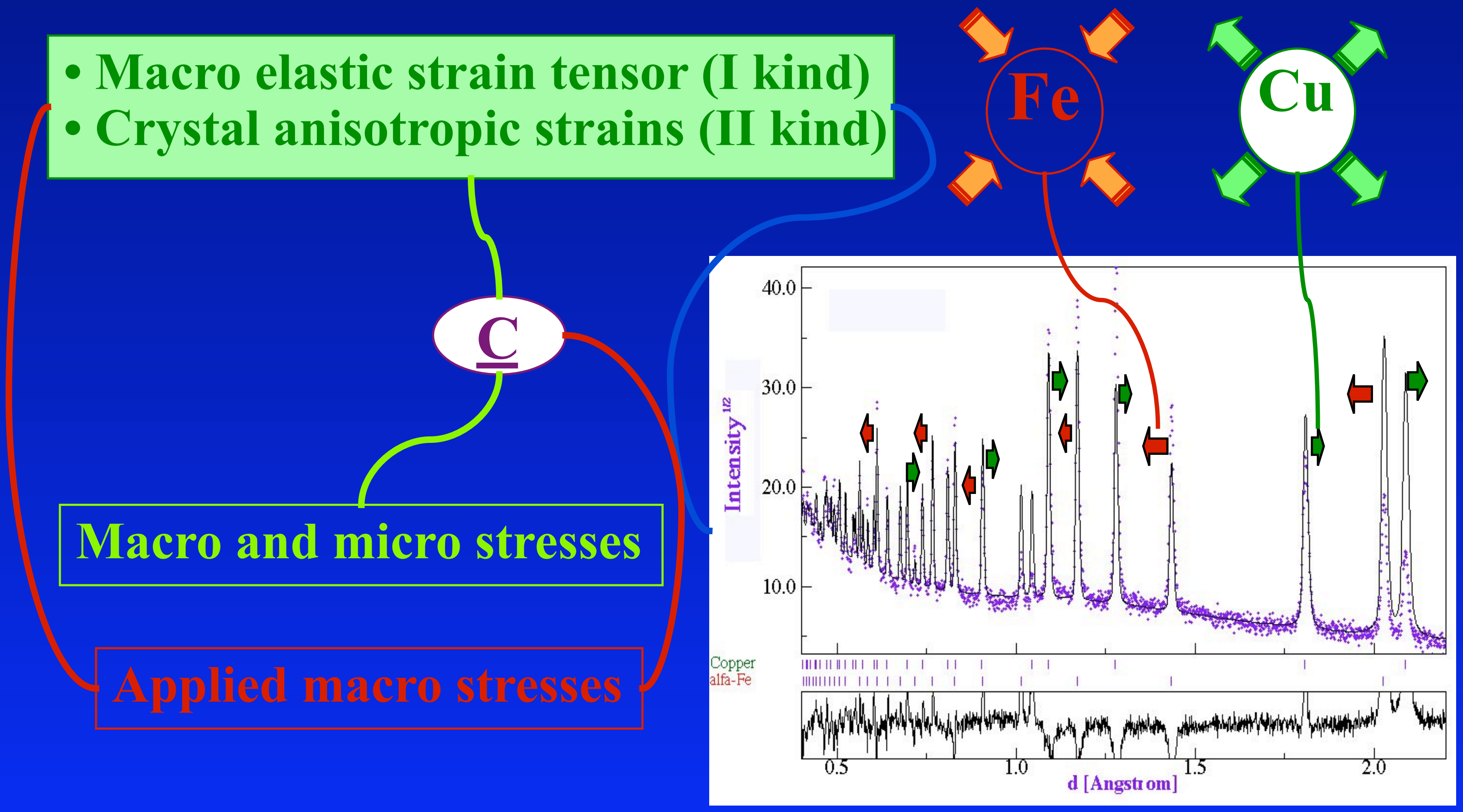
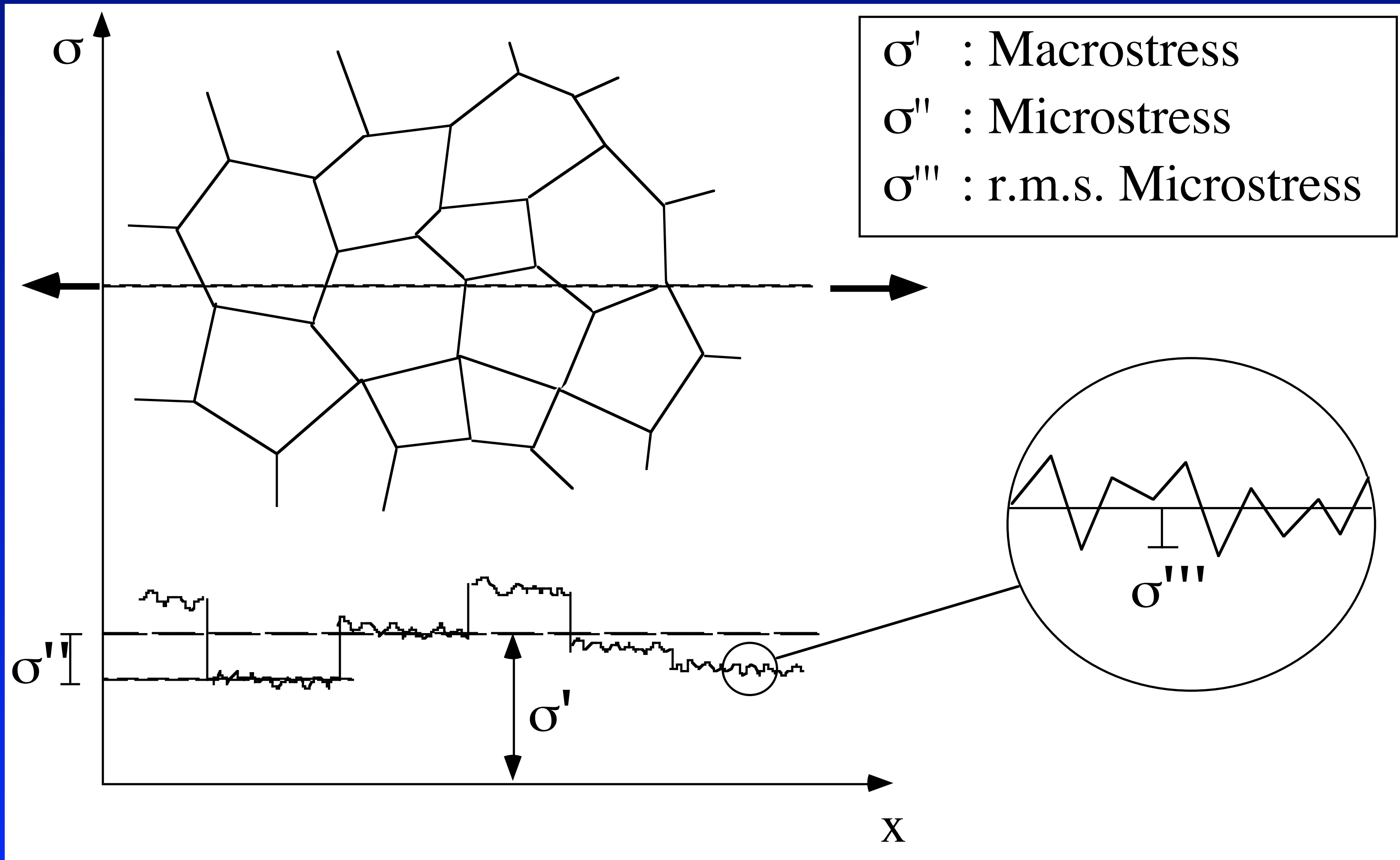
Residual Stress analysis

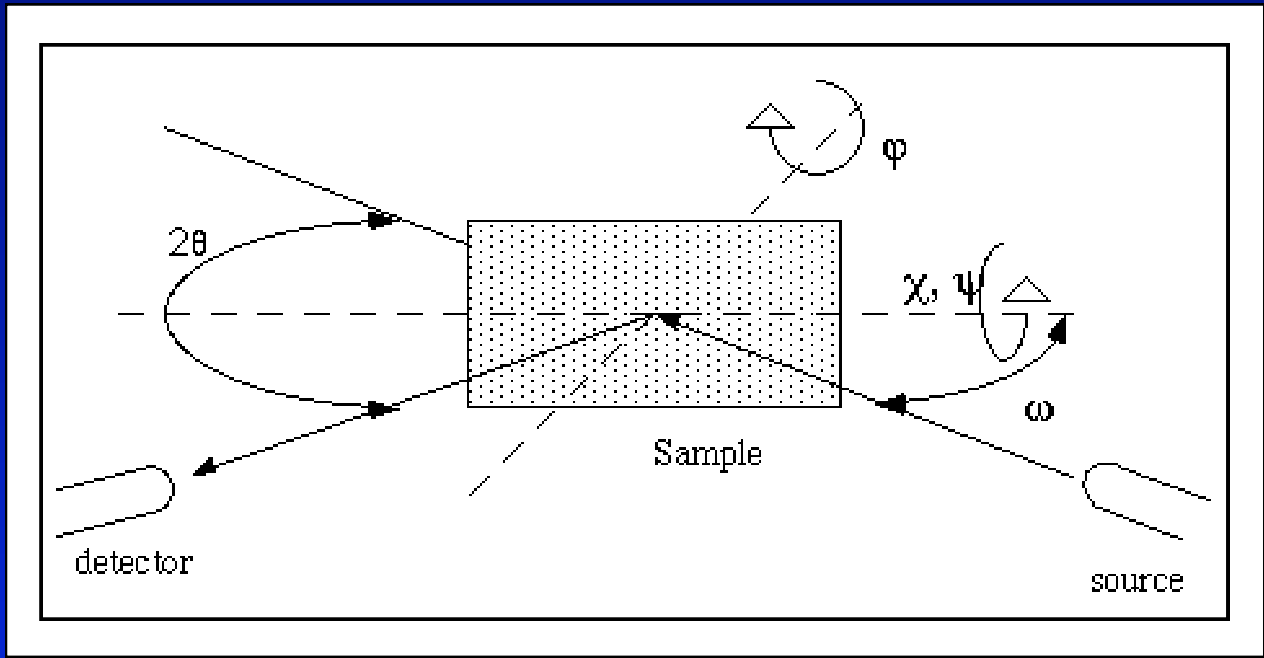
Informations: strains



Residual Stress/Strain definition



Experimental setting



- Measurement of a high 2theta peak position for different tilting of the sample
- The sample can be tilted in omega or psi (chi)
- Changing phi we will scan different direction for the stress in the sample
- The simple behavior is a linear relationship between the measured d-spacing and $\sin^2 \psi$. The slope is proportional to the macrostrain.

Strain measurement

The full formula:

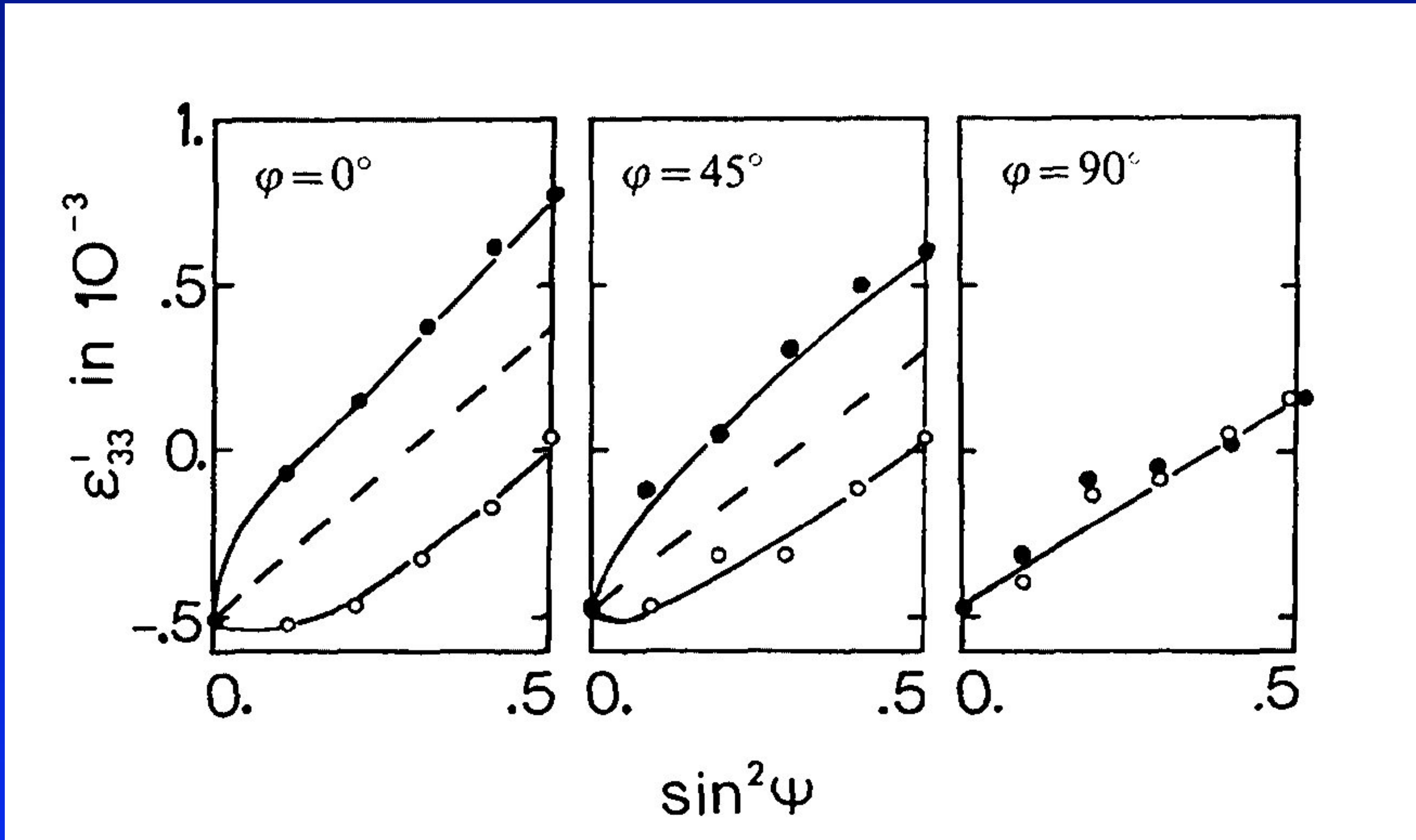
$$e^{L}_{33} \equiv e_{\psi\phi} = d_{\psi\phi} / d_0 - 1$$

$$e_{\psi\phi} = e_{33} + [e_{11}\cos^2\phi + e_{12}\sin 2\phi + e_{22}\sin^2\phi - e_{33}]\sin^2\psi$$
$$+ [e_{13}\cos\phi + e_{23}\sin\phi]\sin 2\psi$$

Isotropic planar stresses:

$$\varepsilon_{\varphi\psi} = [d_{hkl}(\varphi,\psi) - d_0]/d_0 = \tfrac{1}{2}s_2^{hkl}\sigma_\varphi \sin^2\psi + 2s_1^{hkl}\sigma_\varphi,$$

Shear stresses



Non linear behavior

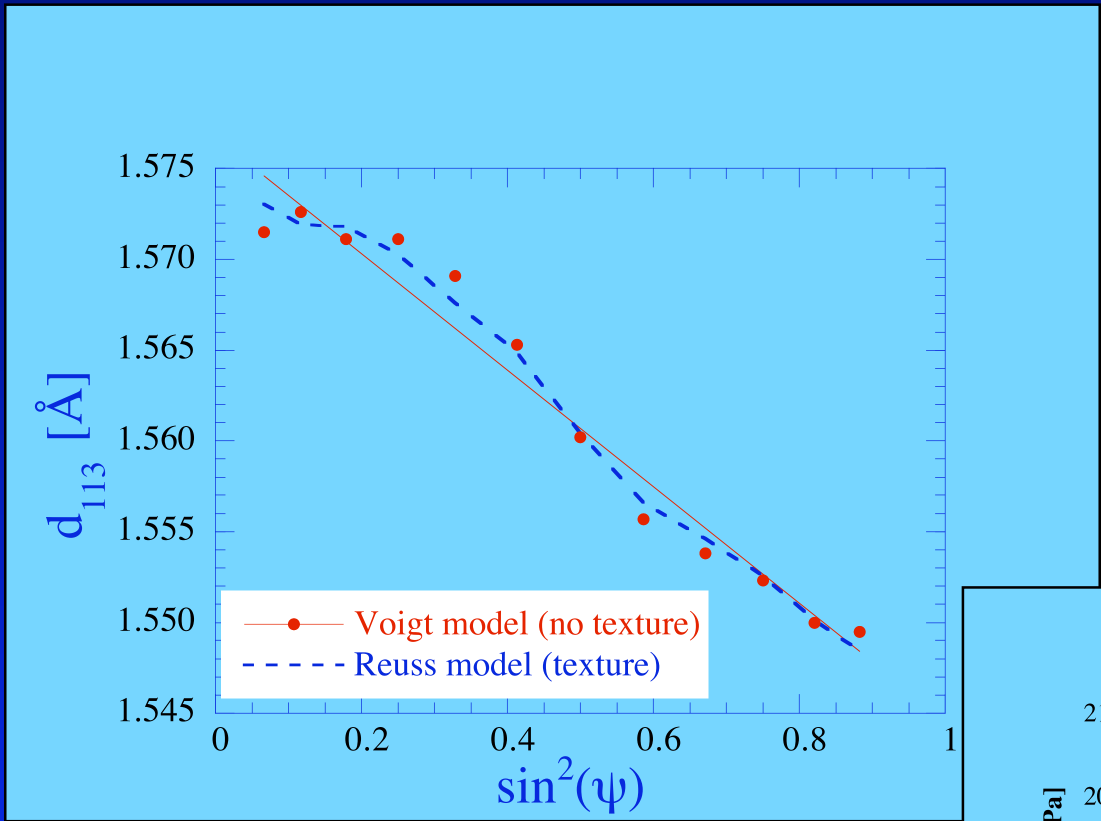
- In many cases oscillation of d vs. $\sin^2\psi$ are observed; some possible causes:
  - Textured sample -> the elastic tensor is anisotropic.
  - Plastic deformation: anisotropy of the plasticity behaviour and elastic tensor results in anisotropy of the residual stresses/strains
  - Thermal expansion anisotropy
  - Shear stresses normal to the surface
  - Coherent and semicoherent interfaces (in thin film….)
  - …………

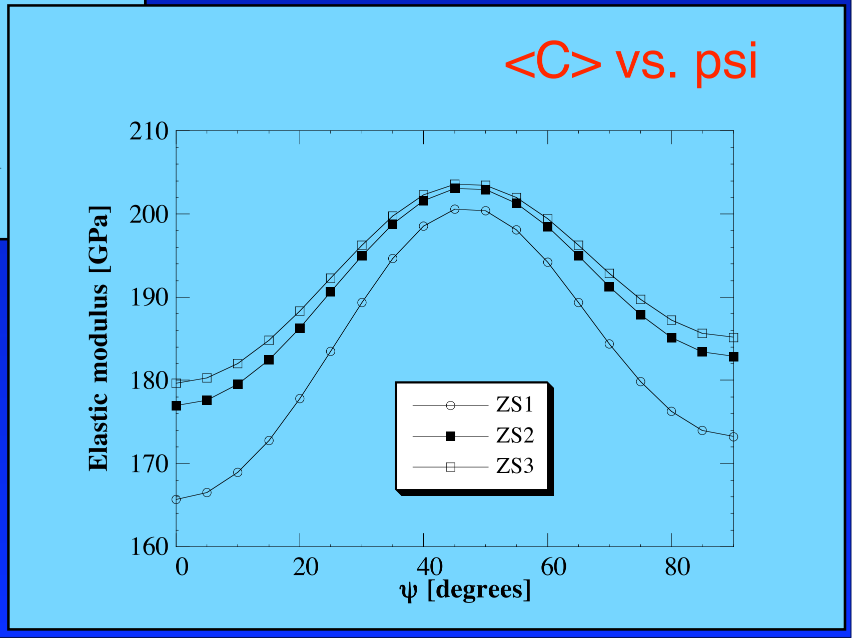
  Dolle in 1979 (J. Appl. Cryst., 12, 489) analyzed the problem in general and was followed by other authors: Noyan and Nguyen for the plastic deformation, Barral et al. for the texture connection.

Texture-Stress

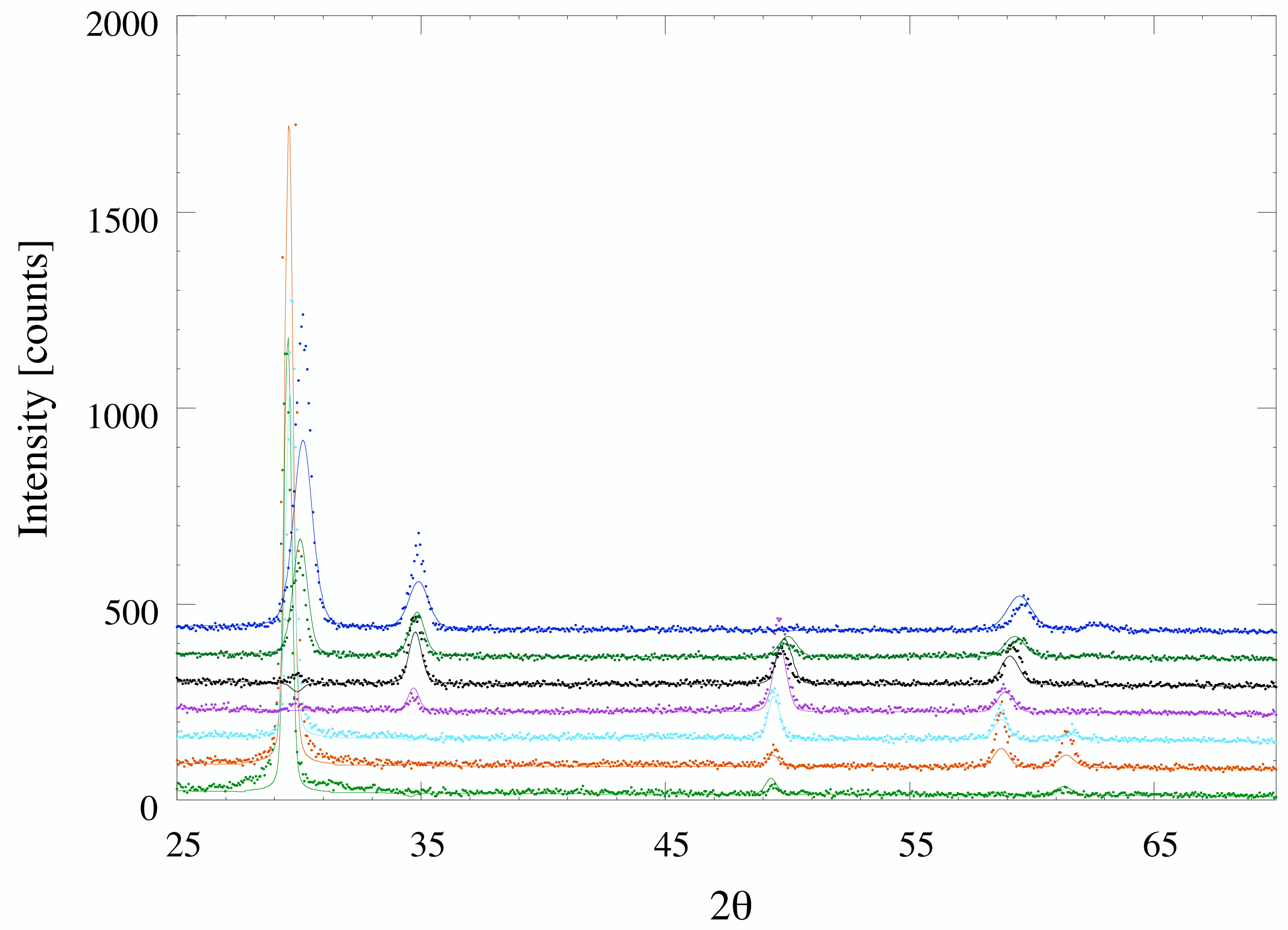
- Procedure:
  - Measurement of the texture ODF by traditional pole figures
  - Measurement of the d-spacing vs. $\sin^2\psi$ for high angle reflections
  - Computation of the effective macro-elastic tensor using single crystal elastic constants and the ODF
  - Different theories can be used to average the elastic tensor over the ODF:
    - Voigt (stress compatibility)
    - Reuss (strain compatibility)
    - Hill (mean value between Reuss and Voigt)
    - Self Consistent, FEA.... (costly)
    - Geometrical mean
  - Analysis of the d-spacing vs. $\sin^2\psi$ using the averaged elastic tensor
- Pro:
  - You control the entire process
- Cons:
  - Lengthly procedure, two measurements, two analyses
  - Does not work (very difficult) for highly stressed or strongly textured materials

Traditional methods for the ZrO_2 films

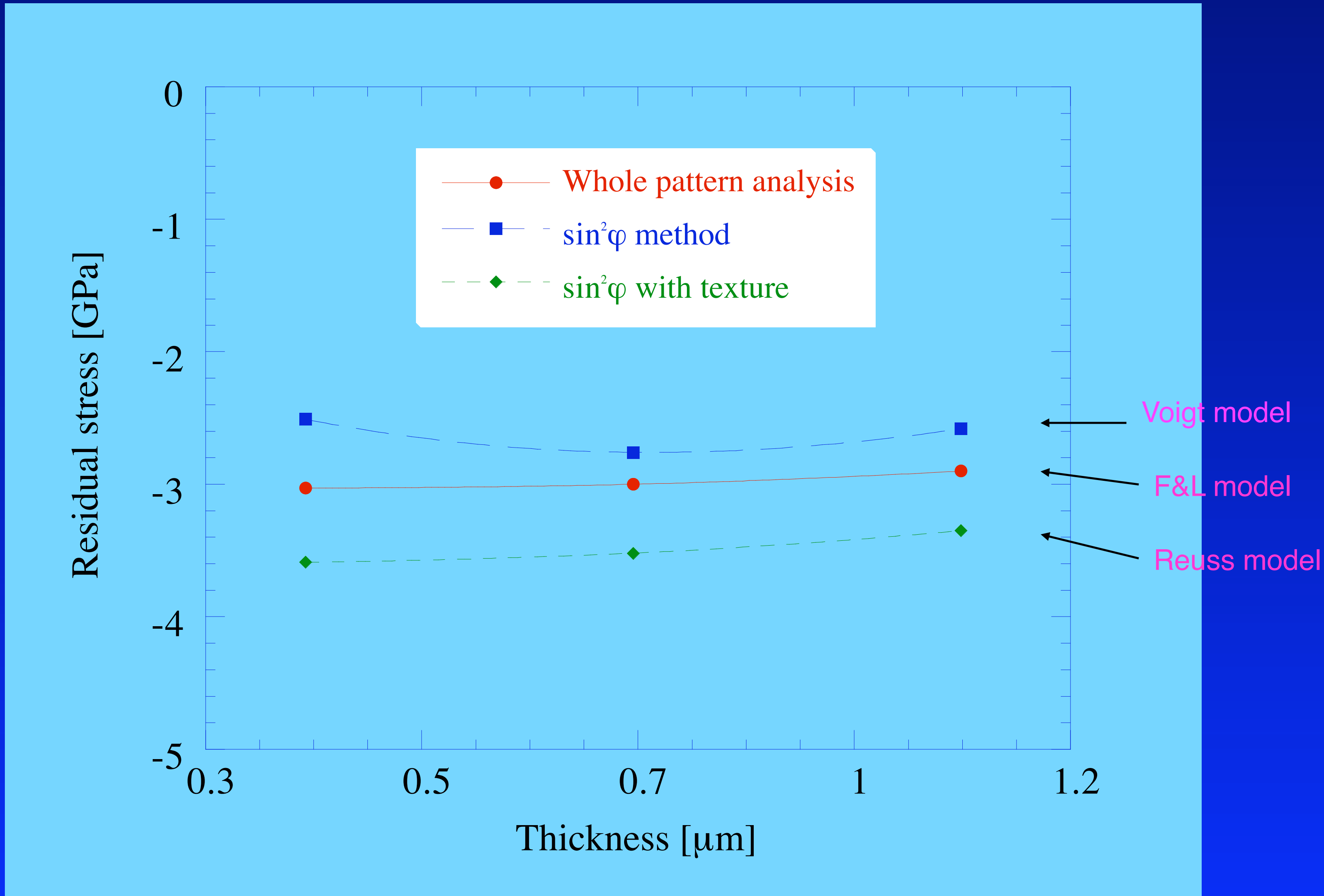




ZrO_2 thin films

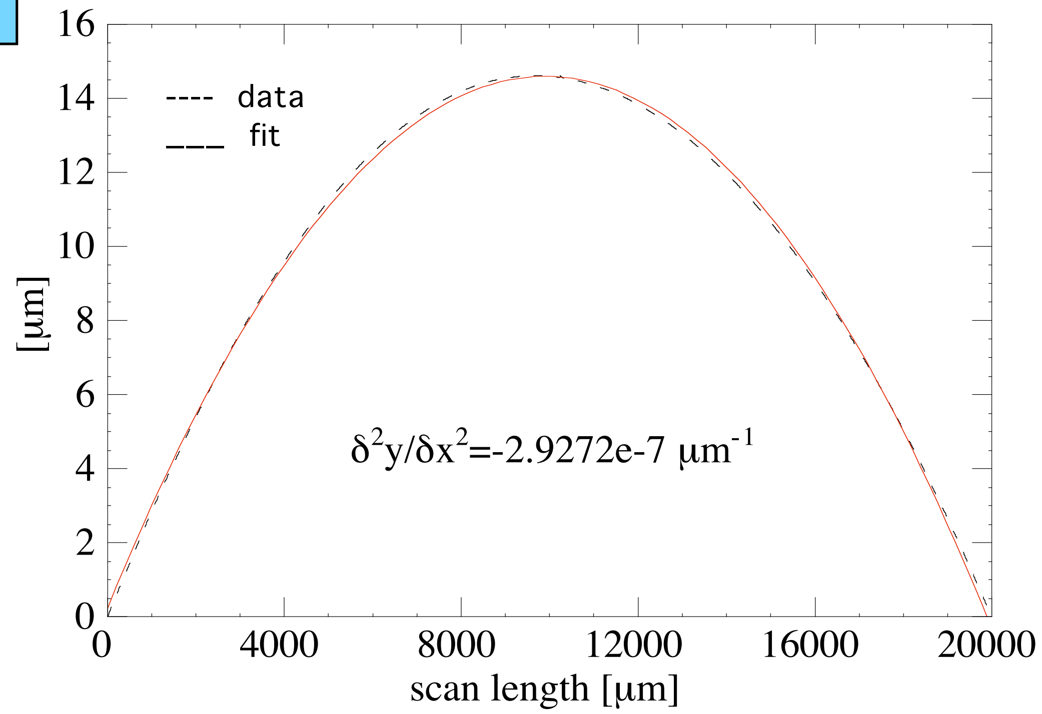


Macro residual stress on the ZrO_2 serie



Measuring the stress also by the curvature

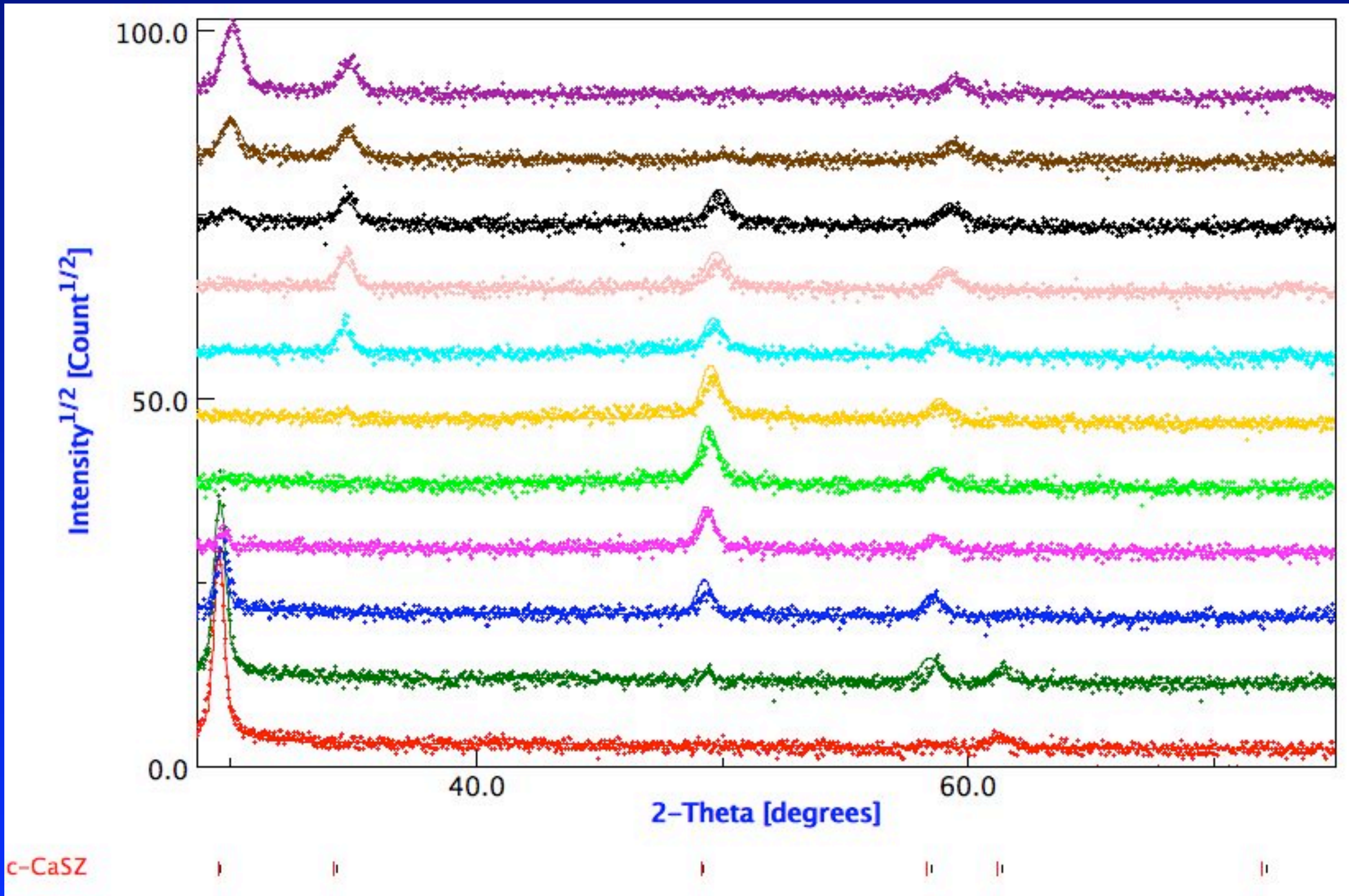
$$\sigma^* = K \cdot \frac{d_s^2}{d_f} \cdot \frac{a_{11}}{2}$$



Comparison of results

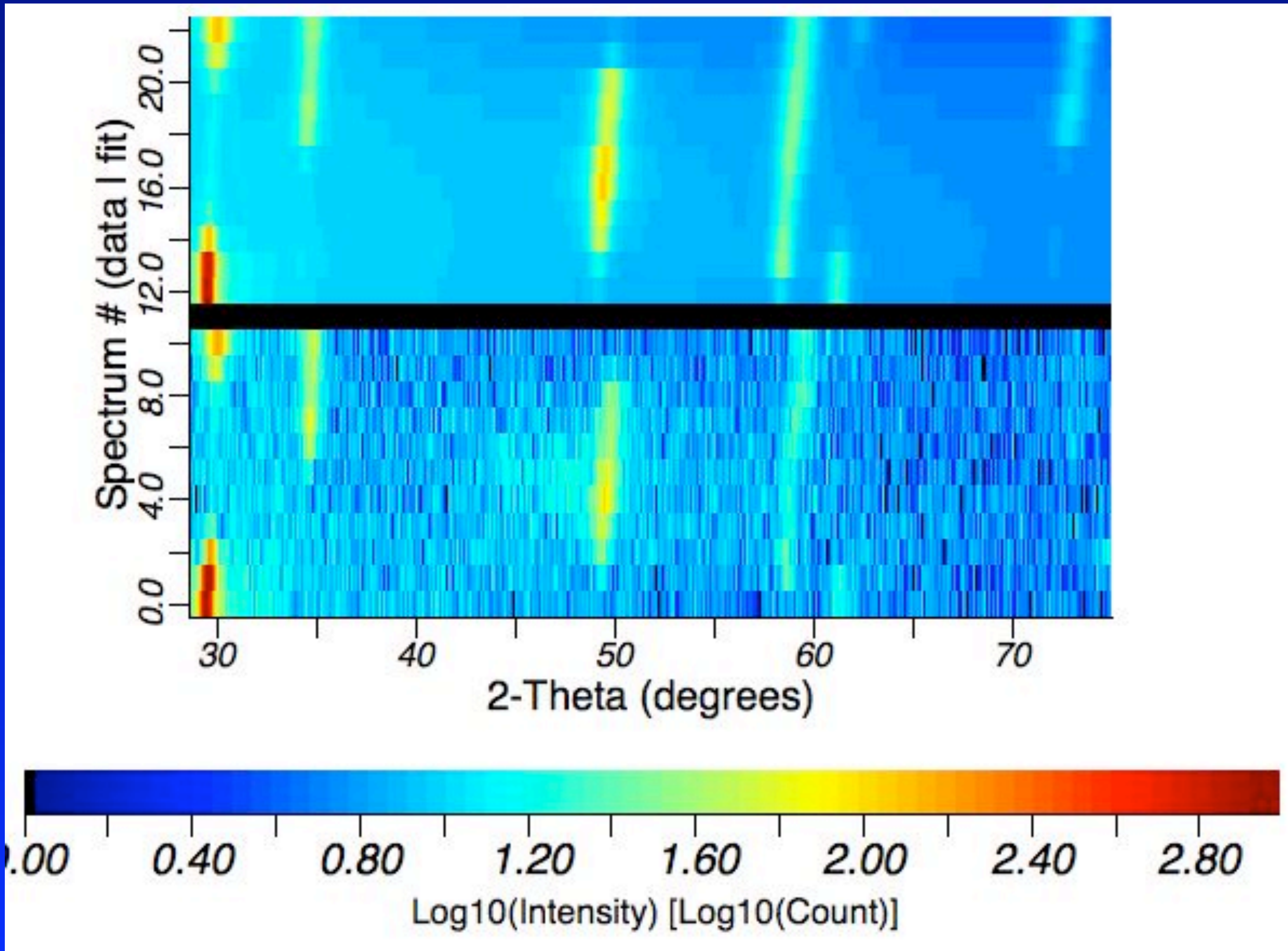
method:	XRD: $\sin^2\psi$			curvature method		XRD
	(220) plane	(200) plane	(113) plane	Stoney's formula	modified formula	Ferrari and Lutterotti
$\tau_{11} = \tau_{22}$ [GPa]	-2.73	-1.66	-3.06	-1.36	-1.48	-2.92
τ_c^*, $i = j$ τ_c^*, $i \neq j$ [GPa]						0.631 0.043

Stress-texture for a zirconia film (WIMV)



Residual Stresses/Texture analysis

- Voigt model + WIMV



ZrO_2 film: results

Very high in plane residual stresses (compression):

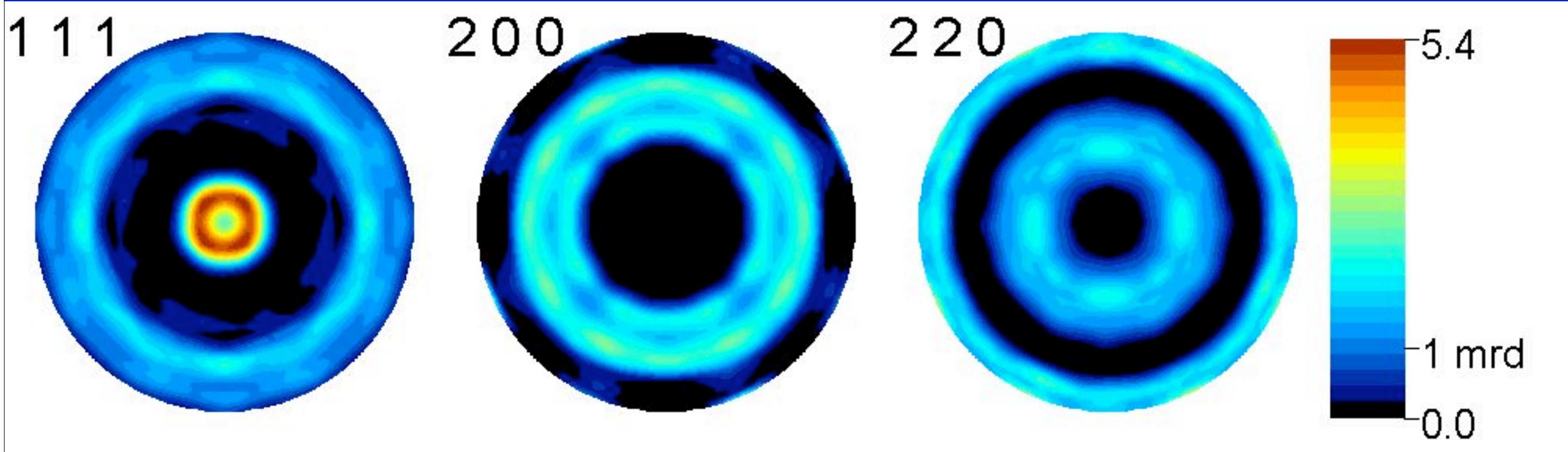
Reuss model: 3.6 GPa

Bulk Path GEO: 3.47(5) GPa

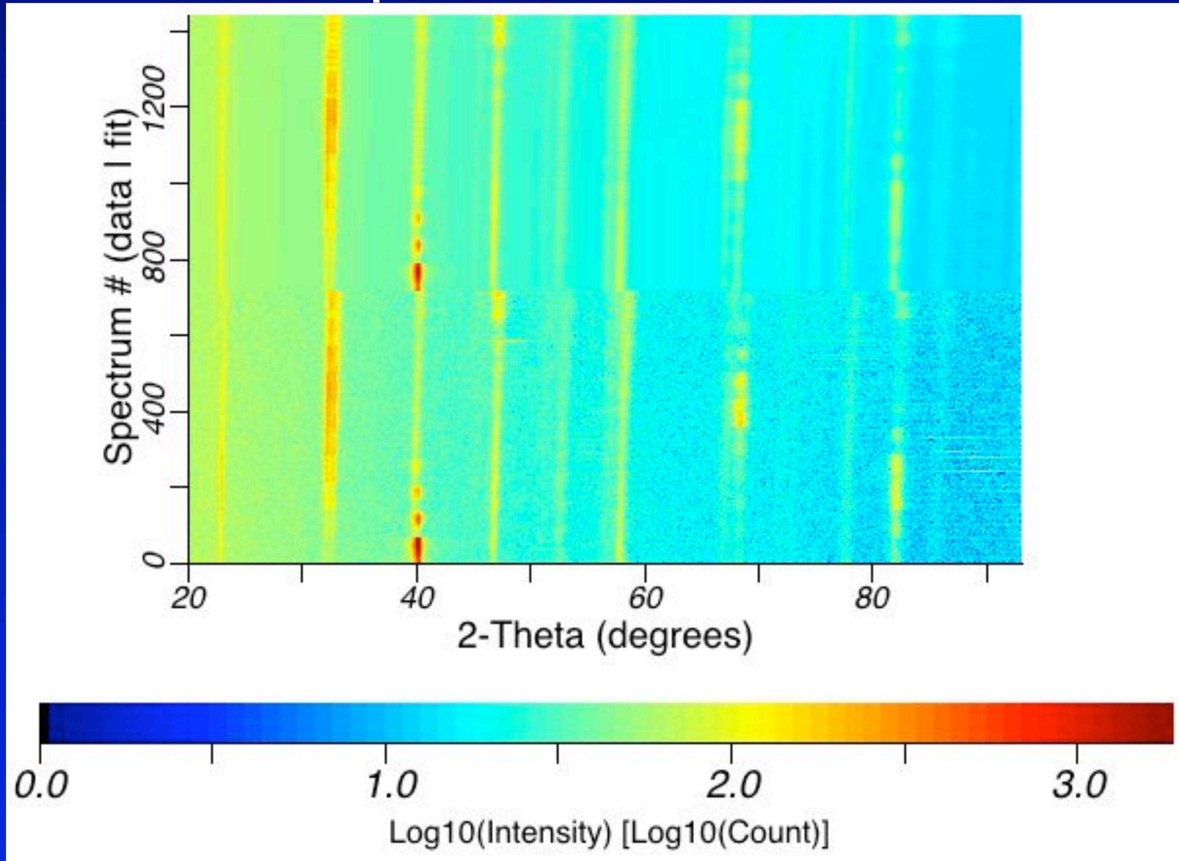
Curvature method: > 10 Gpa !?

Thickness: 320 Nanometer

Reconstructed pole figures



Experimental errors



- Example: the CPT film shows big shift of the peaks increasing χ.
- The shift is not smaller at low 2theta angle.
- In the fitting was perfectly reproduced by a beam 0.59 mm higher than the goniometer center.
- Using the Rietveld method peak shifts from low angle positions are also used normally -> good sample positioning required, perfect alignment of the instrument also.