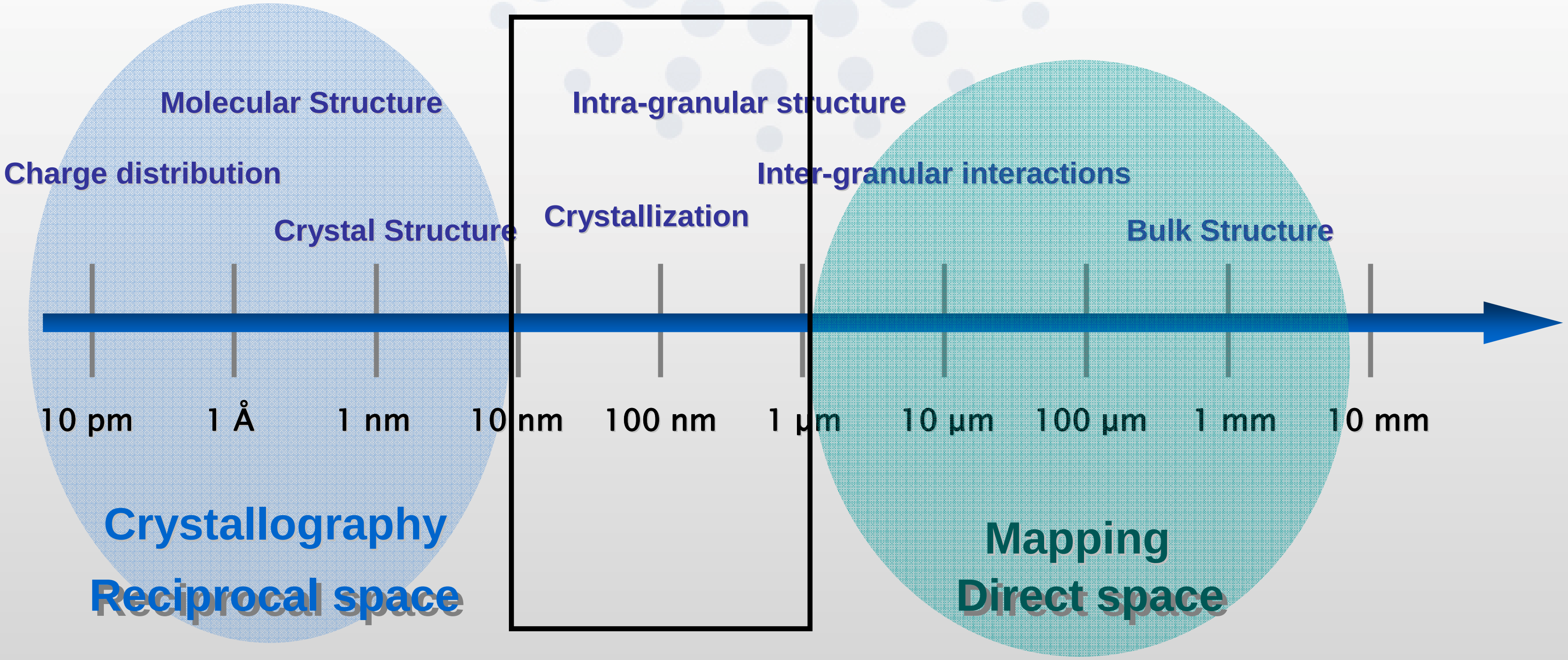
Implementation

Toward Nanoscale?



New Science
In the scale gap

Precision and Detail

- **Reciprocal space** methods classically measure average properties to a high precision
- Generally utilise periodic samples
- Extension to non-crystalline or semicrystalline samples and the measurement of inhomogeneity
  - Pair Distribution Function analysis
  - Total Scattering
- **Direct space** methods can measure local inhomogeneities
- Extension to shorter length scales is a serious but achievable technical challenge
  - Very rigorous implementation to achieve high accuracy results
- Ultimately we aim for simultaneous hierarchical characterization
- Collect high-energy, quantitative data on all length scales, of the distributions of properties

Single Crystal Studies

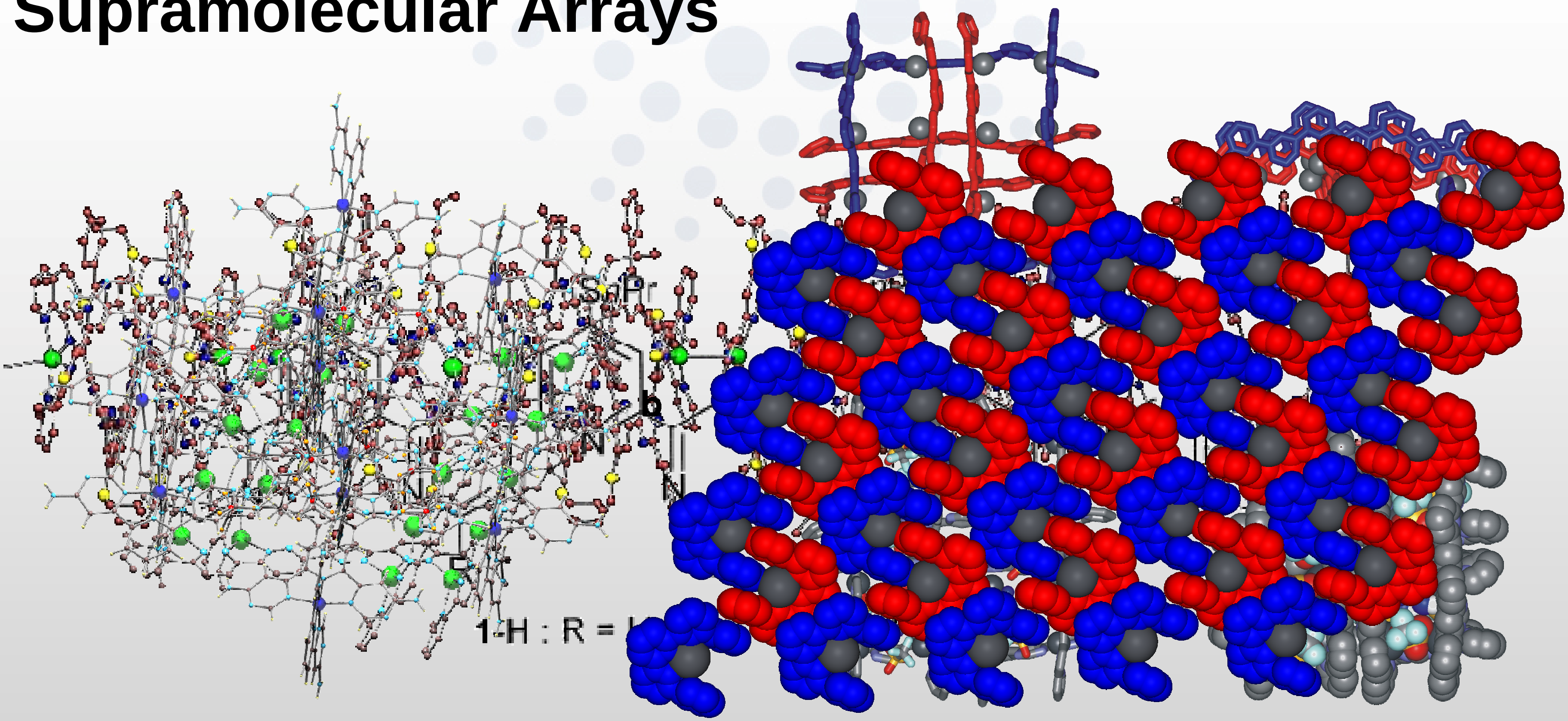
Small and bad crystals

- 10s of microns
- Bad mosaic / twinning
- Air sensistivity

Fine details

- Spin-Flip systems
- Orbital Ordering
- CDW
- (Incommensurate) Superlattices
- (Anomolous Diffraction)

Supramolecular Arrays



c d

Self-assembly into complex structures

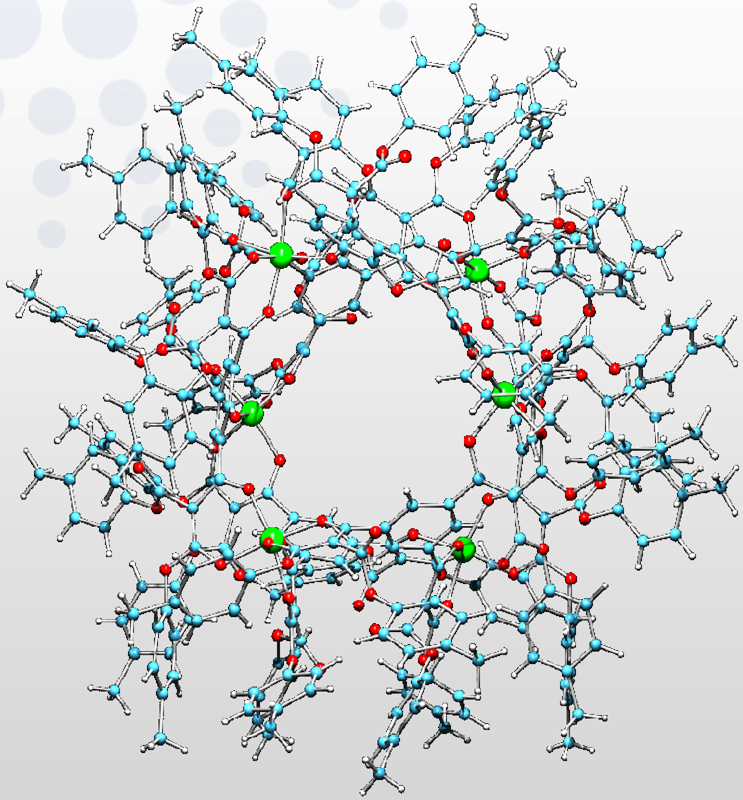
- Ligand Self-assembles into complex grids, helices, zippers …
- Information storage

Lehn Group, Barboiu Group 1998-2008

Self-Assembled Organometallic

Weak intermolecular forces
Frustration
- •Packing
- •H-bonding
- •Ionic interaction

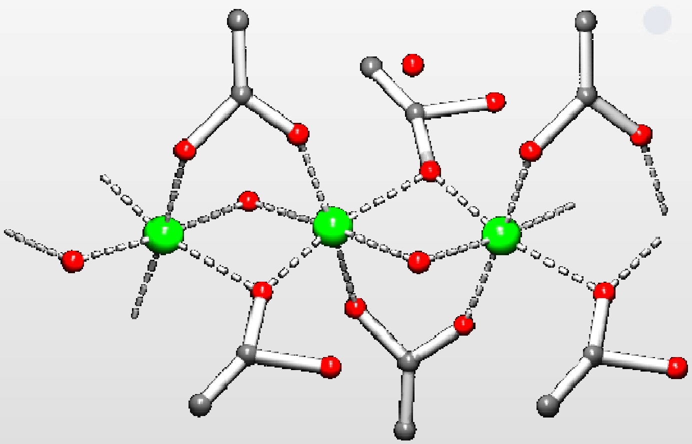
➔ Small, Poor Unstable Crystals

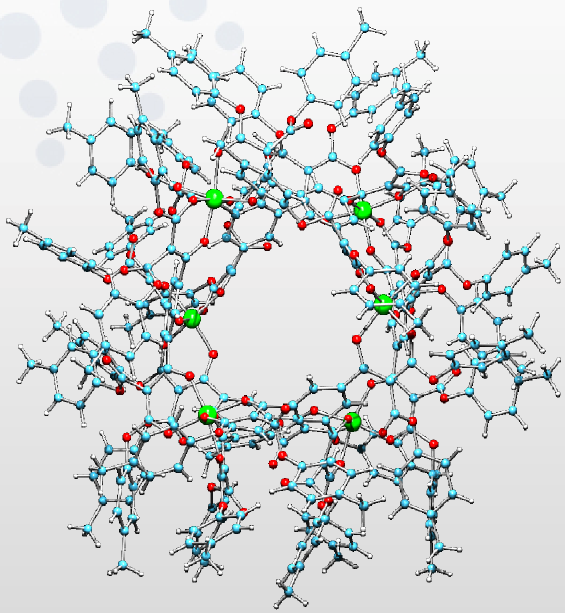


10s microns, twinned, air sensitive, poor mosaic single crystal
Solved, refined with 5000 parameters

Saalfrank et al., *Chem. Eur. J.,* 8(2) 493 (2002).

Solving/Refining Crystal Structures: Bridge the Gulf…



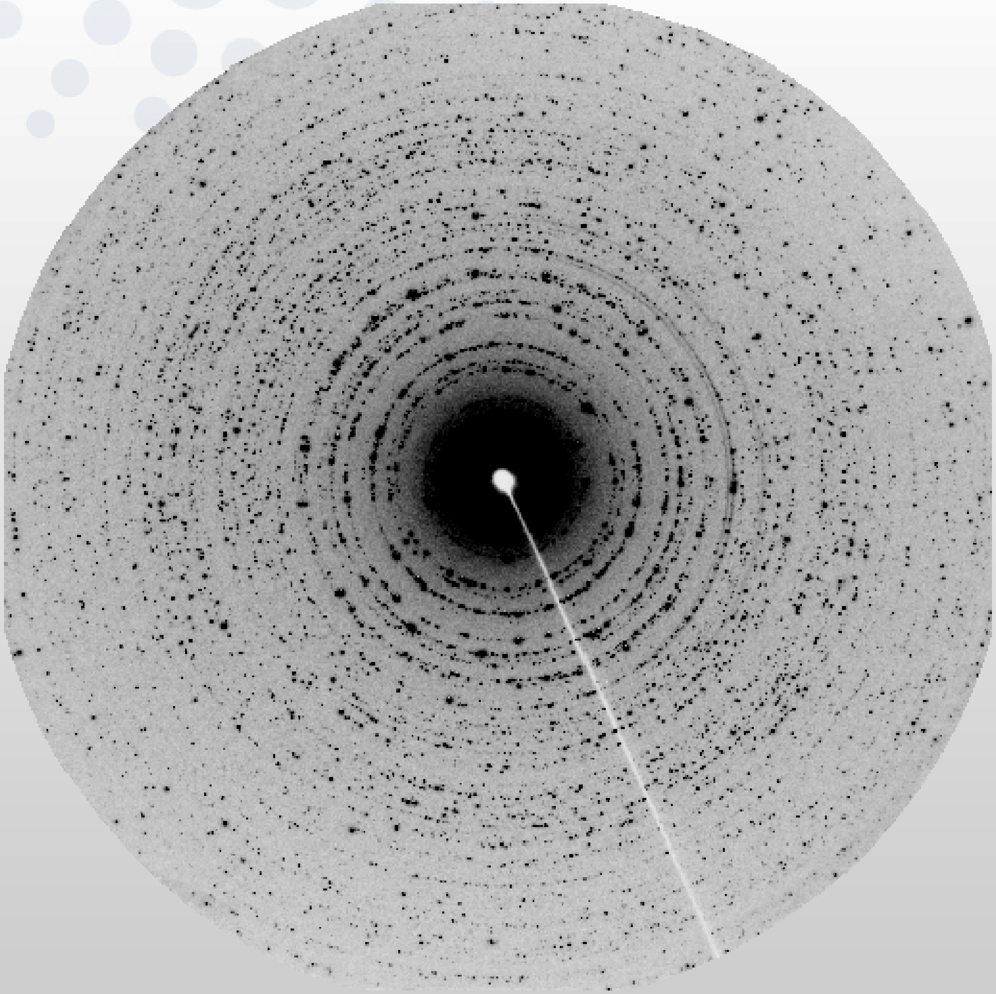


Powder/CCD
35 parameters
Data Collection 1 s

Single Crystal/CCD
5000 parameters
Data Collection 1h

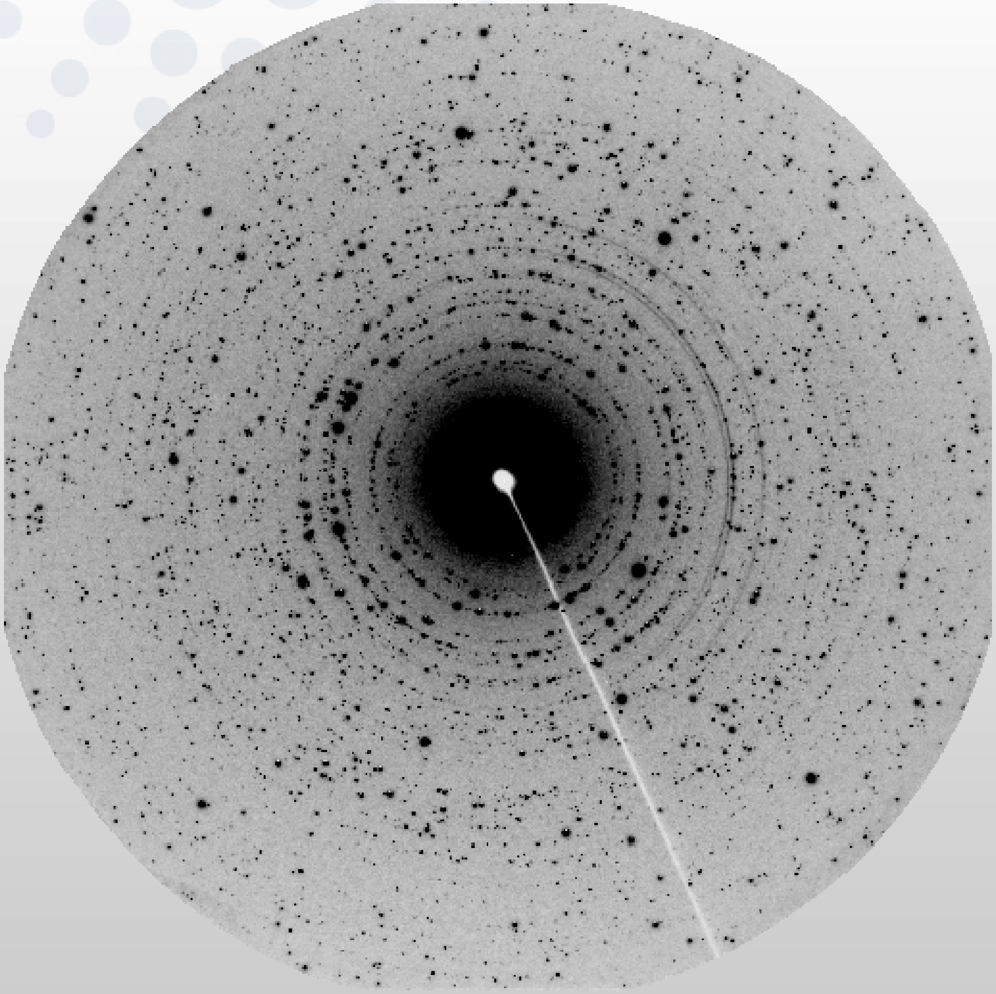
Make a powder into a bunch of single crystals we could index

1000 micron beam
+ turning



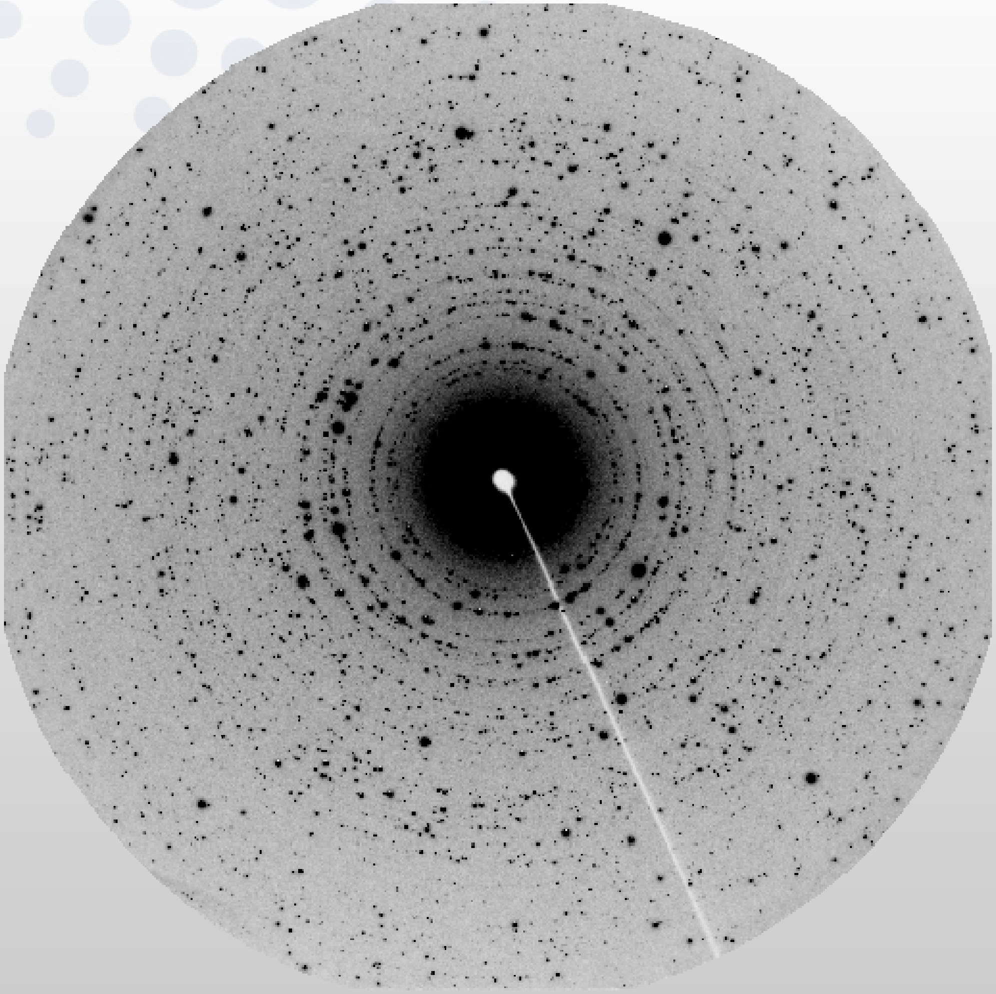
Make a powder into a bunch of single crystals we could index

1000 micron beam



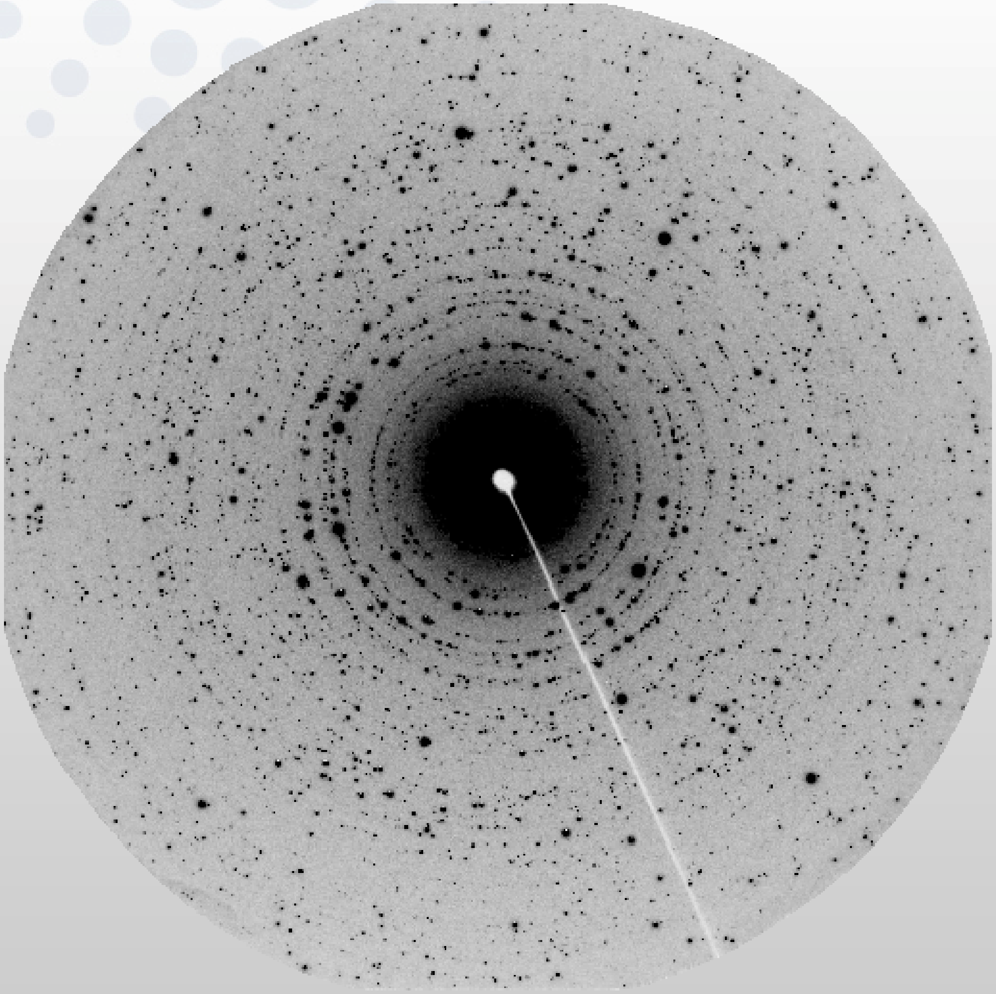
Make a powder into a bunch of single crystals we could index

900 micron beam



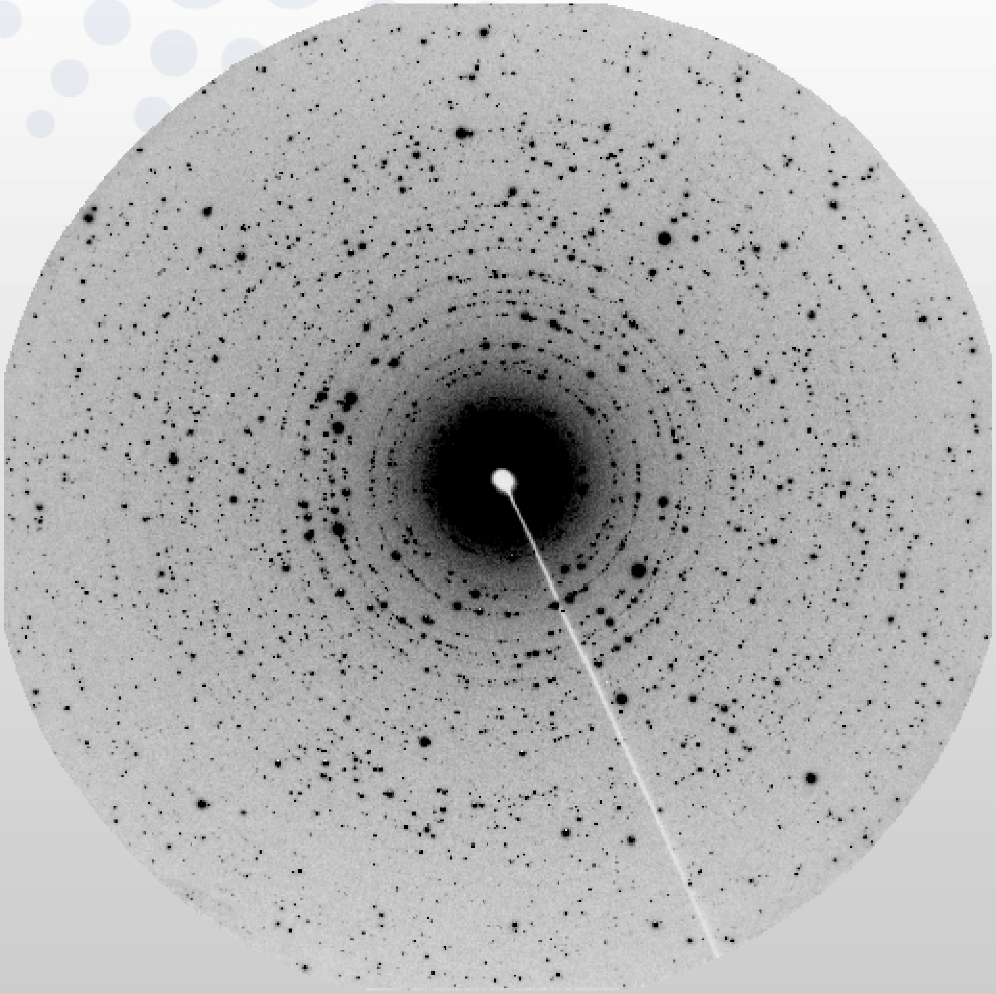
Make a powder into a bunch of single crystals we could index

800 micron beam



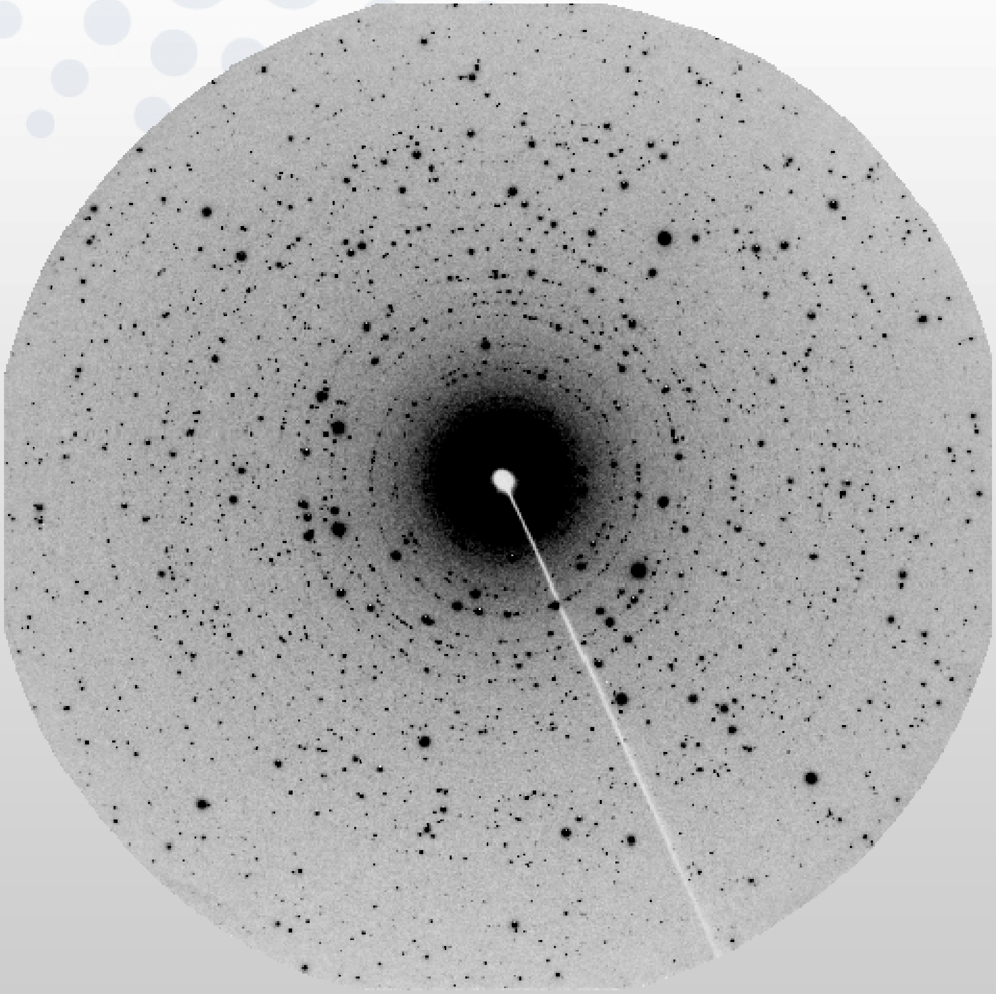
Make a powder into a bunch of single crystals we could index

700 micron beam



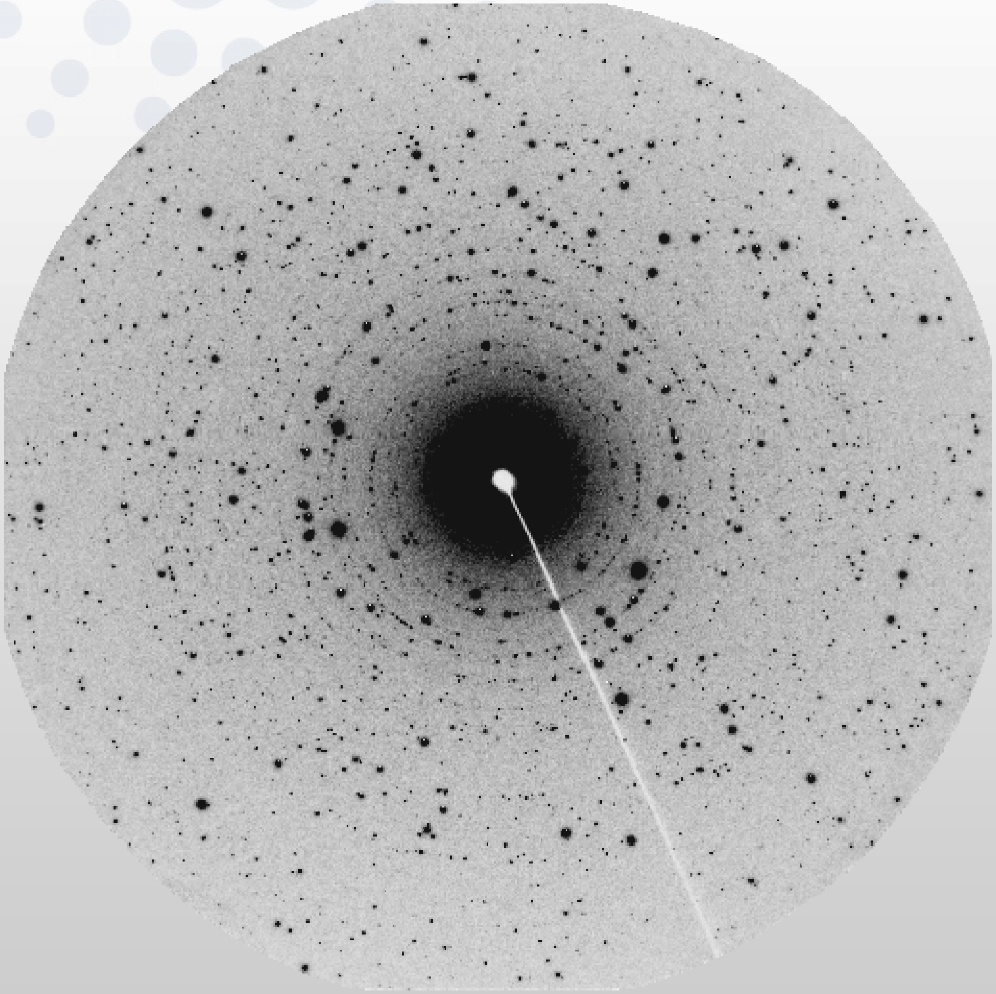
Make a powder into a bunch of single crystals we could index

500 micron beam



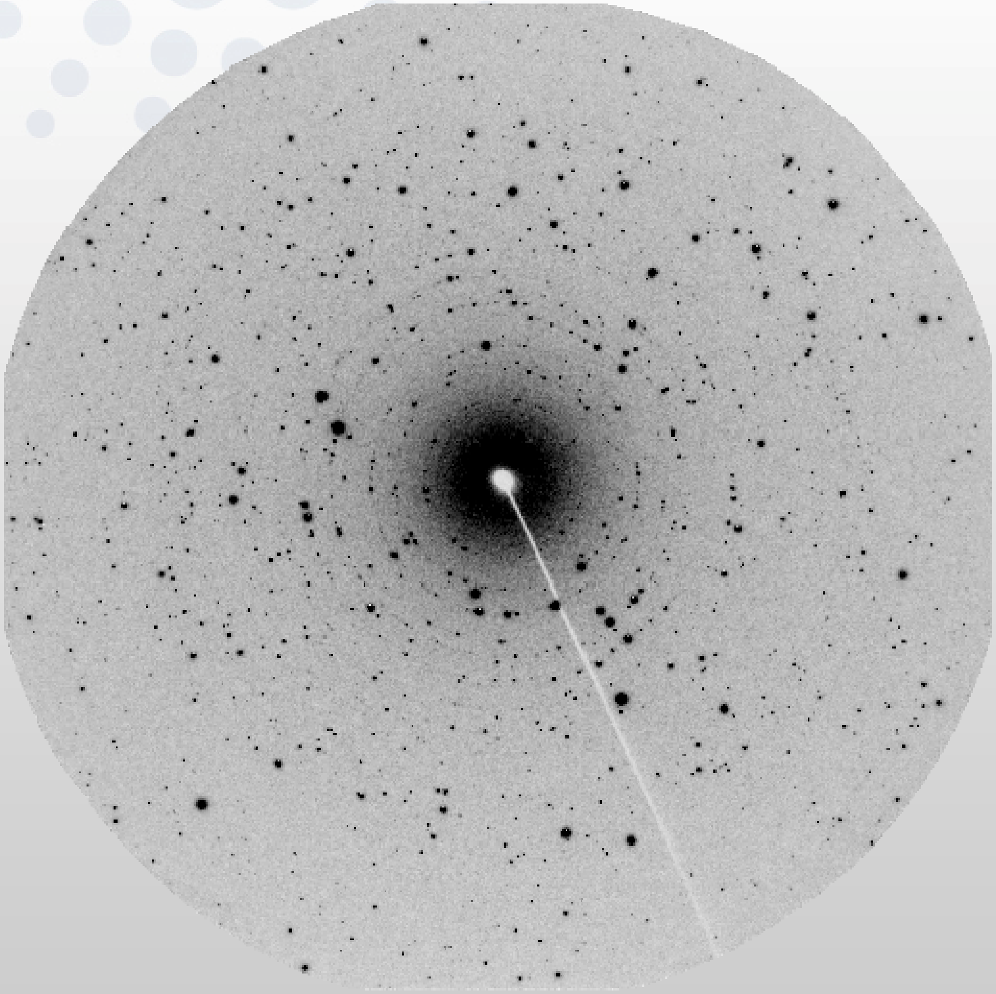
Make a powder into a bunch of single crystals we could index

400 micron beam



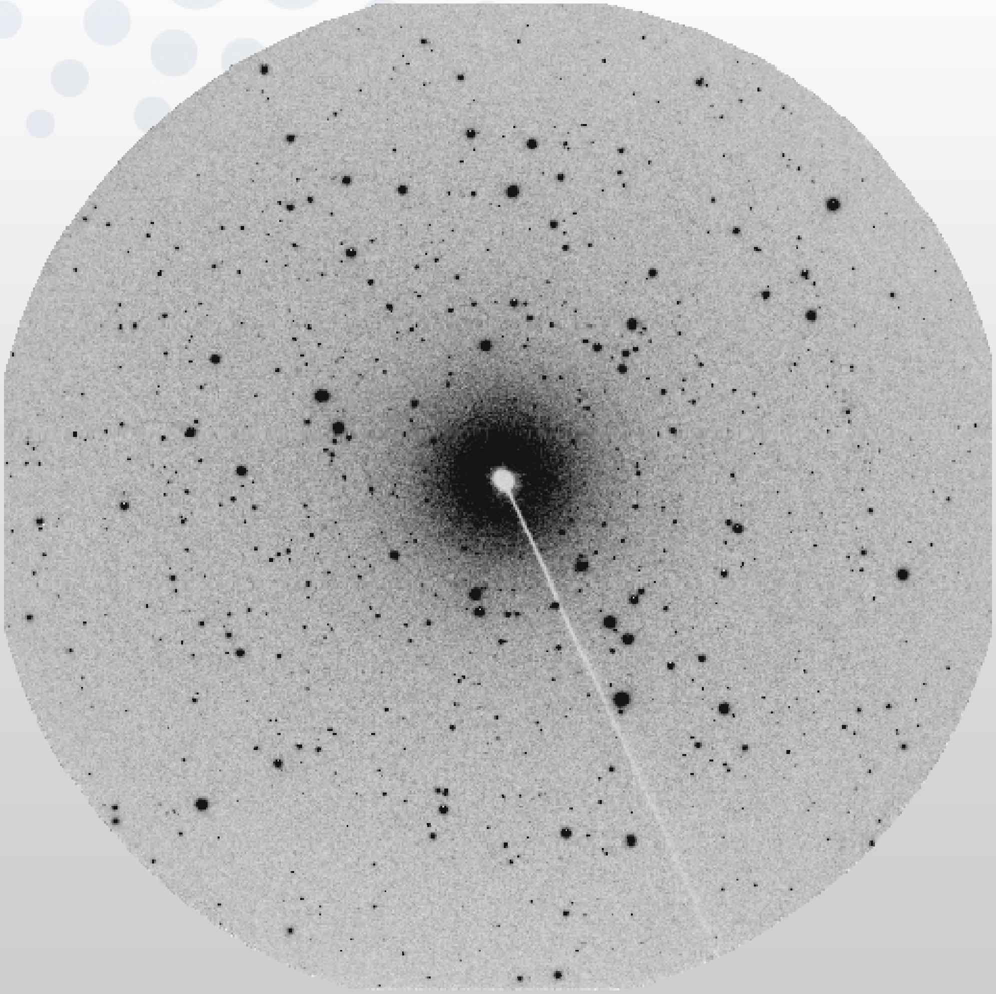
Make a powder into a bunch of single crystals we could index

300 micron beam



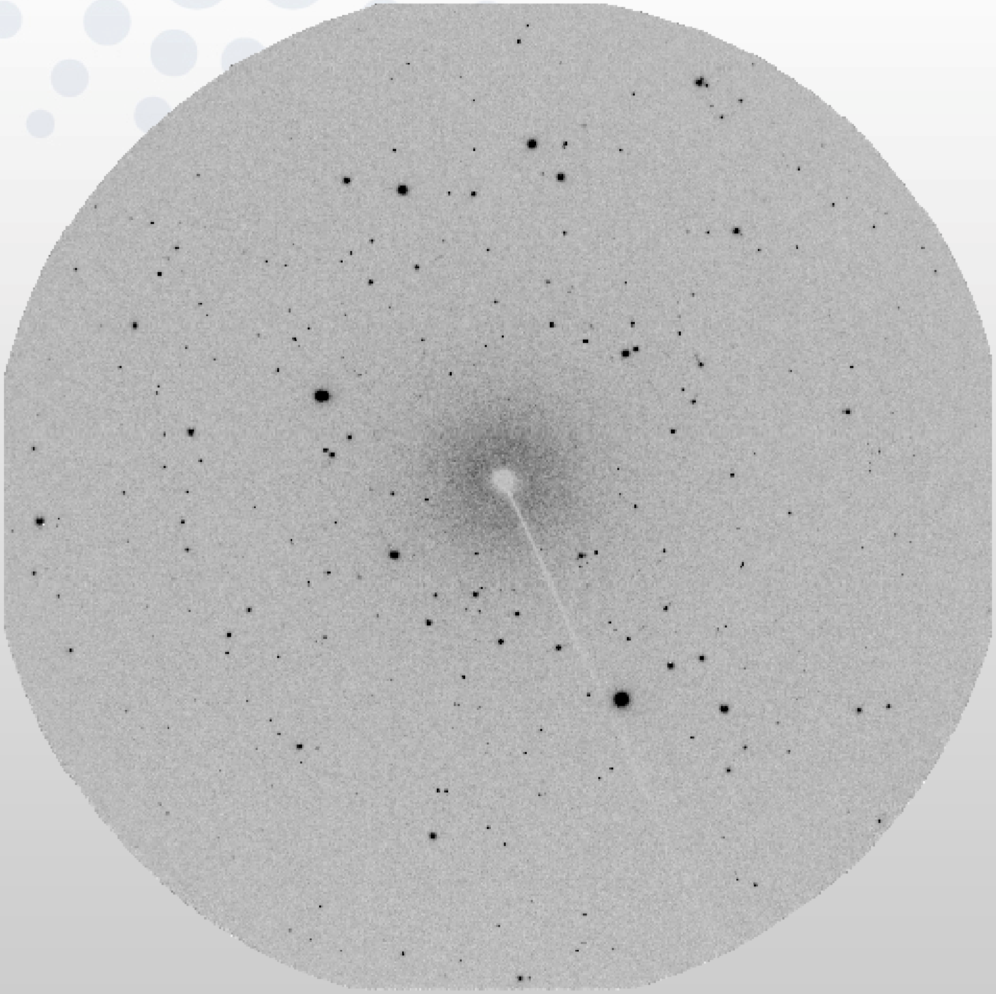
Make a powder into a bunch of single crystals we could index

200 micron beam



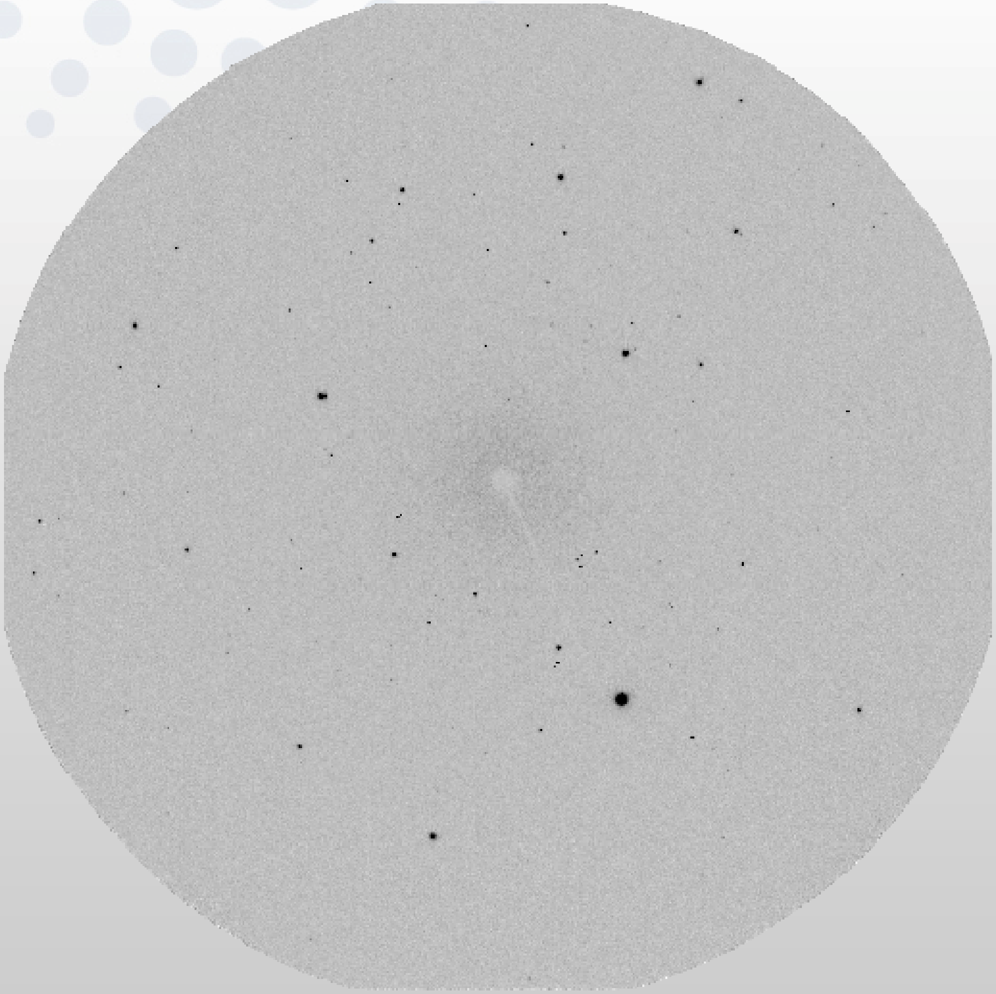
Make a powder into a bunch of single crystals we could index

100 micron beam



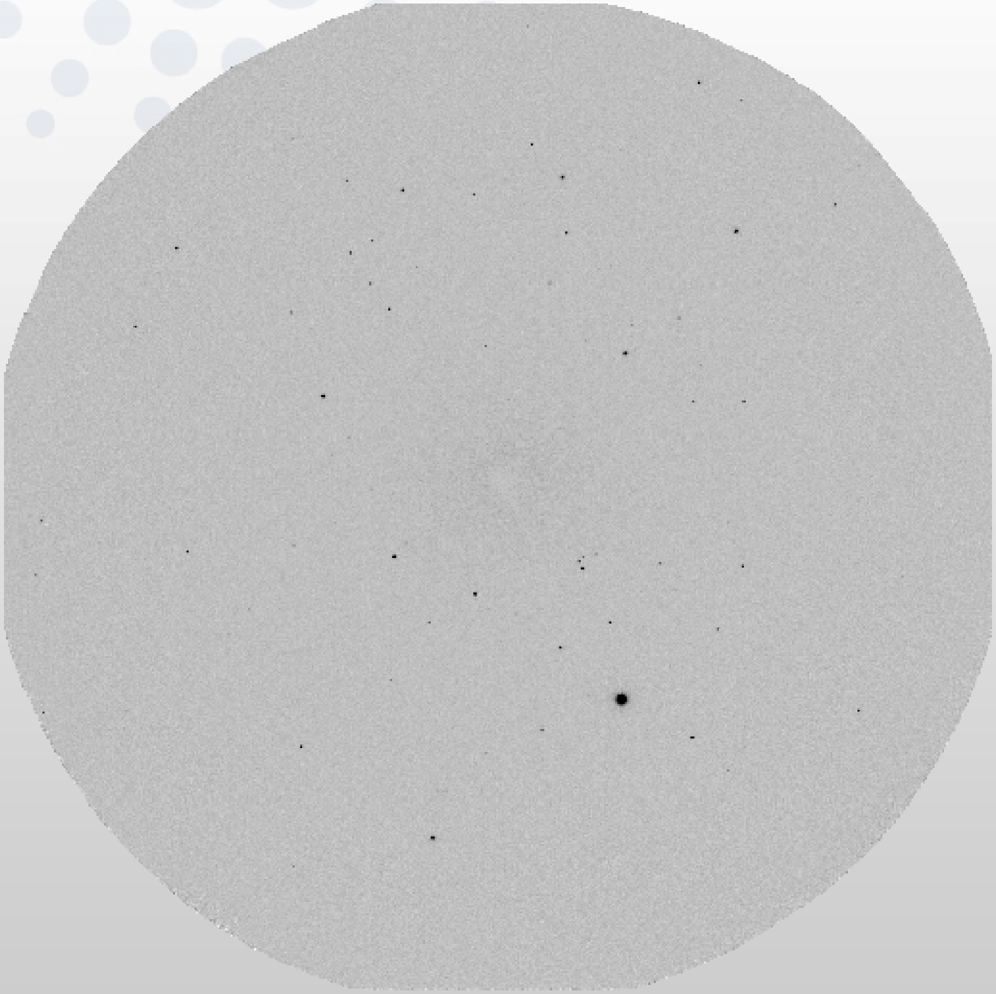
Make a powder into a bunch of single crystals we could index

50 micron beam



Make a powder into a bunch of single crystals we could index

30 micron beam



Experimental Realization

ID11 @ ESRF

Moderate to high energy (25 – 100 keV)

- Absorption
- Extinction
- Resolution

Data: set of 2d rotation images

- CCD camera

Small beam size

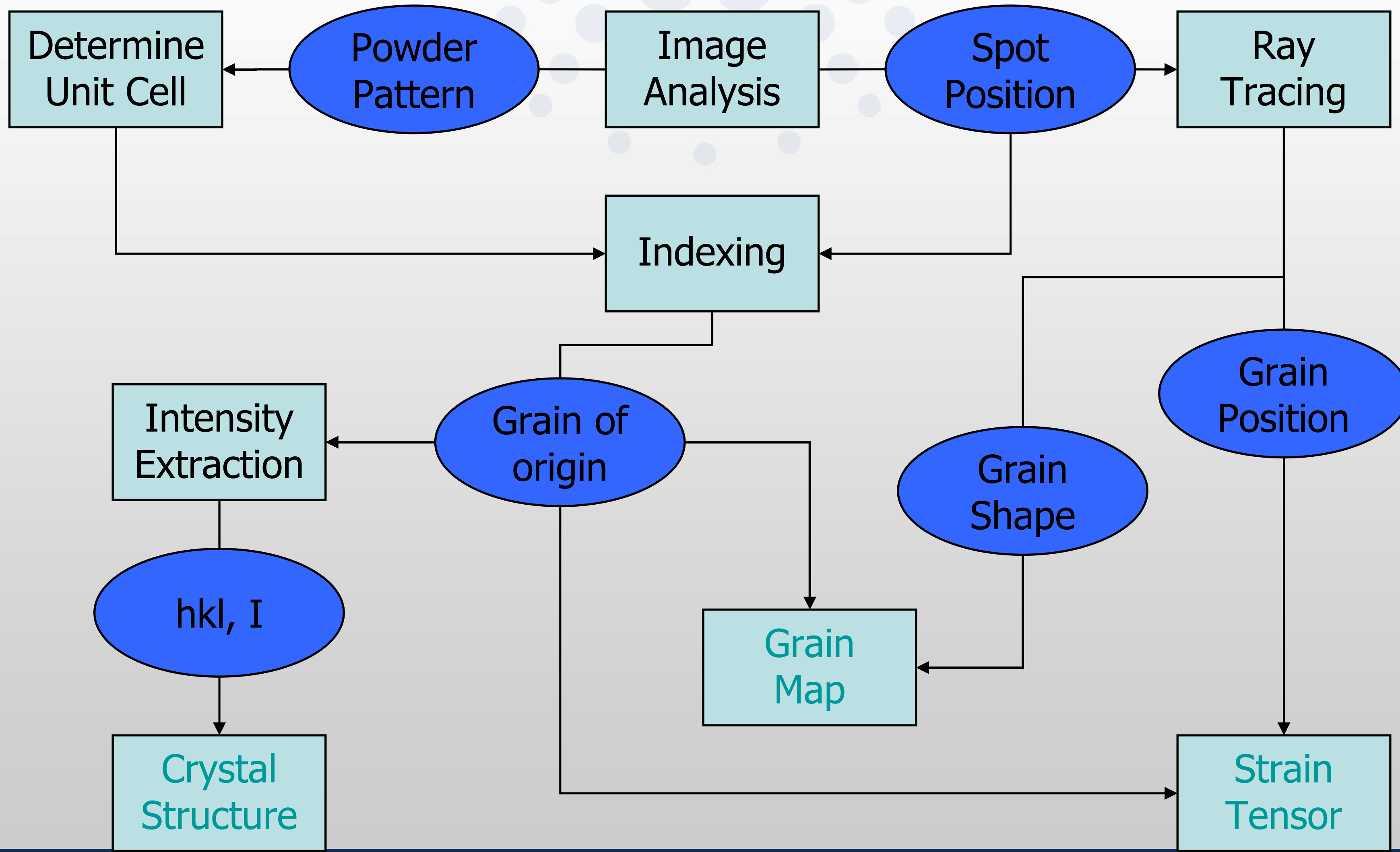
- Down to 2 x 5 μm^2 (50 x 150 nm^2 – 2007)
- Tunable

Fast acquisition

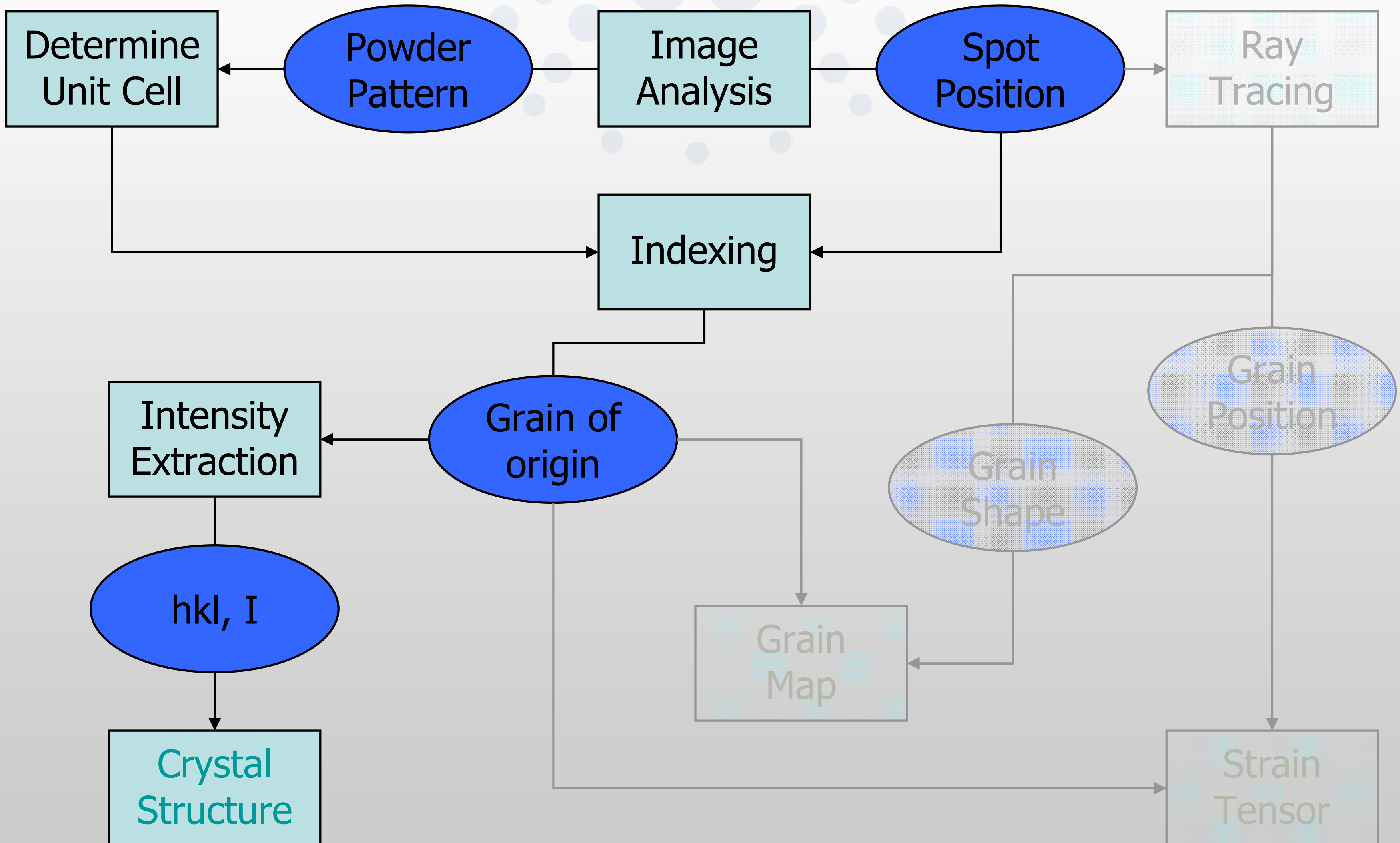
- 100 s / complete data set
- (powder – 10 ms)

Detector (budget) limited

Flowchart for 3dxrd



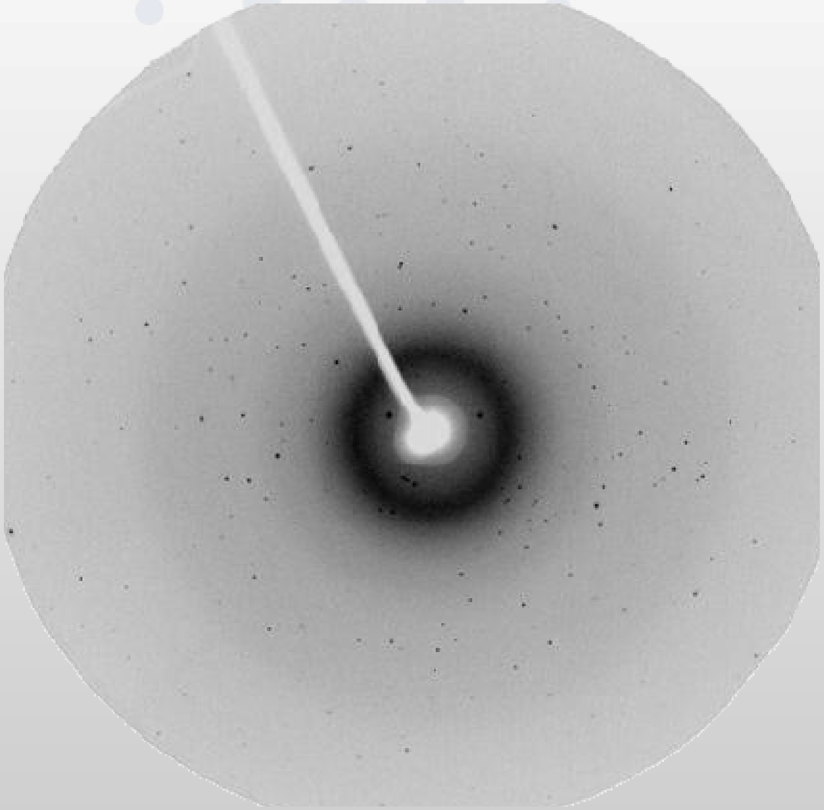
Flowchart for 3dxrd



Determination of Unit cell

Mean – Median pixel by pixel image

- Pseudo-powder pattern
- Averages out errors



Determination of Unit cell

Mean – Median pixel by pixel image

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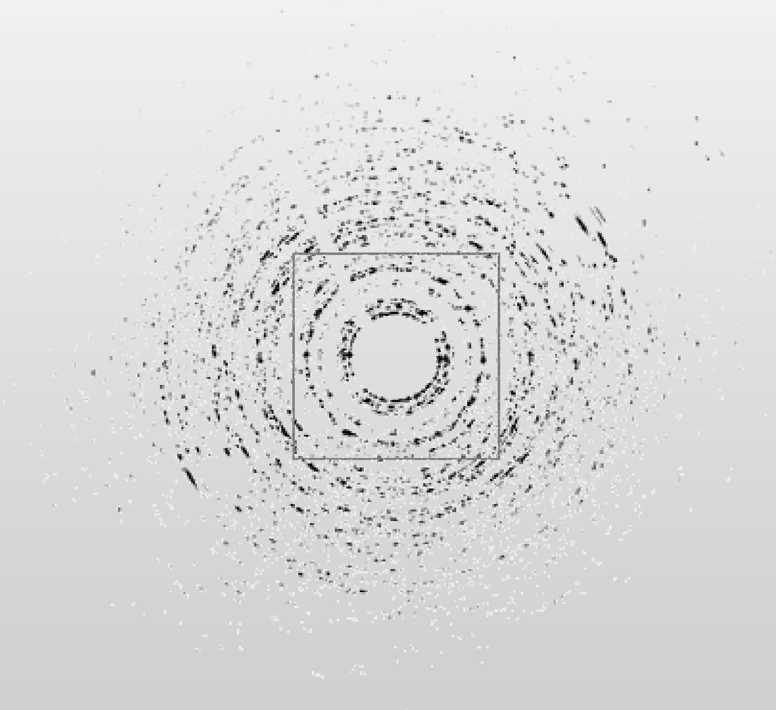


Determination of Unit Cell

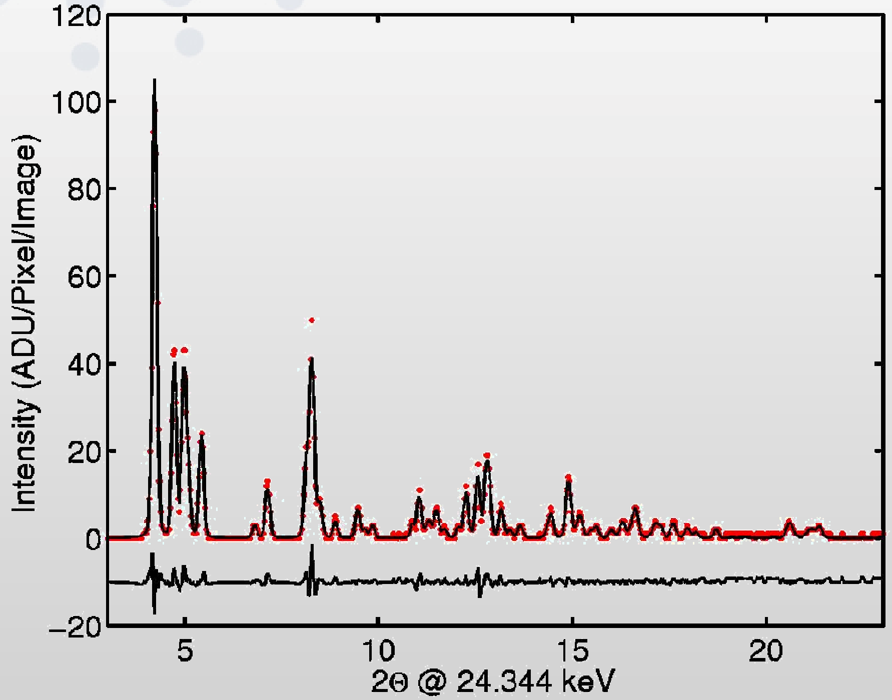
Energy known

Detector calibrated with *e.g.* LaB_6

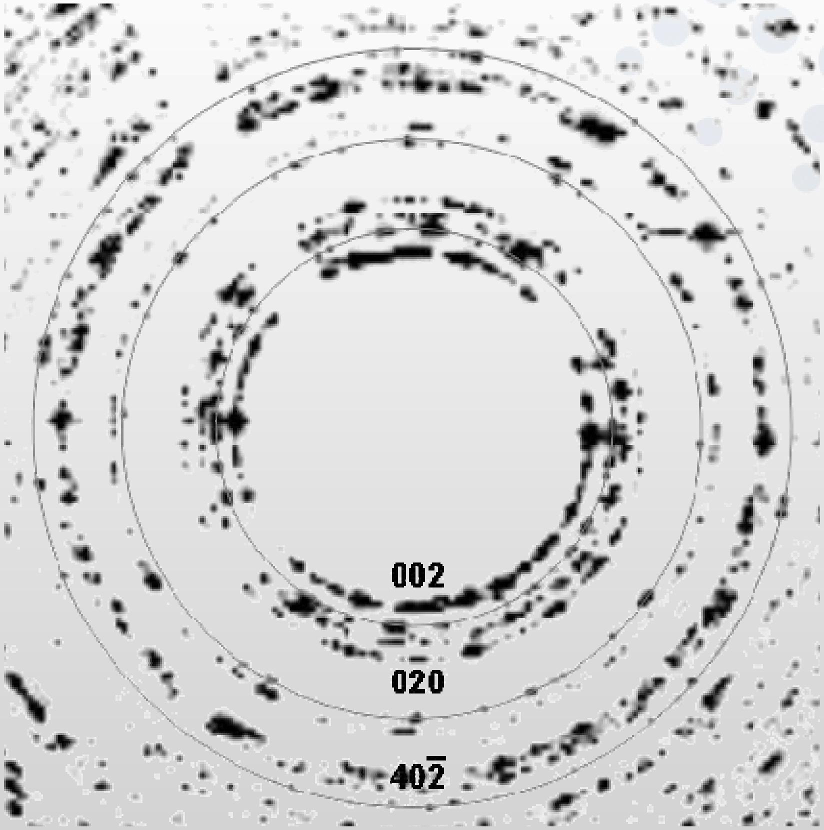
- Distance
- Effective pixel size
- Tilts

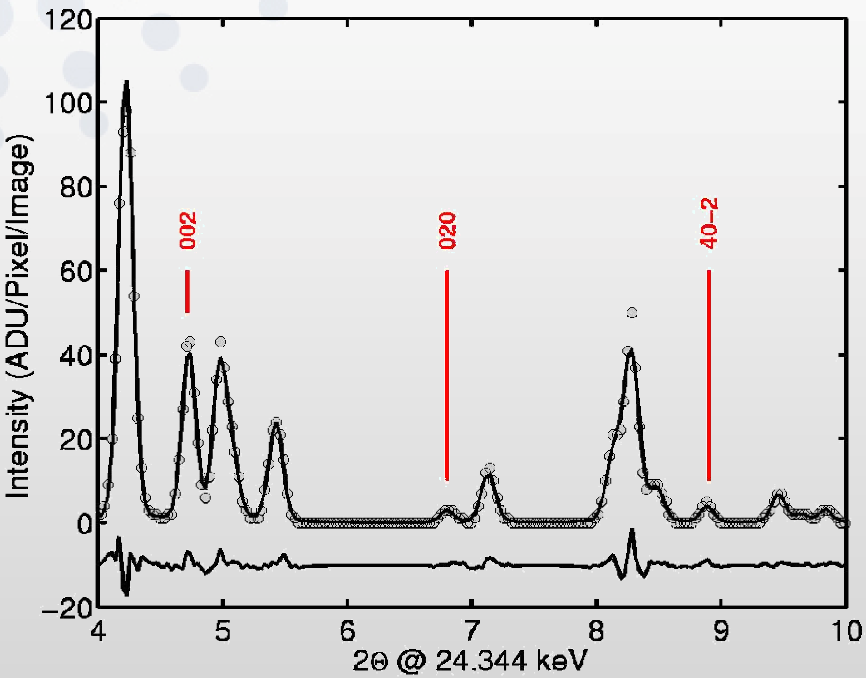
Azimuthally integrate

Index by powder methods



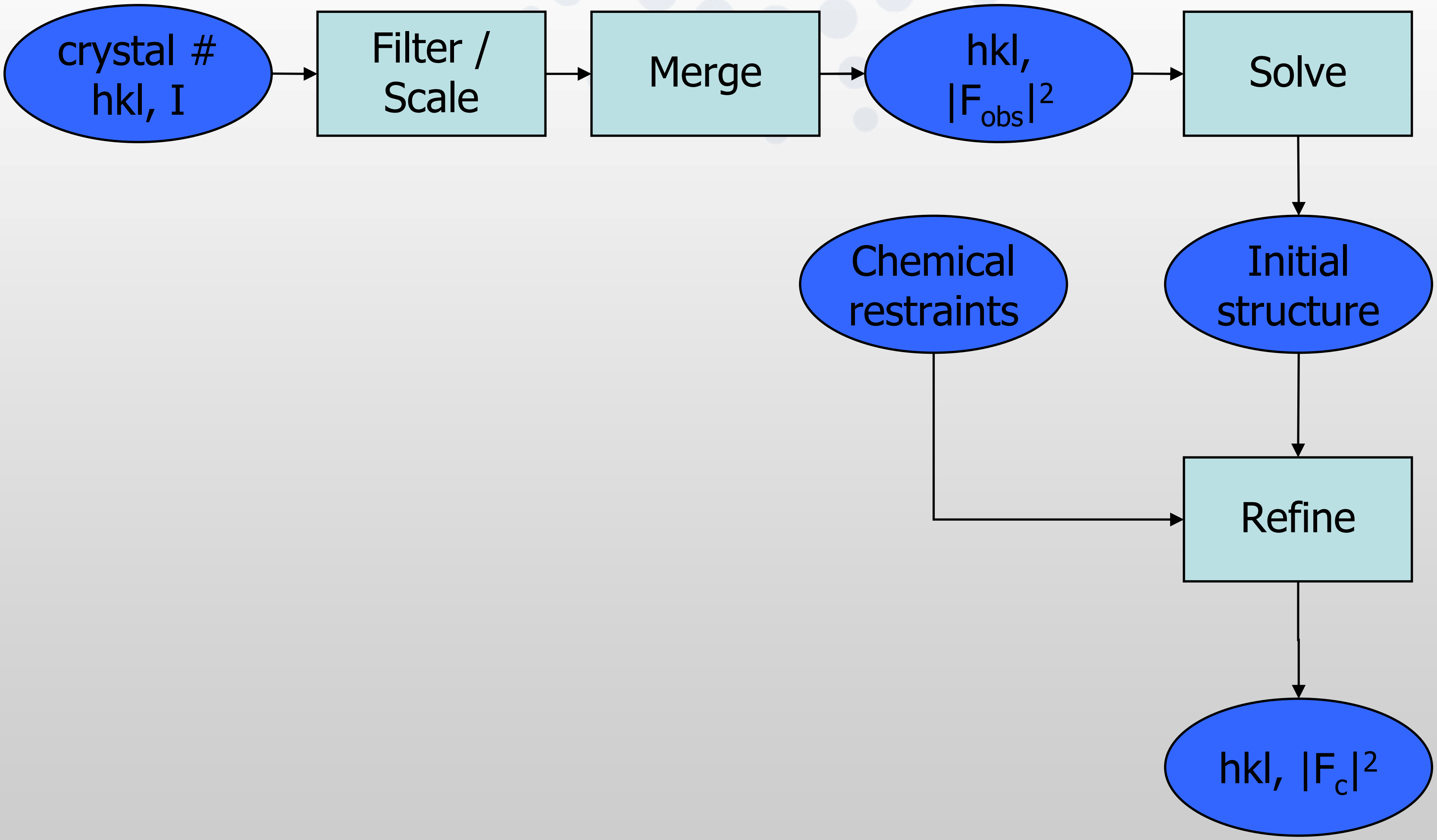
Determine Orientation Matrices





Generally need three unambiguous peaks

Solution and Initial Refinement

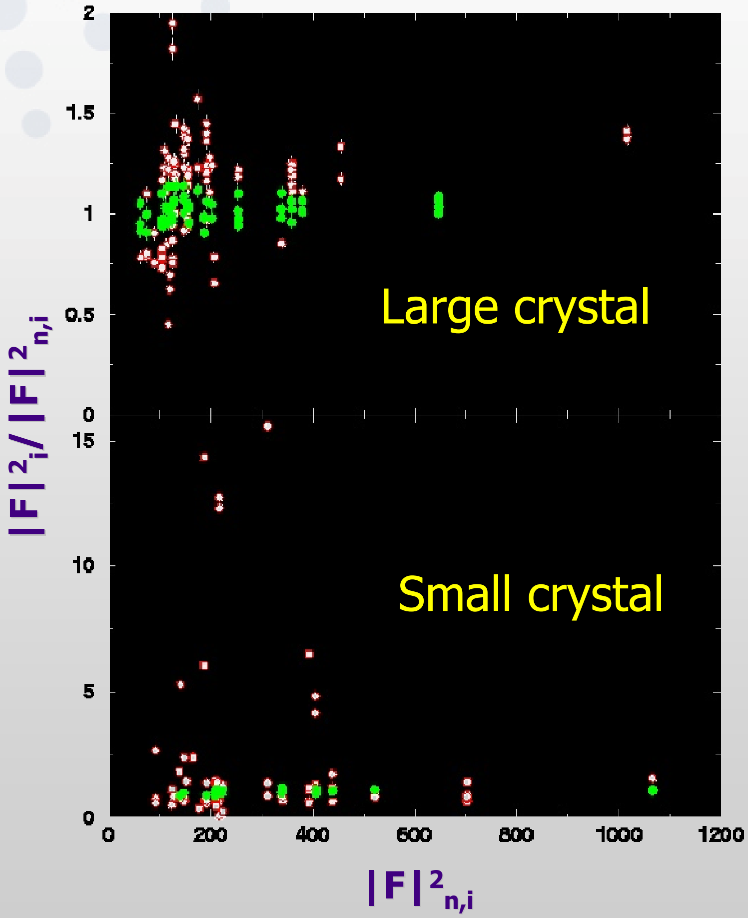


Intra-grain Merging/Filtering

Filter
- Data quality
  - I/σ
  - Spot shape
  - Distance from another (known) reflection
- Equivalent reflection statistics
  - deviation from average
- Expected value

Skewed outlier distribution
- Outliers due (mostly) to unindexed peaks

Reweighting
- Usually filter throughout, reweight at the end



Cupric Acetate Monohydrate

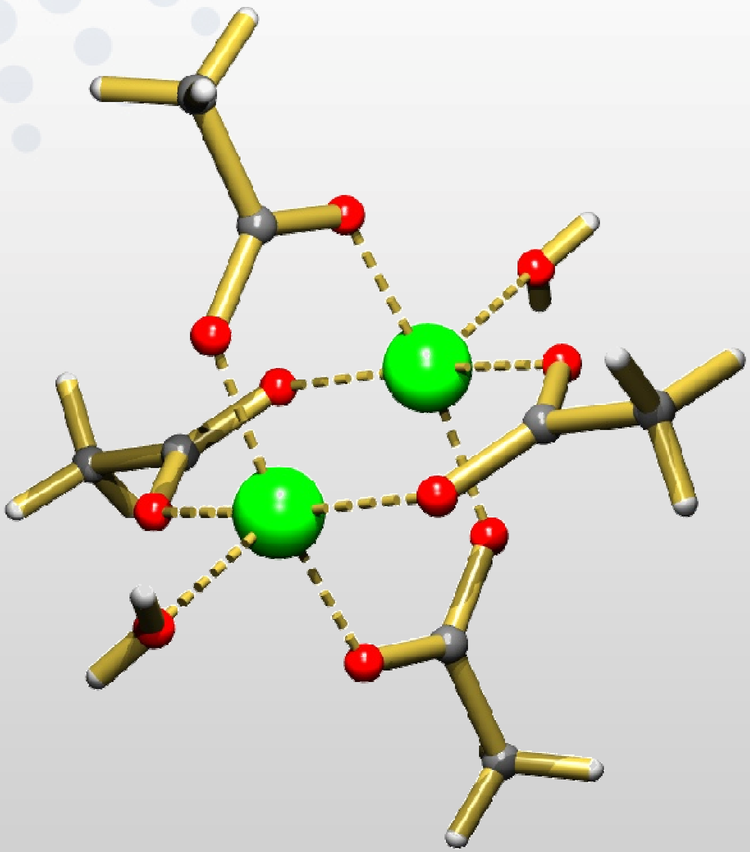
Simple small molecule

Each individual crystal data set incomplete

- Decomposing?

Structure solution / Refinement

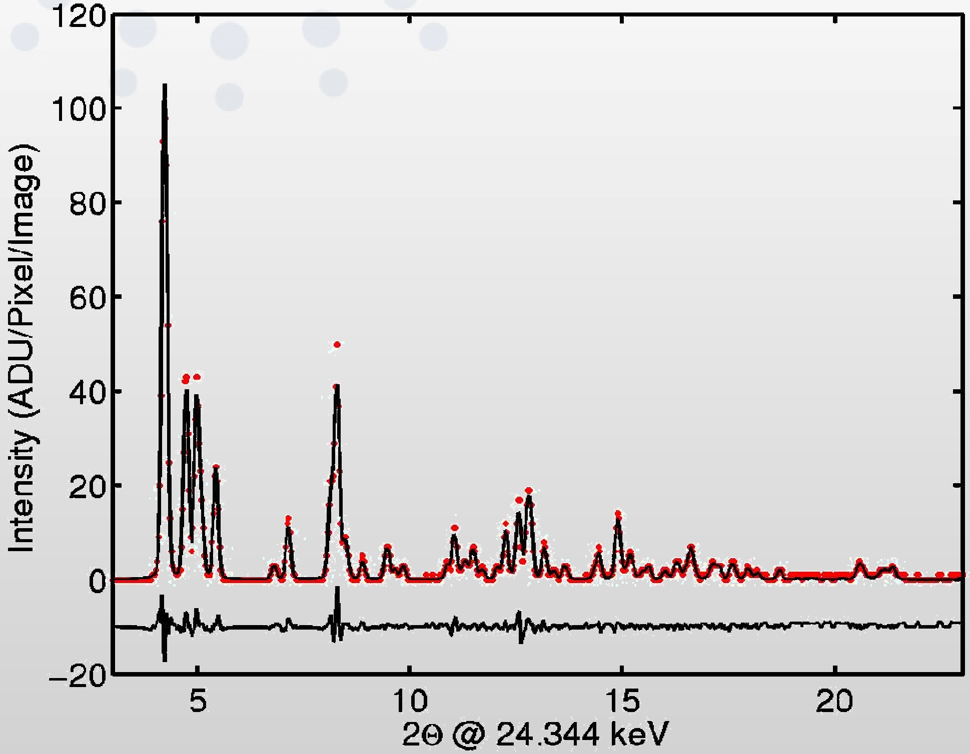
Compare to single crystal and powder refinements



Indexing/Unit cell

pseudo-powder indexed with Ito

a = 13.175
b = 8.569
c = 13.868
β = 117.02
C2/c



18k/130k spots assigned to crystallite

Merging/Filtering/Scaling

Low internal redundancy

- No intragranular equivalent filtering
- Individual data sets incomplete

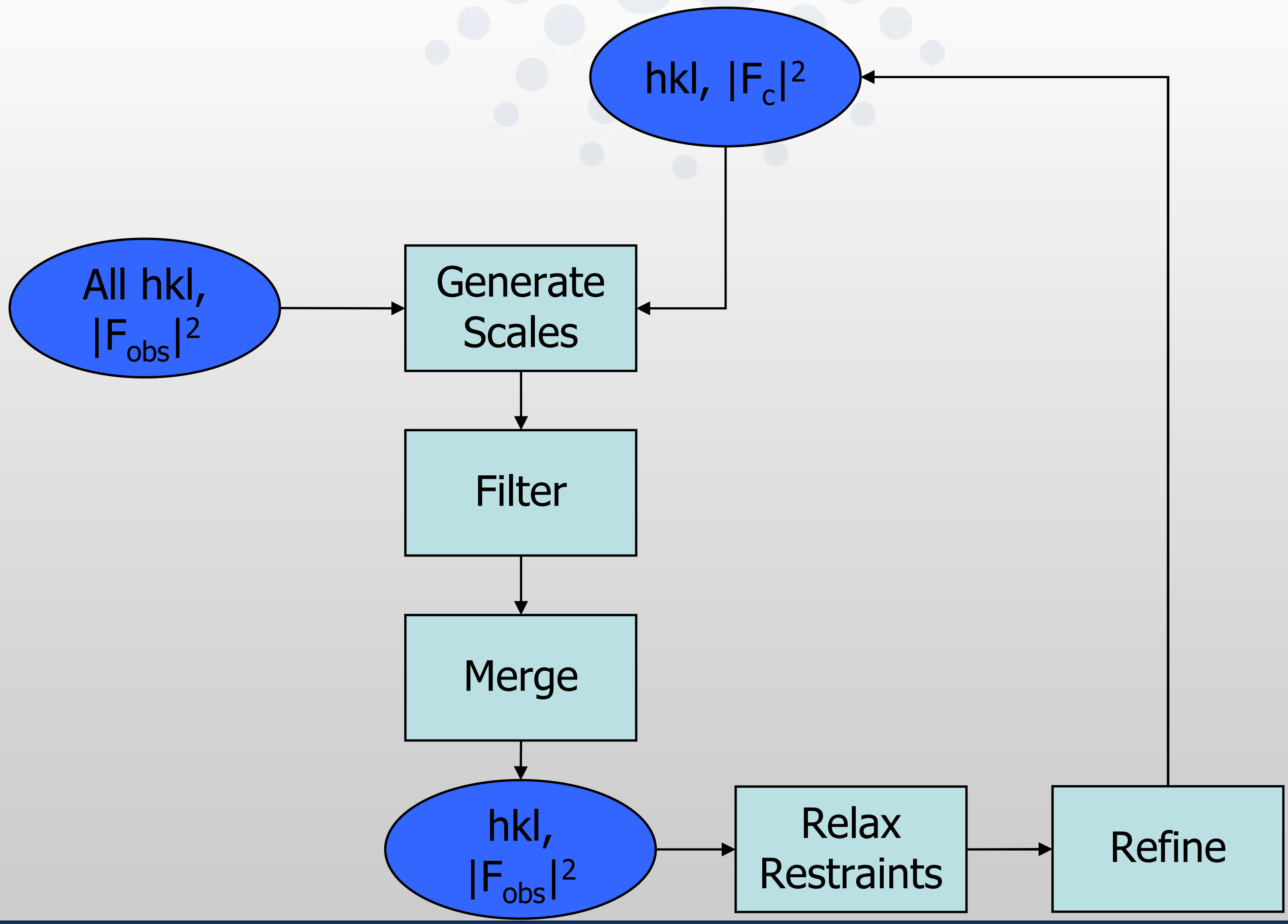
Corrupt, complete data set

- Heavily filtered
- sufficient for structure solution (direct methods)

Initial constrained refinement

Cycling

Cycling Refinement



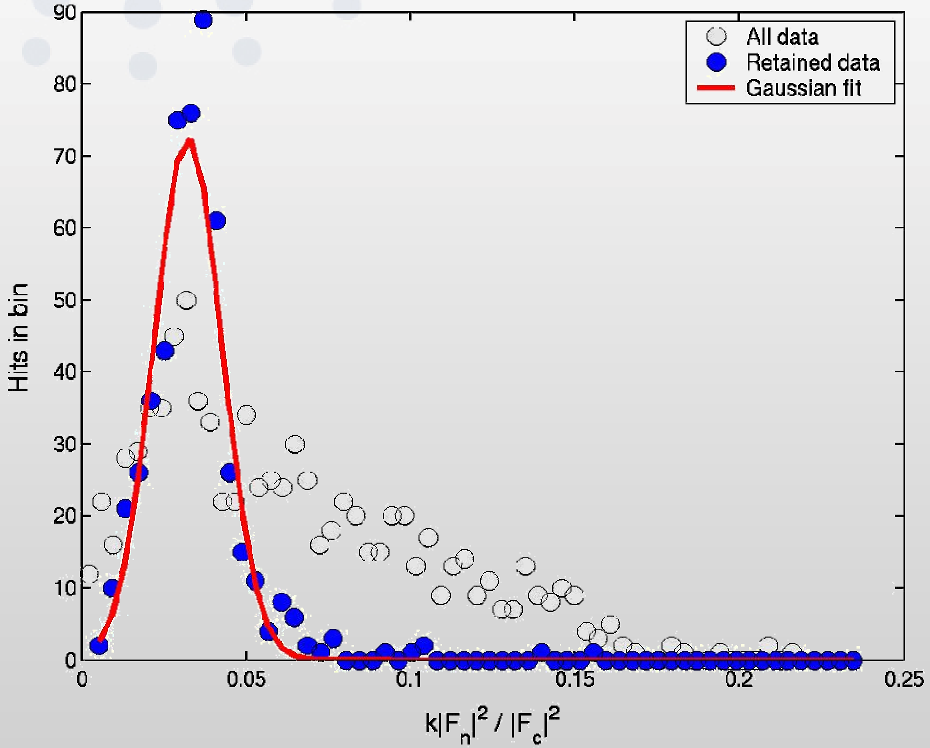
Generation of Final Scales

Histograms of $k|F_c|^2/|F_{obs}|^2$

Peak position gives scale factor

Fit peak

- Gaussian
- Error bar



Final Refinement

After several iterations, get a good refinement

- GOF R-factors fine
    - $R_1 = 5.7$
- Data quality R-factors still high
    - $R_{sym} = 13.6$
    - Redundany ~ 3.5
- Data/Parameter ratio ~ 8
    - 795/98

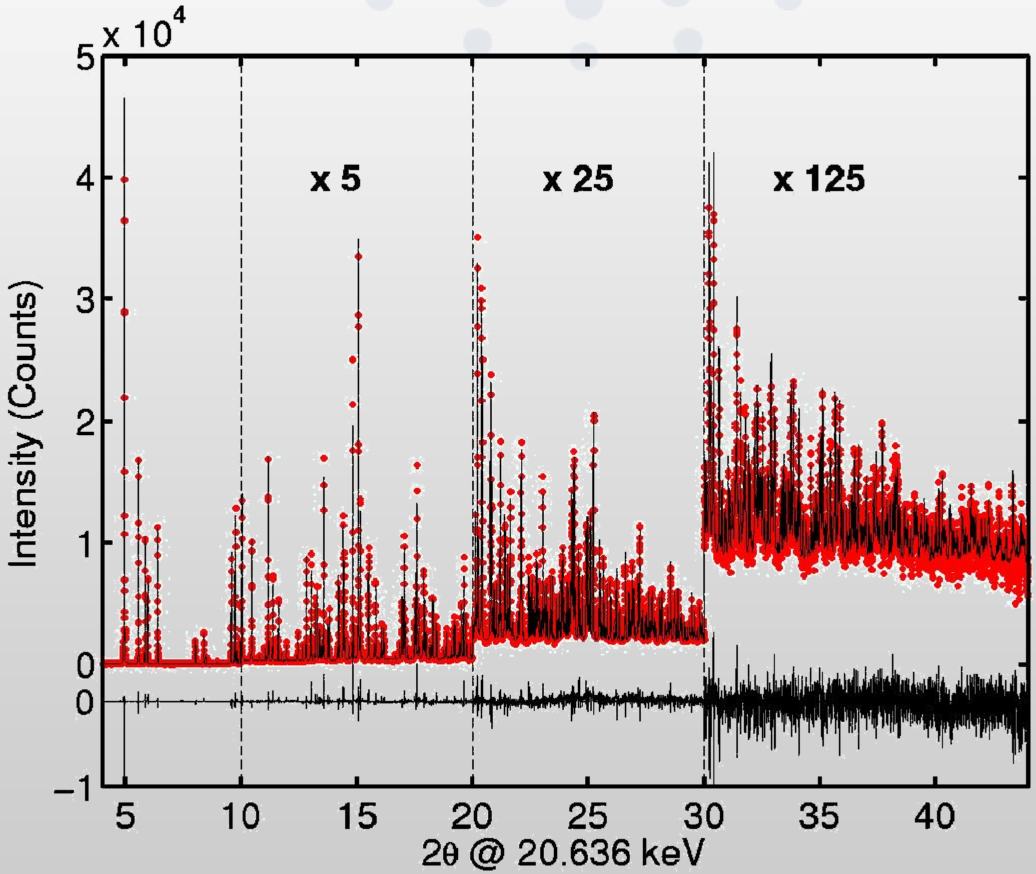
Single Crystal Refinement

Large crystal

- 30 x 30 x 30 μm^3
- Collected data with the same detector
- Complete, redundant (4) data set
- R_1 = 1.8

Powder Refinement

High Resolution Power Diffraction Data From ID31



Comparison of Refinements

Single crystal refinement is “correct answer”

- Unconstrained refinement
- All bonds very accurate and precise
- Thermal ellipsoids look correct
- Found, refined water H-atoms (isotropically)
    - Not uniquely fixed by molecular symmetry

Comparison of Bond lengths

Bond	Single Crystal	Multicrystal	Powder	$\vert d_{mc} - d_{sc} \vert \times 10^3$	$\vert d_{pow} - d_{sc} \vert \times 10^3$
Cu–O1	1.9880(8)	1.985(5)	1.981(4)	3	7
Cu–O2	1.9962(8)	1.991(7)	1.985(4)	5	11
Cu–O3	1.9431(9)	1.945(7)	1.924(4)	2	18
Cu–O4	1.9575(9)	1.963(7)	1.949(4)	6	8
Cu–O5	2.1588(14)	2.149(8)	2.149(9)	11	11
$< \Delta (Cu - O) >$				5.4 (31)	11.0 (24)
O1–C1	1.2601(12)	1.259(11)	1.246(7)	1	14
O2–C1	1.2613(14)	1.257(11)	1.296(8)	4	35
O3–C3	1.2612(15)	1.273(11)	1.309(8)	12	48
O4–C3	1.2588(14)	1.242(10)	1.271(8)	16	12
$< \Delta(O - C) >$				8.2 (92)	27.3 (39)
C1–C2	1.5022(15)	1.497(13)	1.563(8)	5	61
C3–C4	1.5055(18)	1.519(13)	1.496(9)	14	9
$< \Delta (C - C) >$				9.5 (92)	35 (6)
O5–H7	0.829(19)	0.85(13)		20	
O5–H8	0.73(2)	0.99(13)		260	
H7–O5–H8	117.3(13)	101(11)			
$< \Delta (C - H) >$				140 (180)	

Thermal Factors

Single crystal > Multicrystal ≫ Powder

Could not get meaningful anisotropic thermal factors for C atoms in powder refinement

Could not refine H atom thermal factors unconstrained in multicrystal refinement

	Cu	O	C	H
Single Crystal	A	A	A	I
Multicrystal	A	A	A	R
Powder	A	A	I	–

Thermal Factors

	$[(u_{eq}$ or $u_{iso})/u_{eq,sc} - 1] \times 100$		$[(u_3/u_1)/(u_3/u_1)_{sc} - 1] \times 100$	
	Multicrystal	Powder	Multicrystal	Powder
Cu1	4	−29	9	178
O1	−1	27	0	191
O2	2	32	5	163
O3	−7	21	−22	104
O4	2	13	−6	−3
O5	6	30	10	5
C1	1	76	22	
C2	2	27	−4	
C3	6	37	33	
C4	2	49	9	
H7				
H8				
Absolute deviation	3.3	34.1	12.0	107.3
Mean deviation	1.7	28.3	5.6	106.3

Conclusion

Multi-crystal method gives single-crystal quality

- Bond lengths
- Anisotropic Thermal Factors
- H atoms
- At least for simple problems…

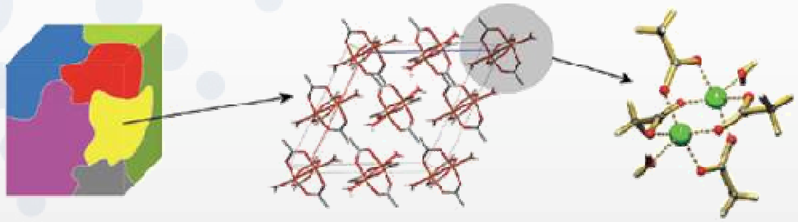
Improvements to algorithm

- Find robust parameters for blind data reduction
- Empirical “absorption” correction
- Improve cycling to include intensity extraction
    - 3d Rietveld

3d Microscope → 3d Nanoscope

Access to all relevant length scales

- *10pm:* *charge distributions*
- *Å:* *molecular structure*
- *nm:* *crystal structure*
- *10 nm*: *initial nucleation*
- *100 nm*: *dislocations/intragranular structure*
- *µm:* *intergranular interactions*
- *mm*: *bulk structures*

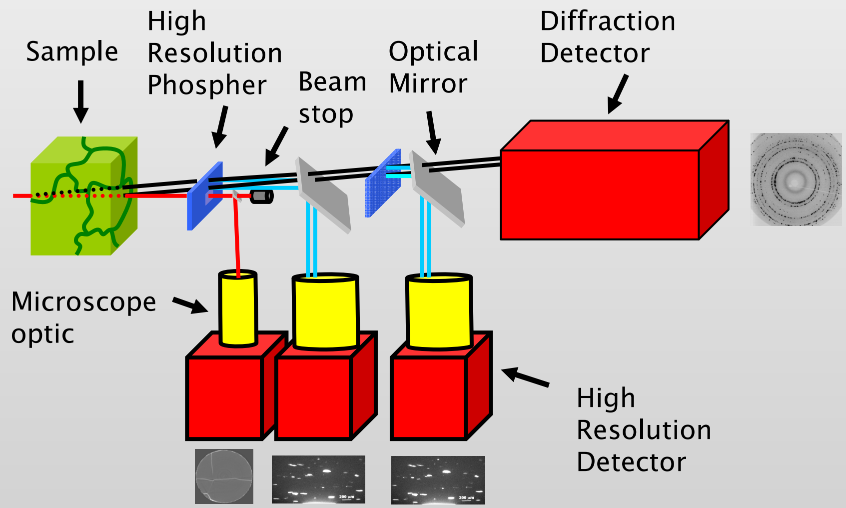


Total Simultaneous Characterisation

- *Crystallography*: *structure of each grain*
- *Microstructure*: *stacking faults, microstrain…*
- *Grain Statistics:* *size, strain, stoichiometry…*
- *Distributions of properties* *rather than means.*
- *Relationship* between *grains*

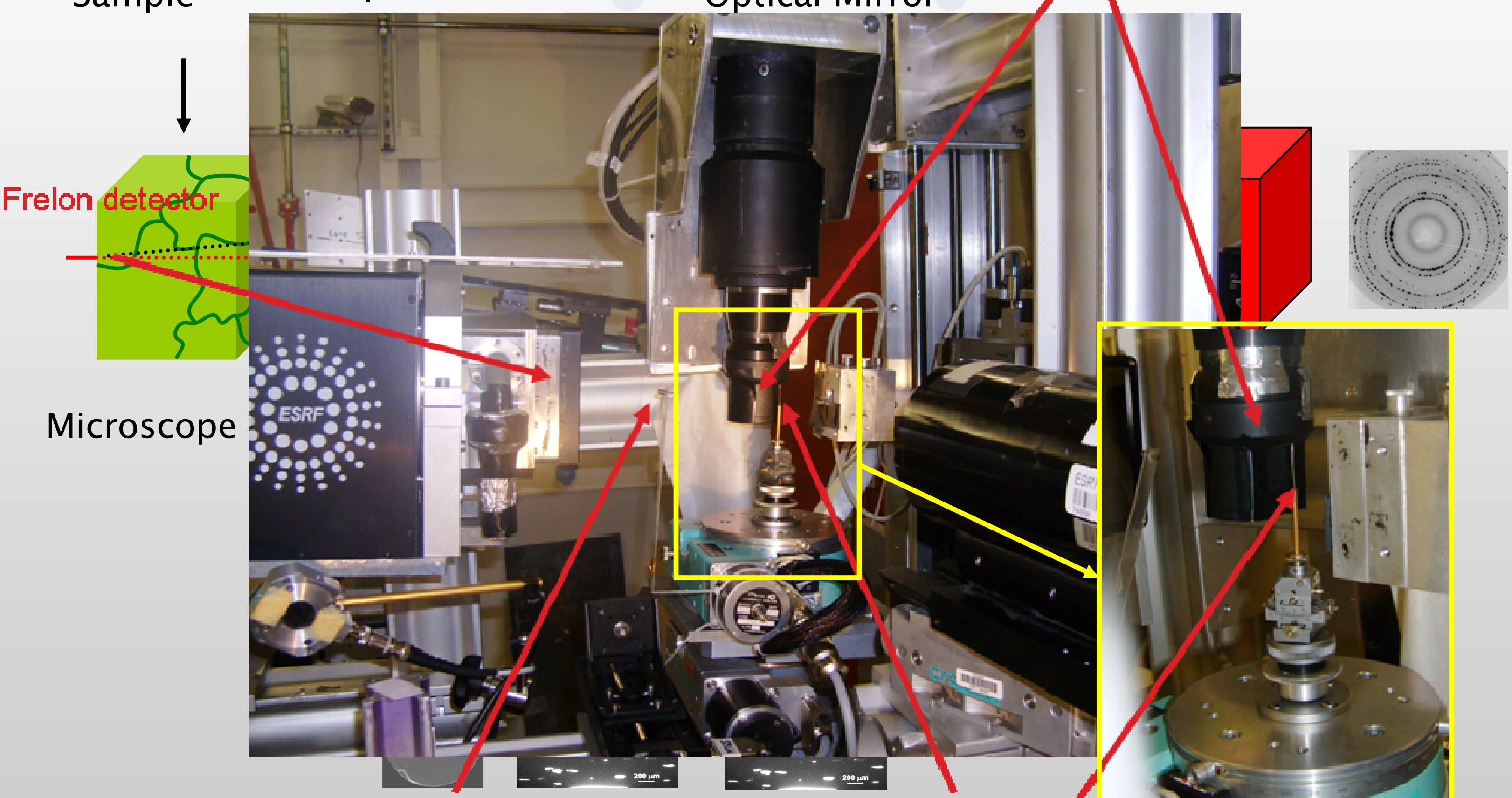
Grain Mapping

- *Quantitative Tool:* *Not just images*
  - *6-dimensional characterisation*
  - *Doesn't relay on Z-contrast*
- *Now*: *resolution limited by detector technology*
- *Future*: *Structured scintillaters*

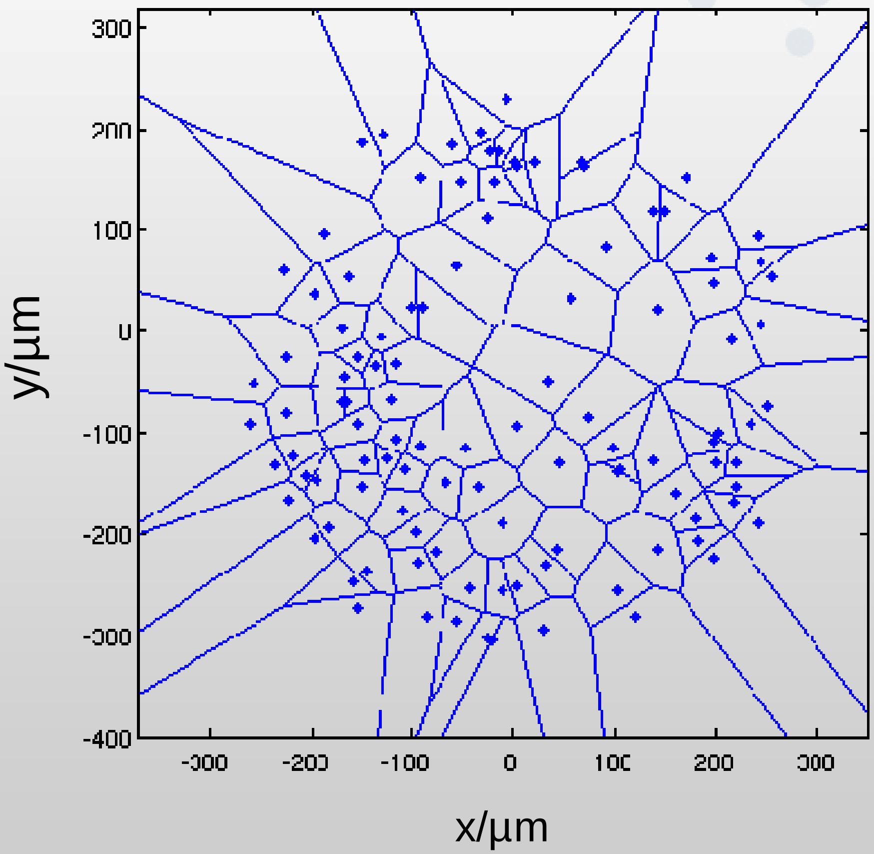


A three-dimensional detector for hierarchical characterisation

Three Dimensional Detector



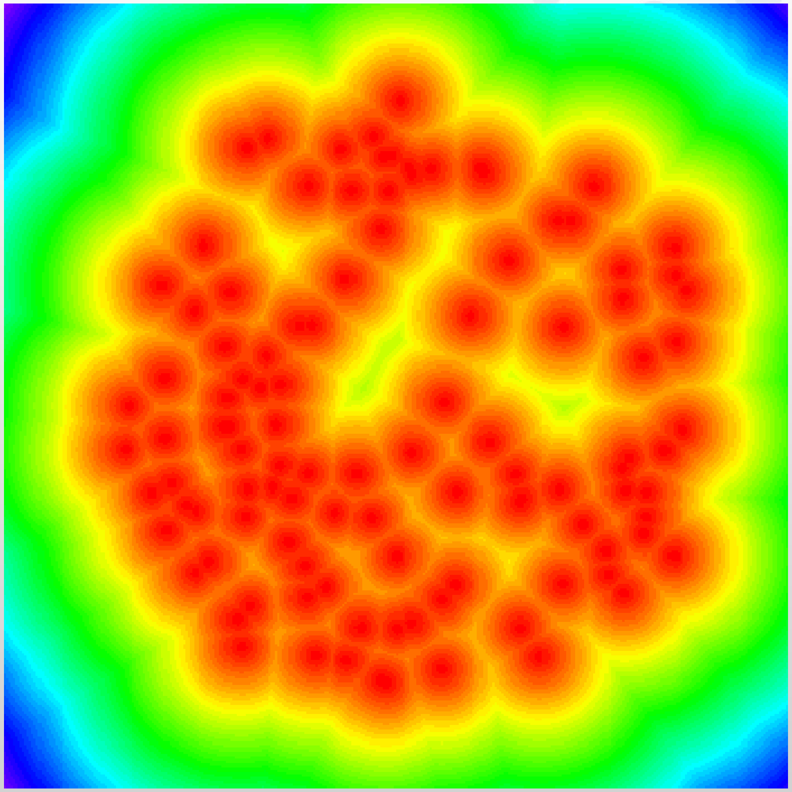
Grain map from grain centre fits



Grain positions, orientations, lattice parameters all simultaneously refined from multi-crystal data

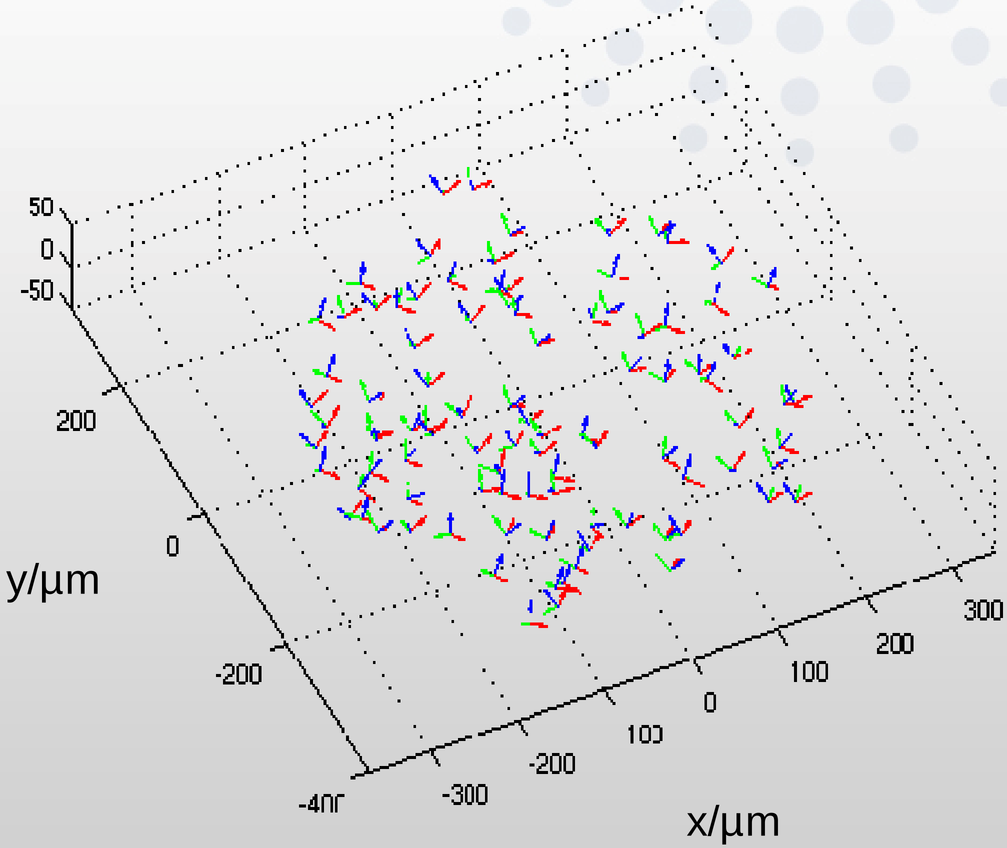
"grain boundaries" from Voronoi calculation: if the grain centre falls in the middle of the reconstructed grain, perhaps nothing is missing.

Better representation?



Here the colours fall away from the centre of mass and end at the boundaries – so that missing or vacant areas become more apparent…

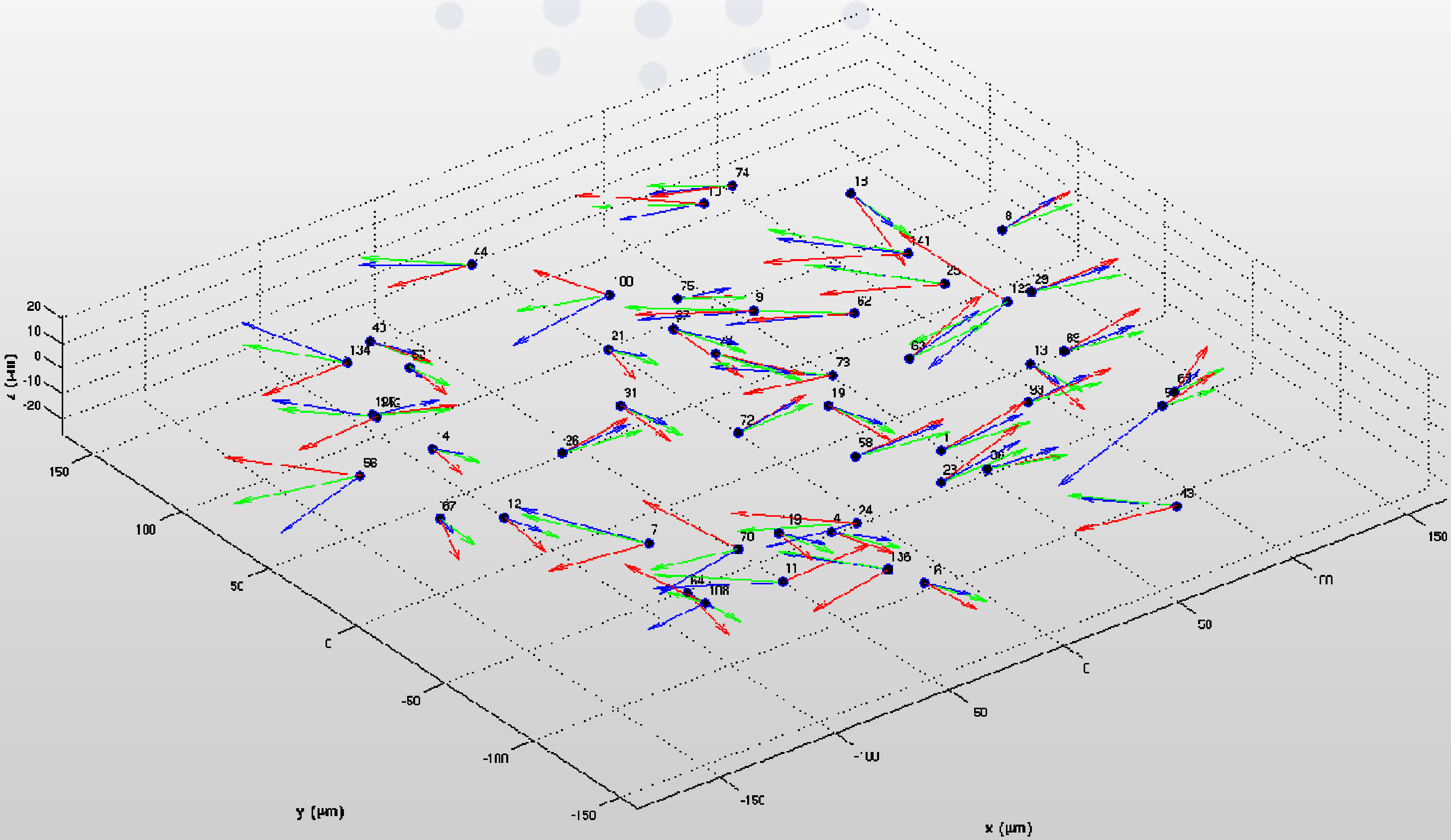
Could add some orientational information



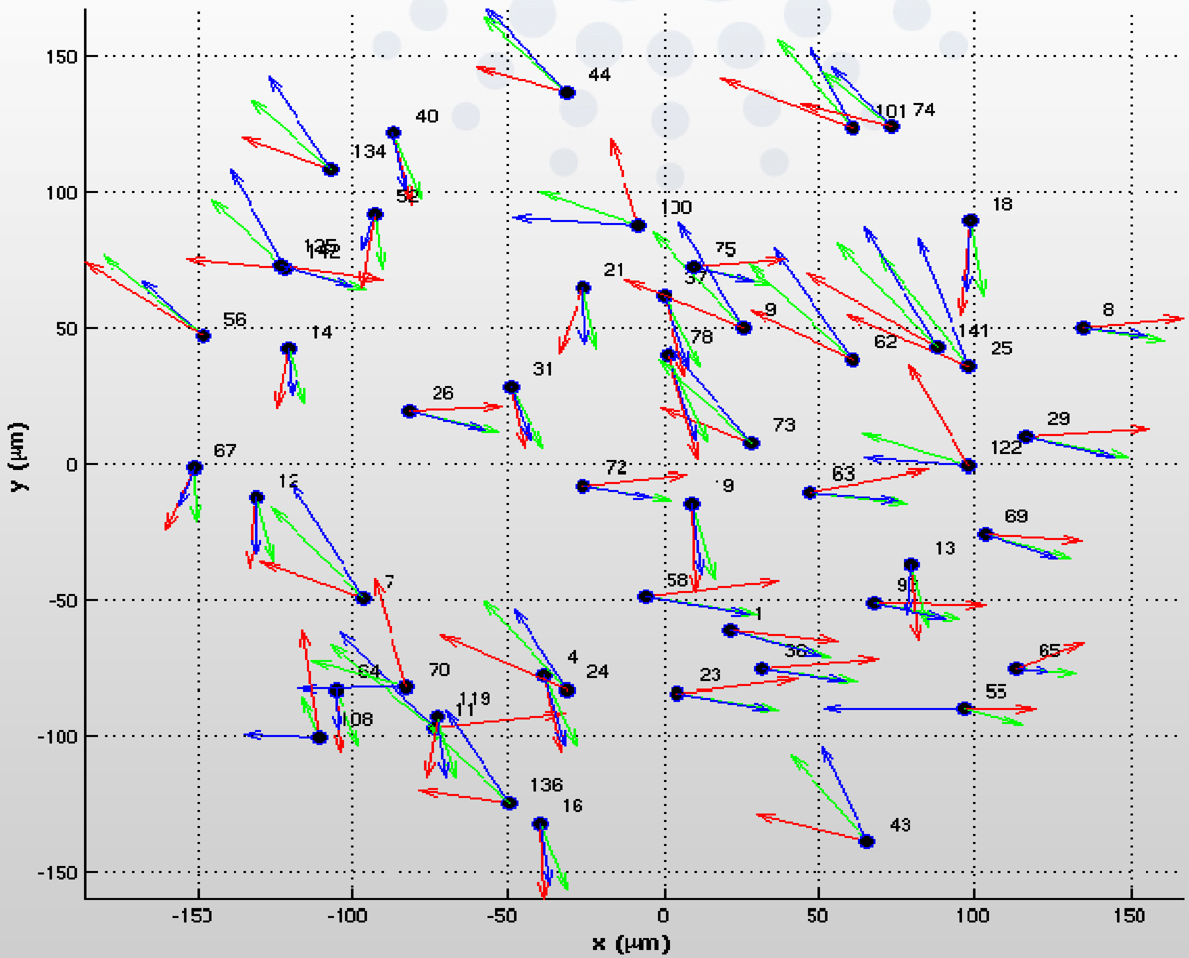
The axes are placed at the crystal centre (this is for one layer).

Rotations after each step

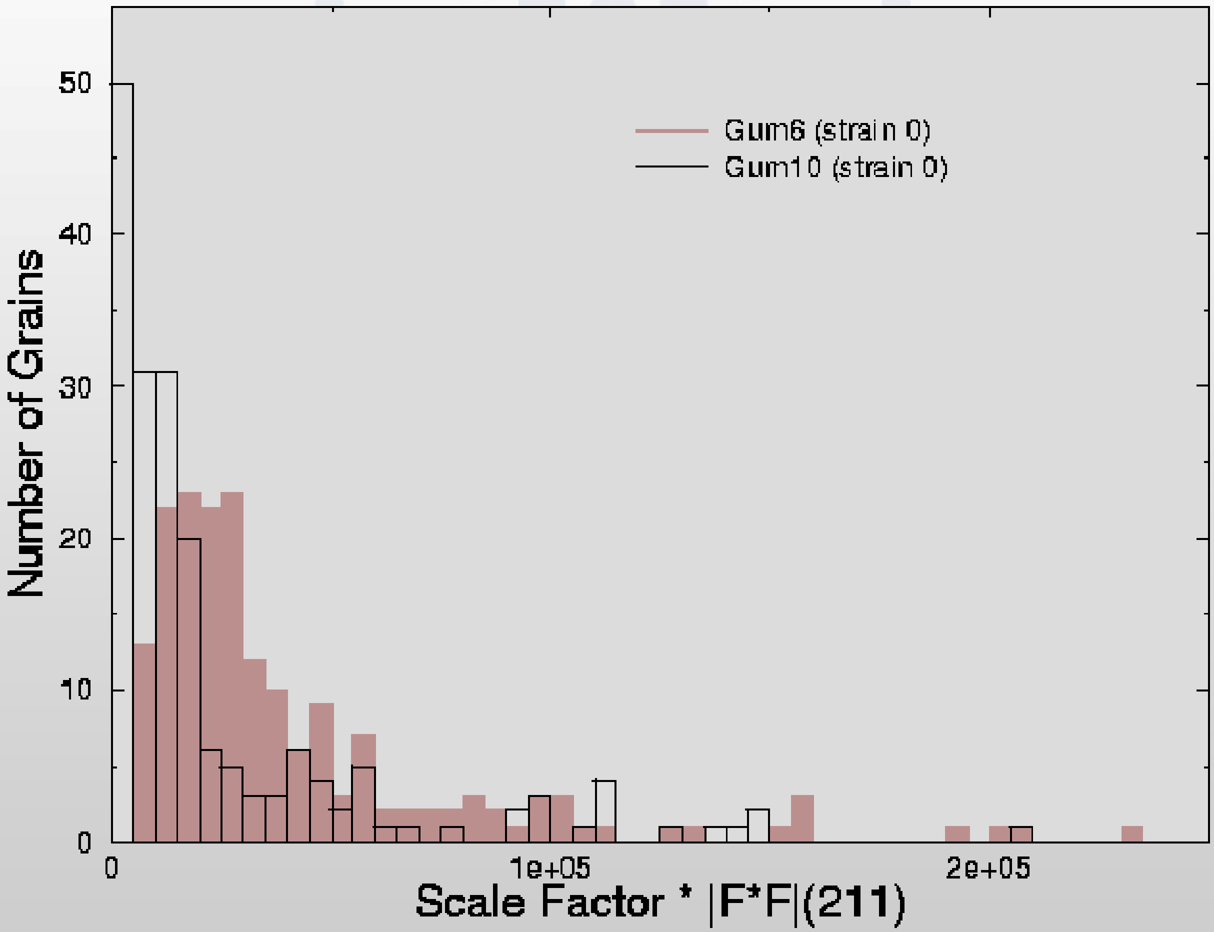
Depicted are the Rodrigues vectors of subsequent rotations after straining a sample



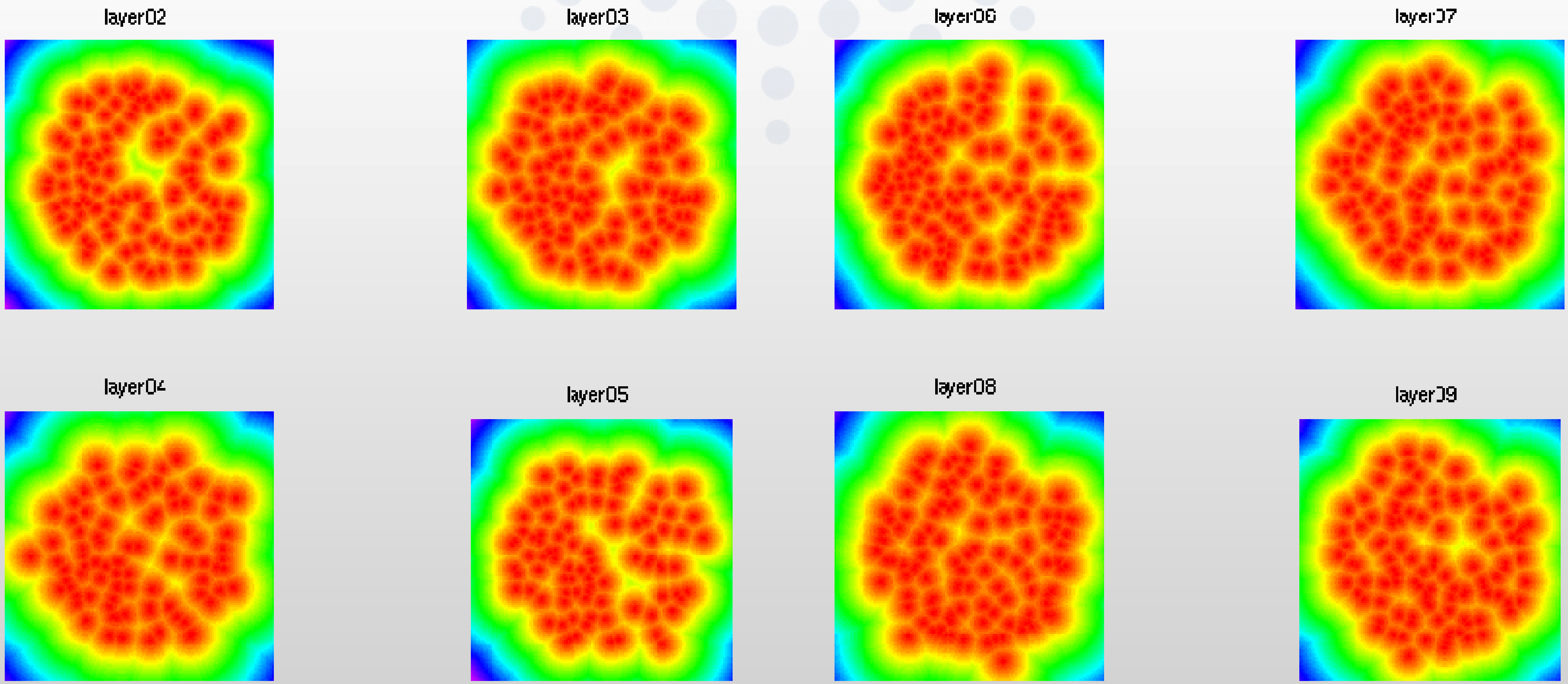
Projection in plane



Also correlate with grain size distribution



Layer by layer maps

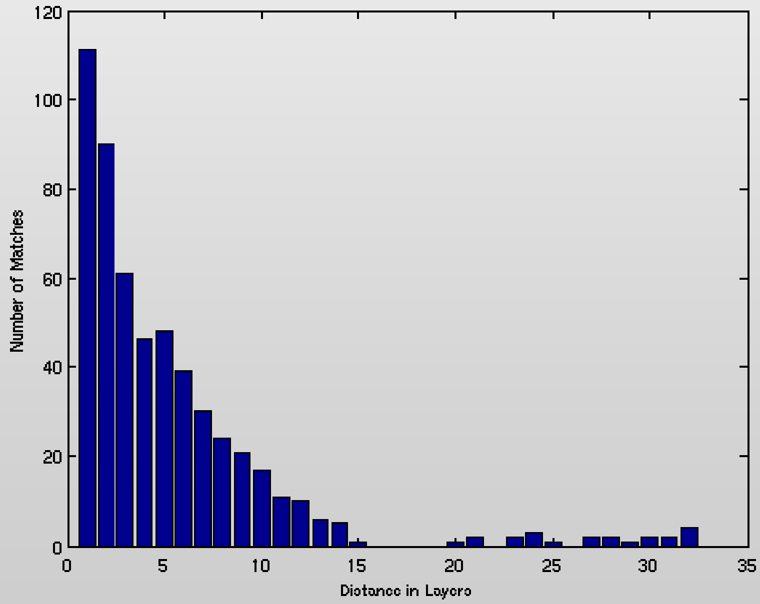


These are constructed using only grains with a match above and/or below

Resistor: Compare different layers

The grains found in different layers are compared based on their orientations and refined positions in order to try to locate the same grain in different layers.

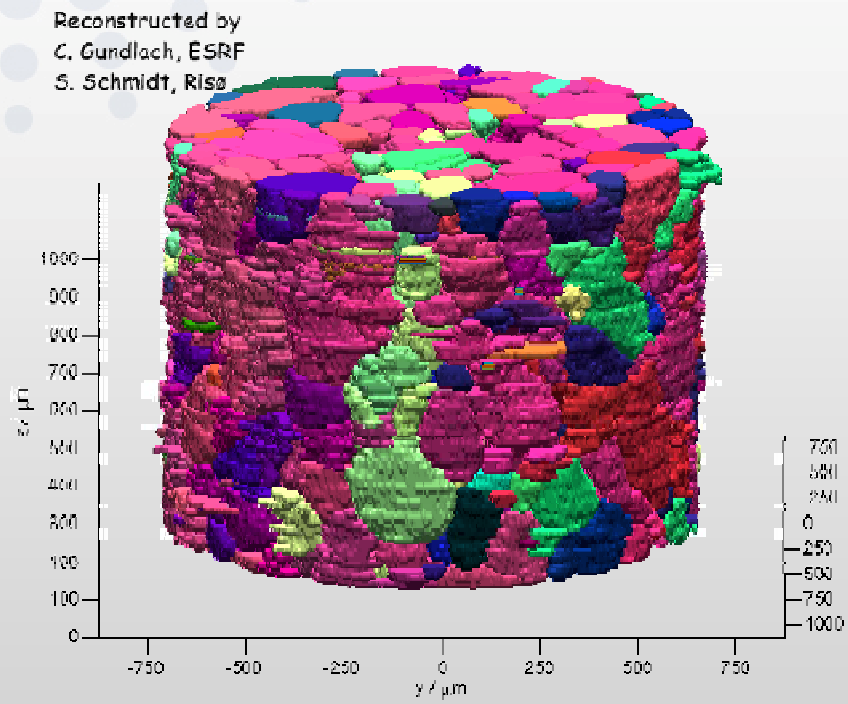
The results in this case are quite complete and unique: most grains match only one other grain in the next layer with precision <0.3° and 50 µm.



This can also give a sort of grain size distribution in z.

High Resolution Grain map

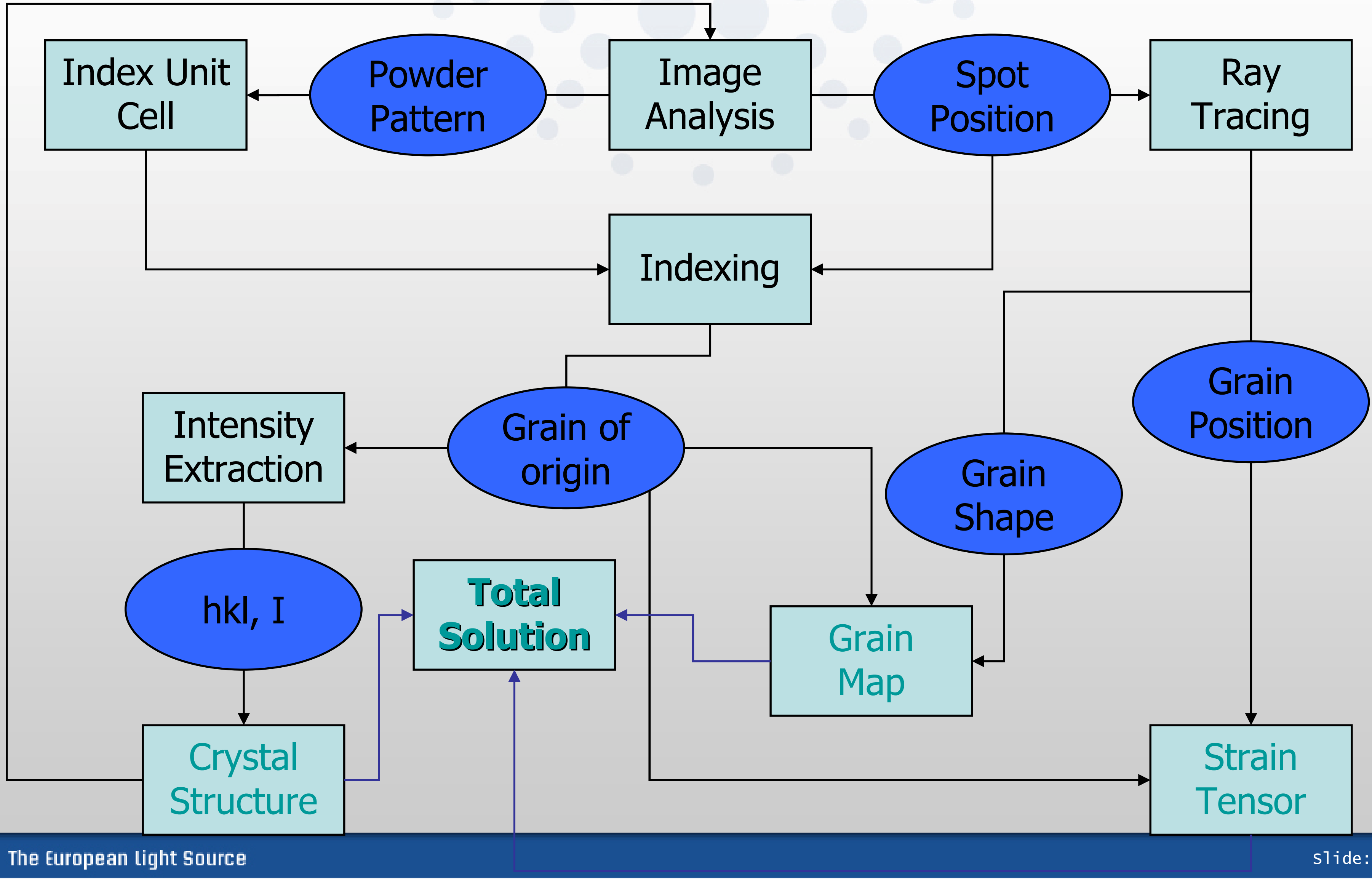
A combination of detectors allows the high resolution map to be constructed while we characterize simultaneously:



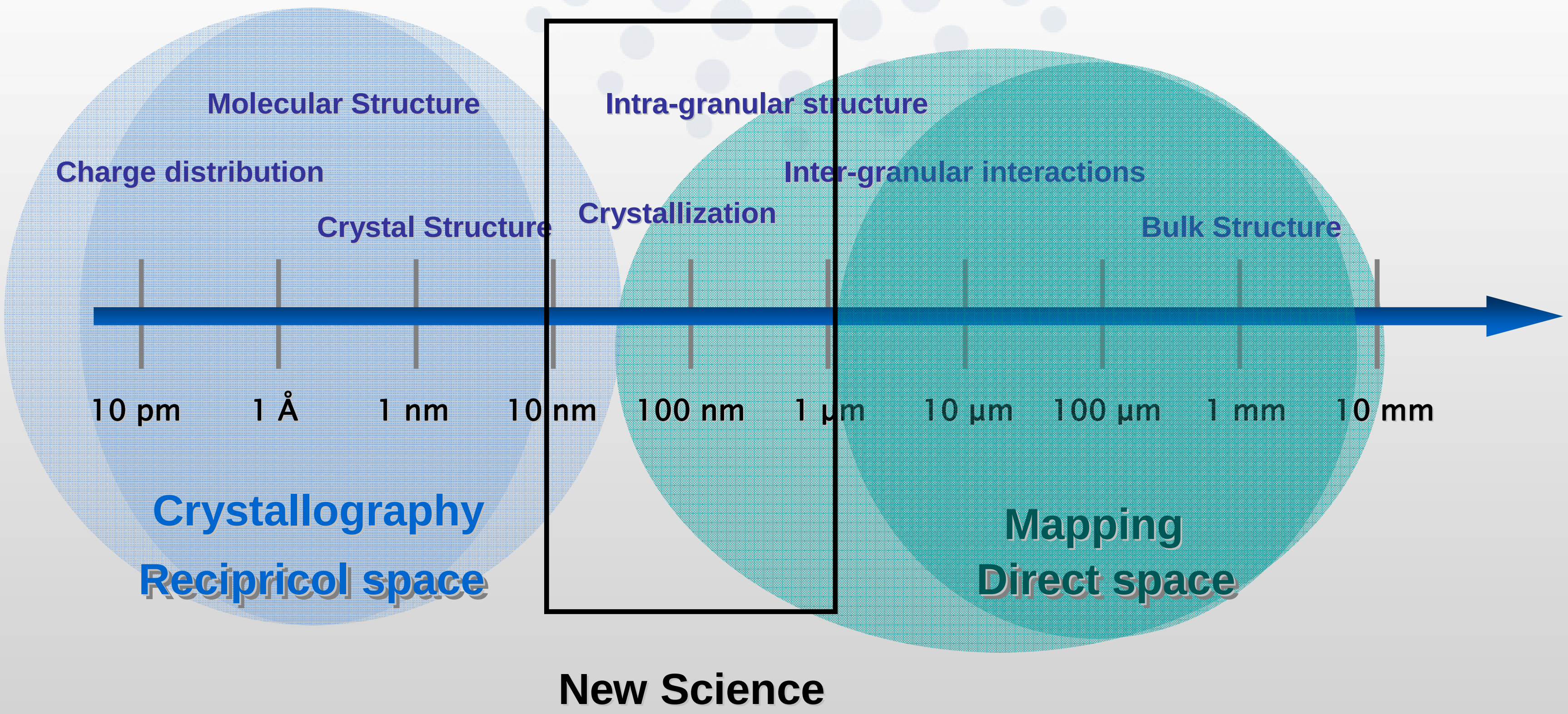
- Grain Shape
- Grain Position
- Crystal Structure
- Strain State

For each crystal independently

Ultimate Flowchart for TX



Allow Total Characterisation



Collaborators at ESRF

Jon Wright
Aleksei Bytchkov
Caroline Curfs
Carsten Gundlach
Henri Gleyzolle
Jean-Michel Reynal
Andy Götz
Gaëlle Suchet
Michel Rossat
Roland Taffut
Jean-Claude Labiche
Alajandro Homs
Denis van Brussel
Jean-Marie Chaize

Funding:

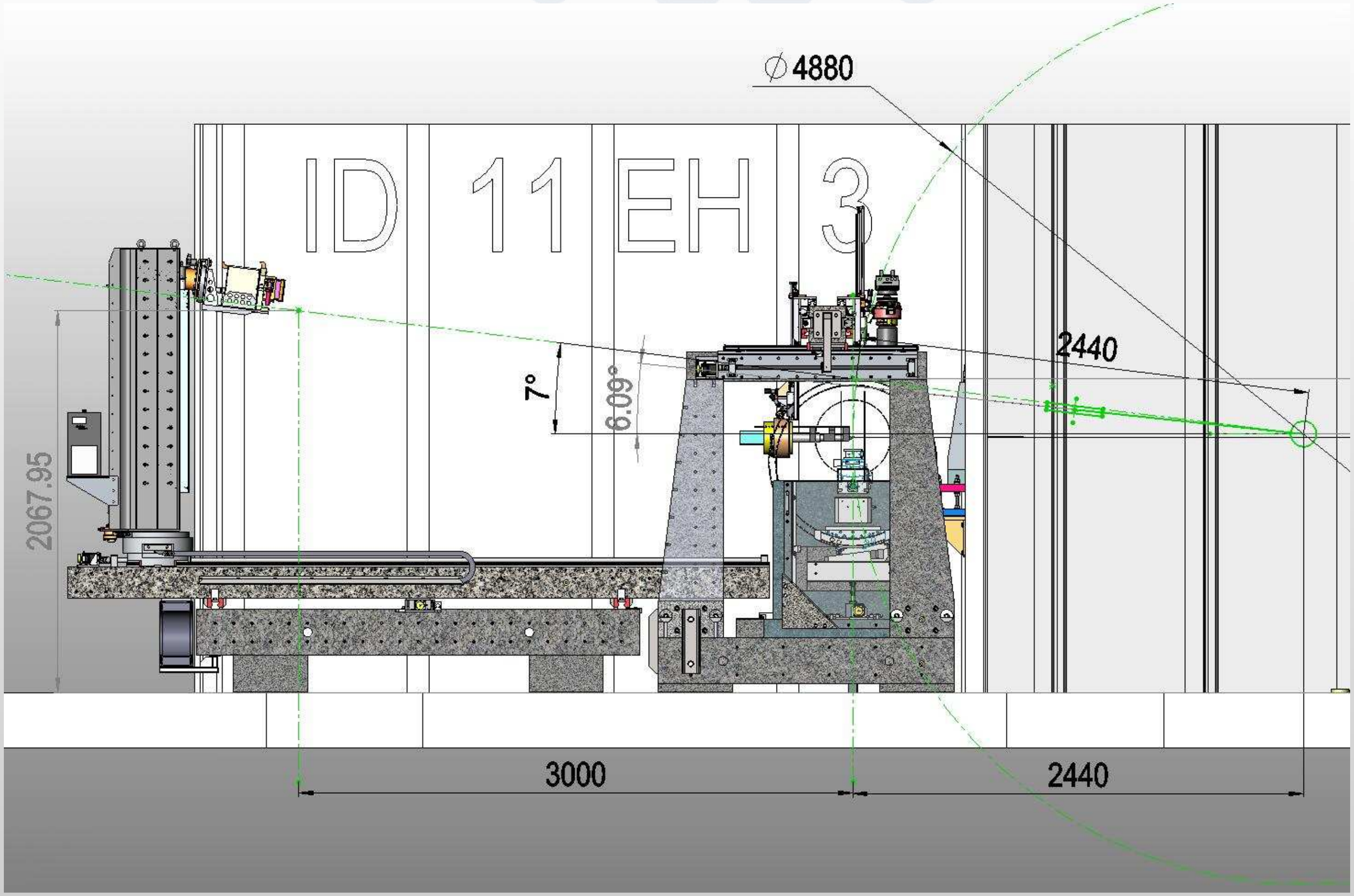
- ESRF
- EU:
  - NEST (Total X)
  - Marie Curie (H-Storage)
  - Marie Curie (BMG)
  - Pull-Nano (micro-electronics)
- CNRS
  - ANR (BMG)
- Industrial:
  - Toyota
  - Lafarge

Outlook

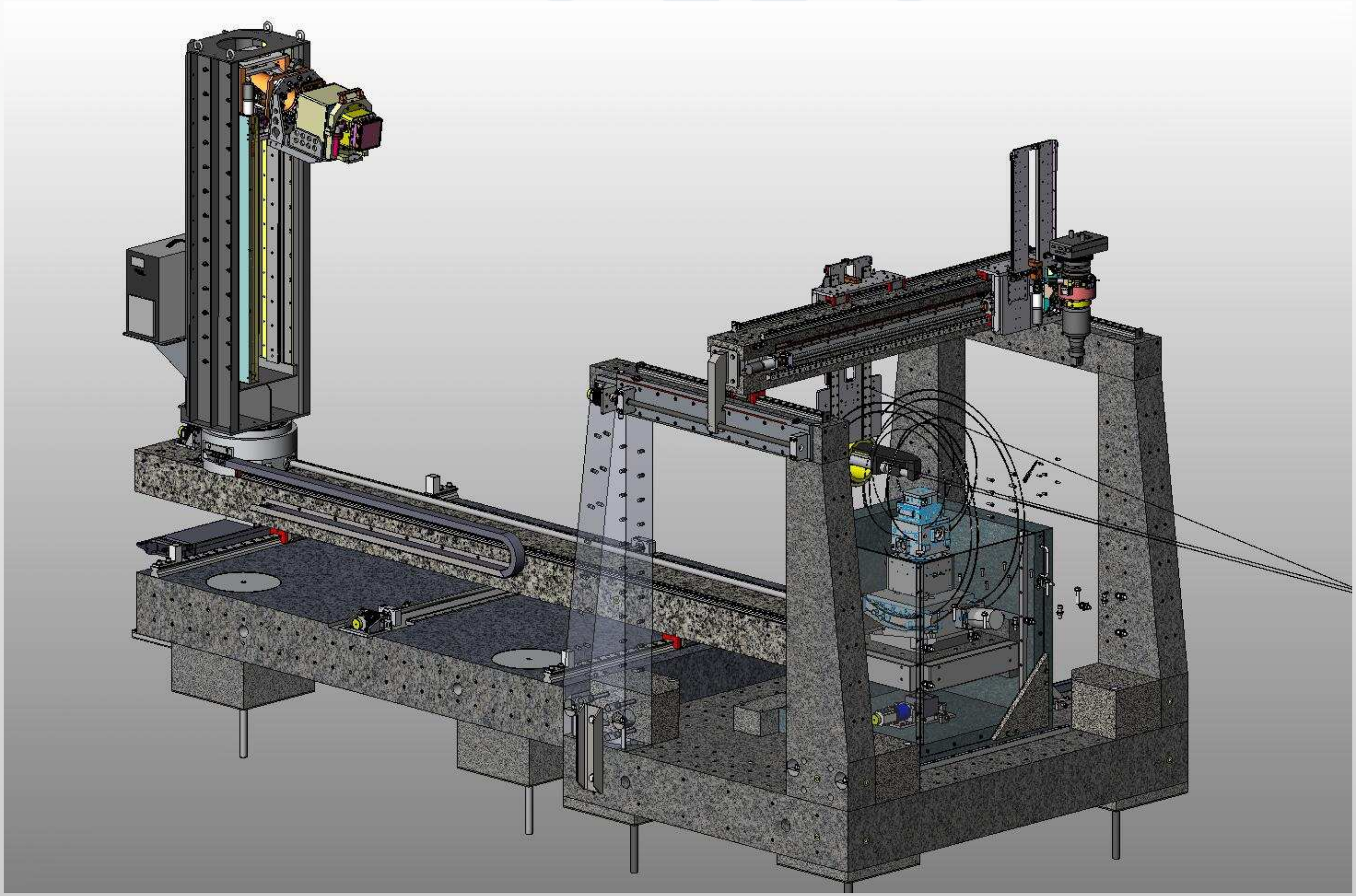
- Spatial resolution is now 1 step away from ultimate target
  - Spatial ~ 10s nm
- These goals will be technically feasible in the next decade

- Technical proposals aim to ensure our compatibility to exploit new development

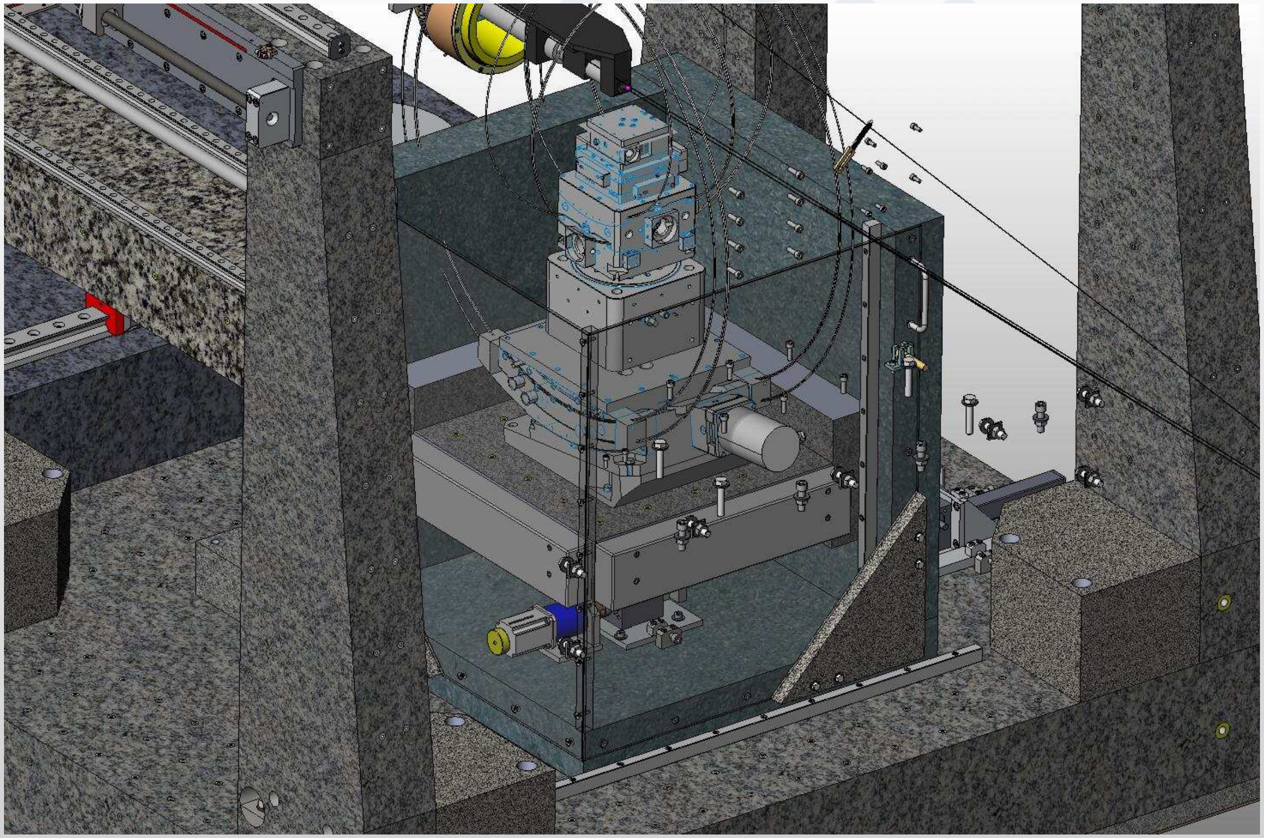
New Diffractometer



Diffractometer mount



Diffractometer mount



Both the global y and z translations will be on “reversible” airpads

Final Conclusion

Beamline evolution follows the path proposed by the last review, with continued evolution as scientific fields develop or regress….

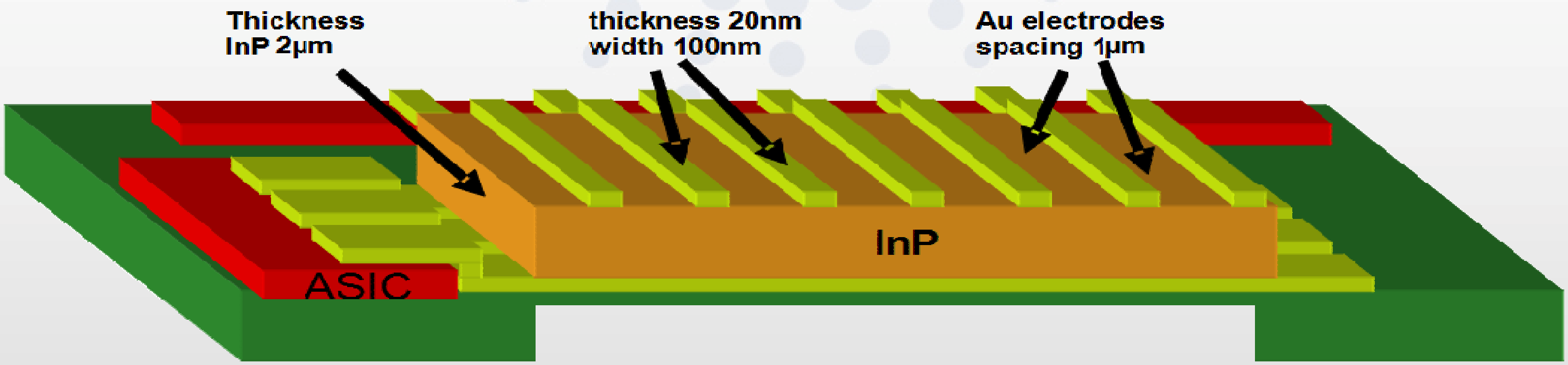
Extension of the line

Refactoring the optics

Refactoring the diffractometer

Advanced feedback schemes based on image recognition

Ultra-high resolution detector

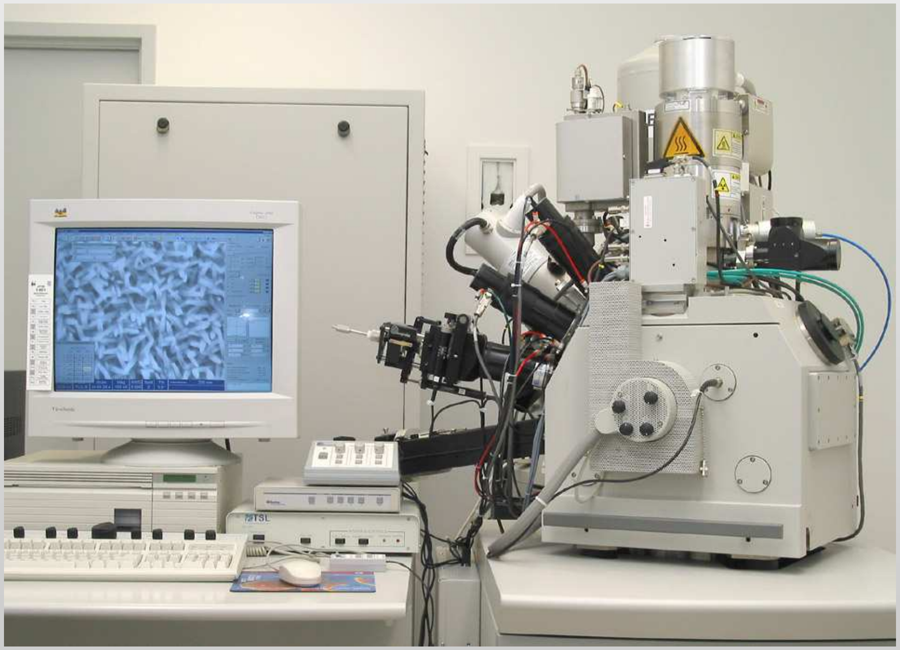


Resolution for direct mapping experiments is essentially determined by detector resolution

We propose to participate in the development of a new kind of detector, which aims to deliver ~100nm resolution

FIB Microscope

- Surface characterization prior to X-ray experiment
- Surface modification or marking for metrology
- Destructive measurement after the experiment
- Used overnight to machine optics (CRLs, zone plates…)
- Sell time on the machine



Ultra high precision measurements

Ultra-high precision crystallography has most of the same needs as our other experiments,

- High Energy
- Beam Stability
- Beam Homogeneity
- Synchronization
- Detector Calibration
- Data Weighting
- Data Extraction

The beamline is currently being optimised with these concerns in mind, which are also important for PDF, Topo-Tomo, ECT, Holography…

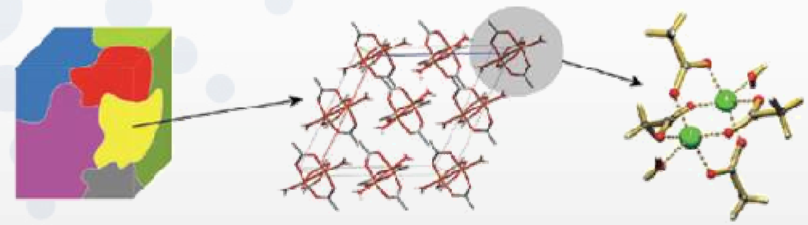
What is medium-term solution? On main station, side station, new beamline…

Pixel Detector

- Photon counting, allowing proper statistics without gain corrections.
- Energy discrimination to minimize effects of fluorescence, Compton, etc.
- Good dynamic range.
- Constant response
- Continuous readout, allowing shutter-less operation
  - Eliminates shutter jitter issue
  - No rewind/acceleration/deceleration issues
  - Infinitely fine slicing
- Almost no electronic background, minimizing peak tail discrimination issues.

Unfortunately, does not yet exist…

3d Microscope → 3d Nanoscope



Access to all relevant length scales

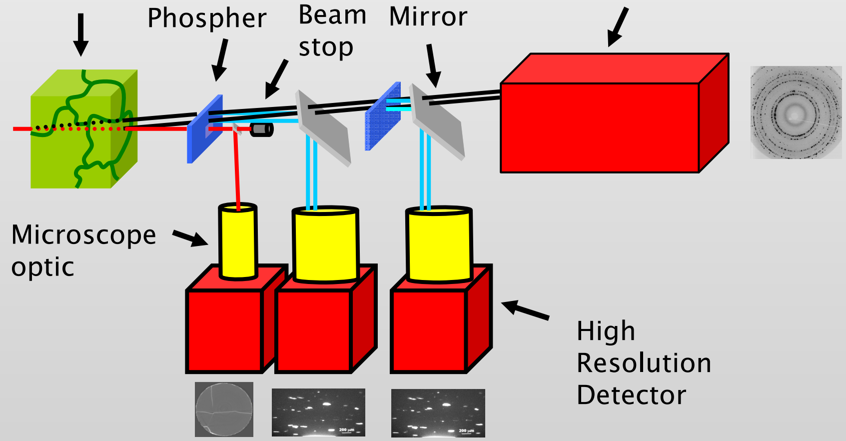
- *10pm: charge distributions*
- *Å: molecular structure*
- *nm: crystal structure*
- *10 nm: initial nucleation*
- *100 nm: dislocations/intragranular structure*
- *µm: intergranular interactions*
- *mm: bulk structures*

Total Simultaneous Characterisation

- *Crystallography: structure of each grain*
- *Microstructure: stacking faults, microstrain…*
- *Grain Statistics: size, strain, stoichiometry…*
- *Distributions of properties rather than means.*
- *Relationship* between *grains*

Grain Mapping

- *Quantitative Tool: Not just images*
  - *6-dimensional characterisation*
  - *Doesn't relay on Z-contrast*
- *Now: resolution limited by detector technology*
- *Future: Structured scintillaters*



A three-dimensional detector for hierarchical characterisation

New opportunities with submicron beams

Example: Crystallization mechanisms in oxide or metallic glasses

Different Possibilities (nucleation in bulk, nucleation at defects, spinoidal decomposition), large theoretical activity

Today, Nucleation mechanisms are deduced from

- *Final microstructure*
- *Powder diffraction*

Data are often ambiguous and incomplete

We aim to directly measure the nucleation mechanism

- *In the bulk*
- *With ~second time resolution*
- *For scales down to ~nanometers*

By simultaneously measuring the evolution *and* interactions of 100s of nuclei.

New opportunities with submicron beams

Example: The drive toward minaturisation has produced objects which require real nano-scale beams to be mapped

Variations in strain over the tiny features in modern electronic chips, in which a wire may only be a few crystals wide, have large effects on the chip's performance and lifetime

Direct mapping with diffraction gives not just spatial information, but also

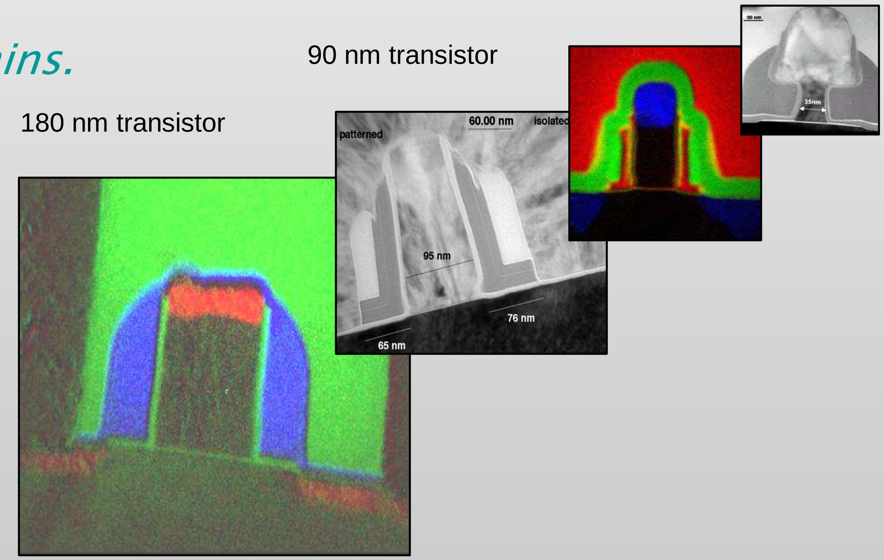
- *grain sizes,*
- *grainorientaions*
- *strain state*
- *The relations* between *grains.*

32 nm transistor

65 nm transistor

90 nm transistor

180 nm transistor

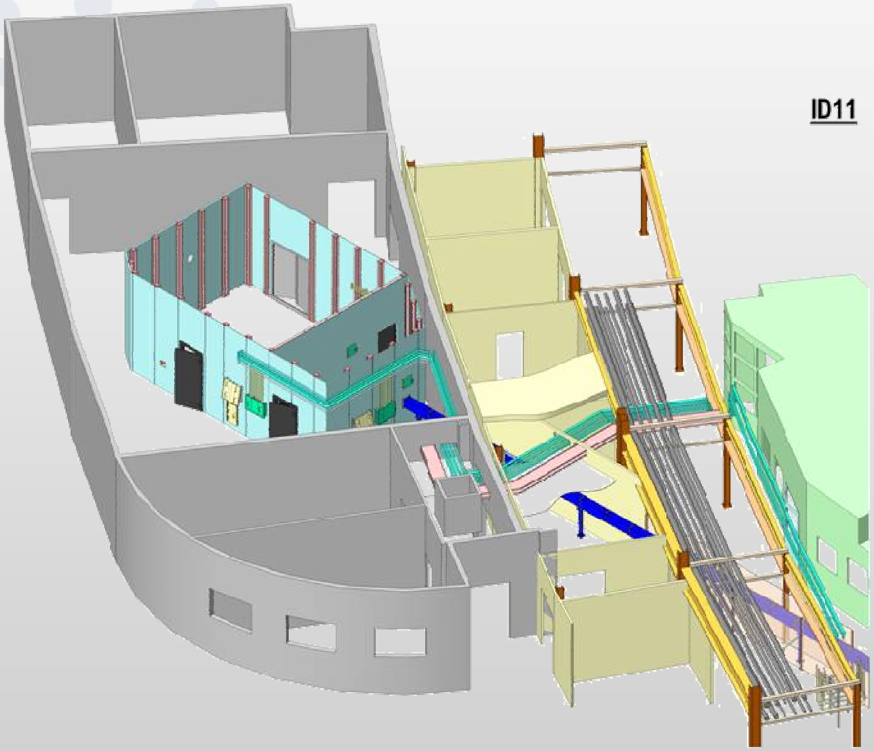


Why a new hutch

- Improve focusing ratio
- Purpose built for temperature and vibration control
- Refactor optics and diffractometer after generations of evolutionary development
- Independent foundation
- More room (2πr)

Current Status of ID11

Building complete
Commissioning began in Dec 2006
User experiments since Feb 2007
1st experimental station operational
Moderate focus optics upgraded
10 Hz Feedback implemented
Diffractometer upgrade in progress



Schedule

- Scientific Program
  - Statistics
  - Scientific Background
- Experimental Realization
- Current Challenges
- Ongoing Evolution

A. Bytchkov
J. Wright
C. Gundlach

- Proposed Evolution
- Conclusion

Schedule

- Scientific Program
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A. Bytchkov
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- Proposed Evolution
- Conclusion

Why Nanofocus?

- Our techniques for high spatial resolololution depend on having a limited (<1000) number of crystals in the beam)
- The smallest features which may be measured depend on the sample mosaic, size and the size of the focal spot
- We aim to characterise the sample on multiple length scales (Å – mm)
- With a smooth transition from direct (mapping/reconstruction) to derived (crystallography) characterisation

Why Nanoscale?

Direct structural studies of phenomena on the submicron to nanoscale, in the bulk, have never before been possible.

This scale is crucial in determining long-range materials properties such as strength, elasticity, etc.

Classical descriptions of these properties, based on average or derived descriptions of their submicron bulk strucutre, are waiting to be tested

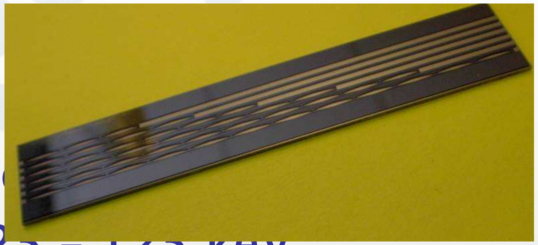
Essentially every experiment we've done so far contradicts the classical models, which ignore

- Heterogeneity
- Inter-grain interactions

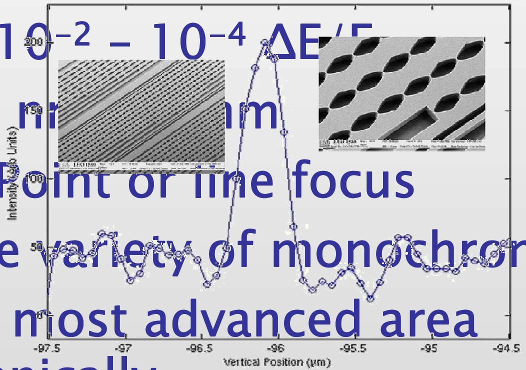
Challenges

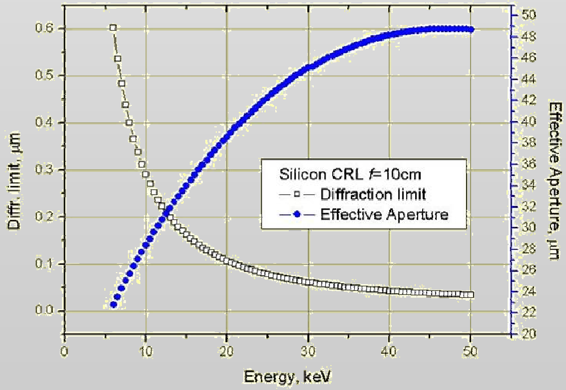
- Optics
- Thermal drifts
- Ambient vibrations
- Vibrations during rotations
- Source size broadening
- Flux density reduction
- Sample Positioning
- Sample metrology

Si Nanolens



- Mon
  - 25 – 125 keV
  - $10^{-2} - 10^{-4}$ ΔE/E
- 250 n m
  - Point or line focus
- Wide variety of monochromators
- The most advanced area technically

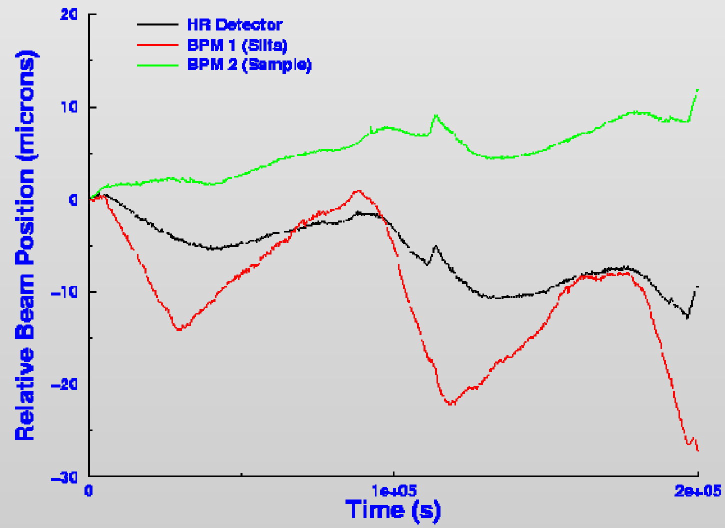




Challenges

- Optics
- Thermal drifts
- Ambient vibrations
- Vibrations during rotations
- Source size broadening
- Flux density reduction
- Sample Positioning
- Sample metrology

•Everything moves!
•Default sample + optics mounts not optimised at all for thermal stability
•Diffractive/Refractive optics multiply effect:
  •Best case: ~µrads/ºC for diffractive/refractive optics
  •i.e., microns at 1 m, 10s nm at 10 mm
  •Multiply with effects of everything else in the stack

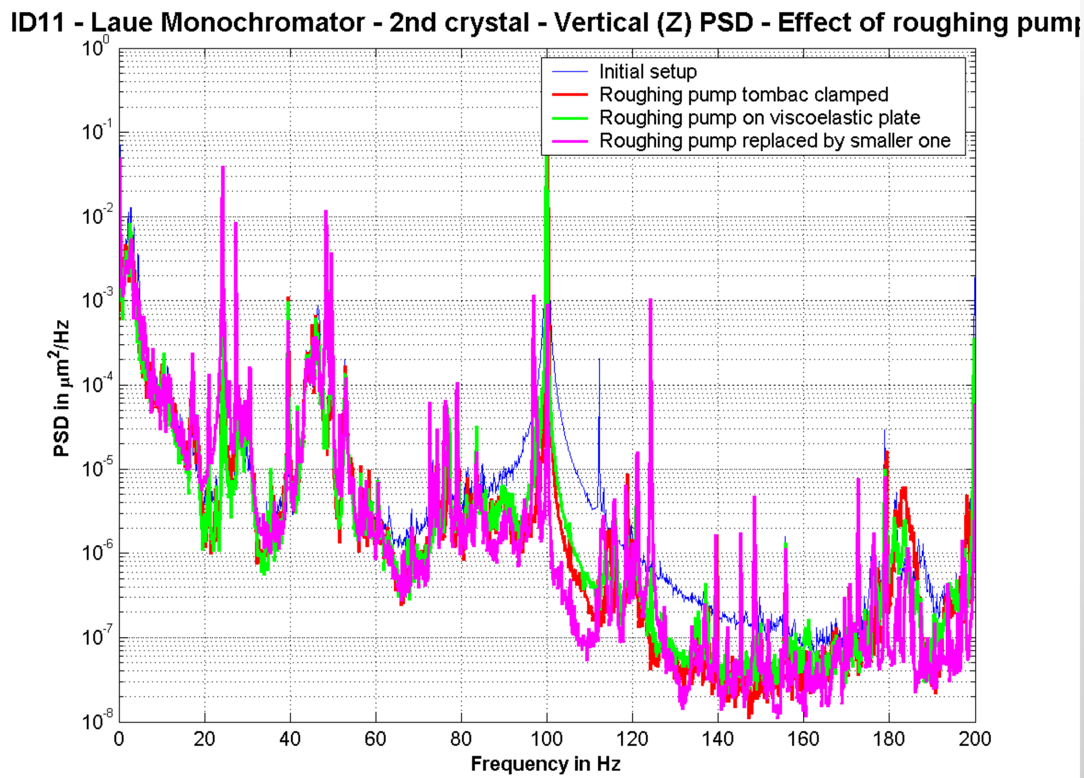


Challenges

- Optics
- Thermal drifts
- Ambient vibrations
- Vibrations during rotations
- Source size broadening
- Flux density reduction
- Sample Positioning
- Sample metrology

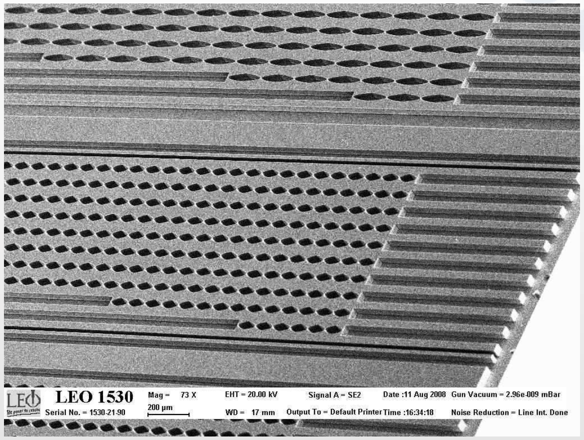
~µm amplitudes on floor, up to high frequencies

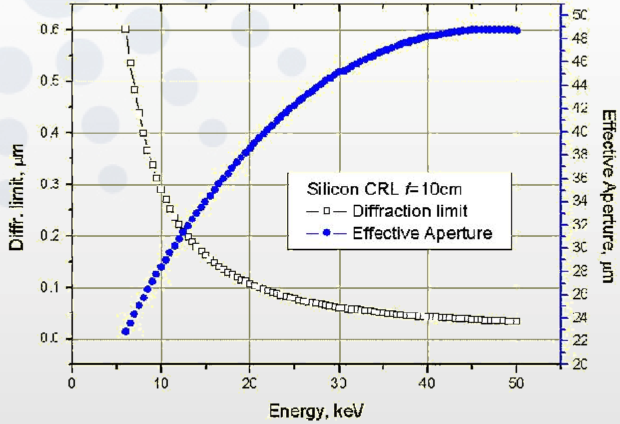
Position – configuration		*Horizontal AC OFF*	*Horizontal AC ON*	*Vertical AC OFF*	*Vertical AC ON*
ID11 Floor	0.5 m	0.56 (*0.09*)	0.53 (*0.08*)	0.85 (*0.14*)	0.70 (*0.12*)
	3m	0.50 (*0.08*)	0.48 (*0.08*)	0.94 (*0.15*)	0.76 (*0.13*)

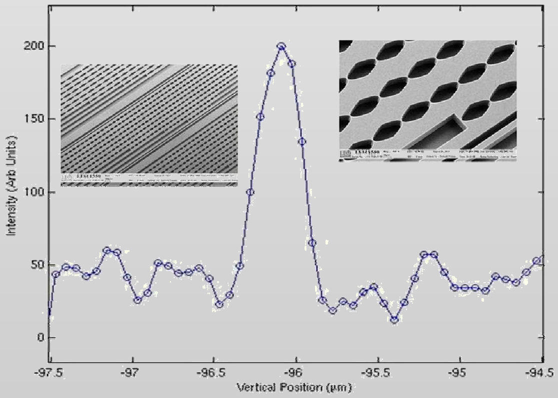


Everything moves!

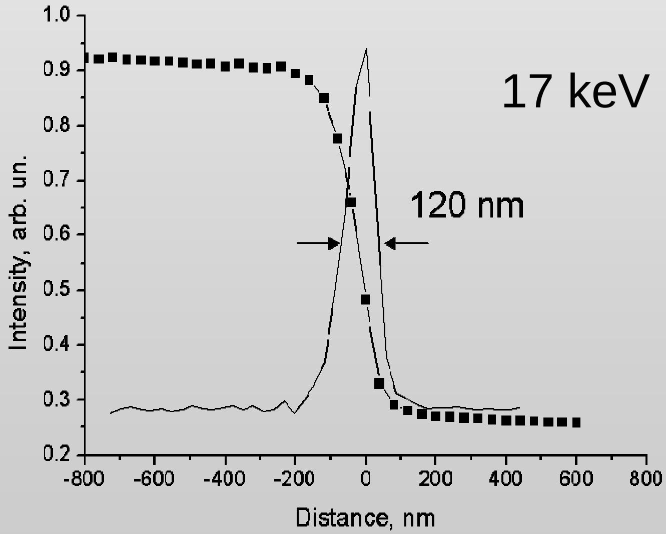
CRL – nanofocusing lenses



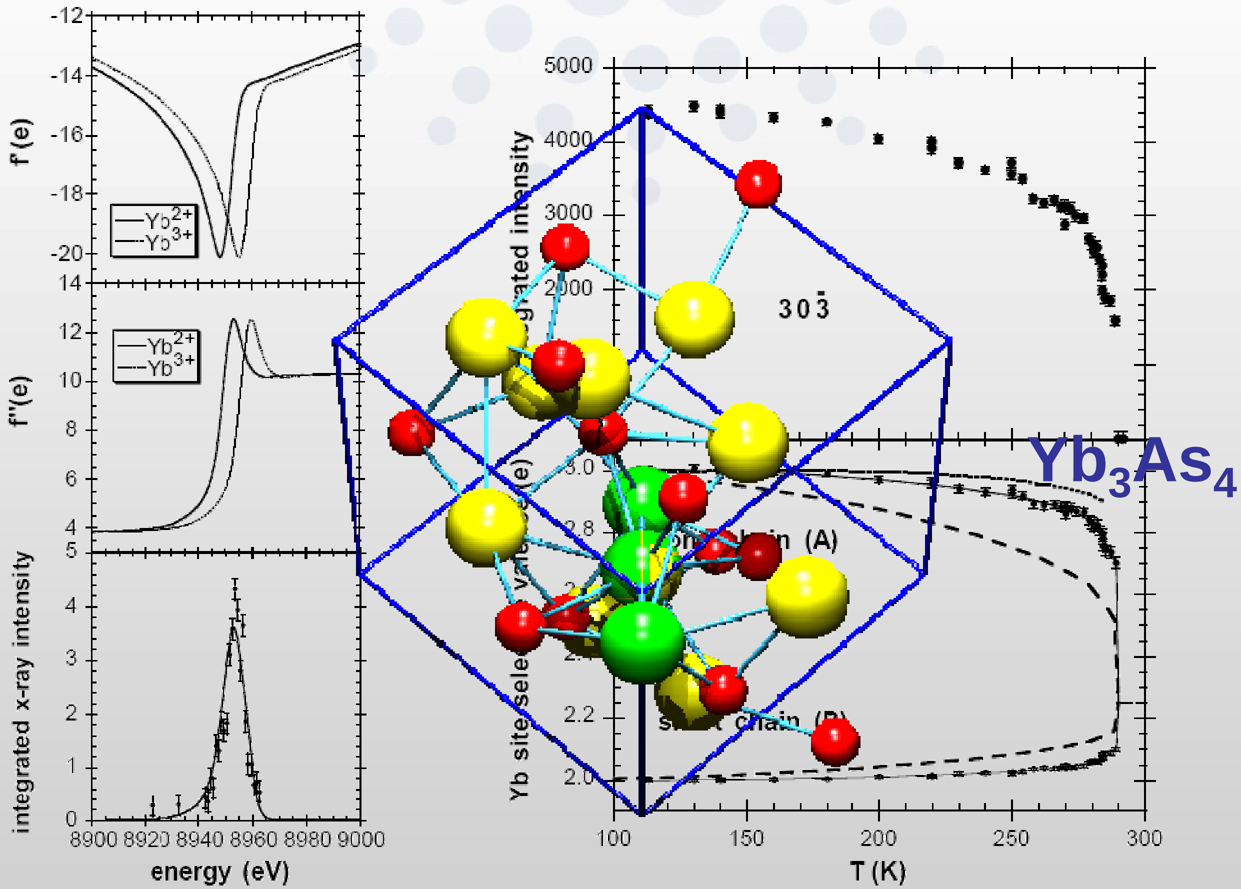




45 keV

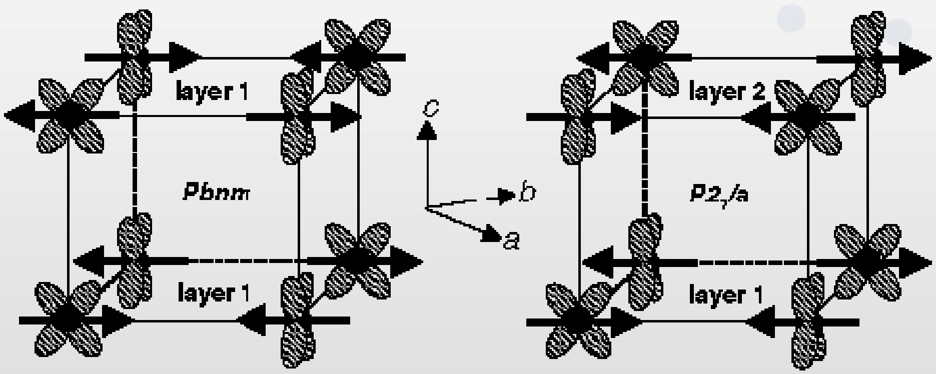


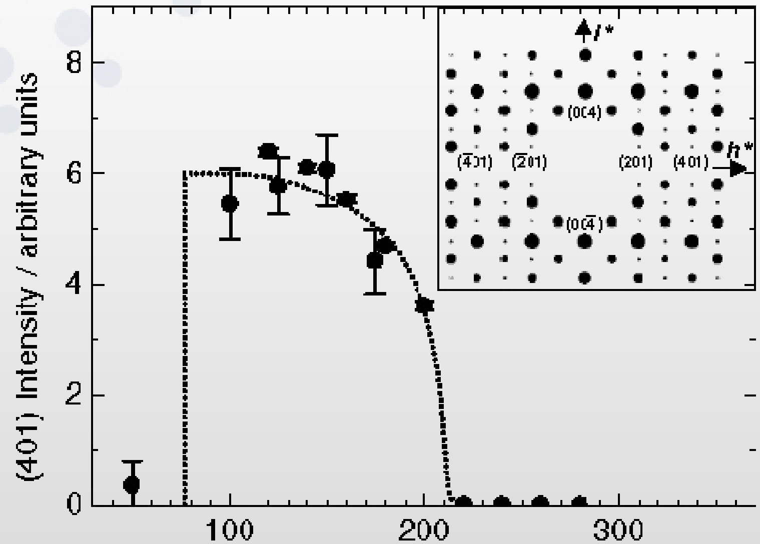
Charge Ordering: Beyond Valence Sums



Using anomalous Diffraction to achieve an independent measure of oxidation state

Orbital Ordering



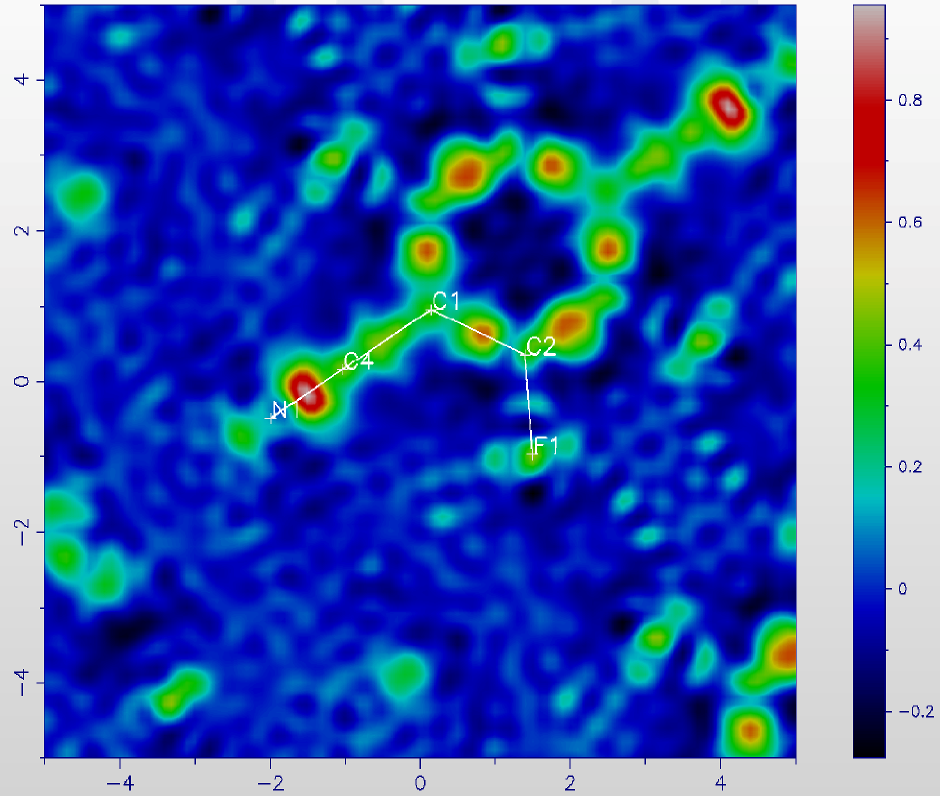


Symmetry lowering due to orbital ordering

$I_{\text{"forbidden peaks"}} \sim 10^{-4} \times I_{\text{principle}}$

Blake et al., *Phys. Rev. Lett.*, **87**(24) 245501 (2001).

Charge Density Studies



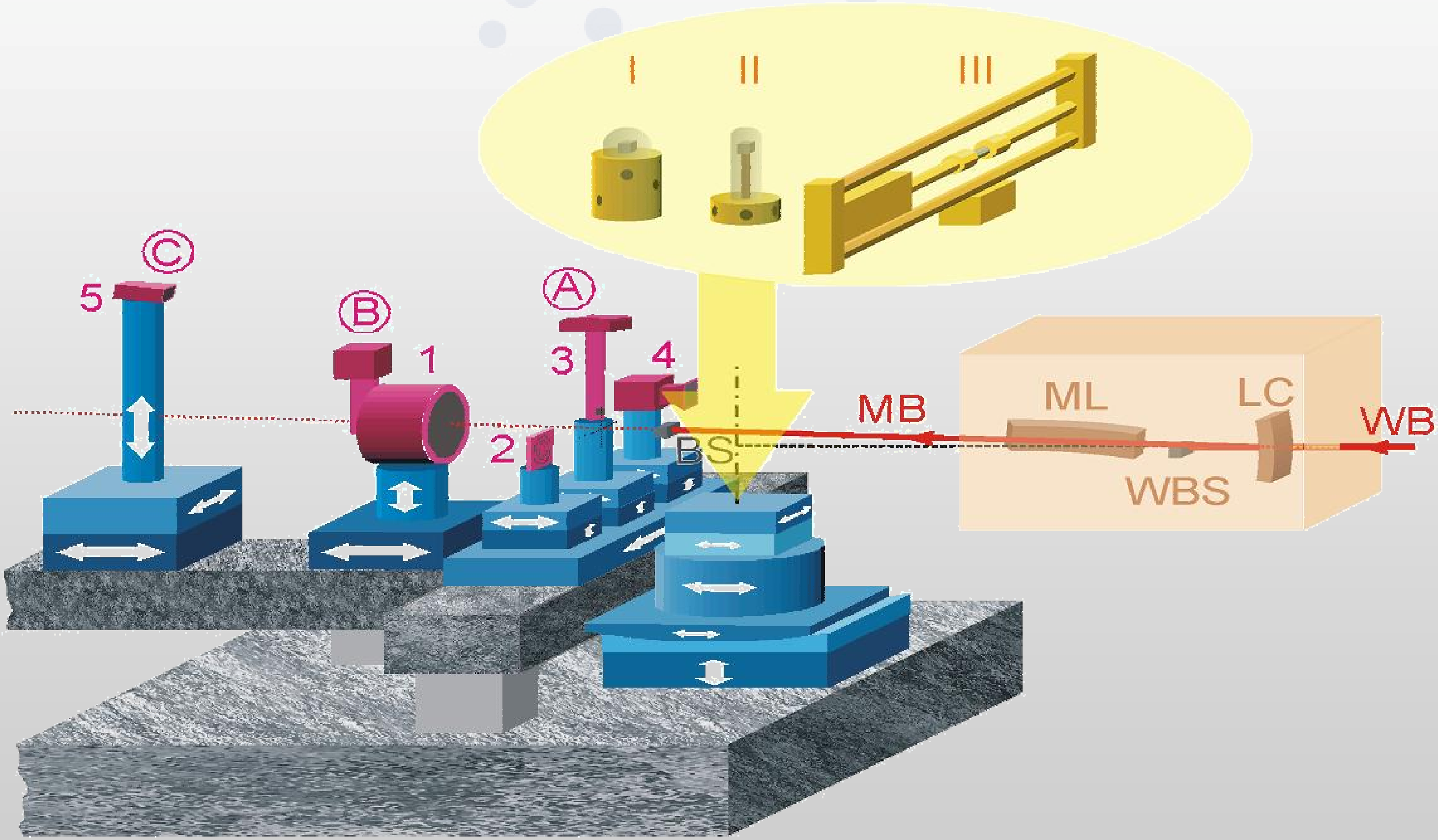
Determine charge distributions beyond the spherical atom limit

Single Crystal Studies

Good structures from bad crystals

Fine details from decent crystals

3DXRD Microscope



Software

Up to 1 Tb/day at the moment – has to be at least preprocessed psedo-online
Much development has been carried out in the last several years

Fable project, for data acquisition, reduction and analysis…demonstrations during BL visit

Diffractometer and environment

Mechanical specifications necessary to perform sub-micron experiments are now realisable. Real spatial resolution determined not by beam size, but by diffractometer and metrology.

Two current experimental stations:

EH1 for large, heavy experiments with moderate (>10 µm) focusing. New diffractometer installed last year.

EH3 for micro and sub-microfocusing (~100nm static, ~750 nm 360º rotation): new diffractometer is being acquired.

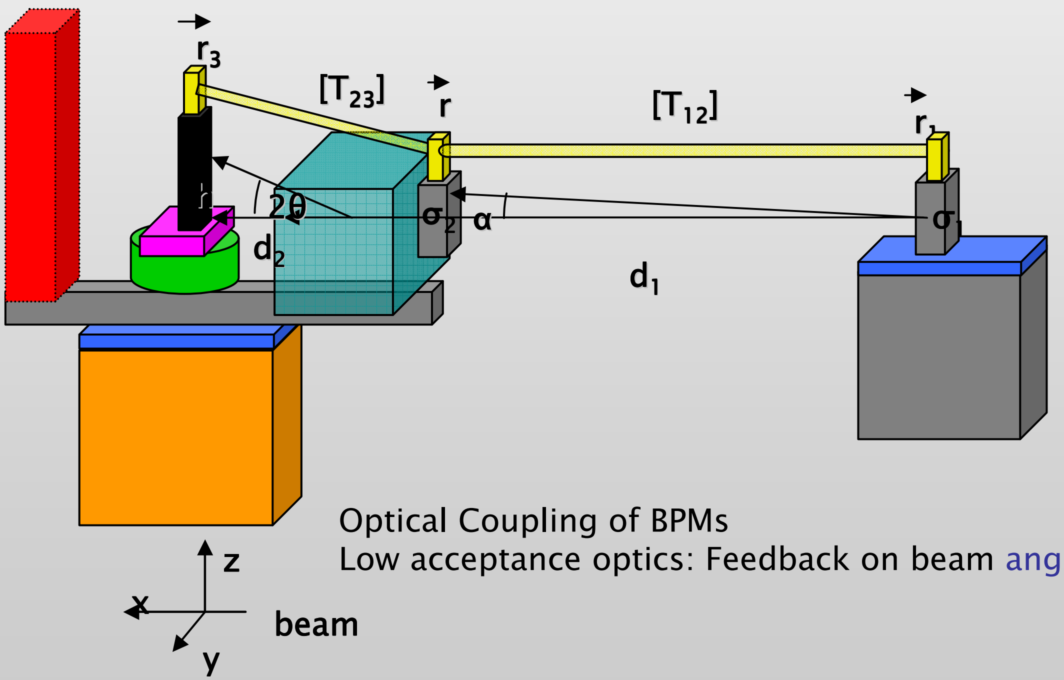
A variety of detectors and sample environments are available

Challenges

- Optics
- Thermal drifts
- Ambient vibrations
- Vibrations during rotations
- Source size broadening
- Flux density reduction
- Sample Positioning
- Sample metrology

Feedback scheme

- BPM near the sample, activating Piezo on optics (i.e., Laue monochromator) angle (=position)
  - Could predict offset via temperature/angle measurements if no BPM available
- Hardware feedback currently functioning at ~10 Hz
- 200 nm rms stability of ~µm beam on s time scale



Optical Coupling of BPMs
Low acceptance optics: Feedback on beam angle

Challenges

- Optics
- Thermal drifts
- Ambient vibrations
- Vibrations during rotations
- Source size broadening
- Flux density reduction
- Sample Positioning
- Sample metrology

•Problem: twice as far from source: ¼ of flux density

•Solution: Collimator/Condensor based on CRLs

•In white beam

•Variable number of Al/Be lenses

•Collimate (Moves source to infinity)

  •Improves energy/spatial resolution

•Focus to 1mm @23 m to 150 μm @ 100 m

  •Similar to acceptance of nano-optics

•25-125 keV

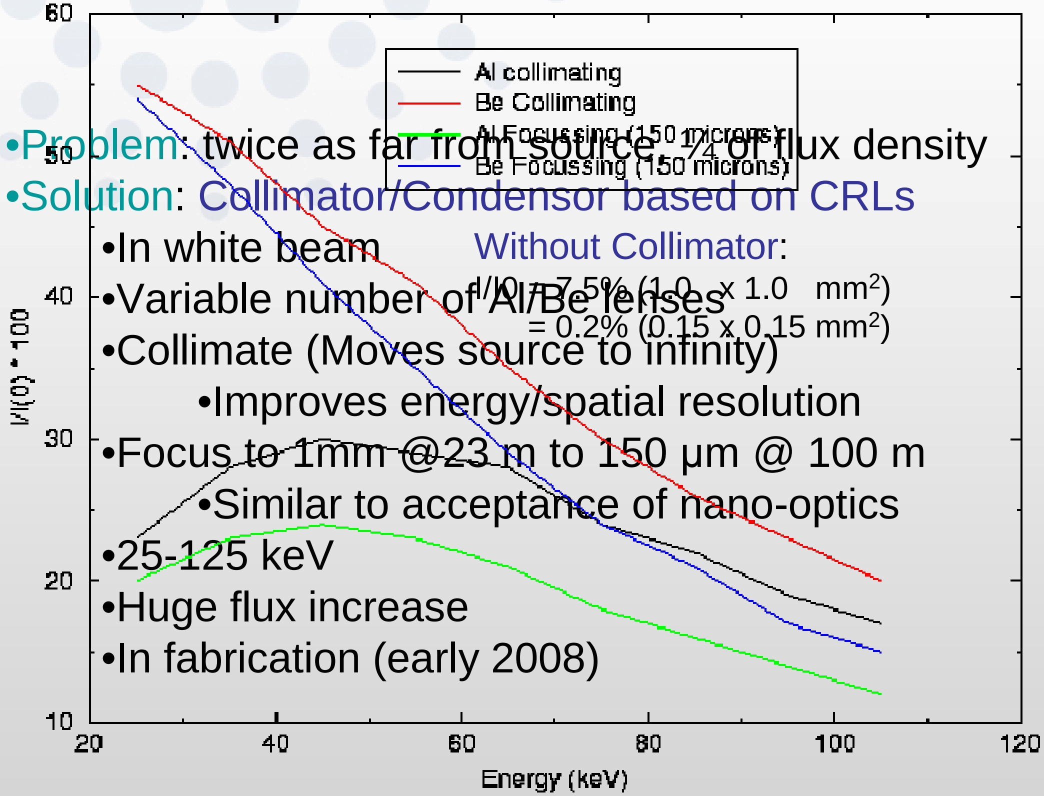
•Huge flux increase

•In fabrication (early 2008)

Without Collimator:

I/I_0 = 7.5% (1.0 x 1.0 mm^2)

= 0.2% (0.15 x 0.15 mm^2)



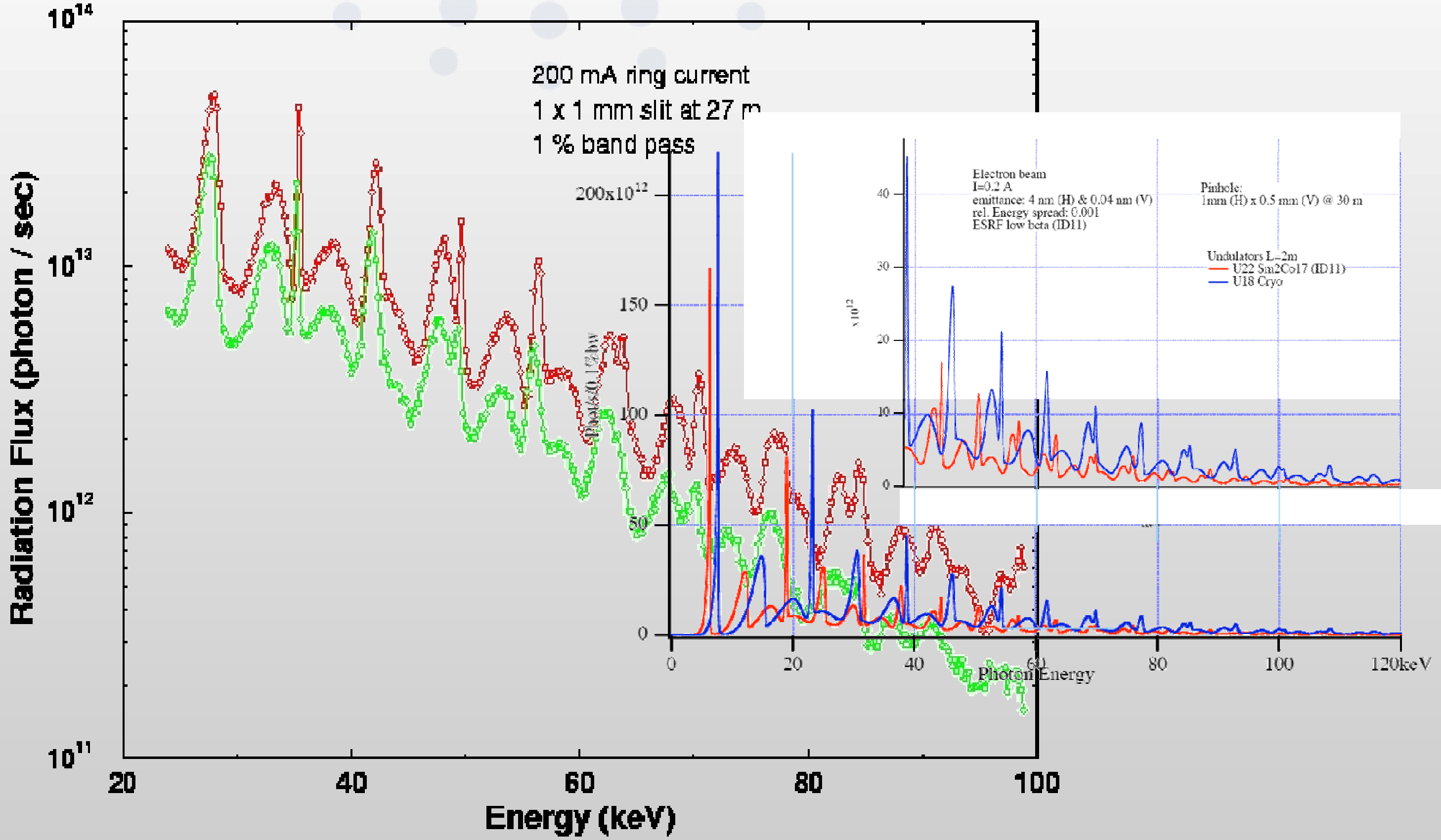
Challenges

- Optics
- Thermal drifts
- Ambient vibrations
- Vibrations during rotations
- Source size broadening
- Flux density reduction
- Sample Positioning
- Sample metrology

Below 2 μm there is a transition
Need a big effort in this area

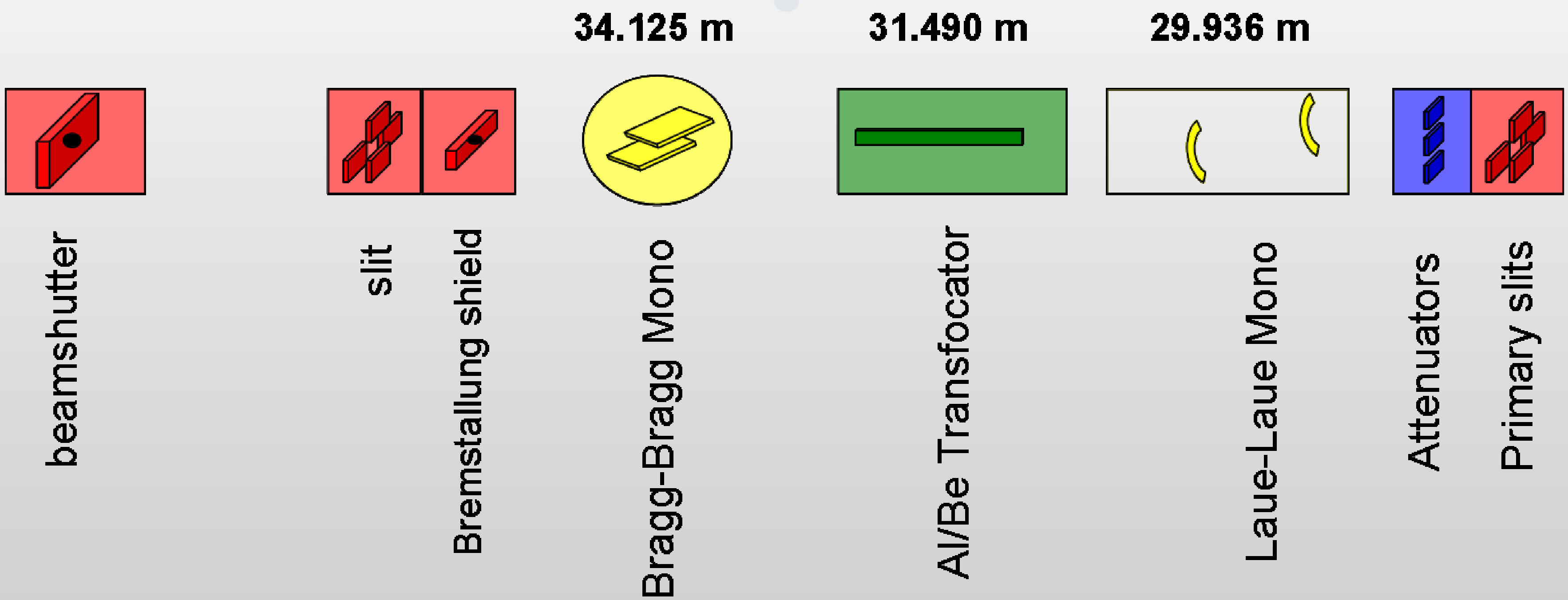
- Interferometry?
- Image recognition?

Source

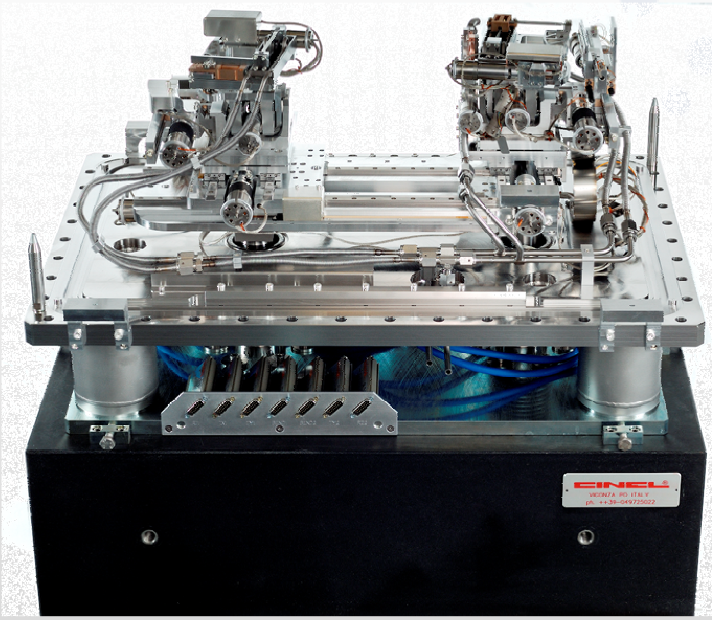


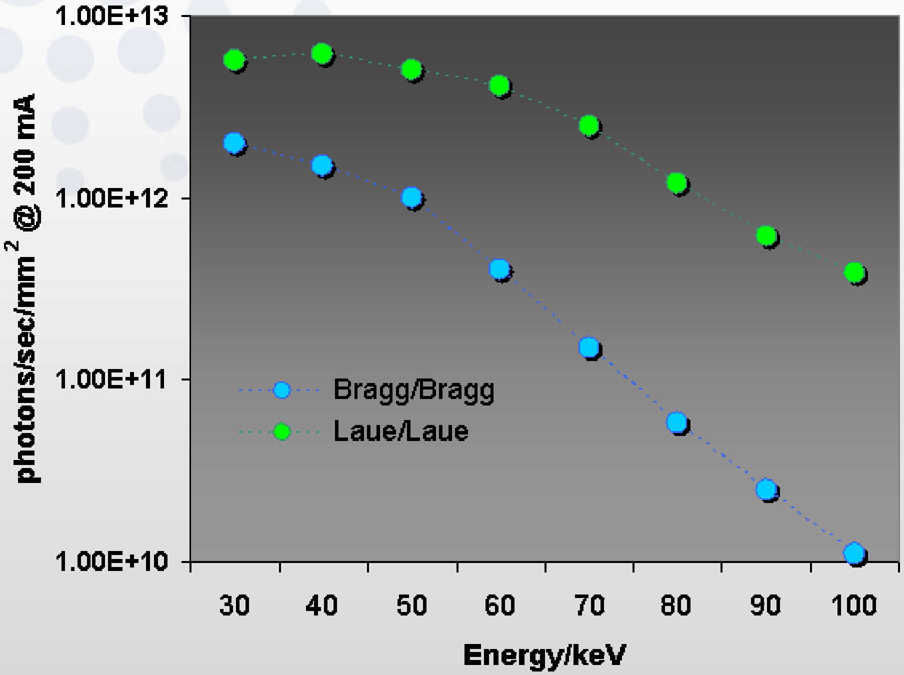
200 mA ring current
1 x 1 mm slit at 27 m
1 % band pass
Radiation Flux (photon / sec)
Energy (keV)
Electron beam
I=0.2 A
emittance: 4 nm (H) & 0.04 nm (V)
rel. Energy spread: 0.001
ESRF low beta (ID11)
Pinhole:
1mm (H) x 0.5 mm (V) @ 30 m
Undulators L=2m
U22 Sm2Co17 (ID11)
U18 Cryo
Photon Energy

Primary optics



Primary Monochromator



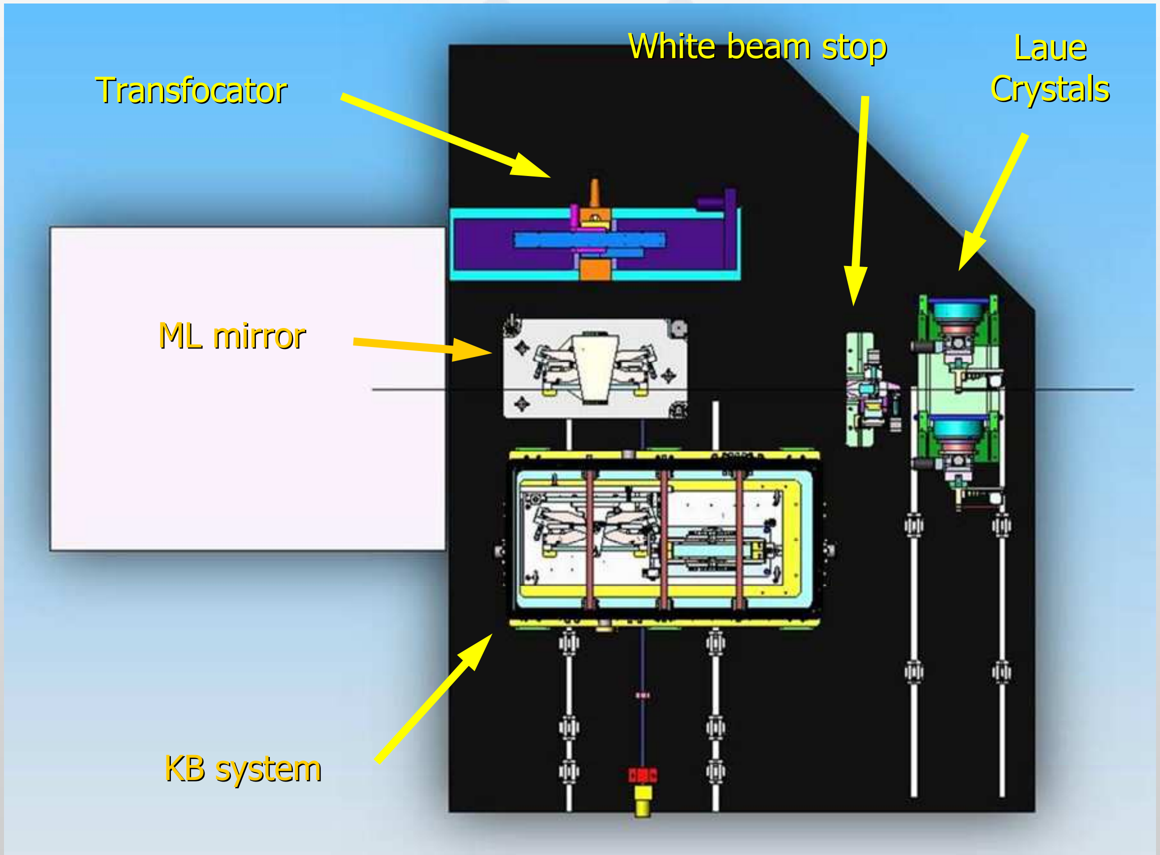


New horizontal Laue-Laue monochromator gives excellent flux, beam stability and homogeneity.

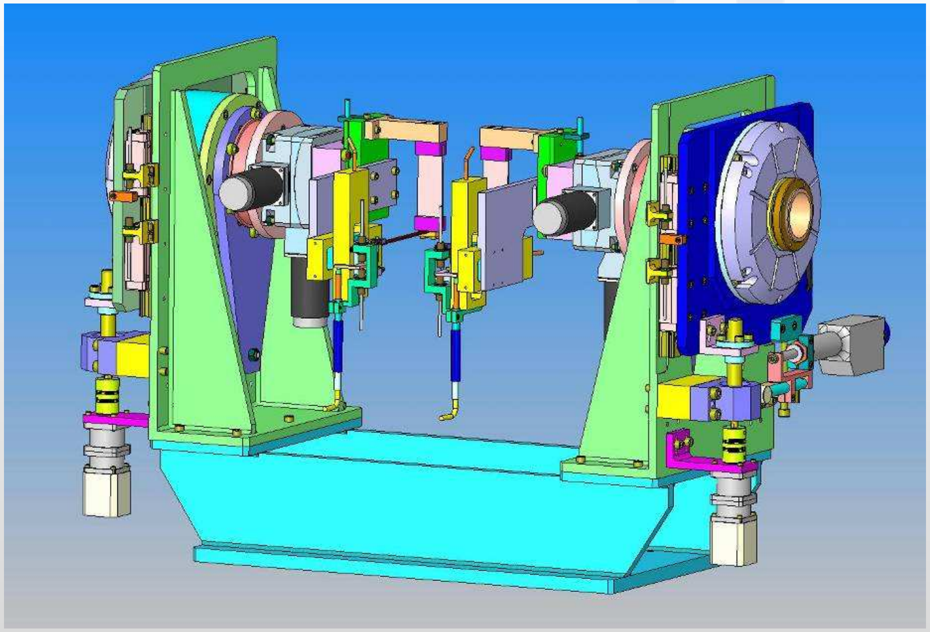
Focussing Optics

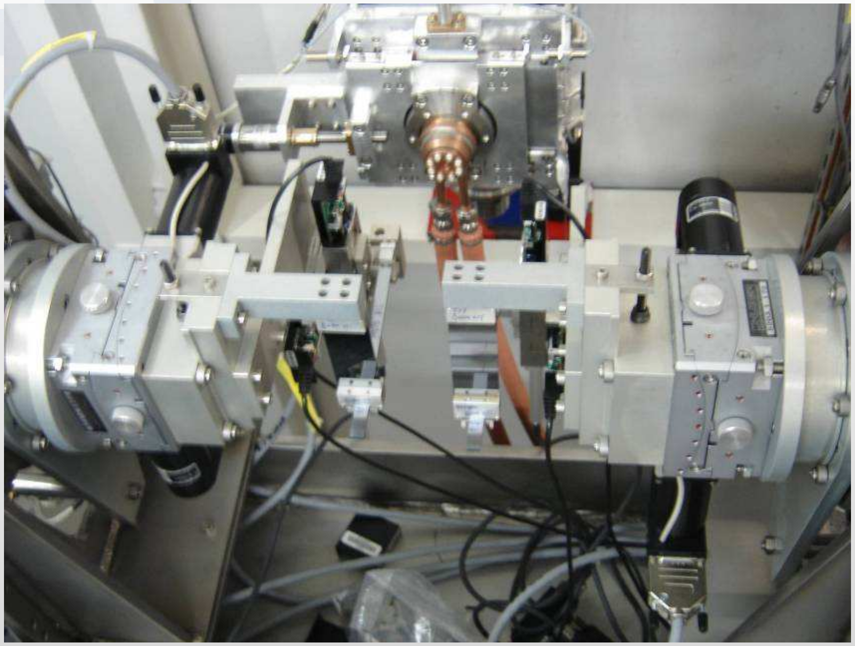
Optical Element(s)	*ΔE/E*	*Focus Achieved (horizontal × vertical, μm)*	*Energy Range (keV)*	*Maximum Flux in spot (photons/s)*
Saggital Bragg/Bragg	10^{-4}	200 × ---	23 - 64	10^{14}
CRL + Bragg/Bragg	10^{-4}	3 × 1.0	23 - 99	10^{12}
CRL + Laue/Laue	10^{-2}~10^{-3}	3 × 1.0	30 -140	10^{14}
nCRL + Bragg/Bragg	10^{-4}	0.50 × 0.25	23 - 80	10^{9}
nCRL + Laue/Laue	10^{-2}~10^{-3}	0.50 × 0.25	30 - 80	10^{11}
Bent Laue	10^{-2}~10^{-3}	--- × 1.2	35 -100	10^{14}
KB + Bragg/Bragg	10^{-4}	4 × 2.5	25 -100	10^{14}
KB + Laue/Laue	10^{-2}~10^{-3}	4 × 2.5	25 -100	5×10^{14}
Bent Laue + ML (h)	10^{-2}	4 × 1.2	50 - 80	5×10^{14}

Focussing Optics



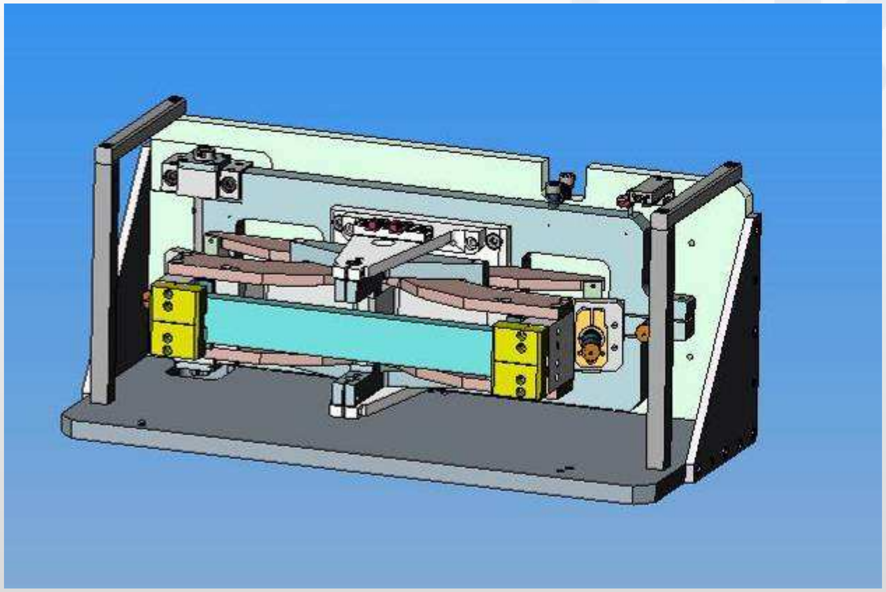
Focussing Optics

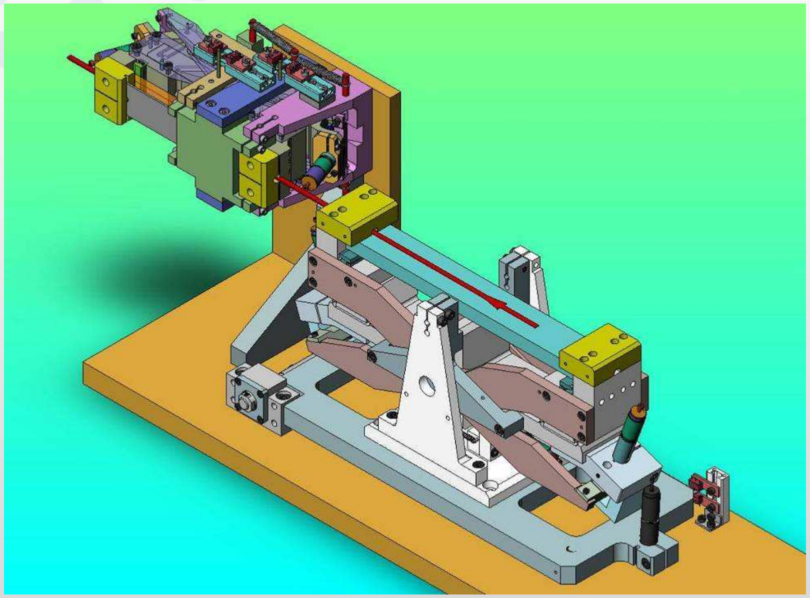




Laue vertical monochromators – High flux and stability for line beams

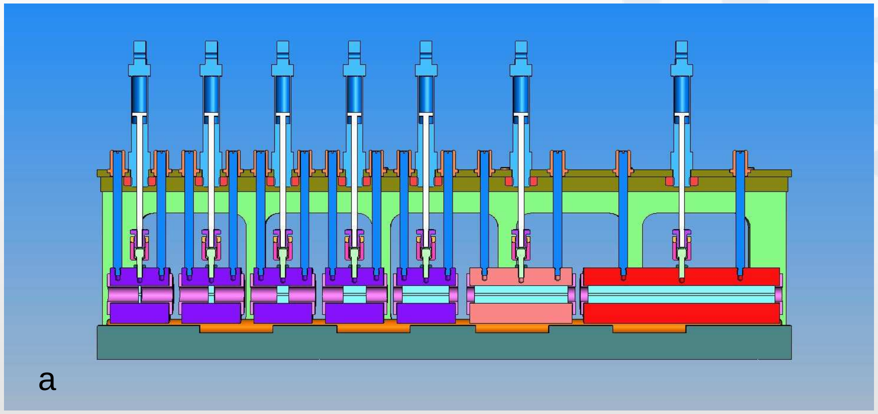
Focussing Optics

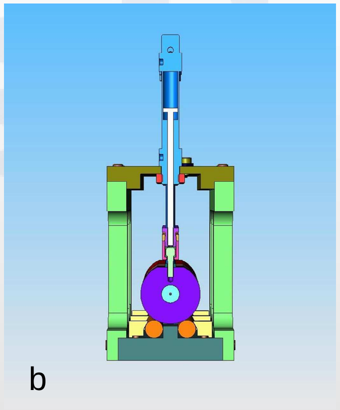


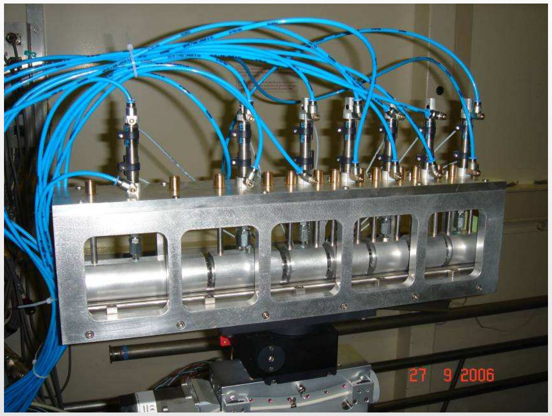


Single or crossed multilayers – high flux but stability more critical

CRL - Transfocator

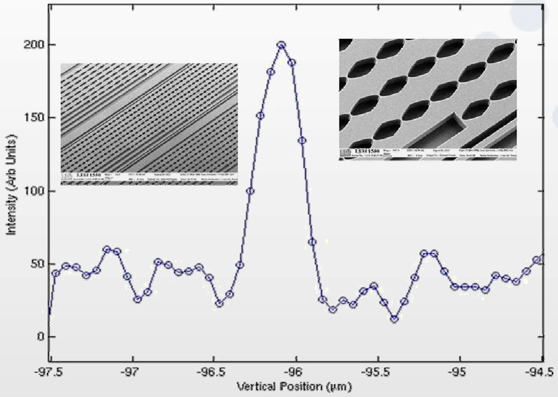




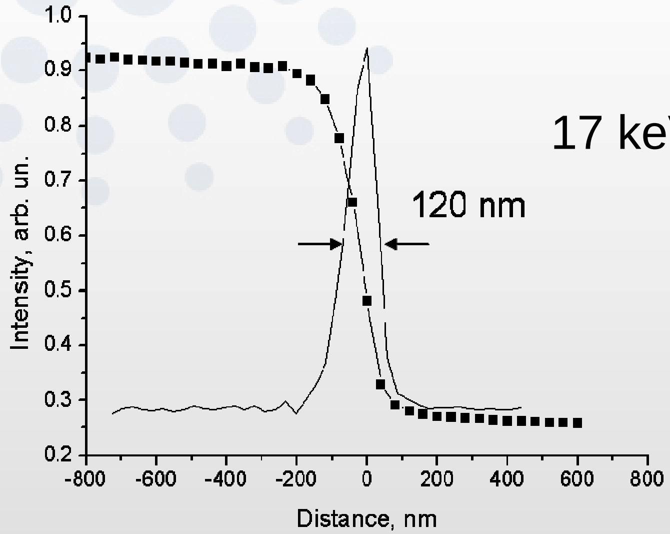


Adjustable number of lenses for focus between 25 - 50 keV (current model)
In vacuum model for focus (100 - 150 µm) or collimation between 25 - 125 keV

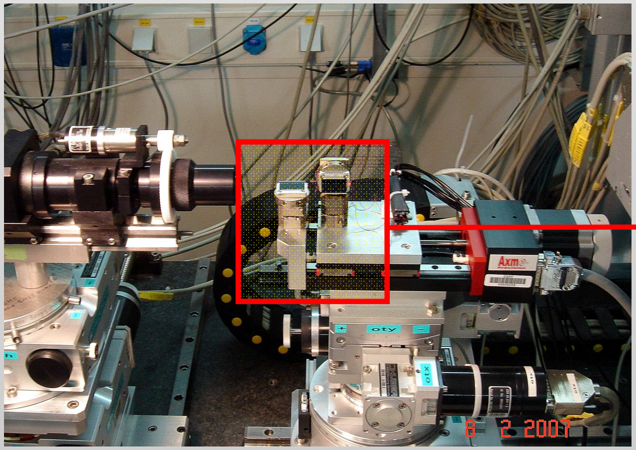
CRL – nanofocusing lenses

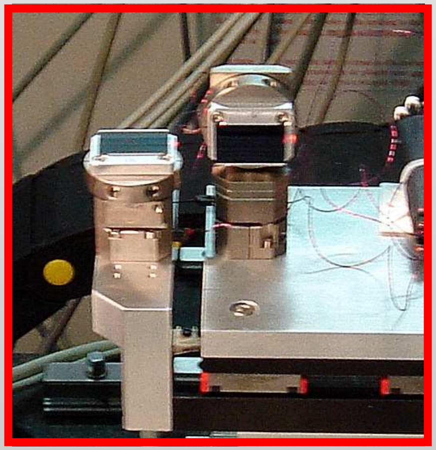


45 keV



17 keV





Can be crossed for 2d focusing

Conclusions

- Many Challenges remain, but goals are achievable
- Proposed extensions will
  - Close the scale gap
  - Allow the characterisation of "intermediate" ordered structures