Flying phase-retarder set-up and Multiple-beam diffraction experiment at beamline P09 at Petra III

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HELMHOLTZ GEMEINSCHAFT

DESY Summer Students Session

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DESY

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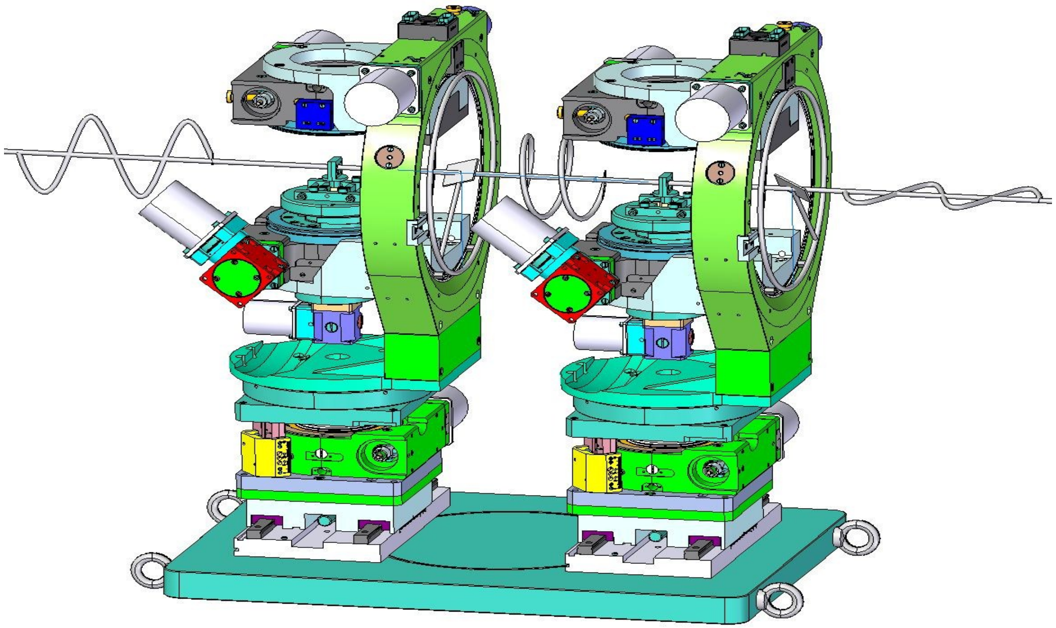
Part 2: Multiple-beam diffraction experiment

Motivation

Phase-retarder in optic hutch:



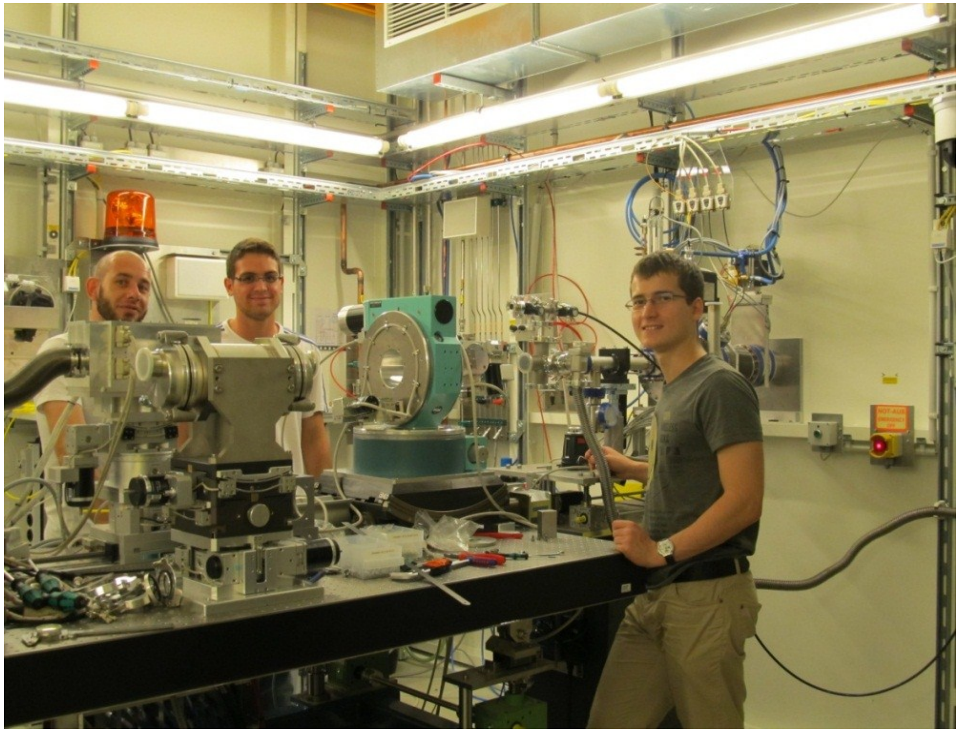
- Three fixed crystal pairs
- Energy range: from 3.5 to 8.5 KeV
- UHV vacuum tank

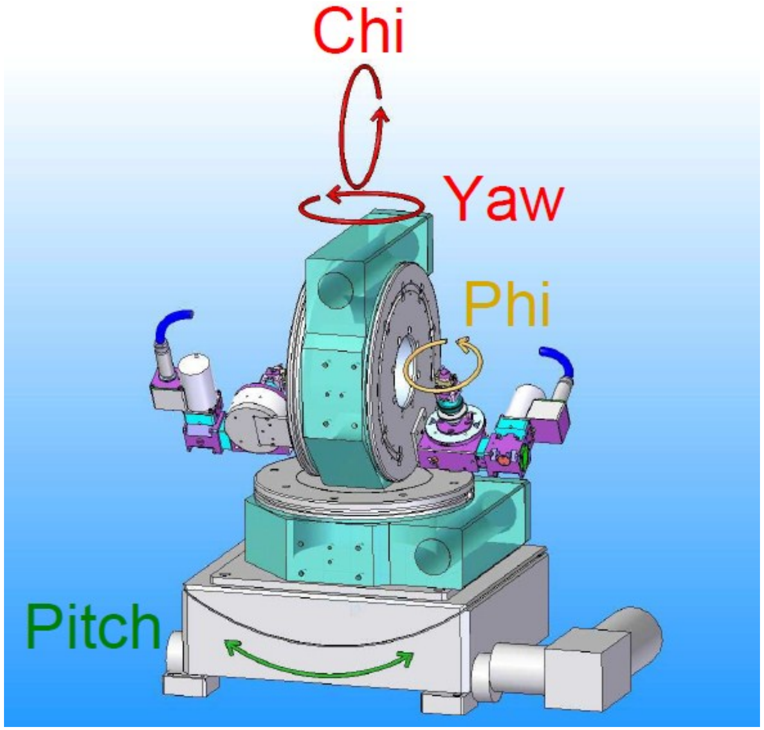
• Want to change crystals easily
• Want energy range >8.5 keV

Flying phase-retarder

Assembly of the phase-retarder

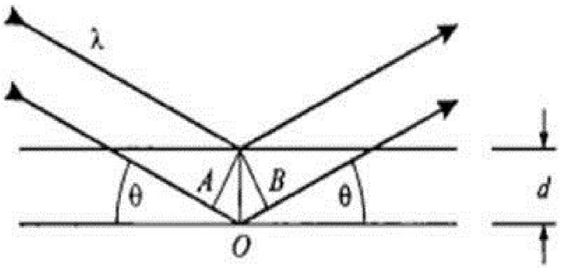
1) FPR was mounted in the experimental hutch 1 at P09 at PETRA III





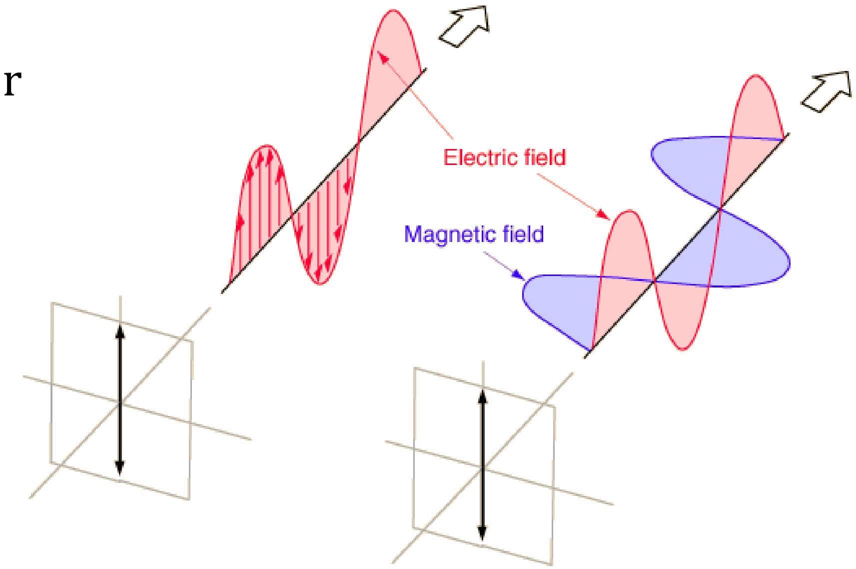
2) Two diamond crystals (680 μm, 640 μm) for FPR were oriented by back-scattering Laue diffraction and then mounted so that the two (1,1,1) and (-1,-1,1) reflections lie in the ring plane when χ=0

Bragg diffraction and polarization control



Classical theory of X-r
Bragg diffraction:

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



Dynamical theory of X-rays: Polarization of the incident beam can be changed by setting the crystal in the transmission Bragg geometry and rocking it near the (1,1,1) Bragg peak.

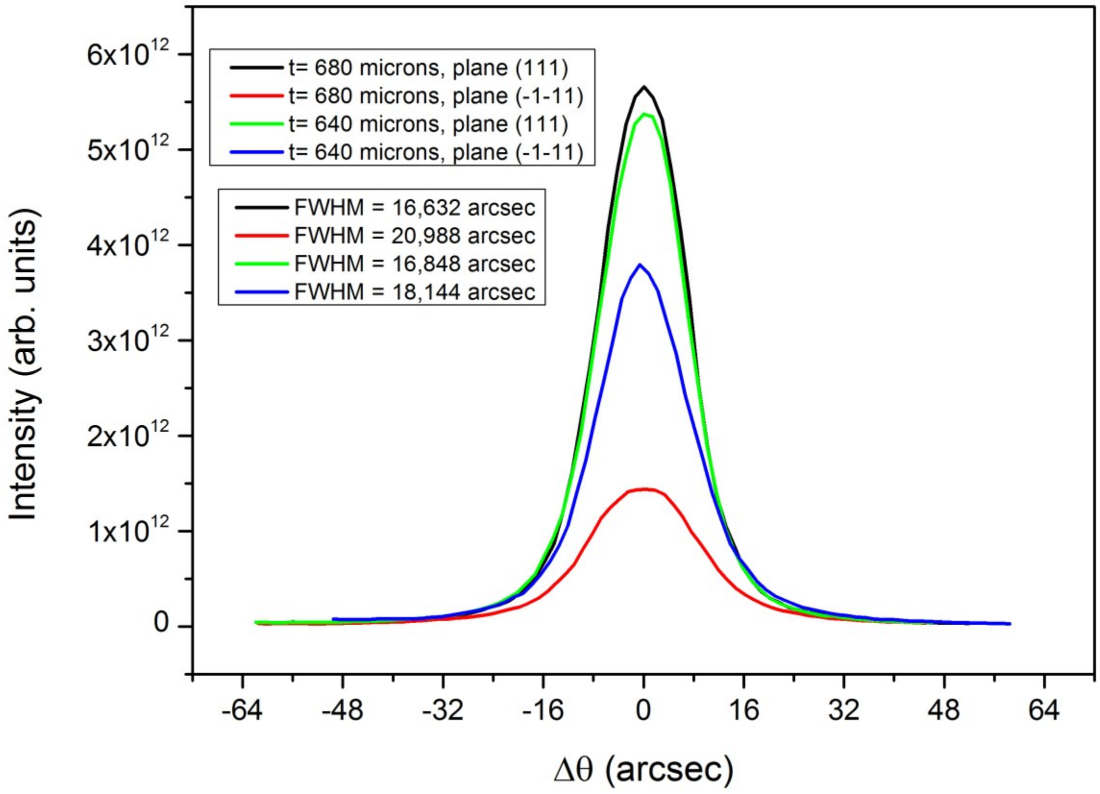
ELECTROMAGNETIC WAVE
ATTENTION TO THE ARROW ON THE BOTTOM, INDICATING A **LINEAR POLARIZATION** OF THE WAVE

There are different angular offsets ($\Delta\theta$) for different polarization conditions ($\phi_{\sigma\pi}$ $- phase\ shift$) of the outcoming beam:

$$\phi_{\sigma\pi} = -\frac{\left(\frac{\pi}{2}\right) r_e^2\, \lambda_x^3 Re\left(F_G F^*_{-G}\right) \sin(2\theta_B) t_{eff}}{\Delta\theta\ (\pi V)^2} \sim \frac{\sin(2\theta_B) t_{eff}}{\Delta\theta}$$

Determination of the diamond mosaicity

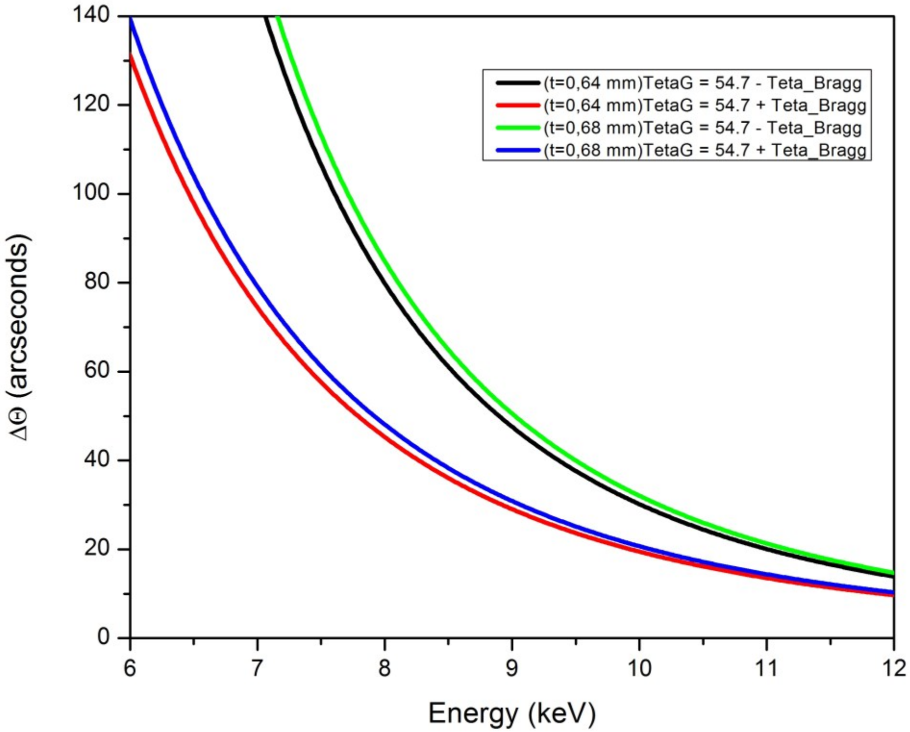
Mosaicity always makes Bragg rocking curve too broad, which can reduce the degree of polarization experiments, when working too close to Bragg diffraction peak.



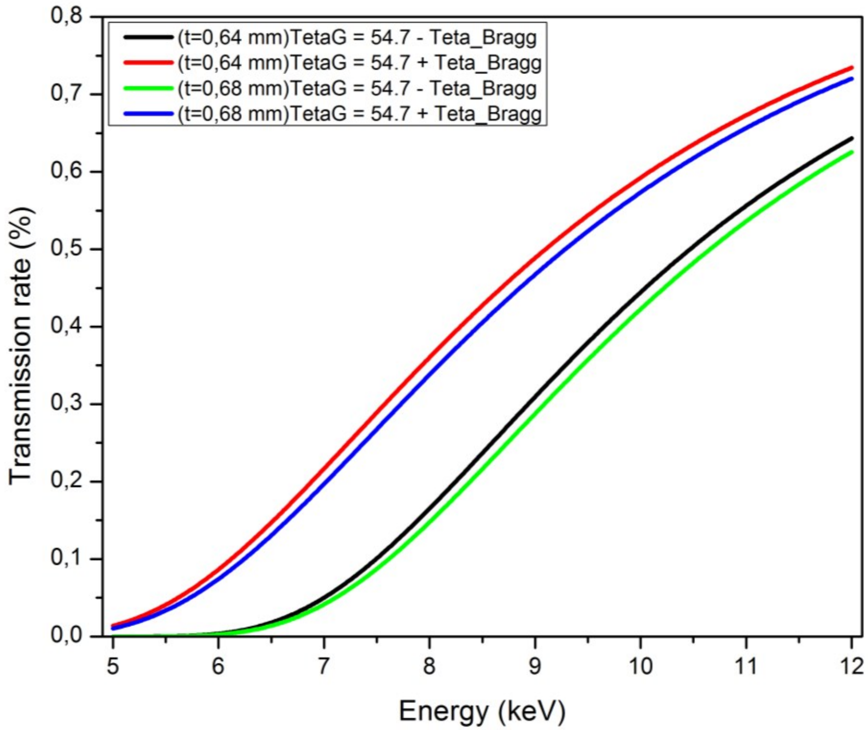
Mosaicity of diamond crystals was determined from rocking curve in Bragg diffraction experiments at (1,1,1) and (-1,-1,1) reflections in series.

Matlab simulations

In our project, we wanted to provide circular left- or right-handed polarization, which means that total phase shift must be $\pm\frac{\pi}{2}$.



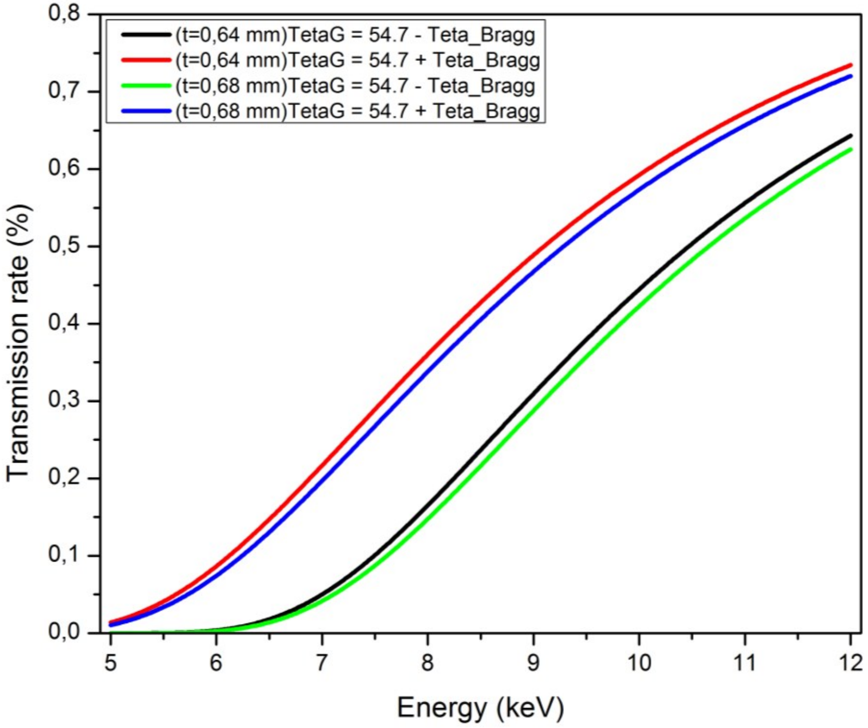
Deviation angle dependence on energy for ¼ Wave plate

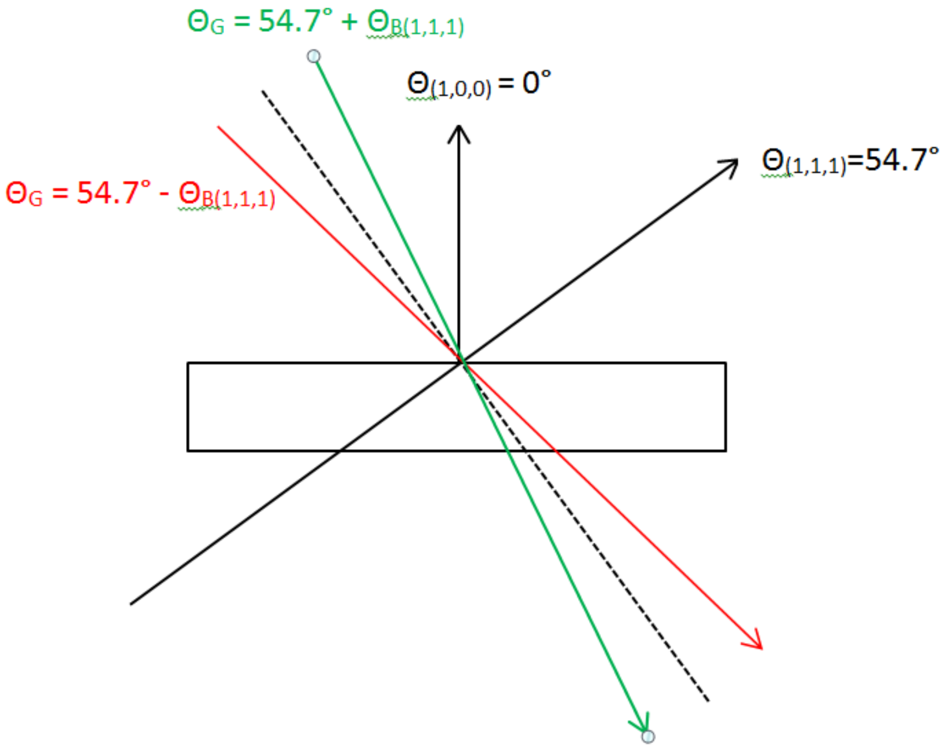


Transmission rate (>10%) is important to have good results

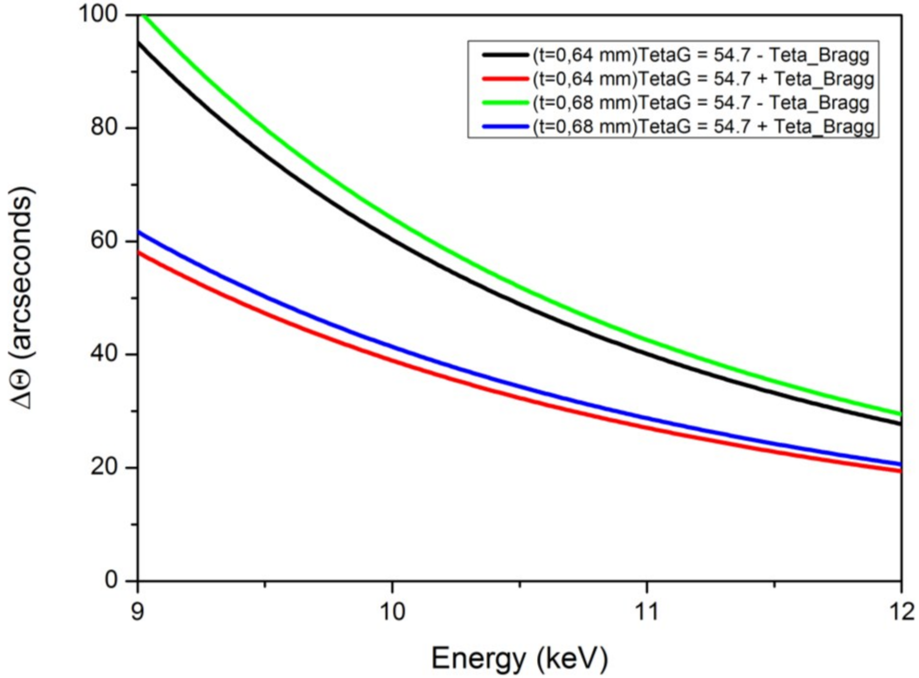
The most comfortable energy range to work with ¼ WP is 7-10 keV. But what if we want more?

Matlab simulations

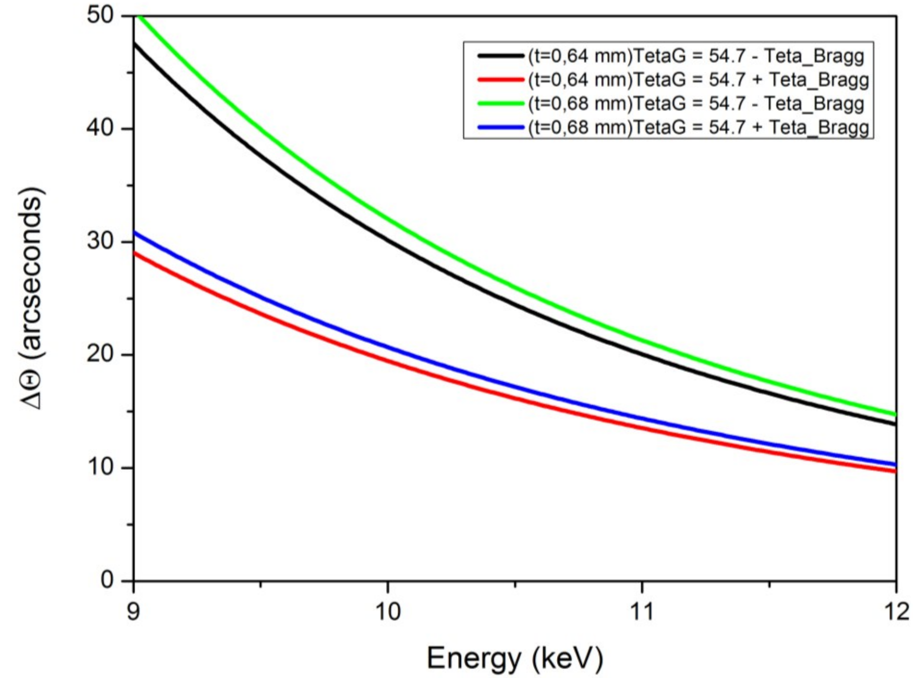




Matlab simulations



Deviation angle dependence on energy for 1/8 WP

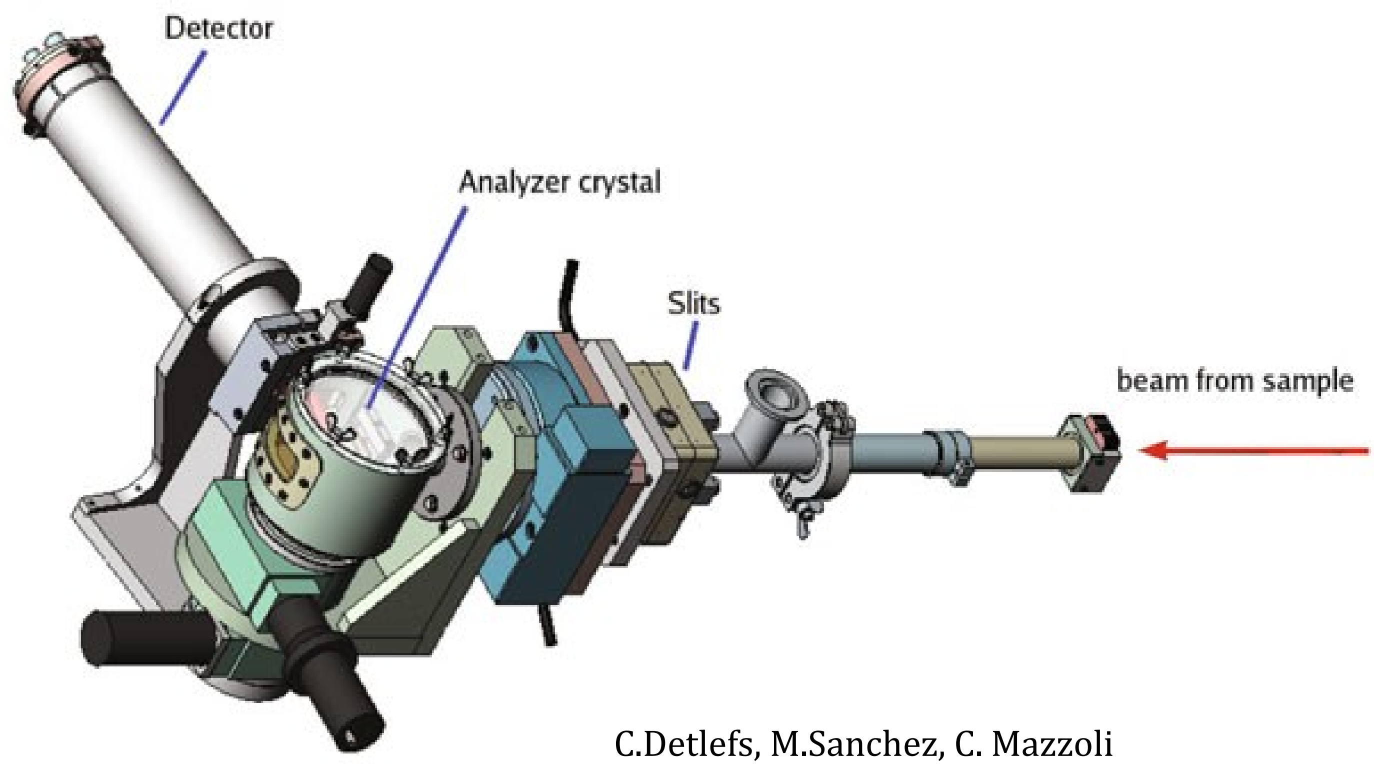


Deviation angle dependence on energy for ¼ WP

Polarization analysis

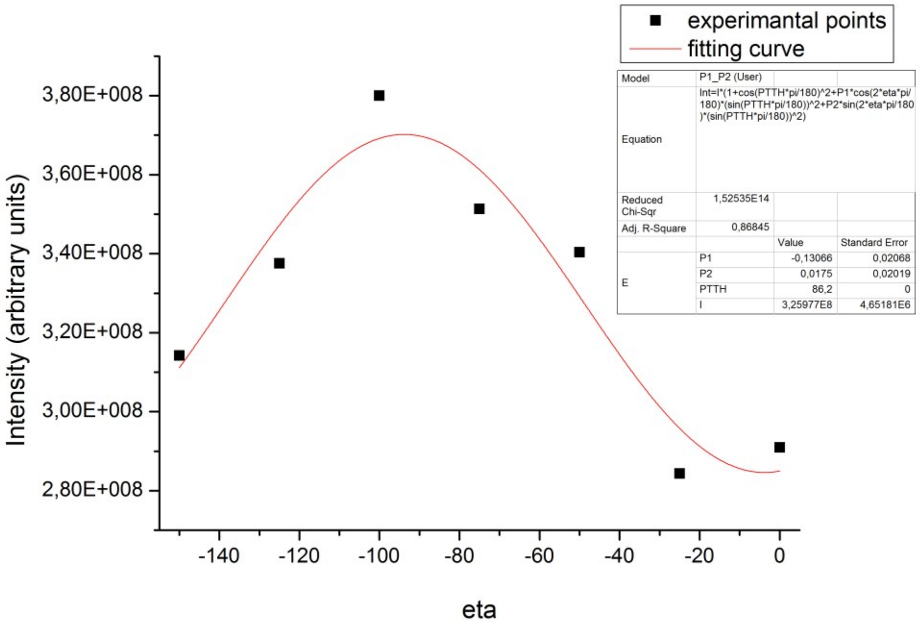
Polarization is defined by *Stokes parameters* P_1, P_2, P_3

In our experiment we made the polarization analysis for circular left- and right-polarized light (which was produced by FPR) to determine P_1, P_2, P_3

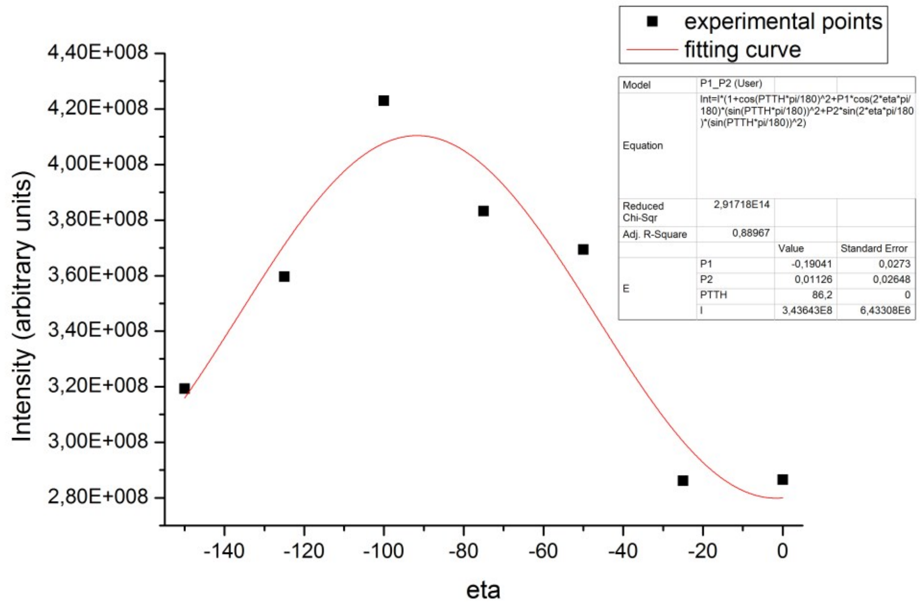


C.Detlefs, M.Sanchez, C. Mazzoli
Eur. Phys. J. Special Topics 208, 359-371 (2012)

Polarization analysis results using two 1/8 WPs



Circular left-polarized light



Circular right-polarized light

Energy = 11.568 keV
(Pt L_{III}-edge)

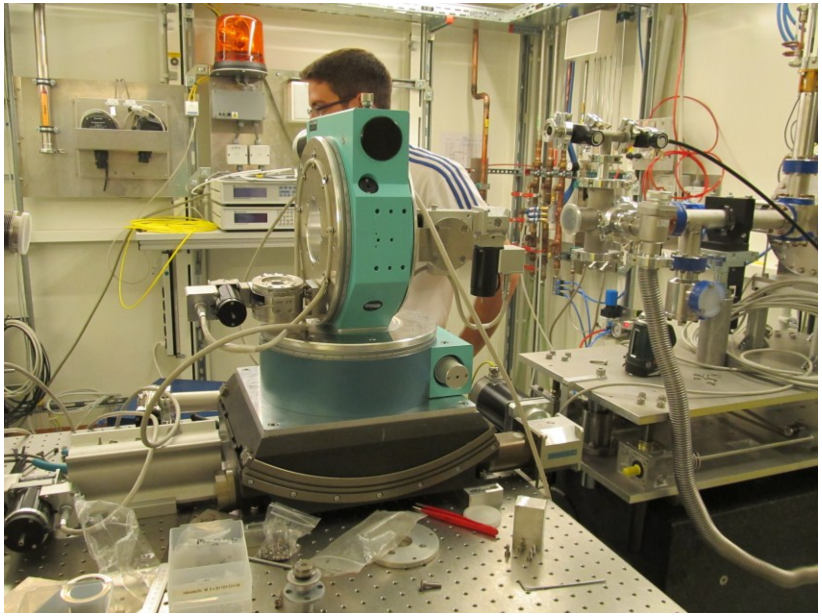
	Circular left-polarized light	Circular right-polarized light
P_1	-0.13 ± 0.02	-0.19 ± 0.03
P_2	0.02 ± 0.02	0.01 ± 0.02
P_3	0.991 ± 0.003	0.981 ± 0.006

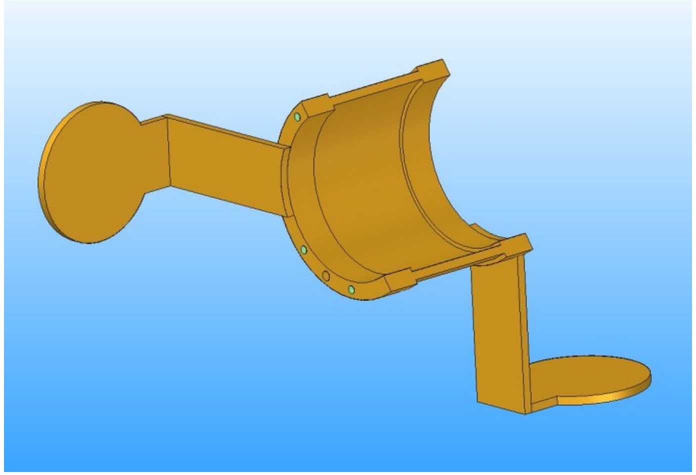
- $P_{un} = 0$
- $\sqrt{P_1^2 + P_2^2 + P_3^2} = 1$
- $I = I_0\,(1 + cos^2(2\theta) + P_1 \cos(2\eta)\, sin^2(2\theta) + P_2 \cos(2\eta)\, sin^2(2\theta))$

Conclusions

Flying Phase Retarder

- Assembly of the phase-retarder sucessful – circular polarized light can be obtained
- Sucessful determination of Stokes Parameters P_1, P_2, P_3
- Disadvantages and improvements:
  - Bigger control of z-position of diamond plate
  - 1-piece composition of goniometer supporter (picture) to guarantee 90° (AP geometry)
  - Reduce sphere of confusion of chi circle





MBD: Multiple-beam diffraction experiment

- ✓ **Basic concepts**
- ✓ **Procedures**
- ✓ **Results**
- ✓ **Conclusions**

Direct determination of P_3: MBD experiment

- $P_{un} = 0$ and $\sqrt{P_1^2 + P_2^2 + P_3^2} = 1$ not always true

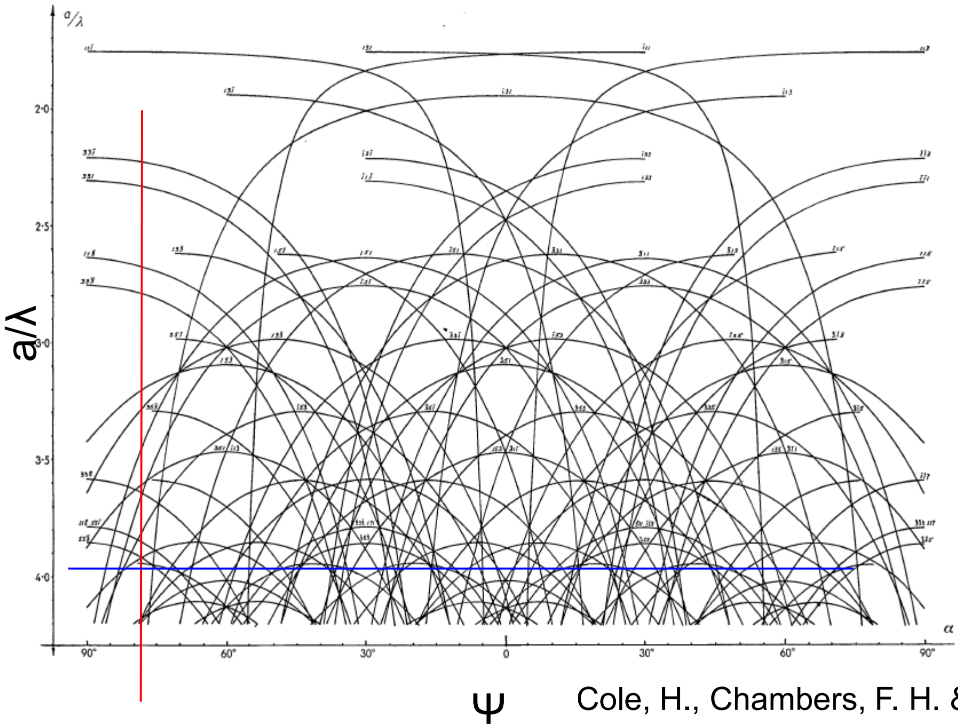
> direct measurement of Stokes Parameter P_3 needed

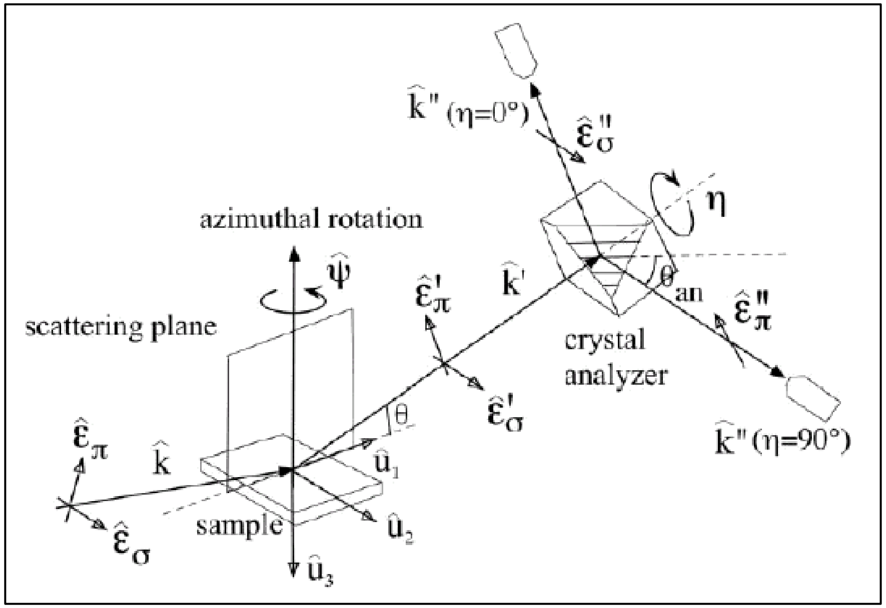
> Possible solution: MBD (Multiple-beam diffraction)

> Procedures: "Complete determination of x-ray polarization using multiple-beam Bragg diffraction", Qun Shen and K. D. Finkelstein, Phys. Rev. B 45 (9), 1992

Direct determination of P_3: MBD experiment

- Definition of ψ
- Map of diffraction planes for a crystal with diamond structure (GaAs in our case) around main reflection H = (2,2,2)
- E = 8,076 KeV
- We found a peak intensity at -84.54 degree => possible indexation: 351/-113

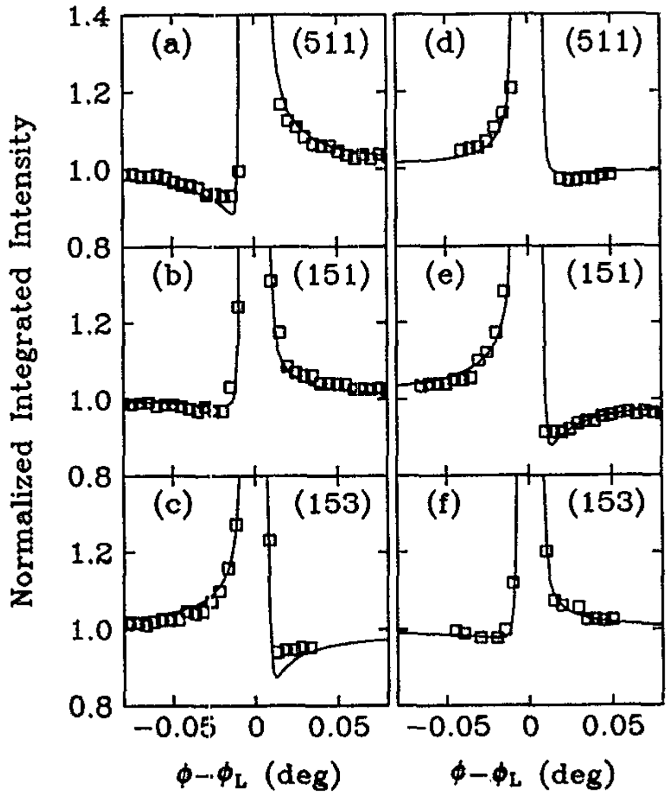




Cole, H., Chambers, F. H. & Dunn, H. M. (1962). Acta Cryst. 15, 138-144.

Direct determination of P_3: MBD experiment

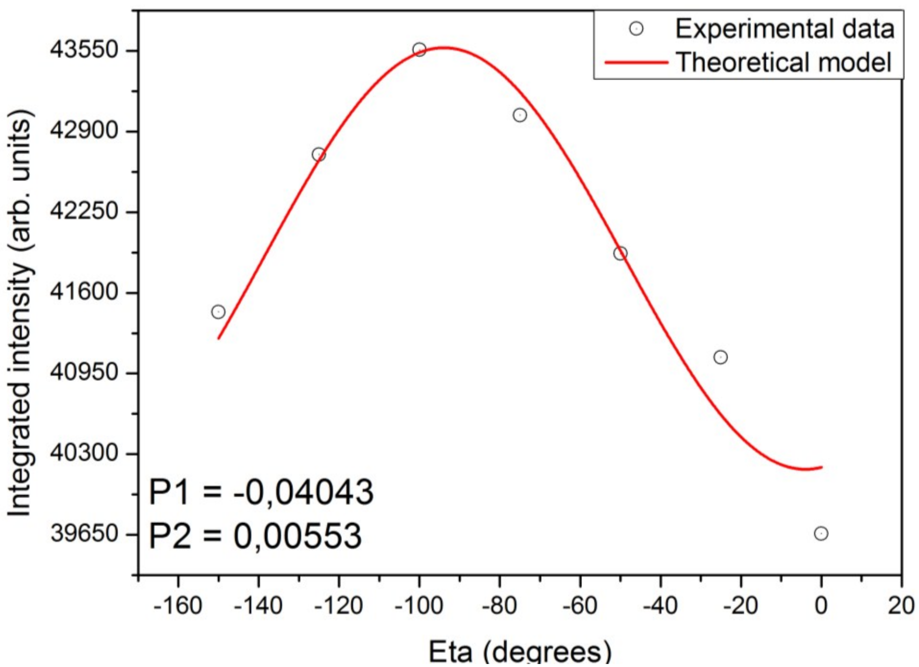
- Find the main (H) and the detoured (L) reflections for MBD
- Rocking the ψ *axis* near L and for each ψ value rock θ axis
- Plot integrated (θ rocking) intensity dependence on ψ (asymmetric curve)



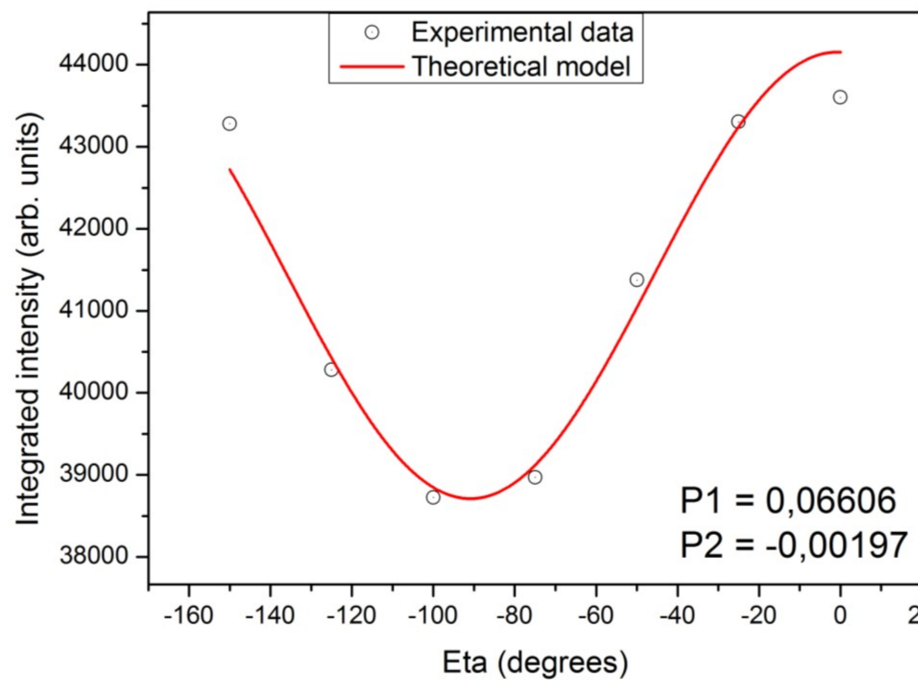
Q. Shen, K.D. Finkelstein
Phys. Rev. B, 45 (1992)

MBD - Results

- Generation of circular left / right: 400 microns diamonds; 1 single plate at QWP
- GaAs sample (diamond structure), multiple scattering condition around H = (2,2,2), "forbidden reflection"
- Polarization analysis with PG001 to get P1 and P2
- 1 single equation to solve; one single multiple scattering condition to find



Circular right

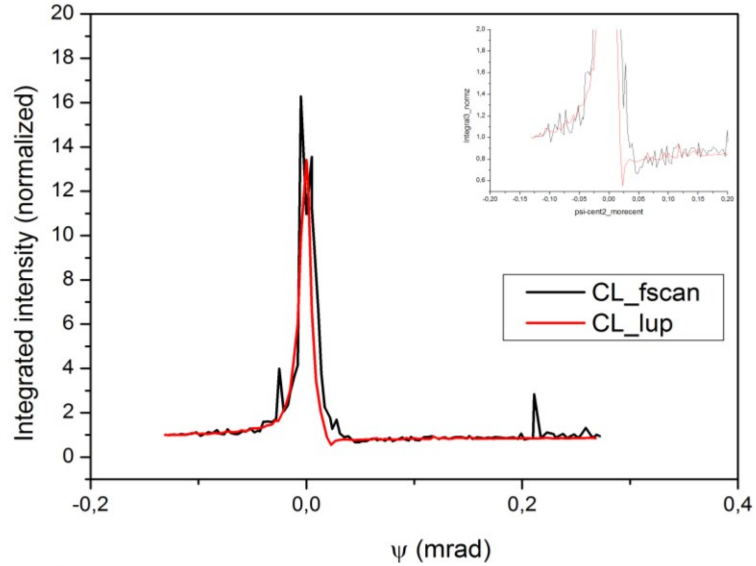


Circular left

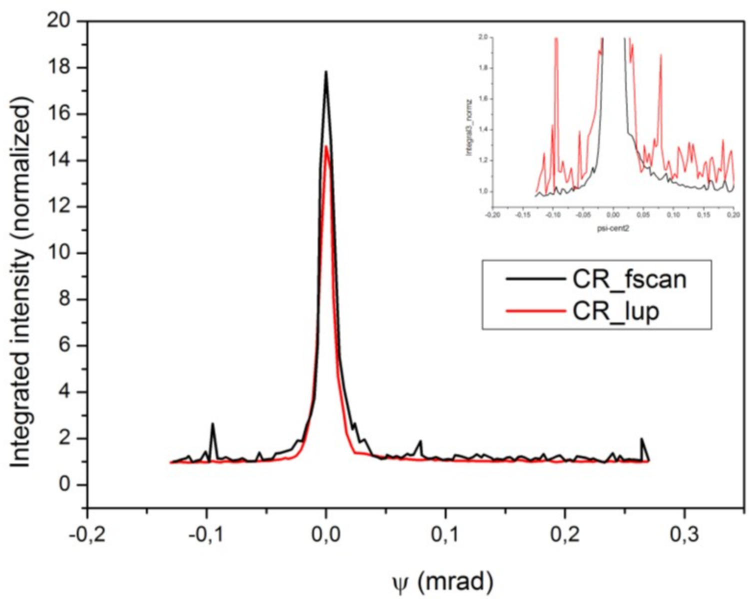
MBD - Results

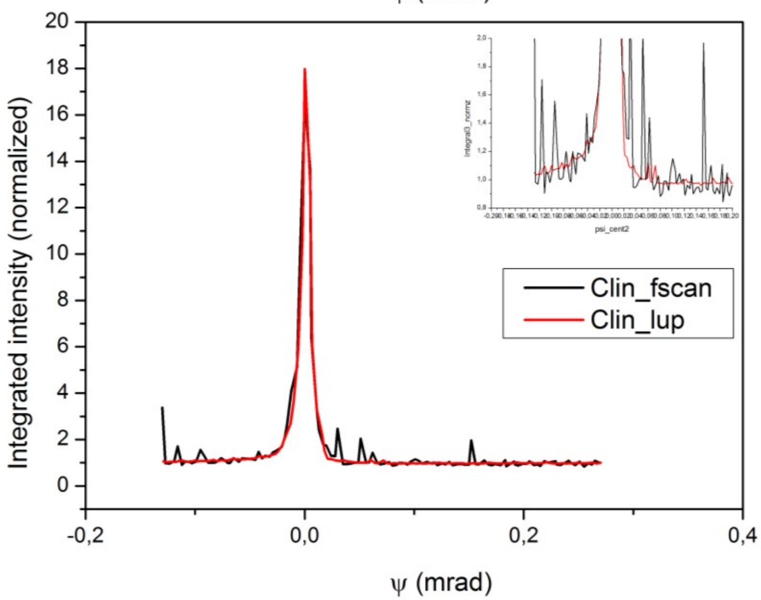
Interpreting the data:

- ✓ **Check for asymmetric profile**
- ✓ Analyze theta scans (movies)
- ✓ Solve the linear system



<u>Constraint in time : fast scan vs lup scan</u>

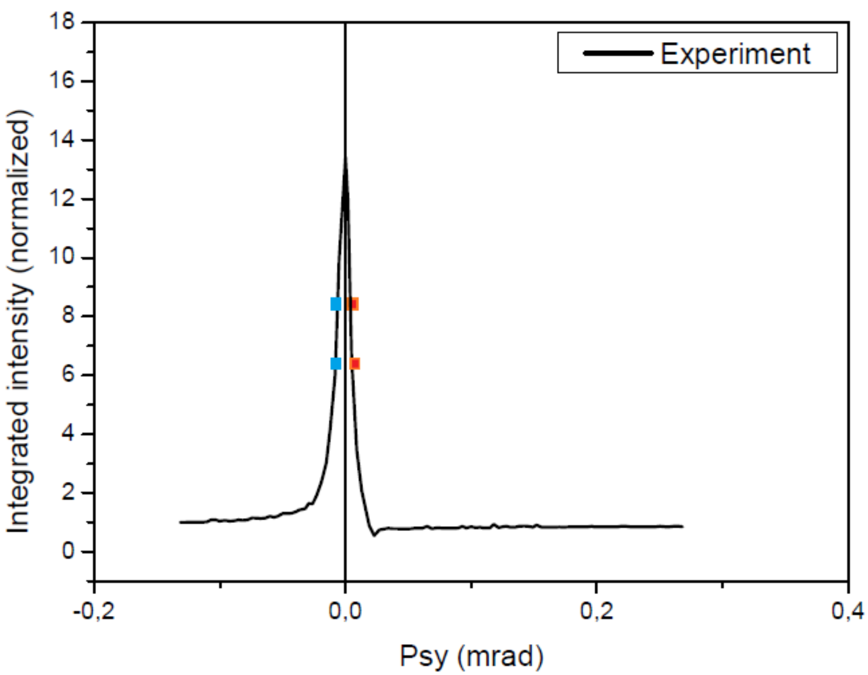


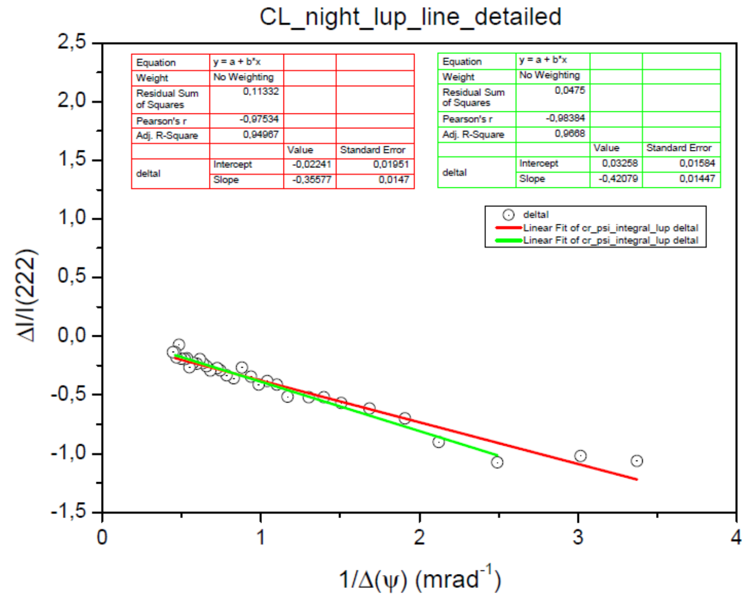


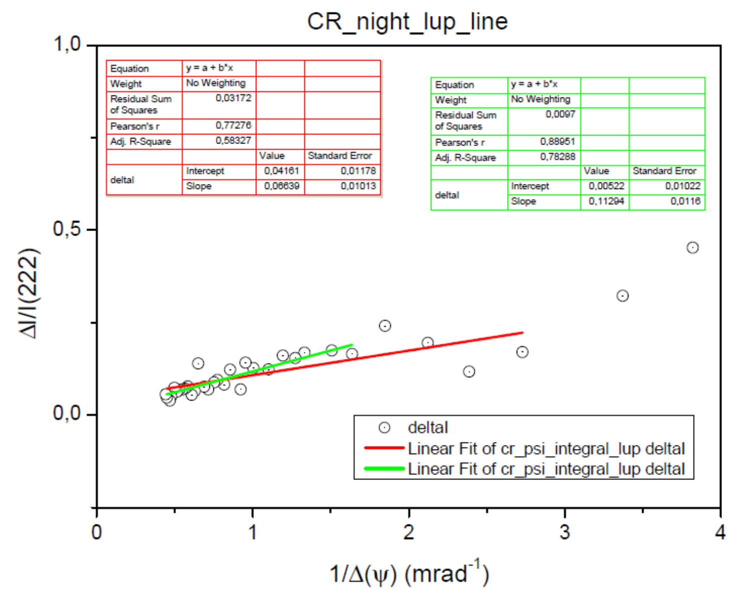
MBD - Results

- Subtract the intensity of symmetric points for each *Δψ and divide by I(2,2,2)*:
  $$\frac{I_{int}}{I(2,2,2)} = I(\Delta\psi) - I(-\Delta\psi)$$
- Plotting this intensity difference versus

1/Δψ, a linear trend should be obtained







MBD – Results: Solve the linear system

Interpreting the data:

✓Check for asymmetric profile
✓**Solve the linear system**
✓Analyze theta scans (movies)

$$I_{int} = I\,B(\phi)\{\cos(\delta)\,[A_{\sigma\sigma} + A_{\pi\pi}\cos(2\theta)] + P1\cos(\delta)\,[A_{\sigma\sigma} - A_{\pi\pi}\cos(2\theta)] + P2\cos(\delta)\,[A_{\pi\sigma} + A_{\sigma\pi}\cos(2\theta)] + P3\sin(\delta)\,[-A_{\pi\sigma} + A_{\sigma\pi}\cos(2\theta)]\}$$

- **When δ = 90 => cos(delta)=0; opposite sign of slopes and same magnitude:**

$$I_{int} = I\,B(\phi)\{P3\sin(\delta)\,[-A_{\pi\sigma} + A_{\sigma\pi}\cos(2\theta)]\}$$

We observe opposite signs but different magnitudes:

Two scenario :

⇒ **δ ≠ 90; We have P1 and P2: P1 and P2 ~ 0; equation simplify as:**

$$I_{int} = I\,B(\phi)\{\cos(\delta)\,[A_{\sigma\sigma} + A_{\pi\pi}\cos(2\theta)] + P3\sin(\delta)\,[-A_{\pi\sigma} + A_{\sigma\pi}\cos(2\theta)]\}$$

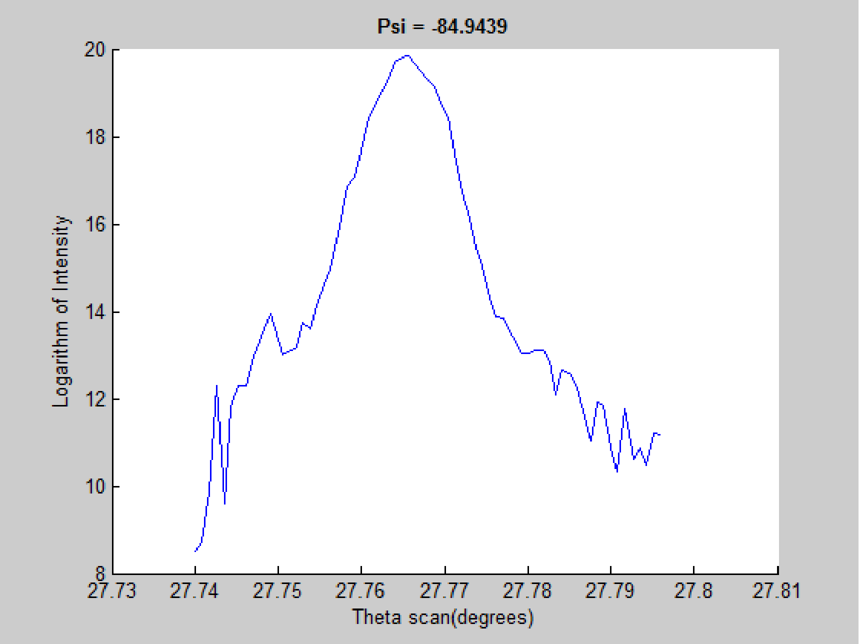
= > δ = 90; Normalization by I(2,2,2) not done properly ?; look into the data again

OR Look into the theta scan again; another peak in the ψ range: contamination of assymetry profile by another detour reflection ?

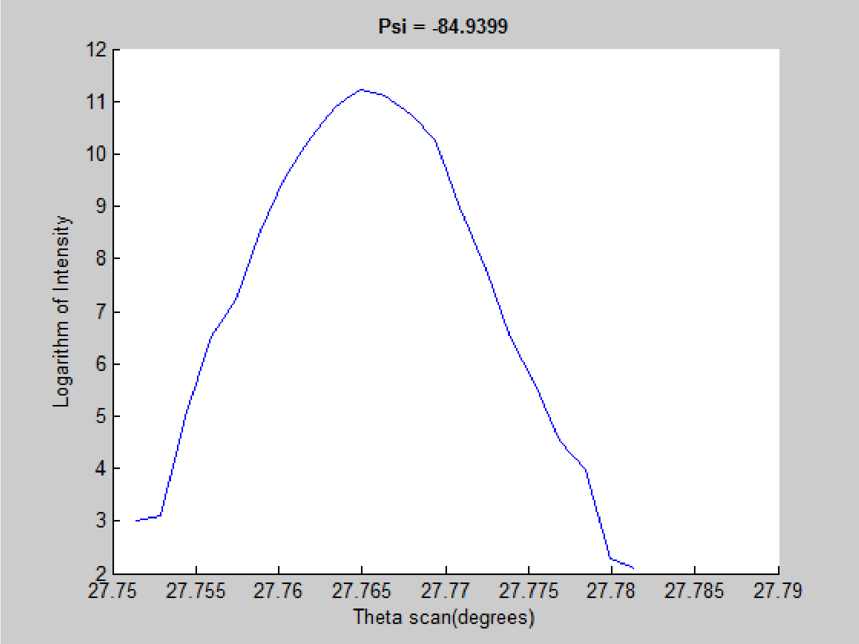
MBD - Results

Interpreting the data:

- ✓ Check for asymmetric profile
- ✓ Solve the linear system
- ✓ **Analyze theta scans (movies)**



Fast scan



Lup scan

Conclusions

PART 2 - MBD Experiment

- Principle of the experiment understood
- Rocking curve of GaAs very sharp
- Fast scans rather than lup scans (azimuthal range of investigation limited)
  ➔ 90° scan would take 30 hours
- Analysis to be finished

Acknowledgments

- Sonia Francoual, Jörg Strempfer
- David Reuther, Dinesh Kumar Shukla

Thank you for your attention!