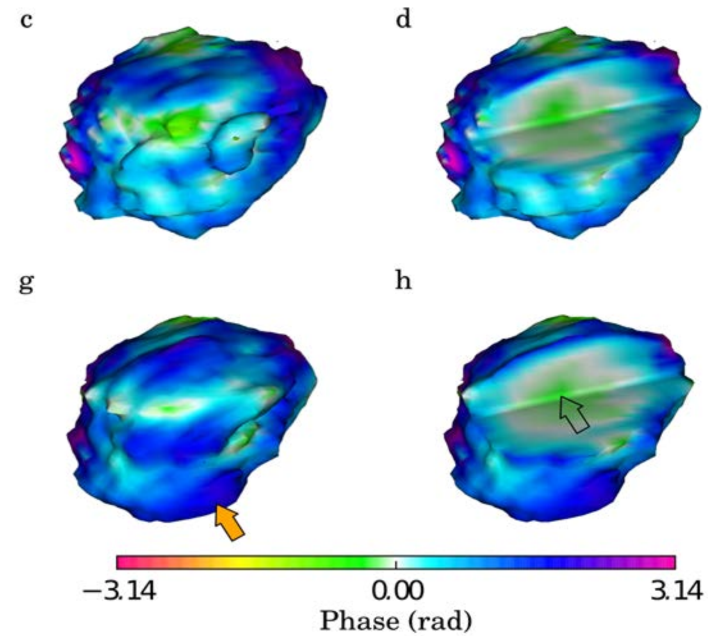
Overheads

Other: Bragg-CDI
Methods development

I13-1 Coherence Branch:

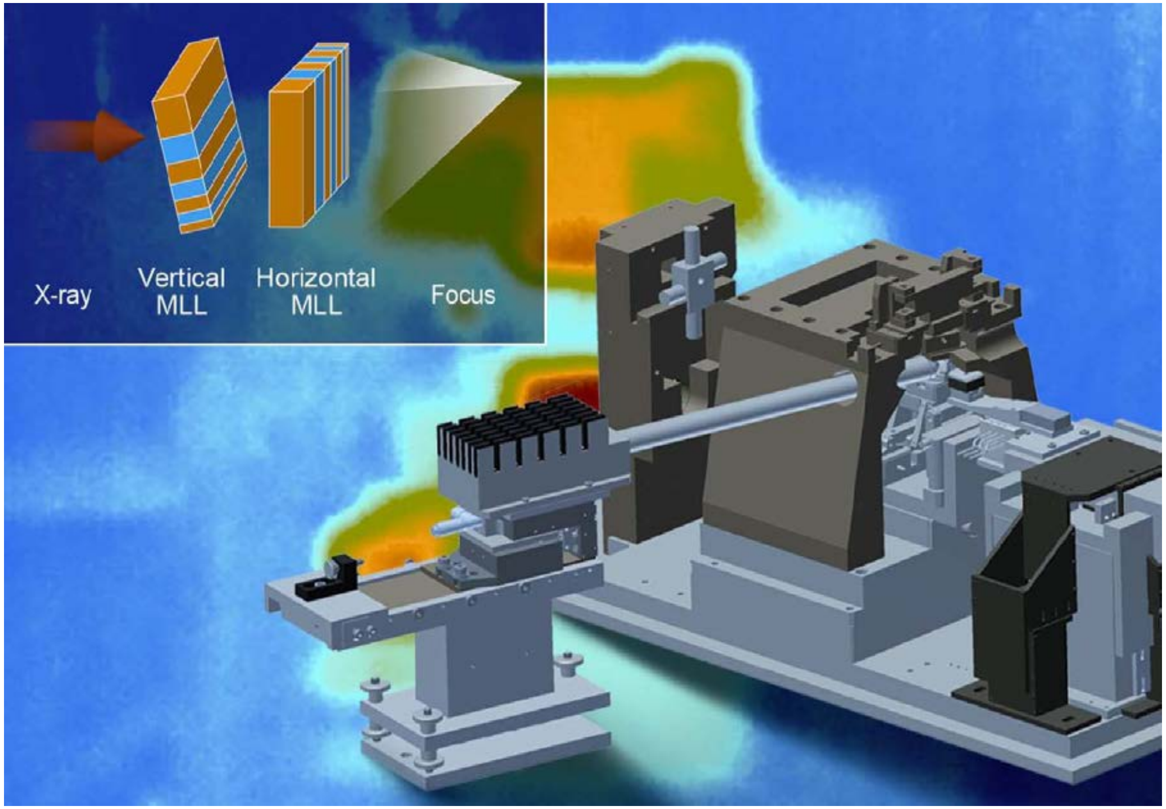
Bragg Coherent Diffraction Imaging of Photo-induced Structural Changes in $BiFeO_3$ Nanocrystals (M. Newton)





- Material for Solar Energy (Multiferroics)
- Crystal under illumination:
- Deformation and Stress recorded with coherent scattering
- Phase shift (right) represents stress on surface

Coherence Branch: MLL microscope



NSLS collaboration

Sub-20nm focusing in 2-D

Imaging chromosomes

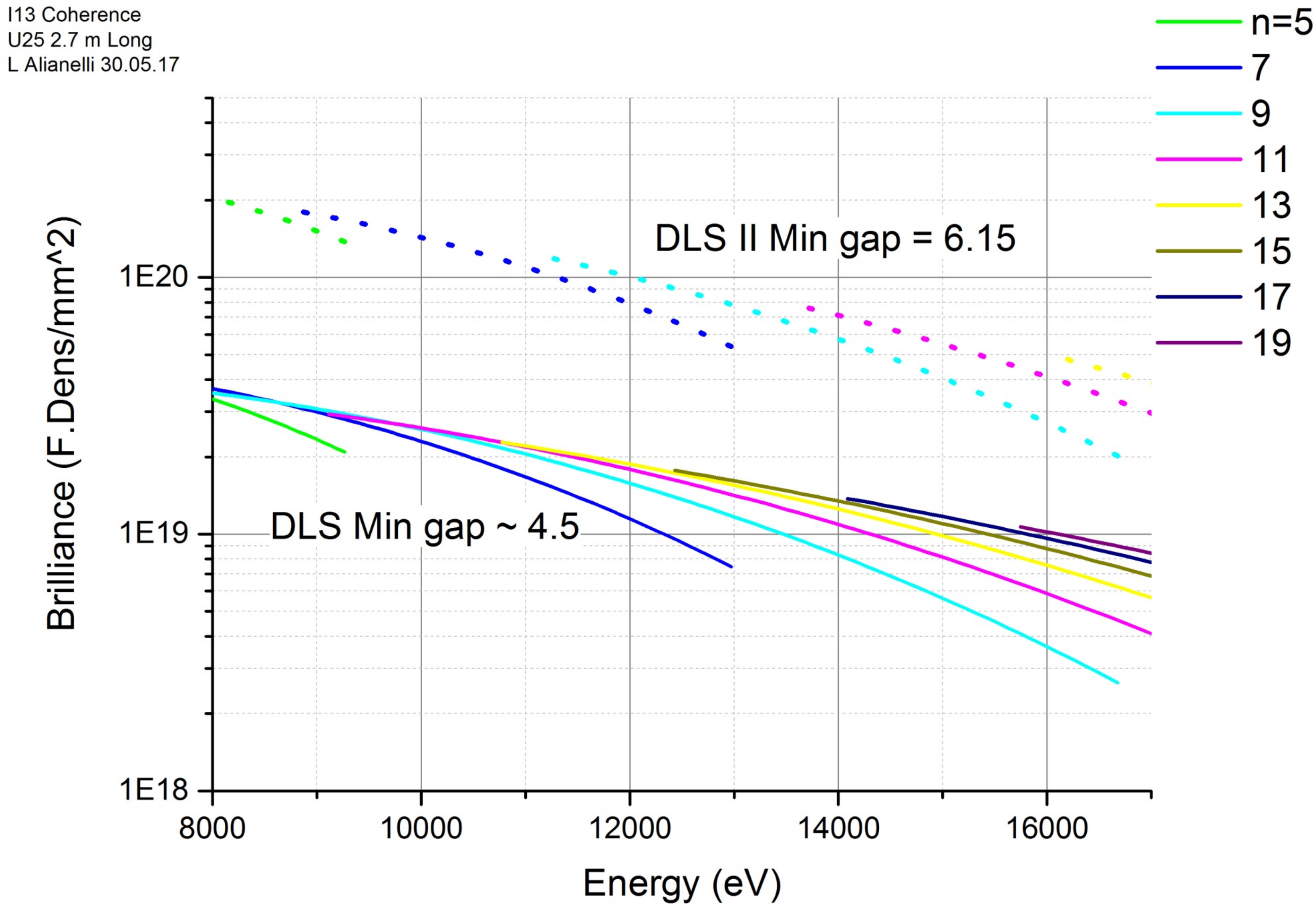
Multimodality hard-x-ray imaging of a chromosome with nanoscale spatial resolution, ***Nature*** *Scientific Reports* **6**, Hanfei Yan, Evgeny Nazaretski, Kenneth Lauer, Xiaojing Huang, Ulrich Wagner, Christoph Rau, Mohammed Yusuf, Ian Robinson, Sebastian Kalbfleisch, Li Li, Nathalie Bouet, Juan Zhou, Ray Conley, Yong S. Chu, 10.1038/srep20112

Journal Of Synchrotron Radiation **22**. 336 – 341, Evgeny Nazaretski, Kenneth Lauer, H. Yan, N. Bouet, J. Zhou, R. Conley, X. Huang, W. Xu, M. Lu, K. Gofron, Sebastian Kalbfleisch, Ulrich Wagner, Christoph Rau, Y. S. Chu 10.1107/S1600577514025715).

Diamond II upgrade

- Low emittance machine: 4BA; 6BA
- Emittance 20x lower; (120pm rad)
- Important for I13
- All beamlines ?
- Other aspects of upgrade?
- New opportunities:
  holography, speckle, grating

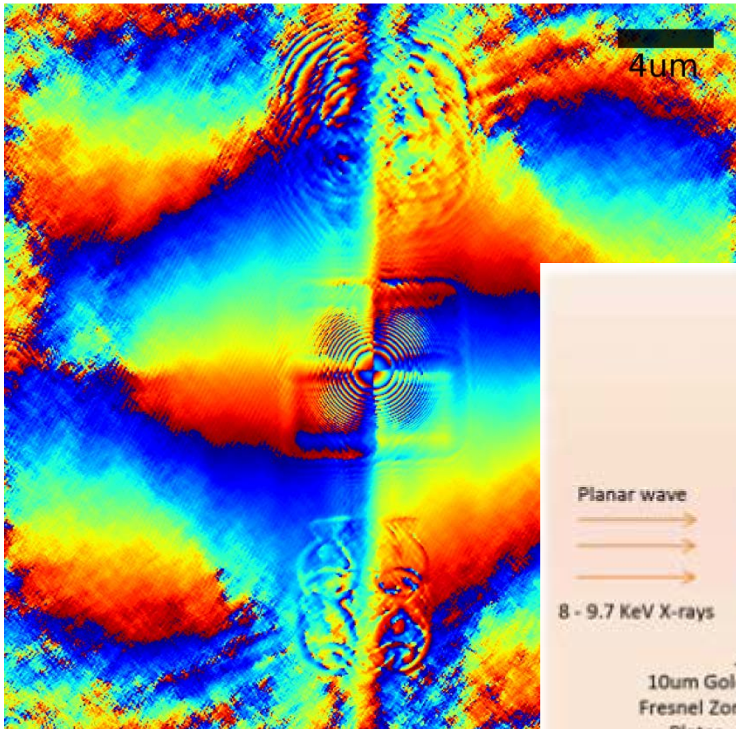
Diamond II upgrade : Gap



Diamond II upgrade

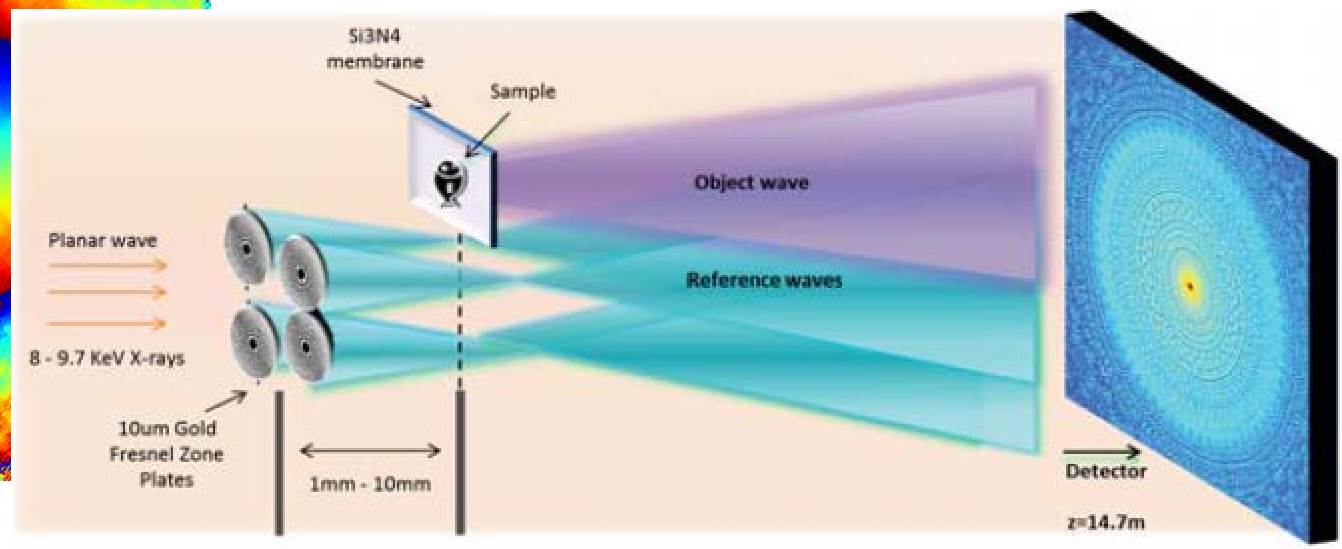
Holography, Speckle and grating

- Holography: Large FOV; t_{exp}~ sec



Holographic Image of Fish test pattern using an array of Zone plate

M. Saliba, P. Thibault (UCL)
U. Wagner, A. Parsons, C. Rau (Diamond)



- Speckle and grating:
  - Measurement of phase -> spectroscopy
  - Darkfield imaging -> phase formation, hierarchical structures

Summary

I13 Imaging and Coherence

- Imaging in direct and reciprocal space
  on Micro- and Nano-Lengthscale
- In-situ studies with dedicated sample environment
- Broad field of scientific applications: Bio-medical, materials sciences, archeology,…

Upgrade

- Increased brilliance important
- Other aspects: ID gap & new methods
- Community

Acknowledgements

I13 team

Imaging

Malte Ogurreck, Andrew Bodey, Shashidhara Marathe, Silvia Cipiccia

Coherence

Ulrich Wagner, Xiaowen Shi, Darren Batey & Silvia

Technician

Simon Logan

PDRA

Irene Zanette

PhD

Marie-Christine Zdora, Charan Kuppili, Elizabeth Reed, Simone Sala

Former Staff

Zoran Pešić, Alberto De Fanis, Aaron Parsons, Joan Vila-Comamala, Mirian Garcia-Fernandez, Mirna Saliba

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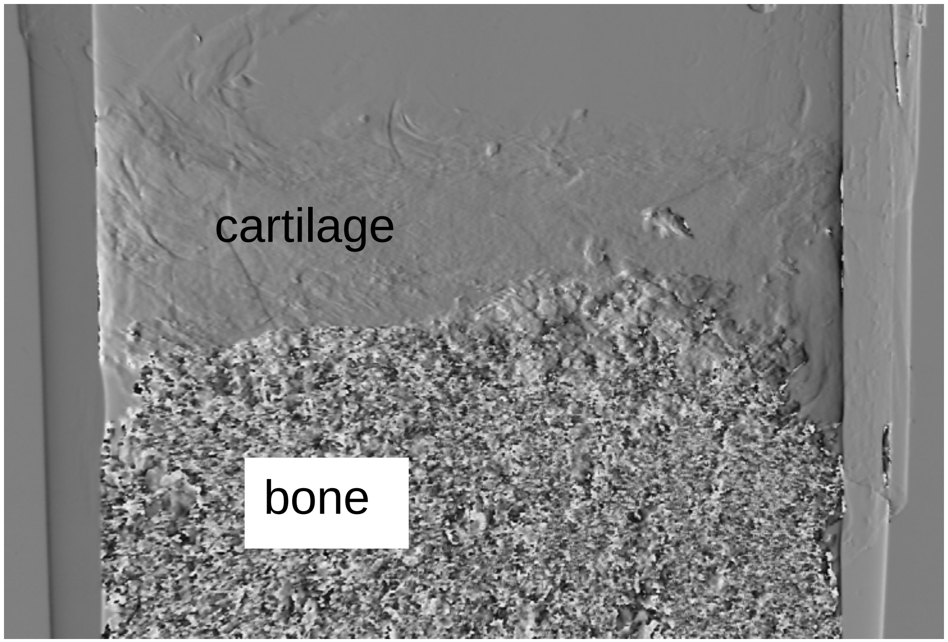
- Collaborators:

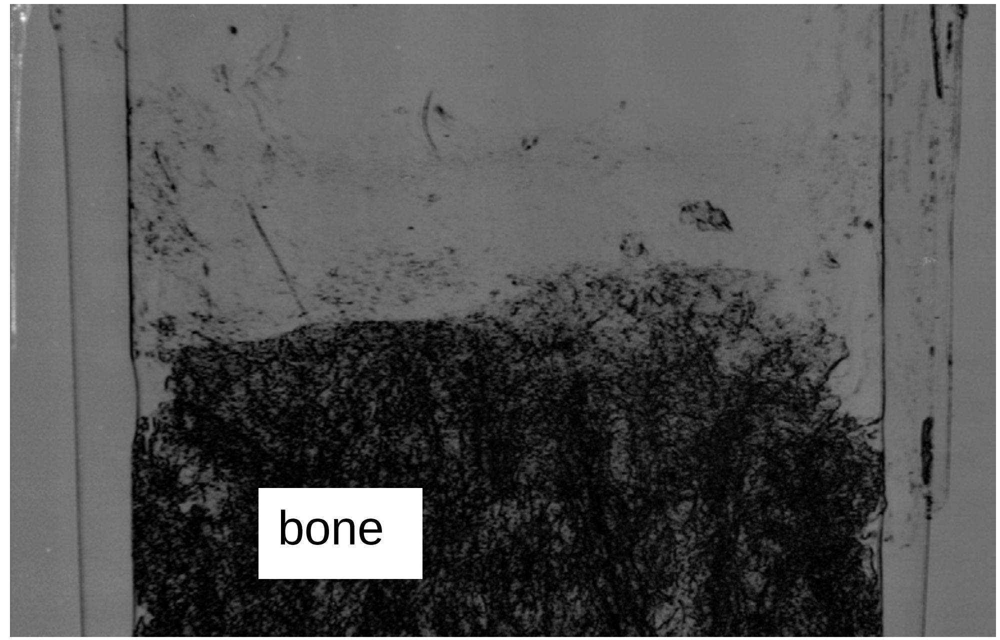
- N. Bourne, D. Eastwood, S. Jacques, P. Lee team
- P. Thibault, S. Sala
- Ian Robinson
- Marcus Newton
- Simon Redfern, Oscar Branson, Lil Read
- Yong Chu, Evgeny Nazaretski

Grating Interferometry

Differential phase



Dark-field signal



- Bone and cartilage chemically similar
- Small angle scattering very different
- Can apply for turtuosity in battery materials (specific surface)

Slide courtesy B. Mueller