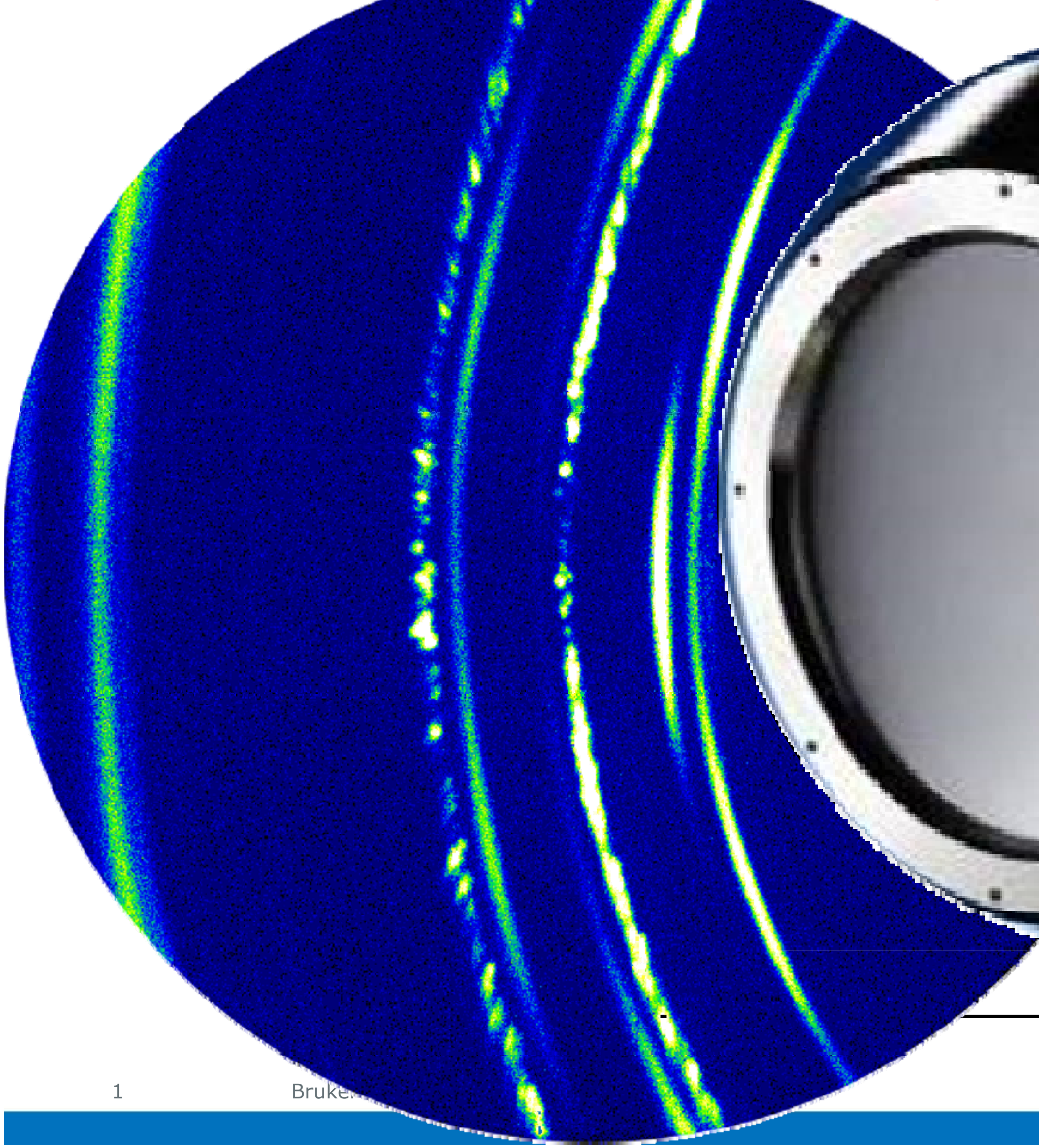
VÅNTEC-500 Area Detector for Pharmaceutical XRD



Bob He

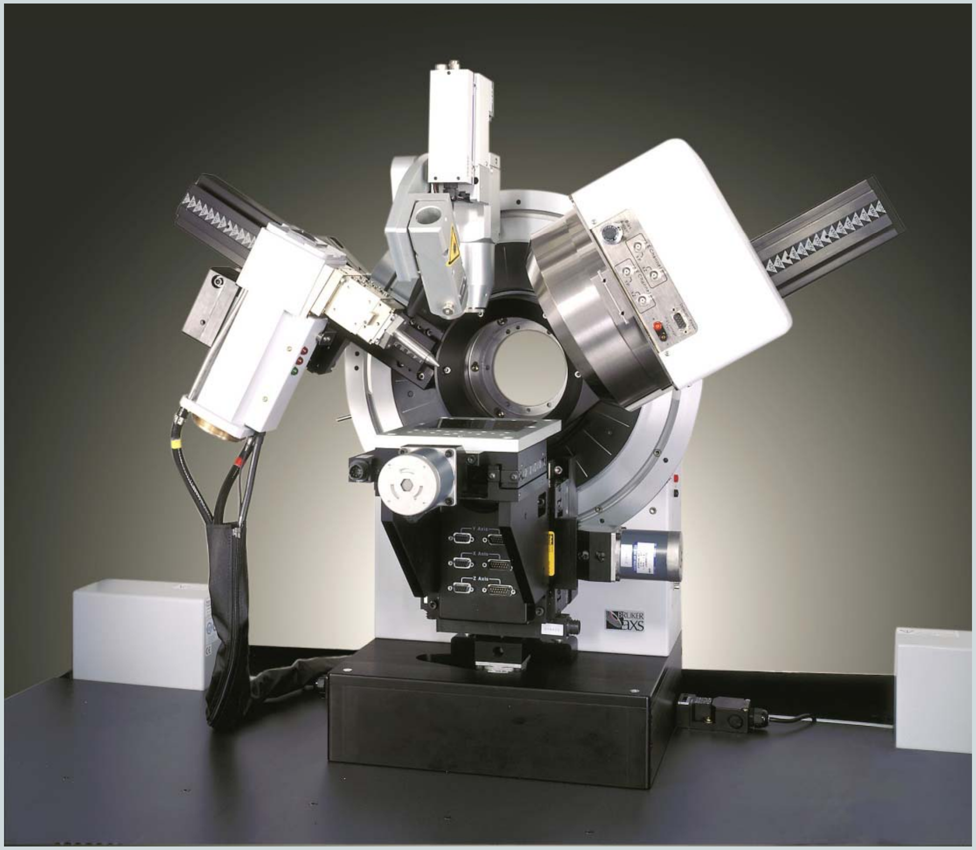
This document was presented at PPXRD - Pharmaceutical Powder X-ray Diffraction Symposium

Sponsored by The International Centre for Diffraction Data

PPXRD Website – www.icdd.com/ppxrd ICDD Website - www.icdd.com

XRD^2 for Pharmaceutical:

Reflection System (CS)



XRD^2 for Pharmaceutical:
Reflection & Transmission (HTS)

US Patent #7,242,745

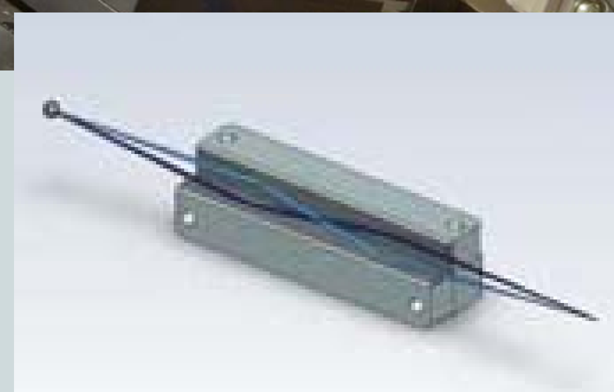
XRD^2 : Innovation and Development

The most dramatic development in XRD^2 happens in three critical components and data evaluation algorithms:

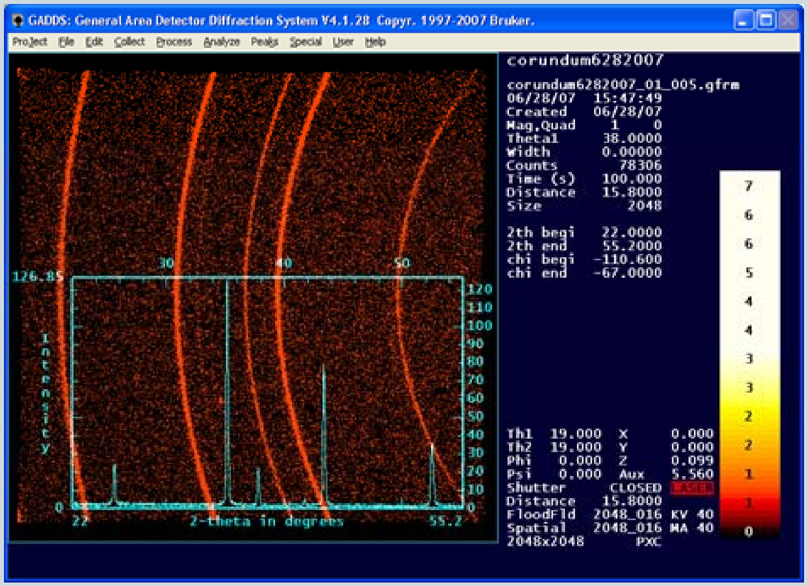
- Source: required radiation energy, focal spot size and intensity.
- Optics: select wavelength, beam profile and divergence.
- Detector: collect 2D pattern with correct intensity and position.
- Data evaluation Algorithm: Diffraction Vector Approach.

X-ray Source for XRD^2:
Incoatec Microsource (IμS)™

- High brilliance
- Low energy: 30 W
- Air-cooled
- Spot size < 100 μm
- Montel mirrow



IμS & VÅNTEC-2000 vs. Classic Set-up
Corundum Comparison



Single 40mm Göbel Mirror,

45kV, 40mA,

0.3mm collimator

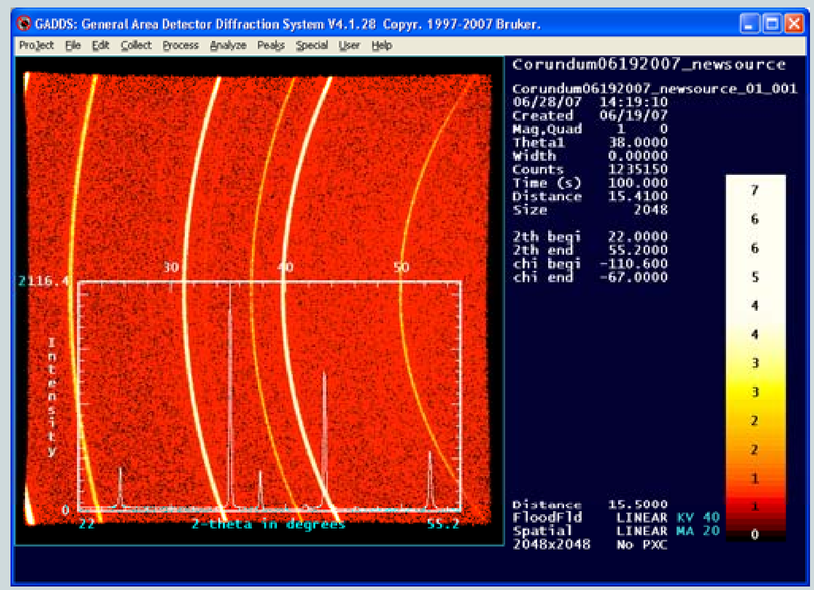
total counts: 78K

IμS & VÅNTEC-2000

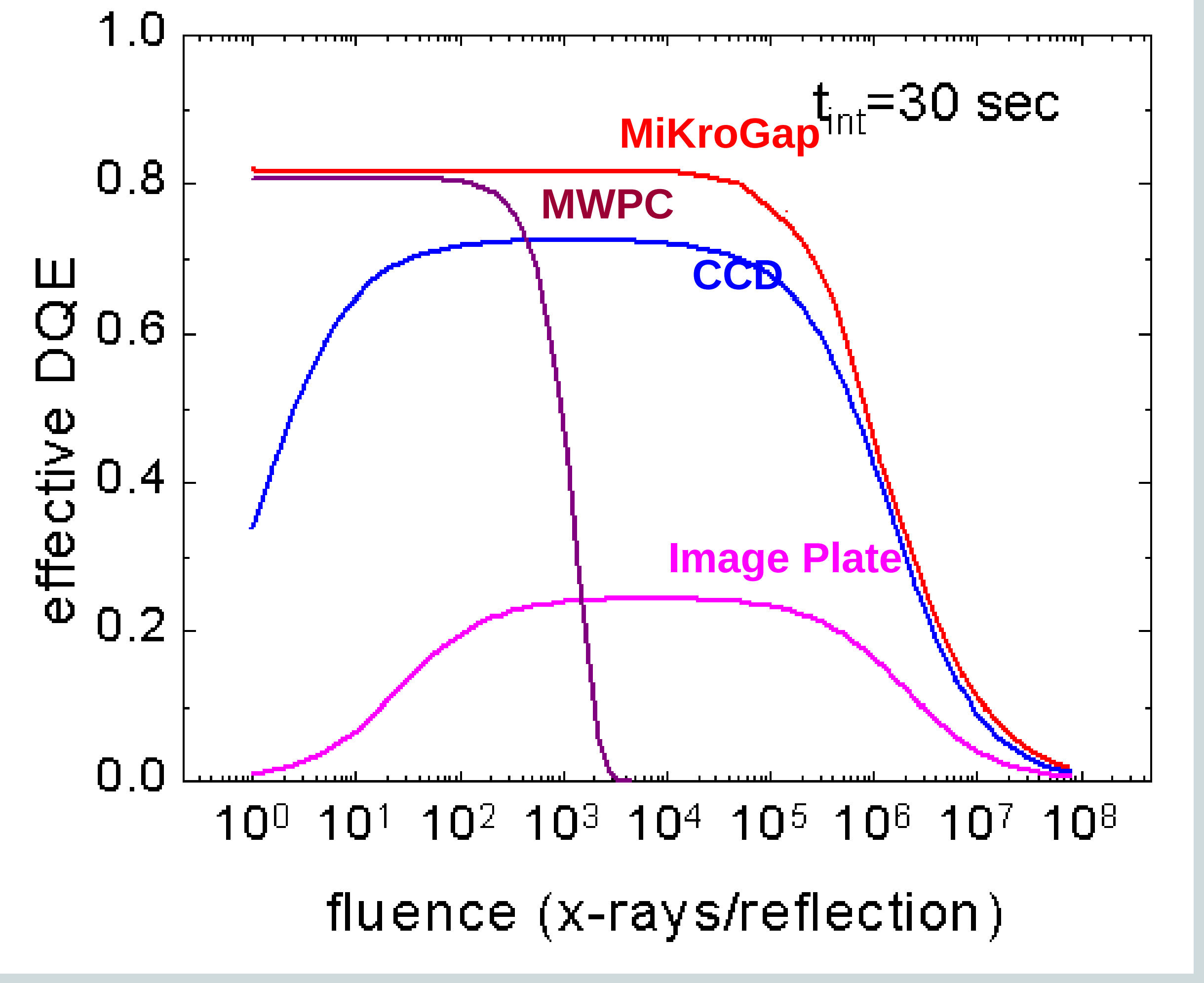
45kV, 0.650mA,

0.3mm snout

total counts: 1235K



XRD²: Choice of Detectors
Sensitivity vs. Count Rate



Detective Quantum Efficiency (DQE):

- The DQE is a parameter defined as the square of the ratio of the output and input signal-to-nose ratios (SNR).

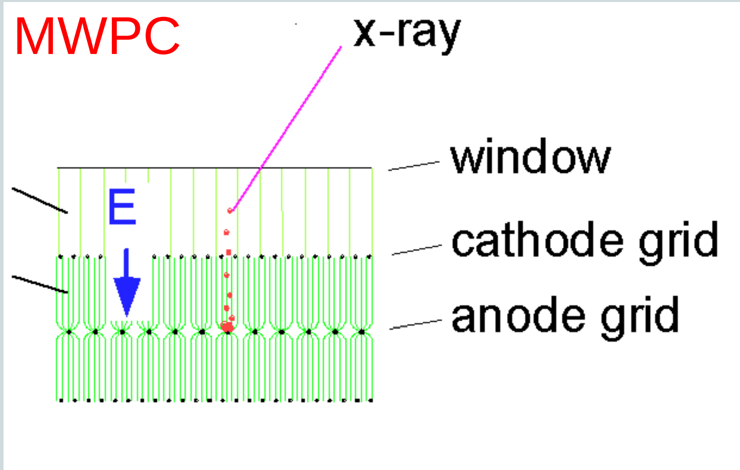
$$DQE = \left(\frac{(S/N)_{out}}{(S/N)_{in}} \right)^2$$

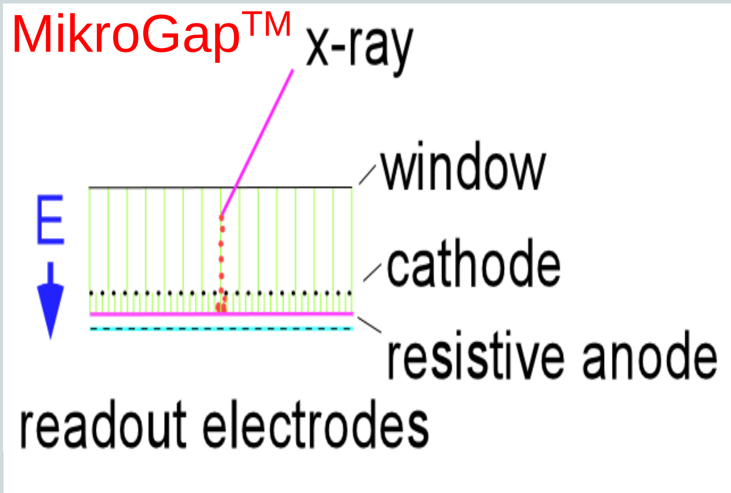
- The DQE of a real detector is less than 100% because not every incident x-ray photon is detected, and because there is always some detector noise.
- MiKroGap™ has the best overall performance.

Detector Technology from MWPC to MikroGap™

- MikroGap™ technology with resistive anode:
  - shortens drift time of ions
  - fast electrons induce charge on readout strips
- Adjusted surface resistance (10^5 - 10^7 Ω/ area):
  - high enough to limit discharges
  - low enough to support high count rates

US Patent US 6,340,819 B1





VÅNTEC-500 – Outperforms all previous gaseous detectors

Similar to Hi-Star (MWPC) detector:

- High sensitivity: 80% DQE (detection quantum efficiency) at 8.04 keV radiation
- Energy range: 3-15 keV (good for Cu, Co, Fe and Cr X-ray sources, not recommended for Mo)
- Energy resolution ($\Delta E/E$): 20% at 8.04 keV radiation
- Low background noise: <5 cps/global
- Readout time: real time
- No cooling
- Curved Be-window to reduce parallax

VÅNTEC-500 – Outperforms all previous gaseous detectors

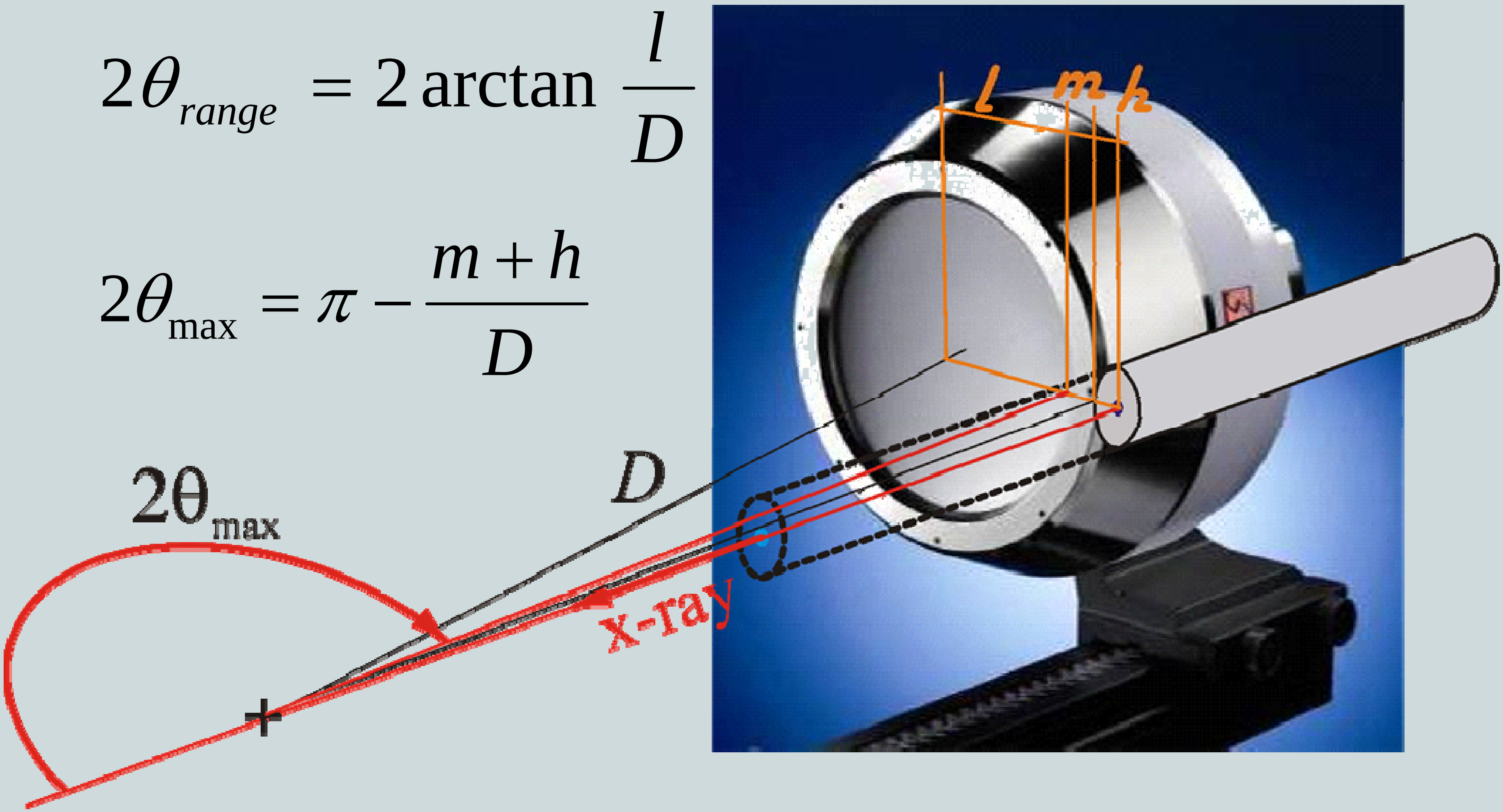
Advances from MWPC:

- Tapered front end for high 2θ angle access and space for large samples and sample stages
- Doubled the spatial resolution: The FWHM of the PSF is 200μm
- Two orders of magnitude higher maximum count rate:
  Global count rate: 1.5Mcps
  Local count rate: 250kcps per point-like reflection
- Radiation hardness: accidental intensive irradiation without permanent damage
- Maintenance-free: no re-gassing

VÅNTEC-500 – Tapered front for low and high 2θ accessibility

$$2\theta_{range} = 2\arctan\frac{l}{D}$$

$$2\theta_{\max} = \pi - \frac{m+h}{D}$$



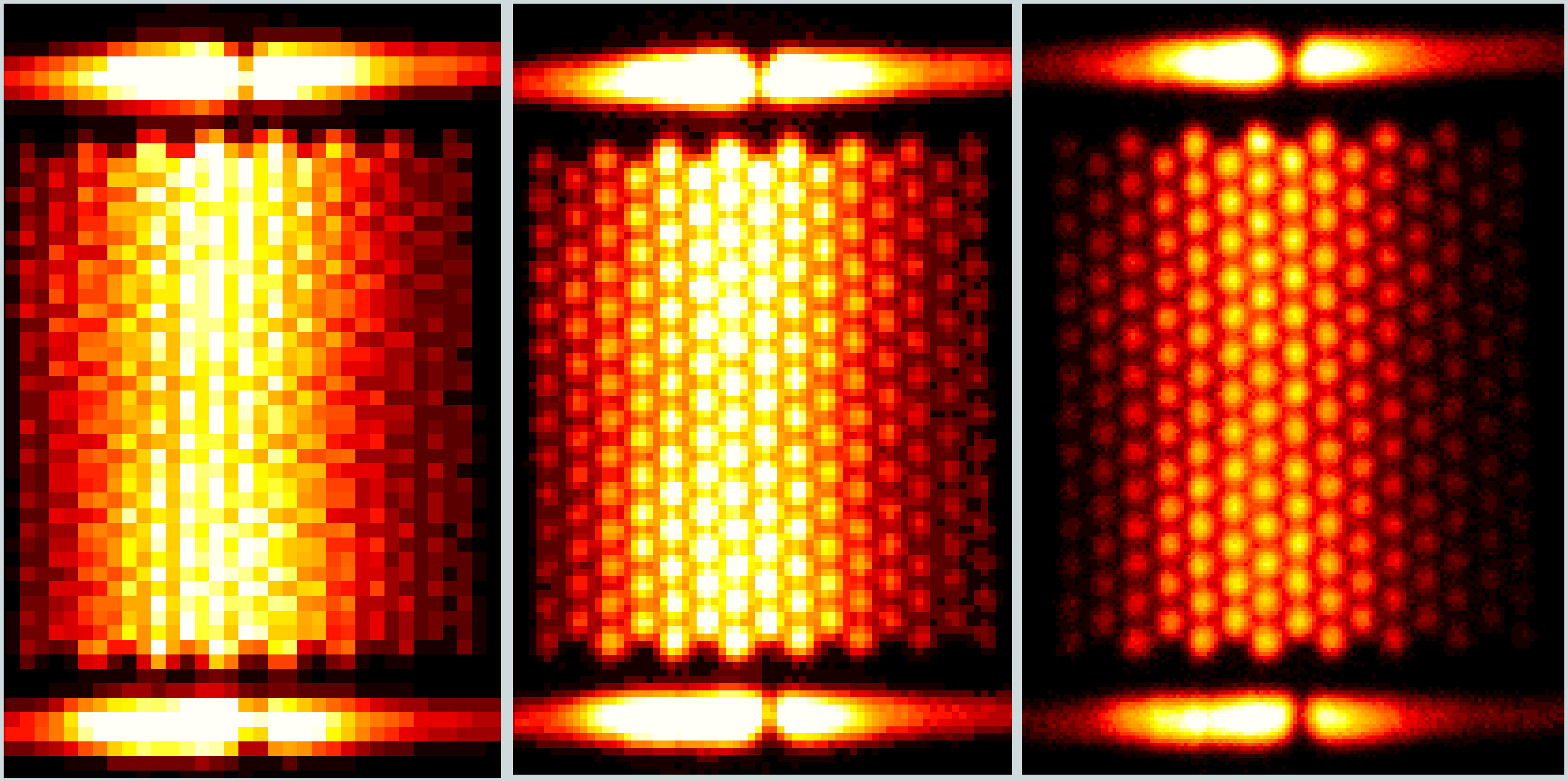
VÅNTEC-500 – Outperforms all previous gaseous detectors

Detector geometry:

- Be-window opening 140 mm in dia.
- Frame size:
  2048 x 2048 pixels
  1024 x 1024 pixels
  512 x 512 pixels
- Pixel size:
  68 μm x 68 μm
  136 μm x 136 μm
  272 μm x 272 μm
- Detector working distance:
  5~30 cm in D8 DISCOVER enclosure
- 2θ range in a single frame:

5 cm	83°
10 cm	56°
15 cm	42°
20 cm	33°
25 cm	27°
30 cm	23°

Hi-resolution with MikroGap™ Technology



272 μm pixel (512x512) 136 μm pixel (1024x1024) 68 μm pixel (2048x2048)

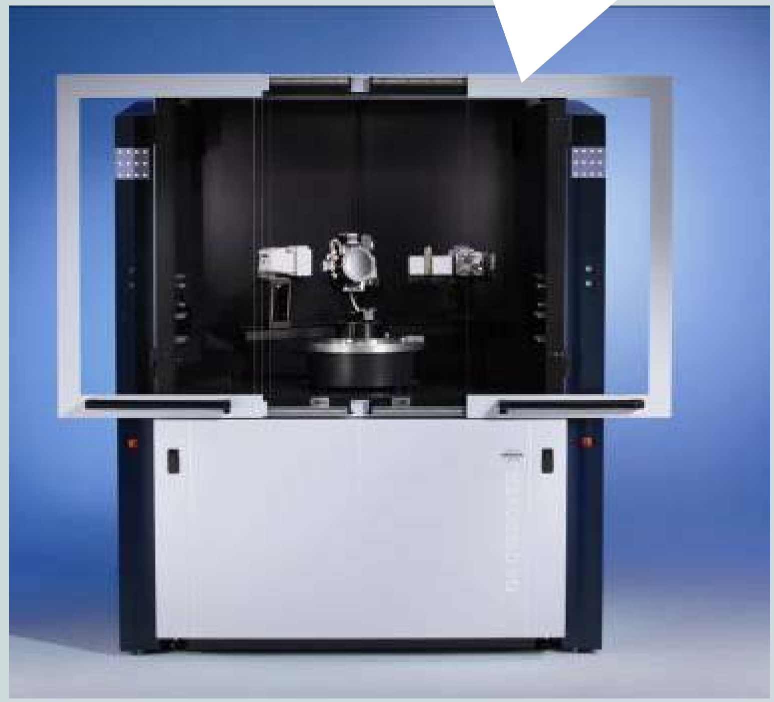
- 68 μm pixel size delivers the best spatial resolution

The New D8 DISCOVER

The New D8 DISCOVER
Patented Door Mechanism

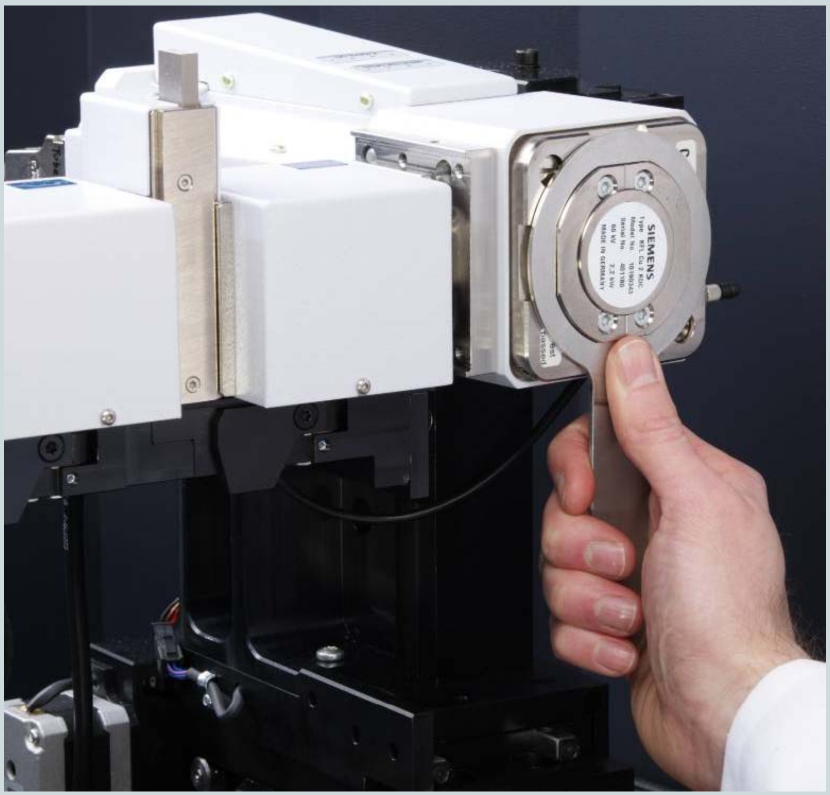
Swing door: wide opening for good accessibility

Sliding door: easy access for sample loading and configuration changes



The D8 DISCOVER with DAVINCI

TWIST-TUBE – from line to spot, and back



- Fast and easy switching between line and spot focus
- Focus direction recognition
- No need to disconnect cables
- Compatible with standard tube design
- Bruker AXS proprietary technology

The D8 DISCOVER with DAVINCI

Tool-free mount & component recognition

DAVINCI.SNAP-LOCK

Tool-free change of optics

DAVINCI.MODE

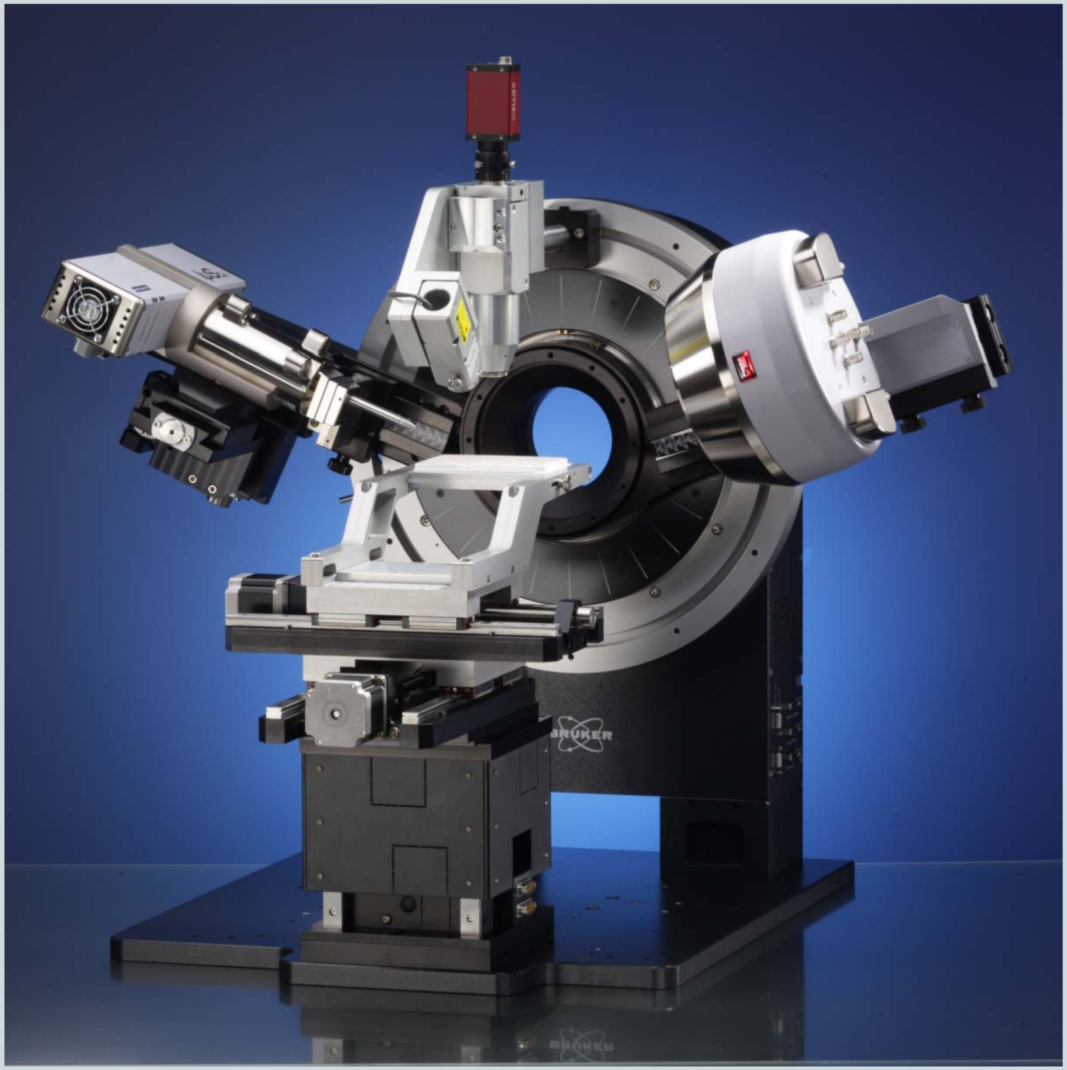
Component recognition

SAXS

- q_{min} = 0.025 Å^{-1}
- d_{max} = 25nm

He beampath, SAXS beamstop, Vantec 500

Configure: GADDS HTS
Vertical theta-theta, Reflection/Transmission

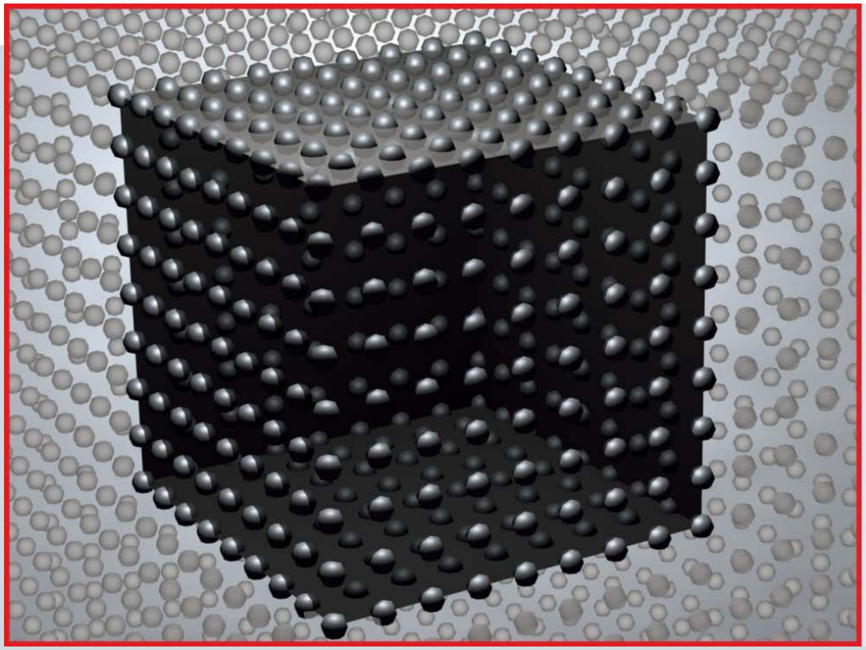


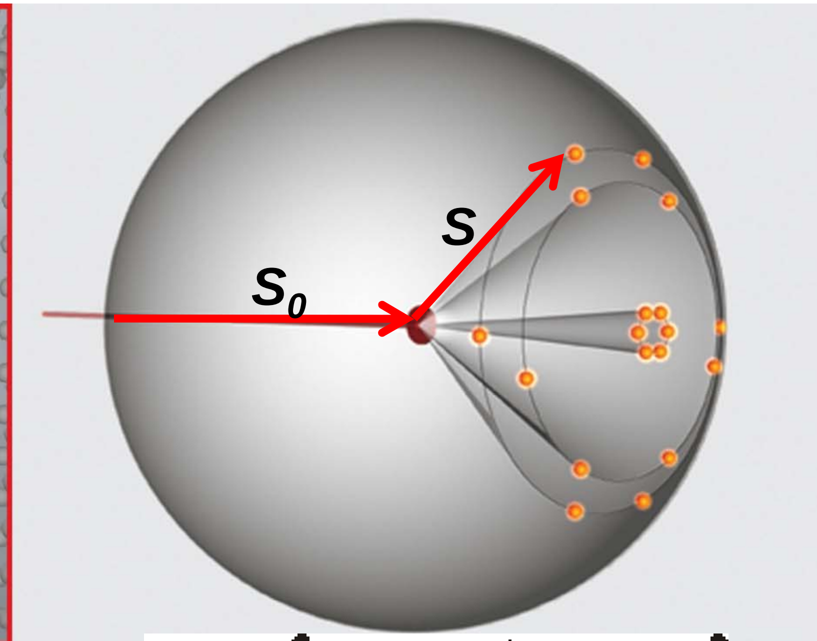
No barrier between 0D/1D/2D

Vertical theta-theta, CEC for microdiffraction/stress/texture, 0D->1D->2D

XRD²: Systems with VÅNTEC-500 Detector

XRD^2 & Single Crystals



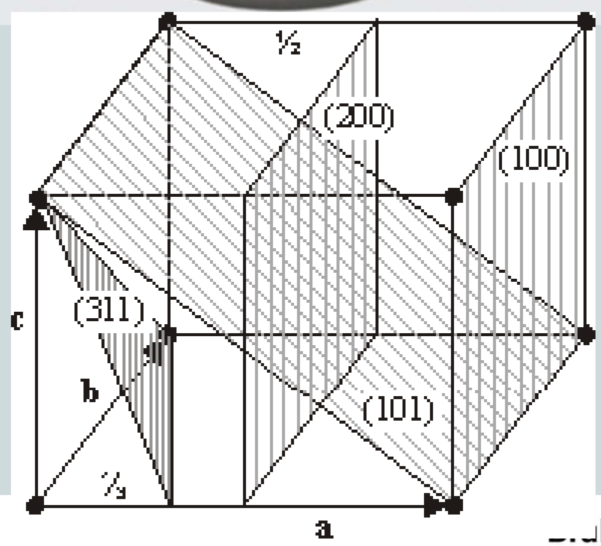


Laue equation

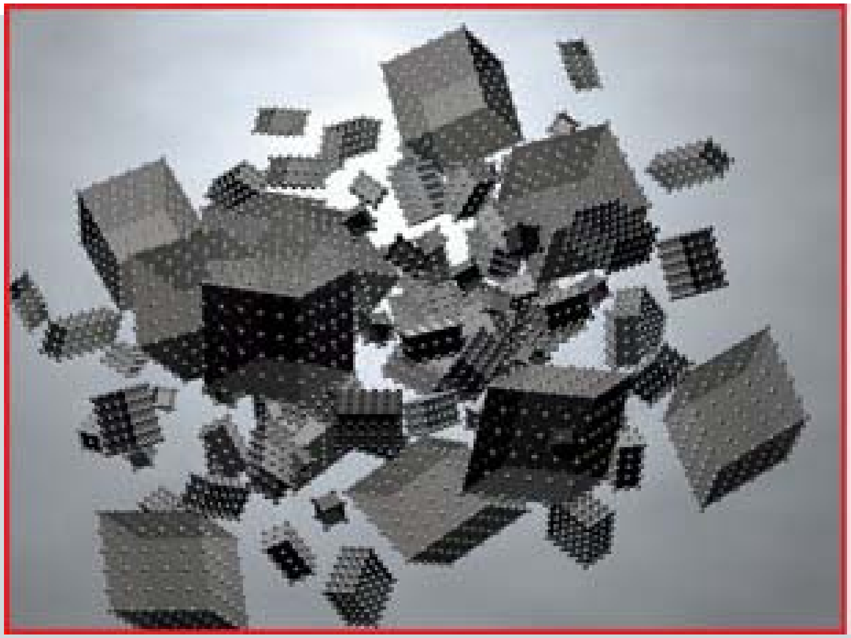
$$\boldsymbol{a}\cdot(\boldsymbol{s}-\boldsymbol{s}_0)=h\lambda$$

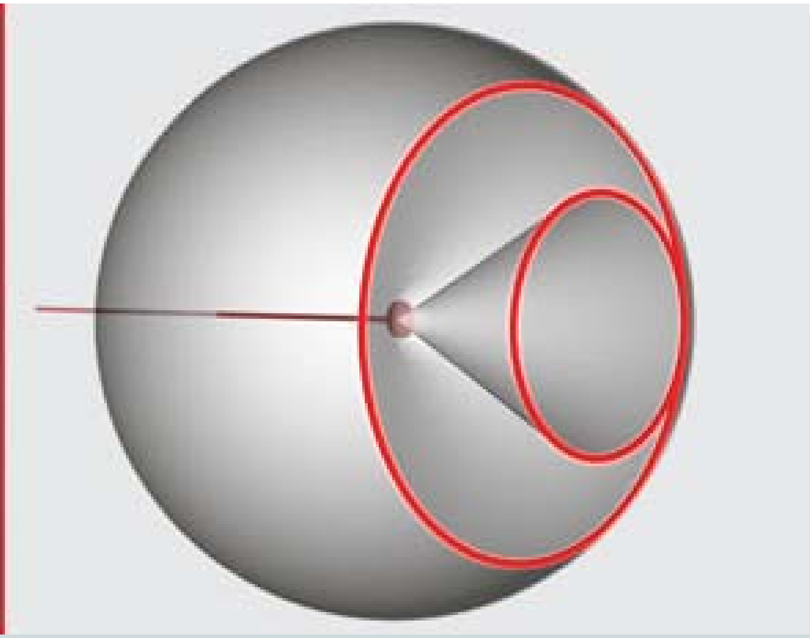
$$\boldsymbol{b}\cdot(\boldsymbol{s}-\boldsymbol{s}_0)=k\lambda$$

$$\boldsymbol{c}\cdot(\boldsymbol{s}-\boldsymbol{s}_0)=l\lambda$$



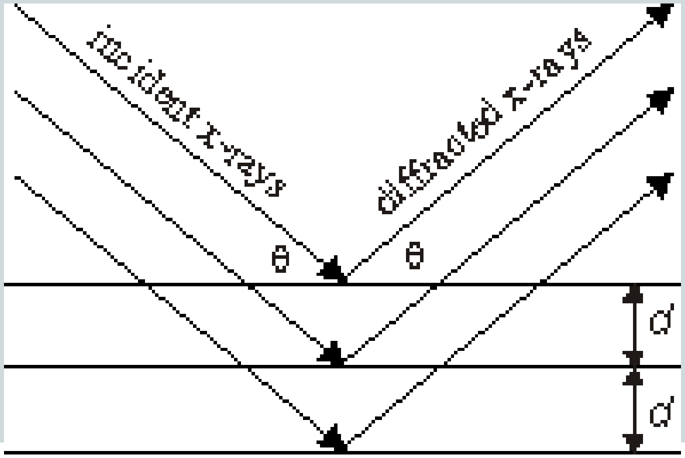
XRD^2 & Powders



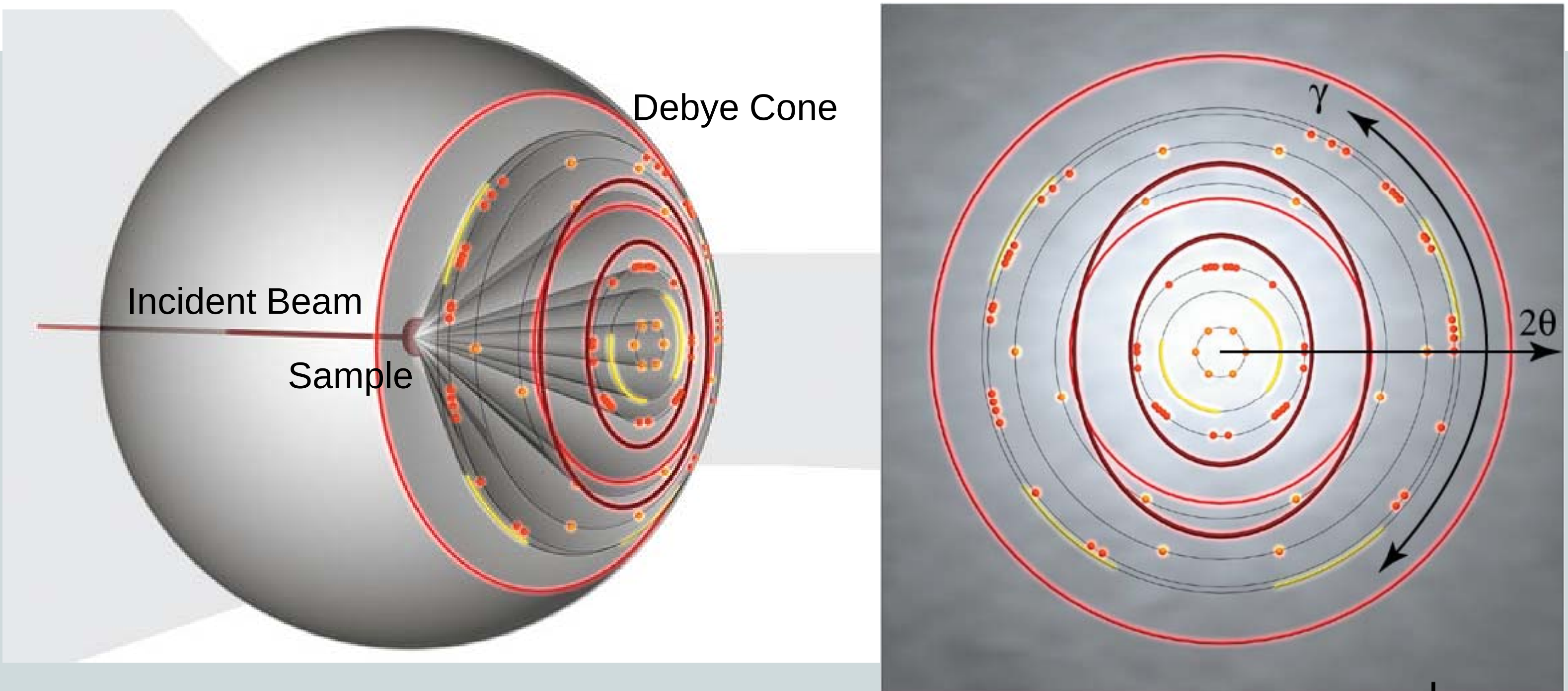


Bragg law

$$n\lambda = 2d\sin\theta$$

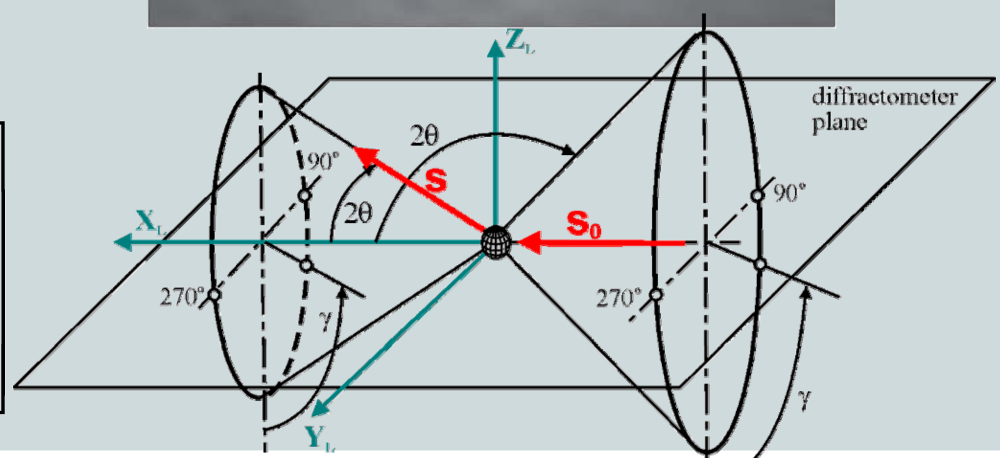


XRD^2: Diffraction pattern with both γ and 2θ information



Diffraction vector with γ

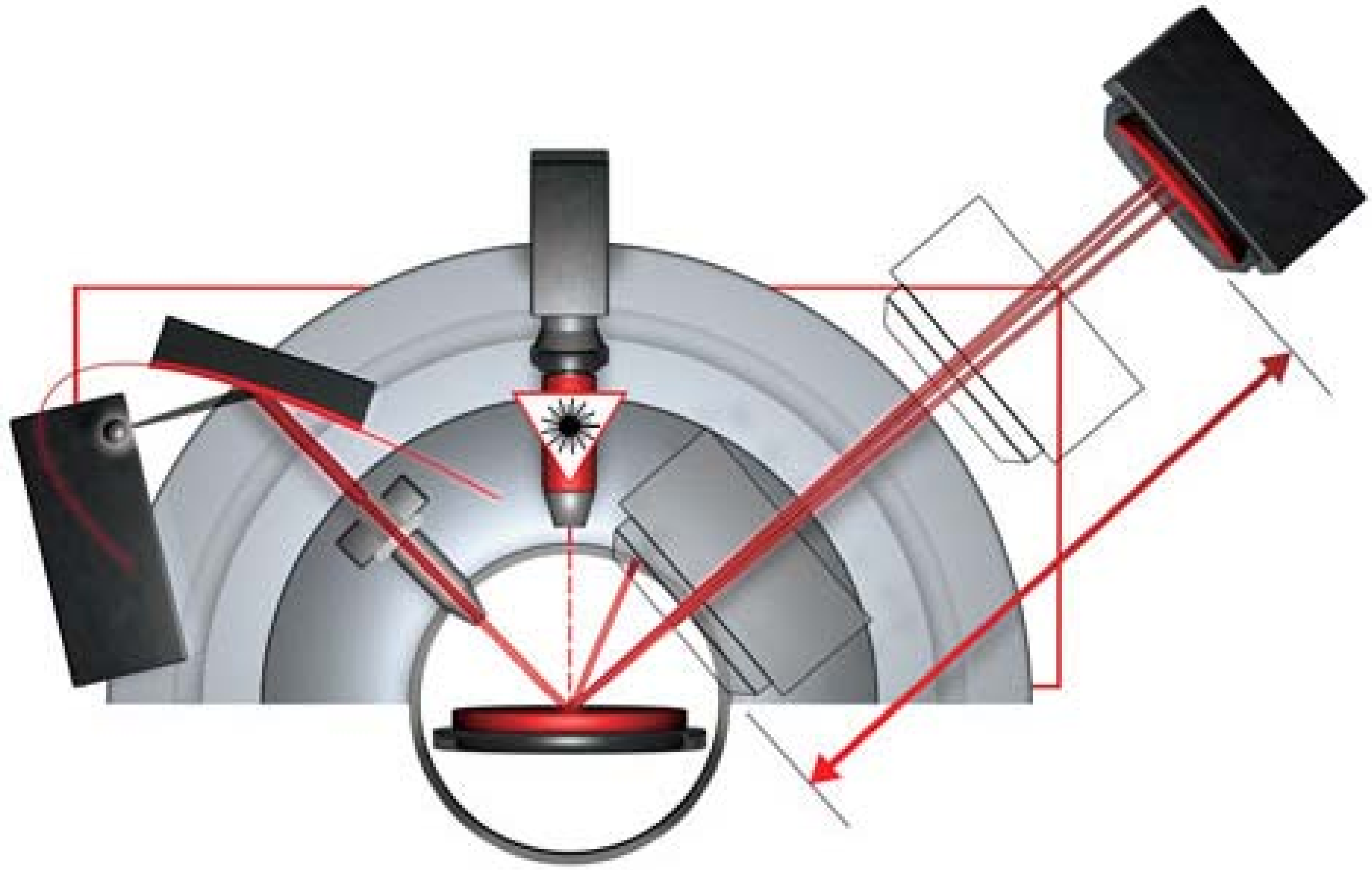
$$\boldsymbol{H} = \frac{\boldsymbol{s} - \boldsymbol{s}_0}{\lambda} = \frac{1}{\lambda}\begin{bmatrix} \cos 2\theta - 1 \\ -\sin 2\theta \sin \gamma \\ -\sin 2\theta \cos \gamma \end{bmatrix}$$



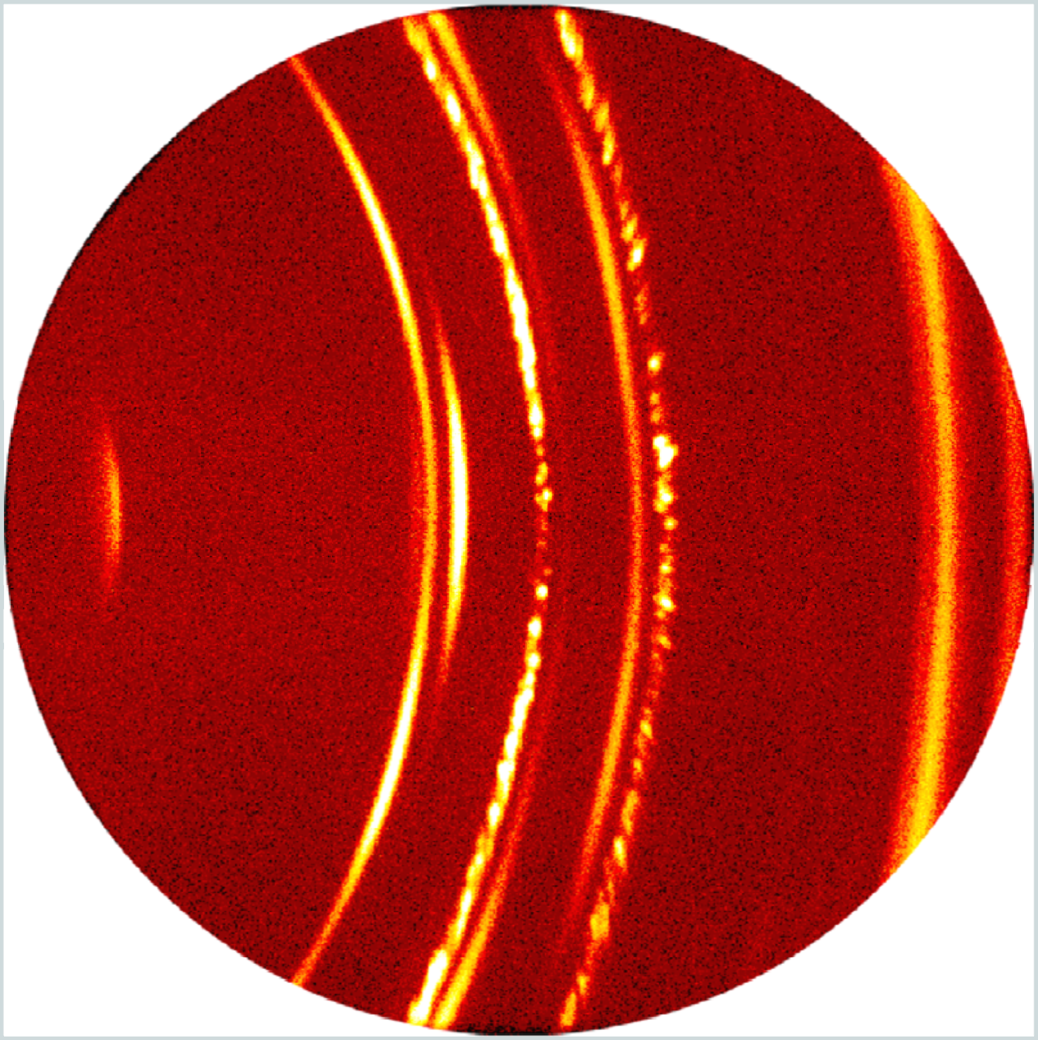
XRD^2: Diffraction vector approach

Applications	Vector approaches
Phase Identification:	Polarization and absorption correction
Texture Analysis:	Orientation mapping angles; Data collection strategy (scheme)
Stress Measurement:	Fundamental equation derived by second order tensor transformation; Data collection strategy (scheme)
Crystal Size Analysis:	Equations for the effective volume calculation at both reflection and transmission modes.

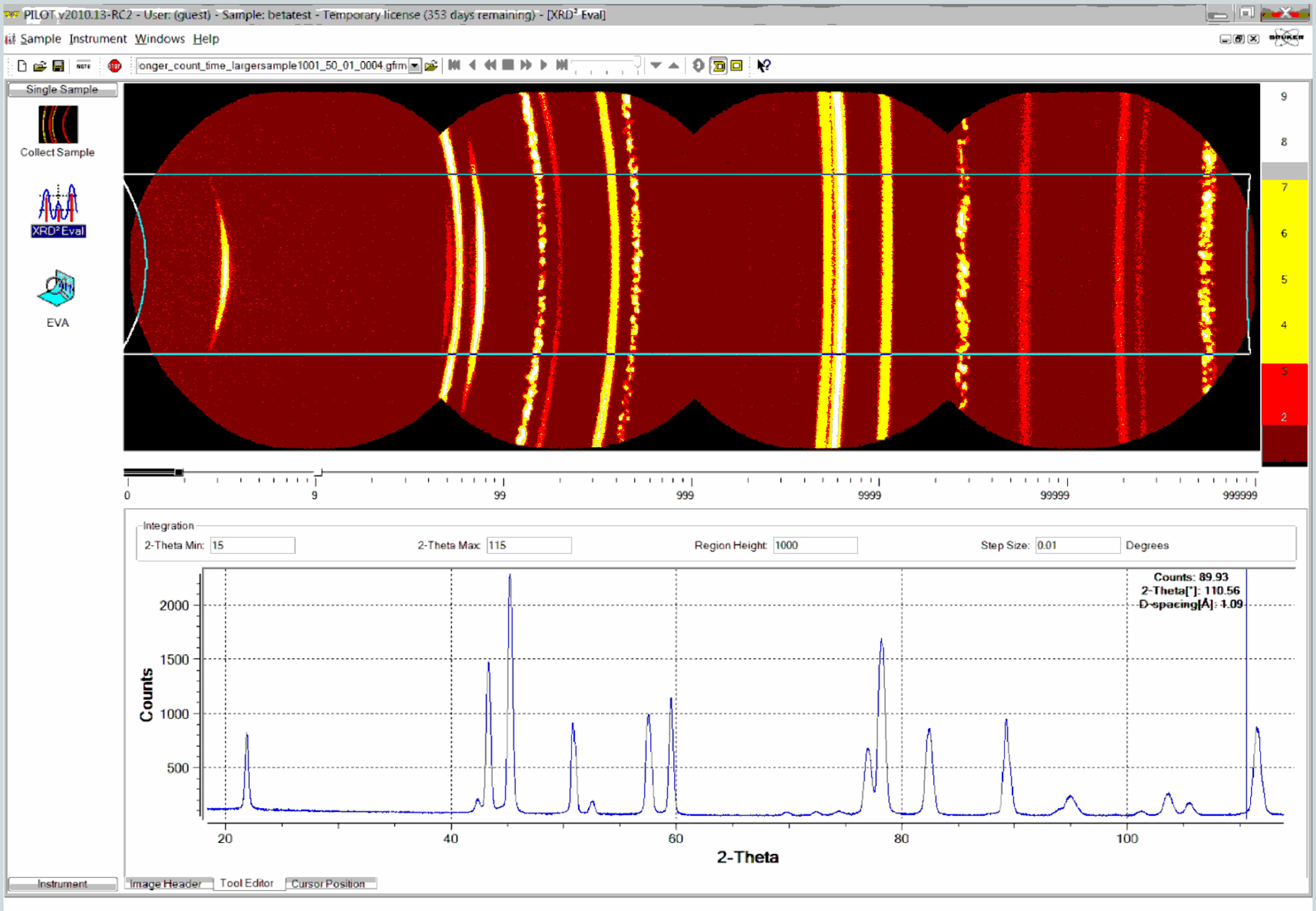
XRD^2: PhaseID Measurement Geometry



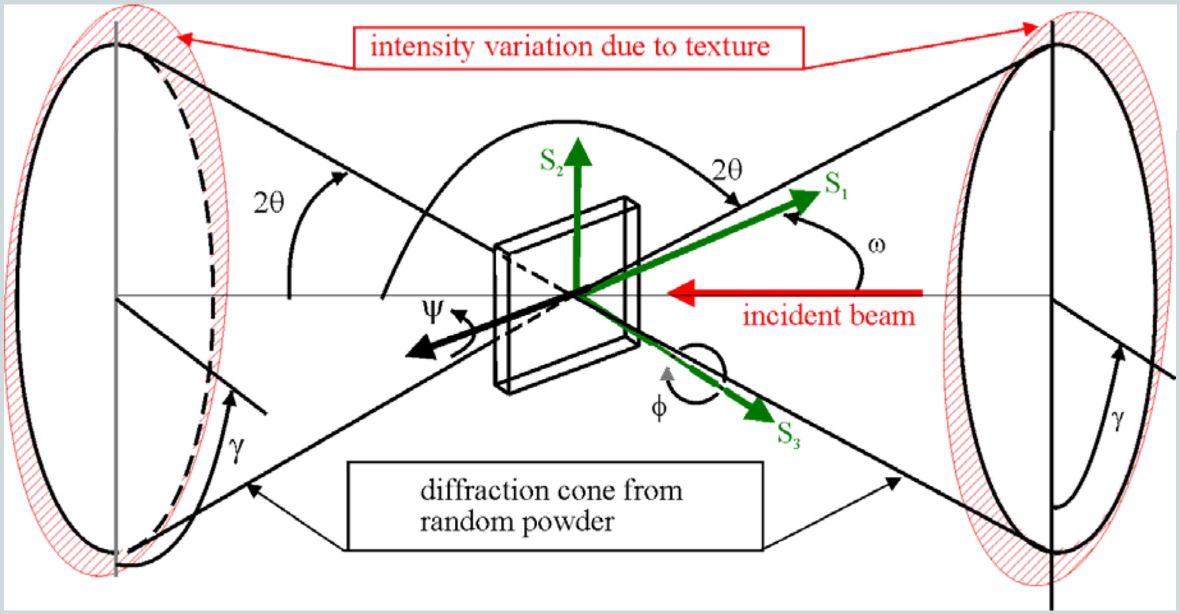
XRD^2: Single Frame Covering All

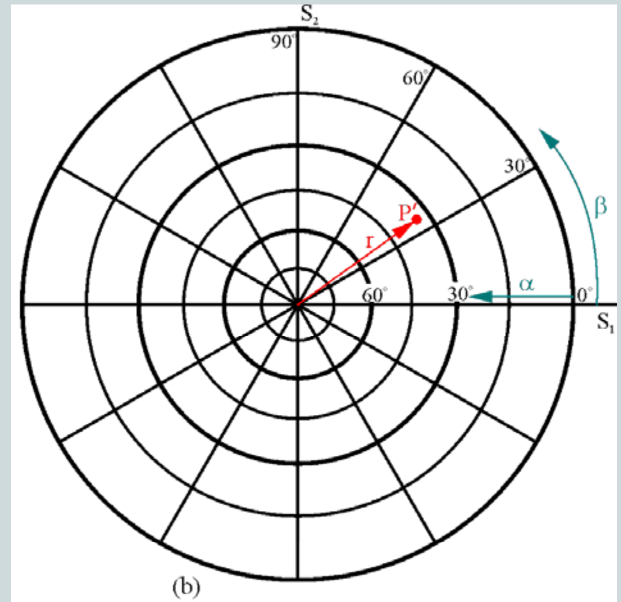


XRD²: Frame Merge and Integration



XRD^2: Fundamental Equation for Texture Analysis



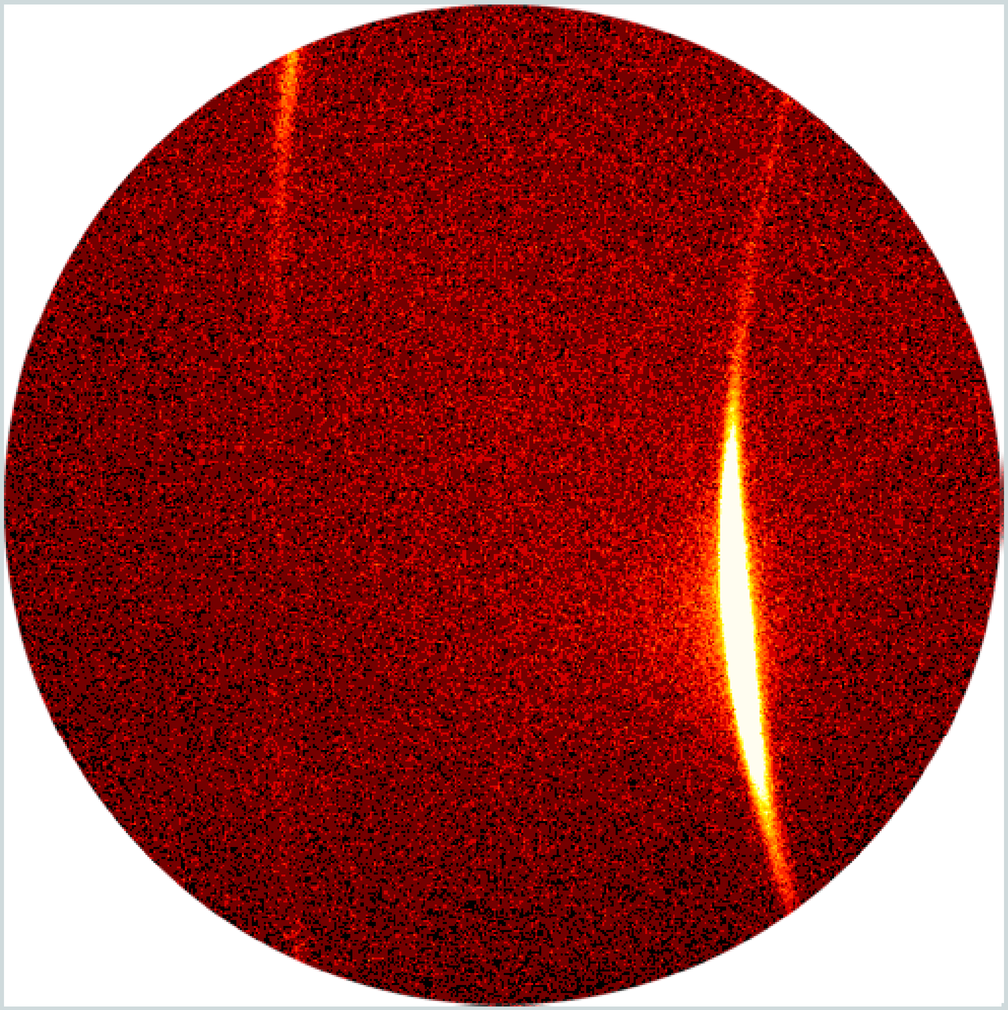


The pole figure angles (α,β) can be calculated from the unit vector components by the pole mapping equations:

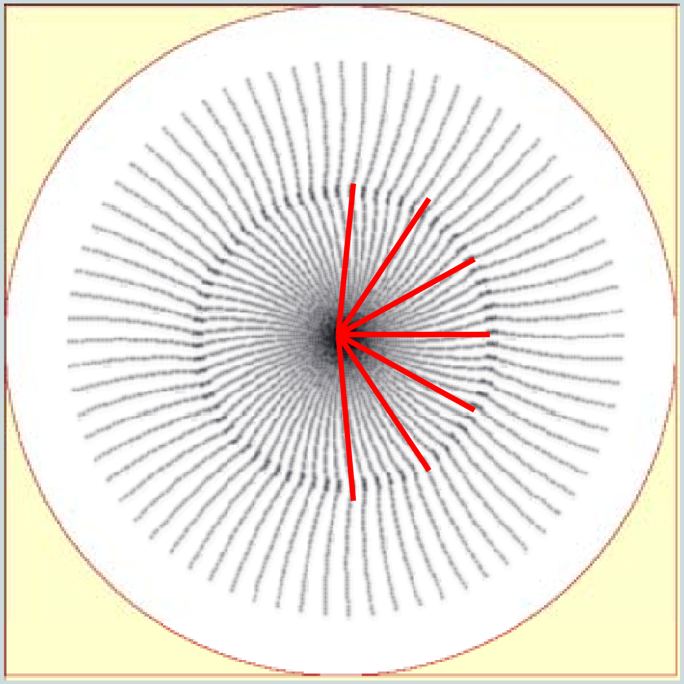
$$\alpha = \sin^{-1}|h_3| = \cos^{-1}\sqrt{h_1^2 + h_2^2}$$

$$\beta = \pm\cos^{-1}\frac{h_1}{\sqrt{h_1^2 + h_2^2}} \qquad \begin{cases} \beta \geq 0^\circ & if \quad h_2 \geq 0 \\ \beta < 0^\circ & if \quad h_2 < 0 \end{cases}$$

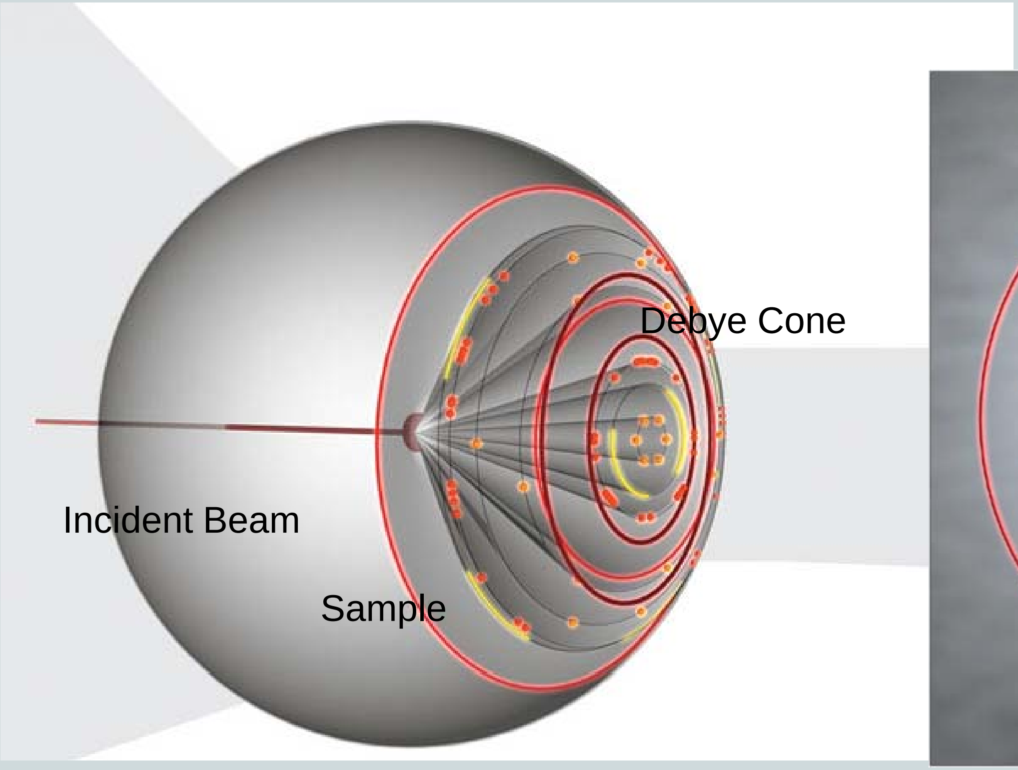
The D8 DISCOVER with DAVINCI
VÅNTEC-500 for texture measurement



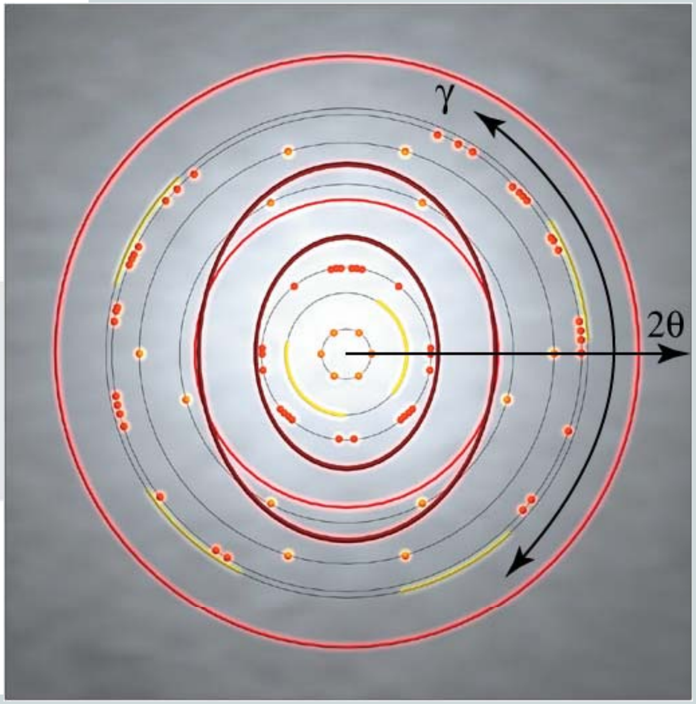
- Steel can
- (200) & (110) rings
- Intensity variation during ϕ scan



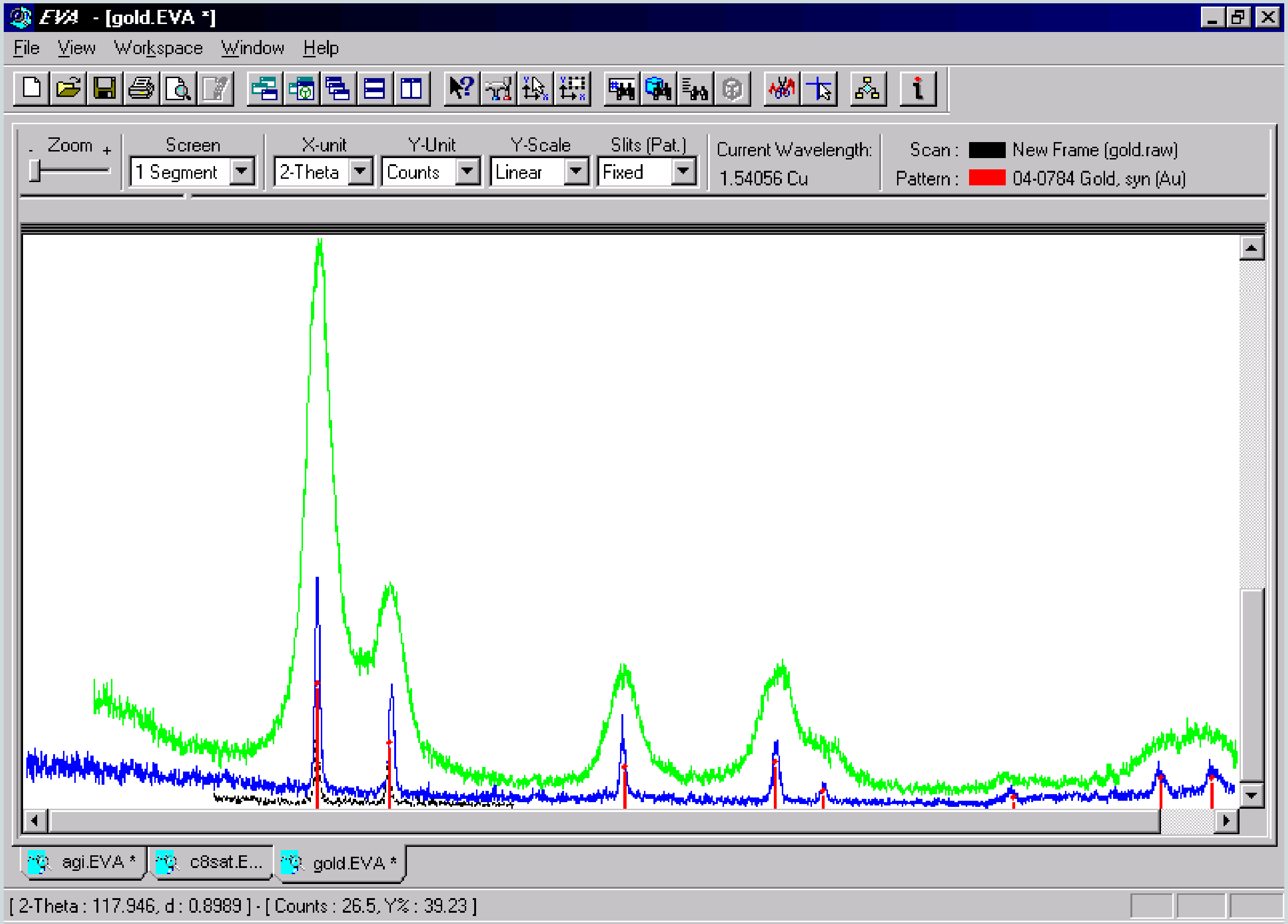
XRD²: Particle size measurement by 2θ & γ profile analysis:



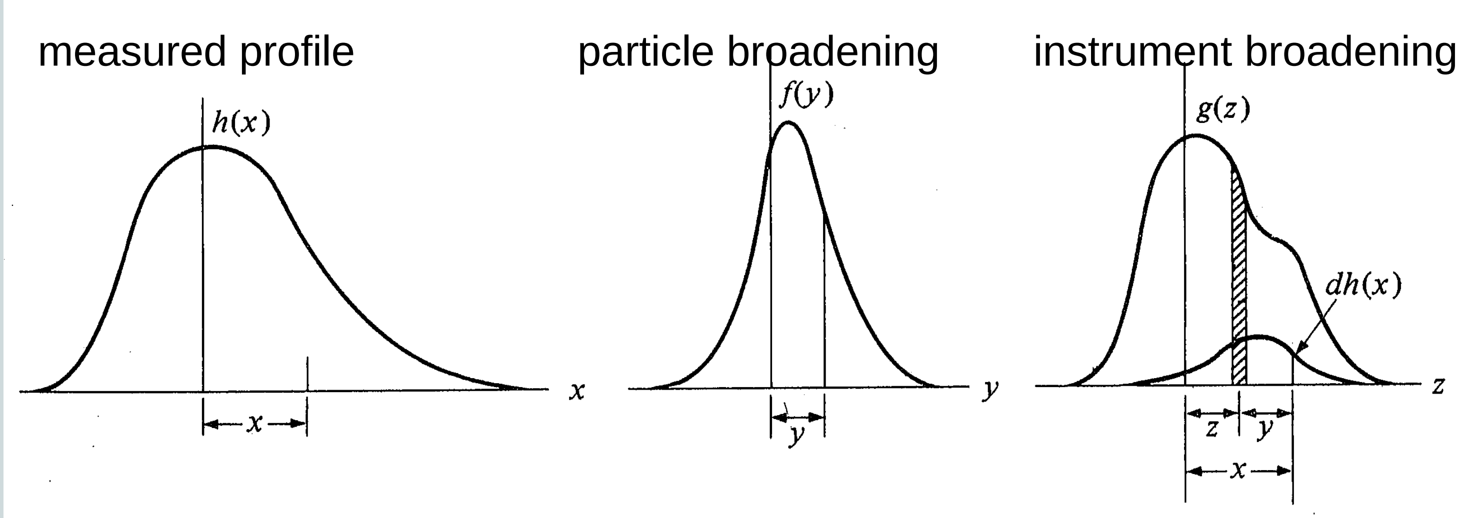
XRD² Pattern



XRD²: Peak broadening-gold Nanoparticles



XRD²: Particle size and instrument broadening:



The measured profile is a convolution of the functions representing particle-size broadening and instrument broadening

$$h(x) = \frac{1}{A}\int g(z)\, f(x-z)\,dz$$

where *A* is the area of the *f(y)* curve and *y*=*x*-*z*.

Ref: B. E. Warren, *X-ray Diffraction*, Dover Publications, Inc. New York, 1990.

XRD²: Particle size calculation:

Scherrer equation:

$$t = \frac{C\lambda}{B\cos\theta}$$

where λ is wavelength (Å), B is FWHM (radians) corrected for instrument broadening, θ is Bragg angle, C is a crystal shape factor from 0.9~1.

For Gaussian profiles,

$$B^2 = U^2 - S^2$$

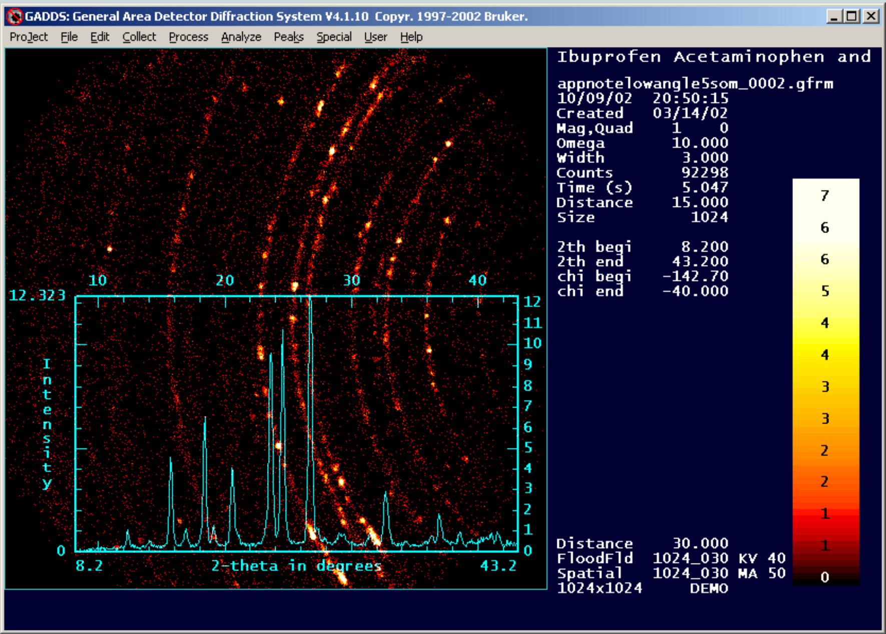
while for Cauchy profiles,

$$B = U - S$$

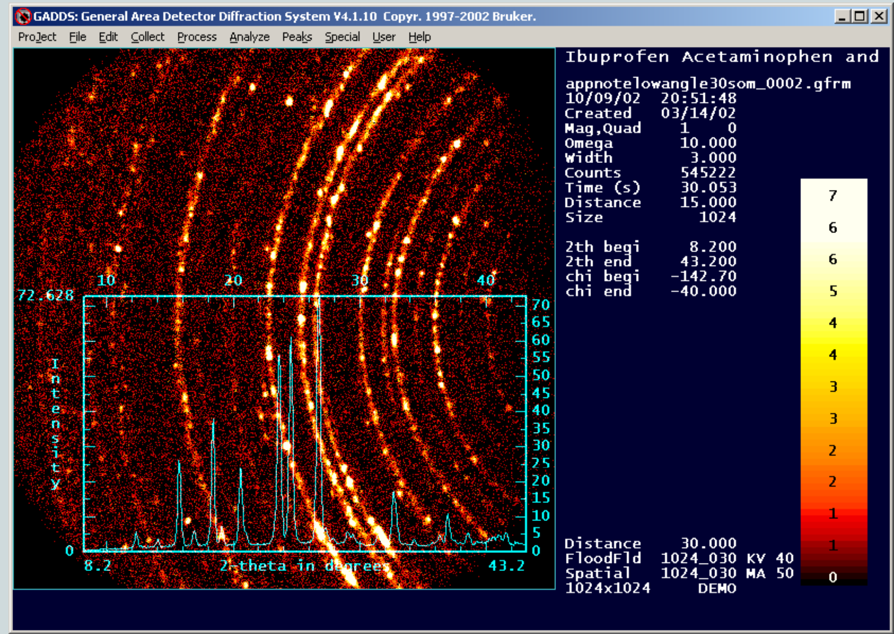
where *B* is the corrected FWHM for crystallite size calculation by Scherrer equation, and *U* and S are the FWHM's of the unknown and standard peaks, respectively.

XRD²: Data Collection: Acetaminophen powder

5 second data collection



30 second data collection



- The spotty diffraction ring is due to the large crystallites compared to the sampling volume (beam size).
- The number of spots on the ring is determined by crystallite size, instrumental window (γ-range), multiplicity of the crystal plane, and effective diffraction volume.

XRD²: Particle size measurement by γ profile analysis:

For XRD² in reflection mode, the particle size is given by

$$d = k\left\{\frac{p_{hkl} b^2 \arcsin[\cos\theta \sin(\Delta\gamma/2)]}{2\mu N_s}\right\}^{1/3}$$

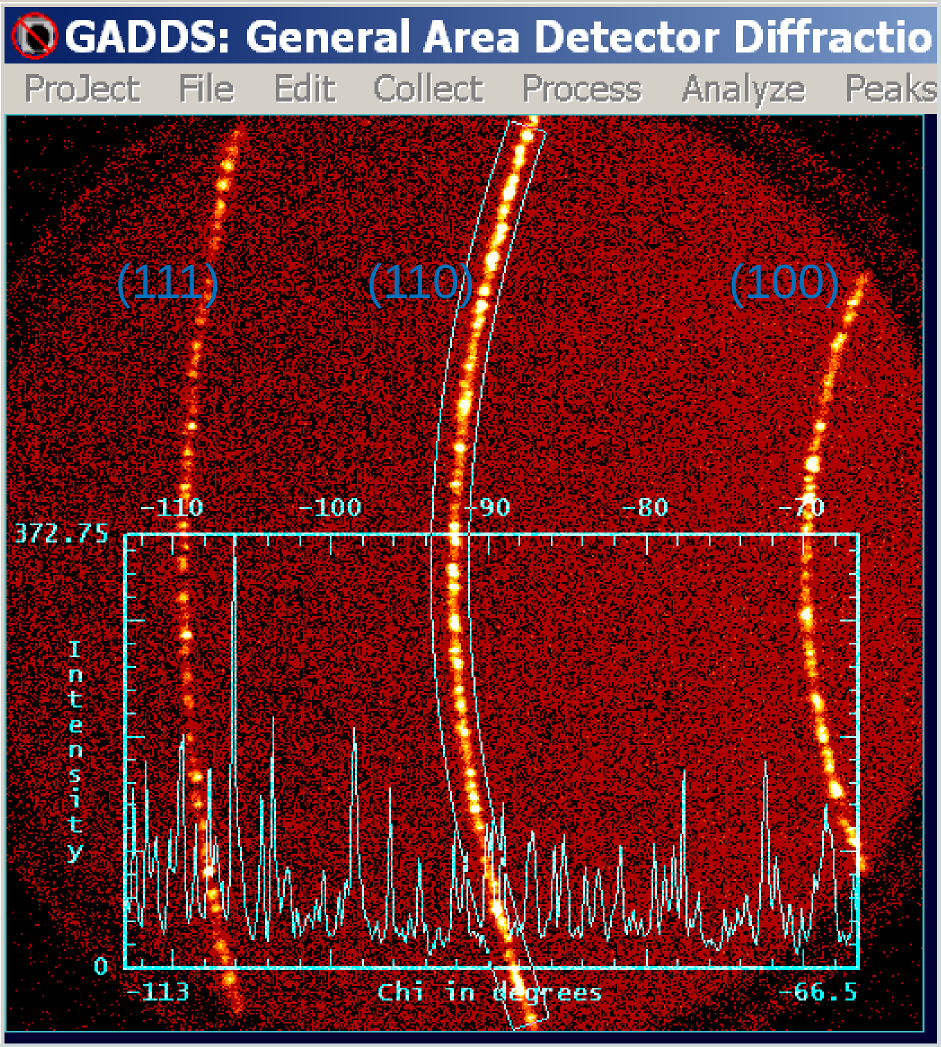
where *k* is the instrumental calibration factor or can be calculated from $k = \left(\frac{3\beta}{4\pi}\right)^{1/3}$ if the instrument broadening in 2θ direction is known.

For transmission mode with the incident beam perpendicular to the sample surface, the particle size is given by

$$d = k\left\{\frac{p_{hkl_i} b^2 t \arcsin[\cos\theta \sin(\Delta\gamma/2)]}{N_s}\right\}^{1/3}$$

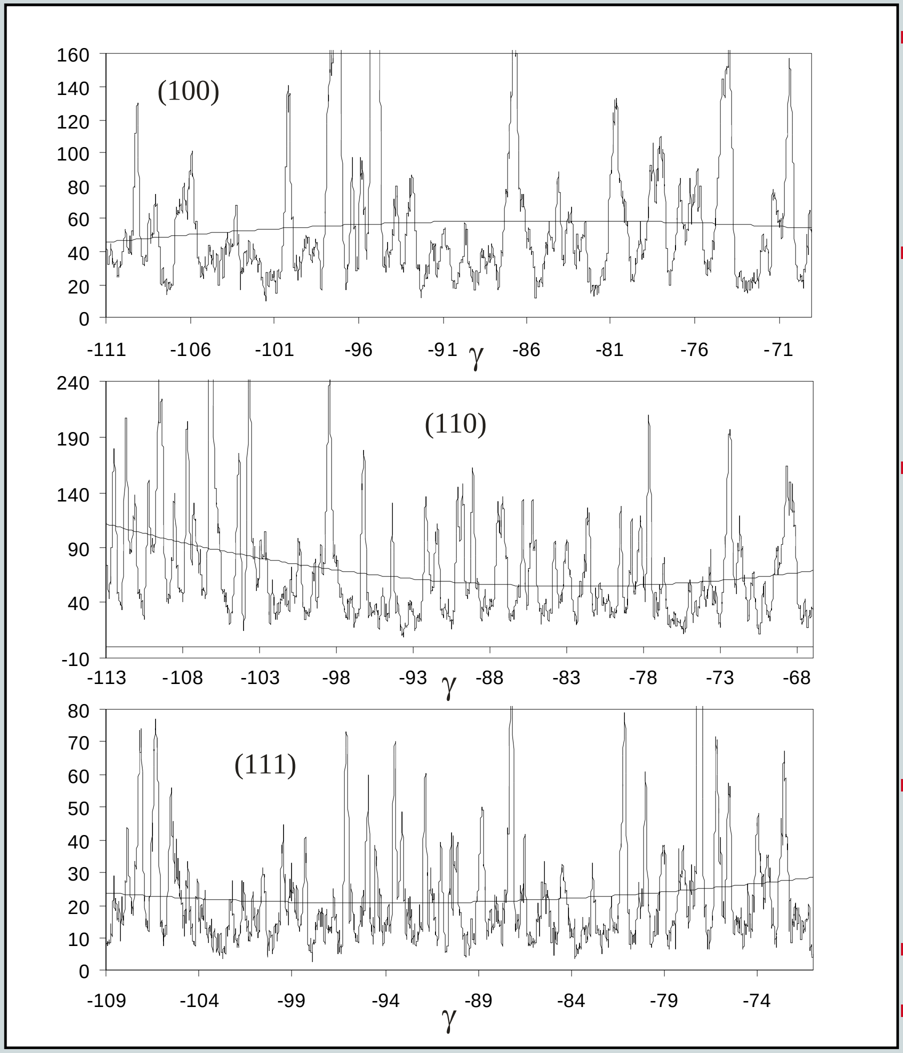
where *k* is the instrumental calibration factor or $k = \left(\frac{3\beta}{4\pi}\right)^{1/3}$

XRD²: Particle size measurement by γ profile analysis:



- The frame was collected from a SRM660a (LaB6) sample in transmission mode and Cu-Kα x-rays.
- The 2D detector (Hi-Star™) is set at 23.75 cm from the instrument center.
- The beam (collimator pinhole) size *b* is 200 μm.
- The sample thickness *t* is 7.0 μm, based on the calculated μ of 1138 cm-1 and the measured transmission of 0.45.

XRD²: Particle size measurement by γ profile analysis:



- The 2θ-integrated plots (γ-profiles) of three rings from (100), (110) and (111) planes are displayed.
- The number of crystallites is counted from the number of intersections of the γ-profile with a threshold line.
- To cancel out the effects of the overall intensity fluctuation (texture, etc.), a 2nd order polynomial trend line is fitted to each γ-profile as a threshold line.
- Every two intersections of γ-profile with the threshold line represents a crystallite.
- New analysis strategy?
- Size distribution?

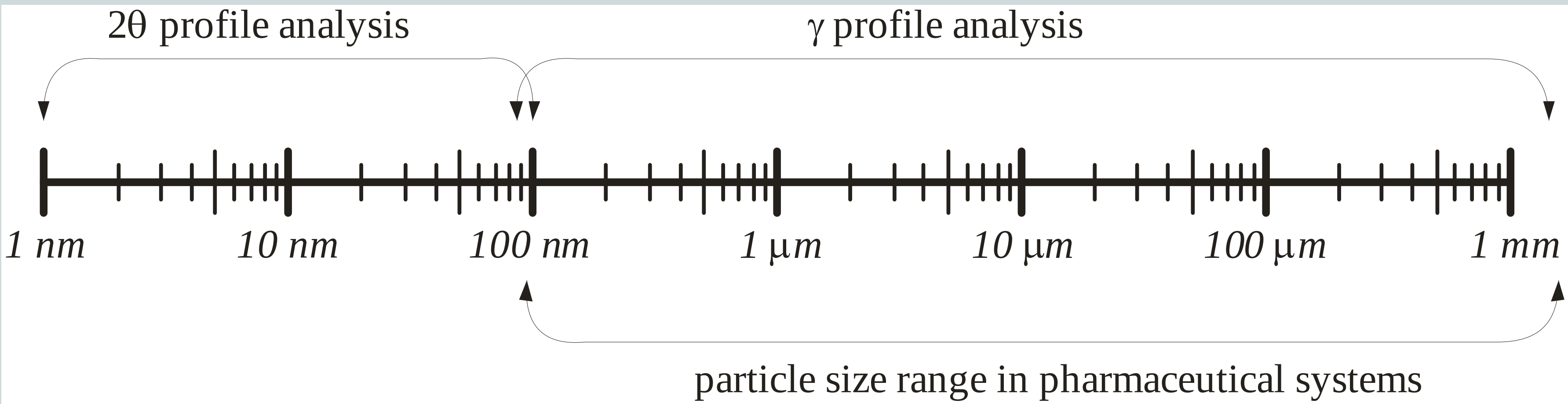
XRD^2: Particle size measurement by γ profile analysis:

Calibration Results:

(hkl)	P_{hkl}	2θ	$\Delta\omega$	N_s	k
(100)	6	21.36	38	23	0.1217
(110)	12	30.38	46	41	0.1106
(111)	8	37.44	42	38	0.1281

- The average scaling factor *k* is 0.12 in this calibration. The system can then be used to measure the crystallite size of unknown materials if the data can be collected in approximately the same condition.
- It is always necessary to calibrate the system with a known standard, preferably with a comparable sample geometry and crystallite size.
- For reflection mode, it is critical to have a standard with a comparable linear absorption coefficient so as to have similar penetration.

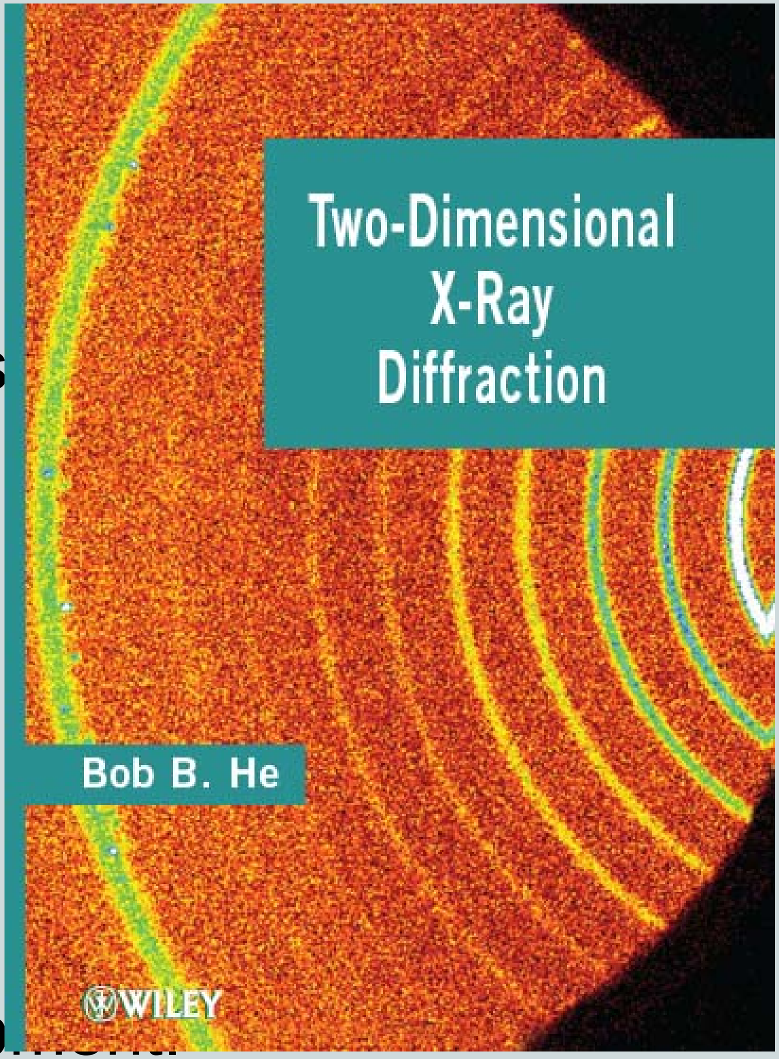
XRD²: Particle Size Analysis by X-ray Diffraction:



- 2θ profile analysis, including measurement from peak FWHM by Scherrer equation, or profile analysis by Stokes and Wilson, is suitable for particle size below 100 nm.
- γ profile analysis, based on sampling statistics, is suitable for particle size from sub-micrometer to a few millimeters.
- The particle size range of pharmaceutical substances is from sub-micrometer to a few millimeters.

More About XRD^2

1. Introduction.
2. Geometry Conventions.
3. X-Ray Source and Optics.
4. X-Ray Detectors.
5. Goniometer and Sample Stages.
6. Data Treatment.
7. Phase Identification.
8. Texture Analysis.
9. Stress Measurement.
10. Small-Angle X-Ray Scattering.
11. Combinatorial Screening.
12. Quantitative Analysis.
13. Innovation and Future Development.



Thank You for Your Attention