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Neutron volumetric test of a high perfect crystal quality

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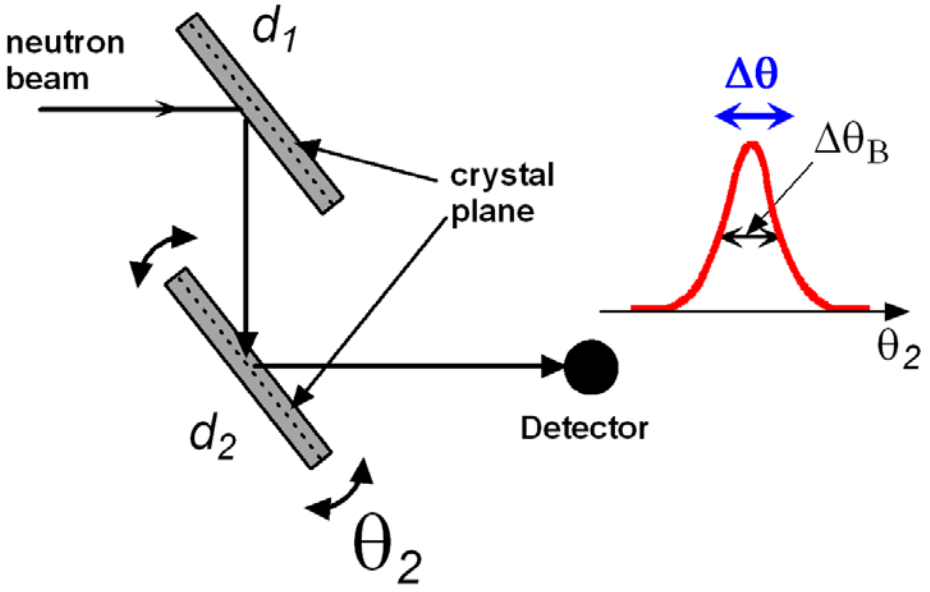
Motivation

- Crystal-diffraction nEDM project
  (report of Fedorov Valery)
- Crystal diffraction method to measure neutron electric charge and inertial to gravitational mass ratio
  (poster of Voronin Vladimir)

Require high perfect crystal with
$\Delta d/d \sim 10^{-6}$ for the sizes **$10 \times 10 \times 10\ cm^3$**

Standard principle

- To measure the two crystals rocking curve



$$\frac{\Delta d}{d} \equiv \frac{d_1 - d_2}{d} = -\frac{\Delta\theta}{\tan(\theta_B)} \xrightarrow{\tan\theta_B \sim 1} \Delta\theta$$

Problems –

- $\Delta\theta \sim 10^{-6}$-$10^{-7}$
- How to measure absolute value of Δd?
- Crystal preparation
- This is the test of surface only

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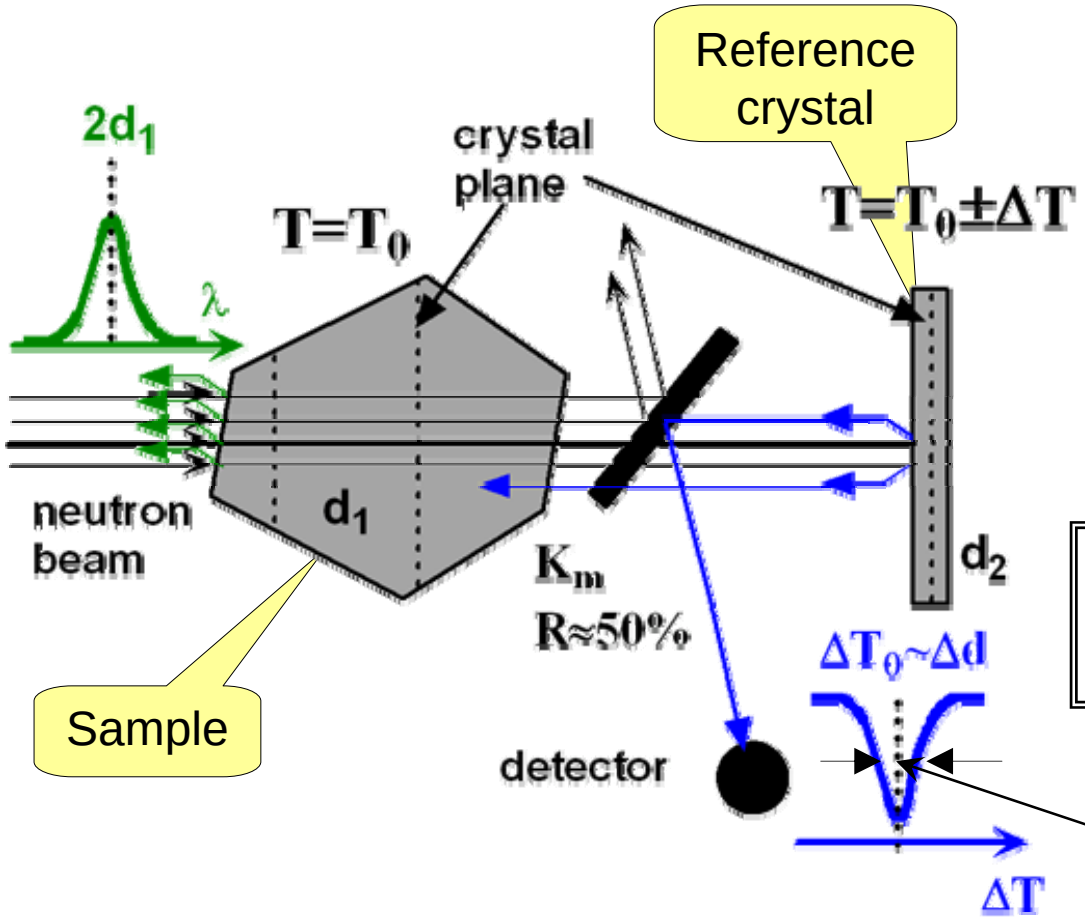
Our requirements

- Low cost
- Short time
- Test whole crystal volume
- Possibility to compare **d** of different samples
- Possibility to check crystal without preliminary preparation (cutting off, polishing, orientation)

Main idea

- Backscattering geometry $\lambda = 2d\sin\theta_B \xrightarrow{\theta_B \approx \pi/2} 2d$



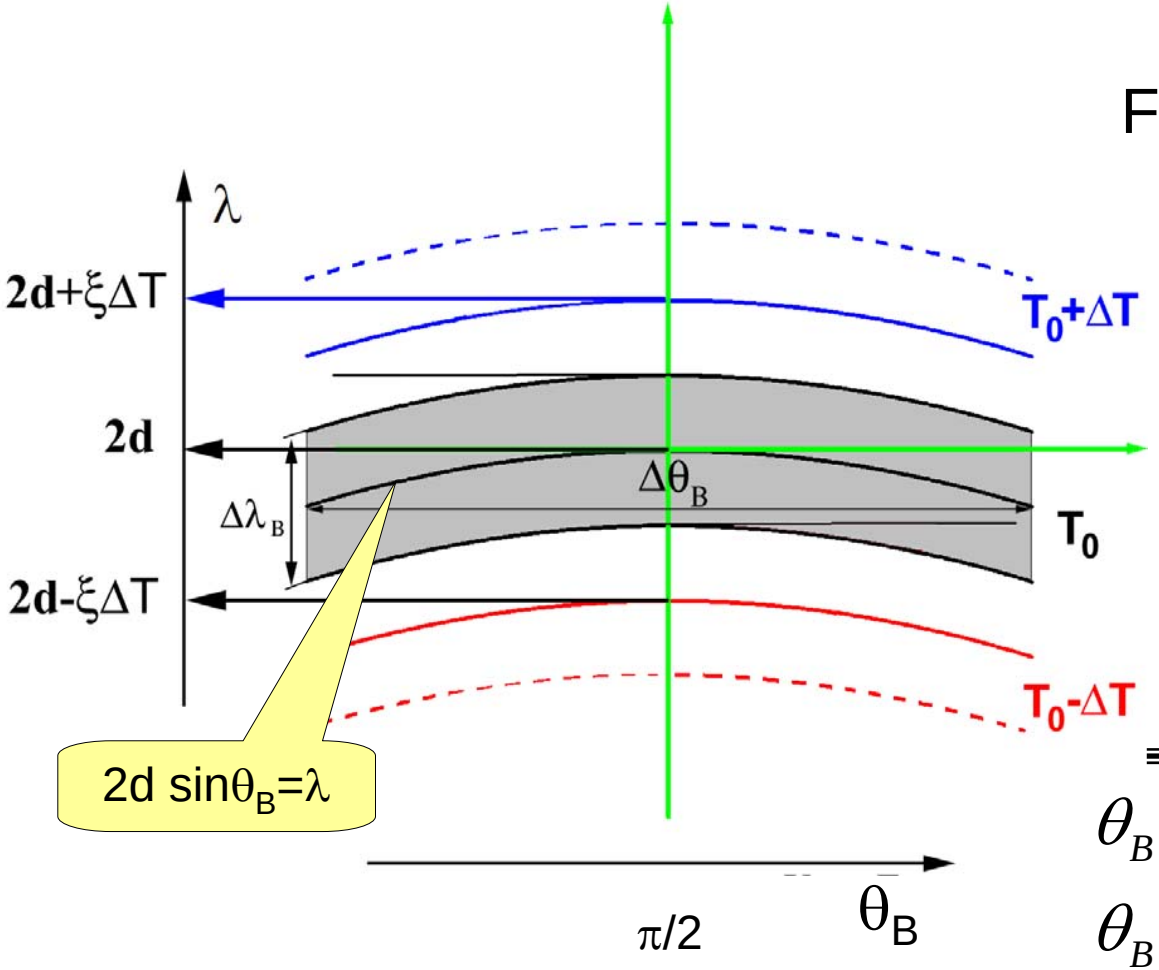
$$\frac{\Delta d}{d} = -\xi \cdot \Delta T$$

$$\xi \sim 10^{-5} / K$$

$$\frac{\Delta d}{d} \approx 10^{-7} \Rightarrow \Delta T \approx 0.01^0 K$$

Bragg width of neutron reflex in Δd/d is ~10^{-5}

Bragg width for backscattering



For cold neutron (λ~5Å)

$$\frac{\Delta\lambda_B}{\lambda} = \frac{4F_g d^2}{V\pi} \sim 10^{-5}$$

$$\Delta T_B \sim 1^0\,K$$

Angular Bragg width

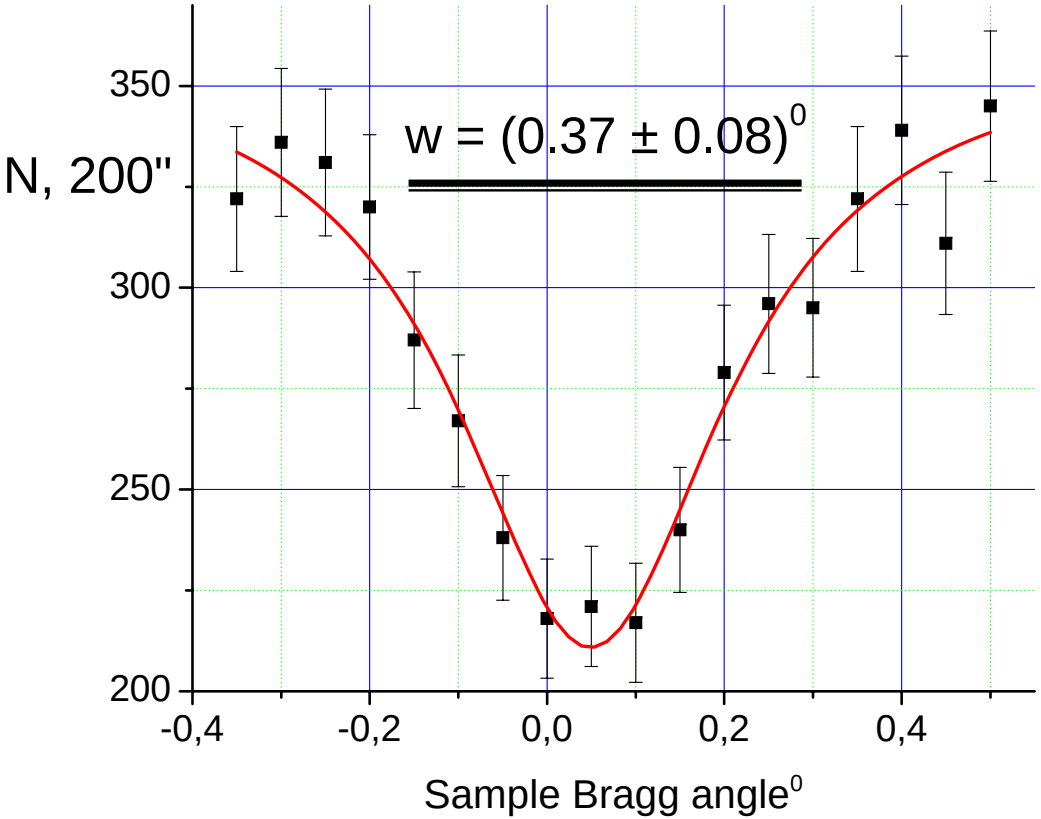
$$\theta_B \sim 45^0 \Rightarrow \Delta\theta_B \sim (1-2)''$$

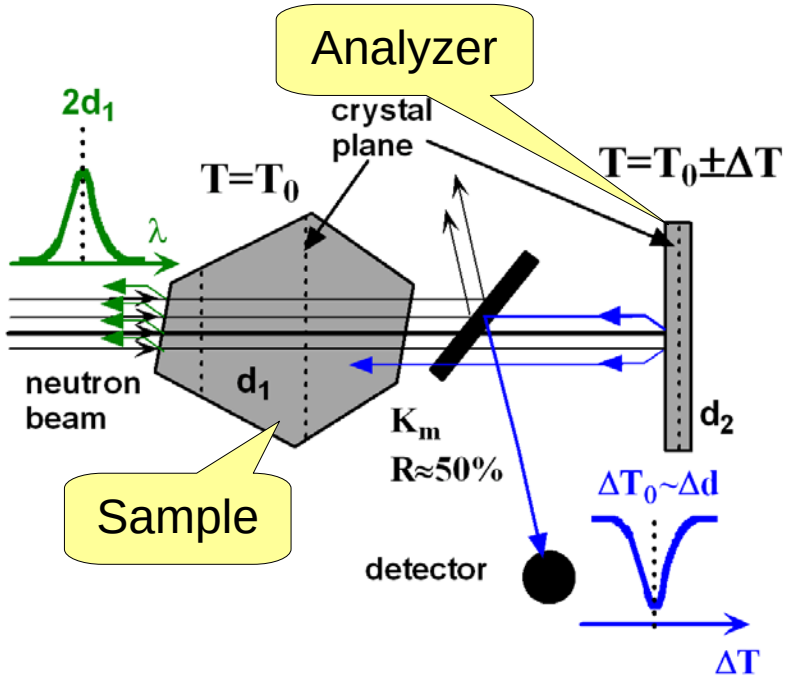
$$\theta_B \sim 90^0 \Rightarrow \Delta\theta_B \sim 0.5^0$$

1000 times

Experiment

- Quartz (110) plane





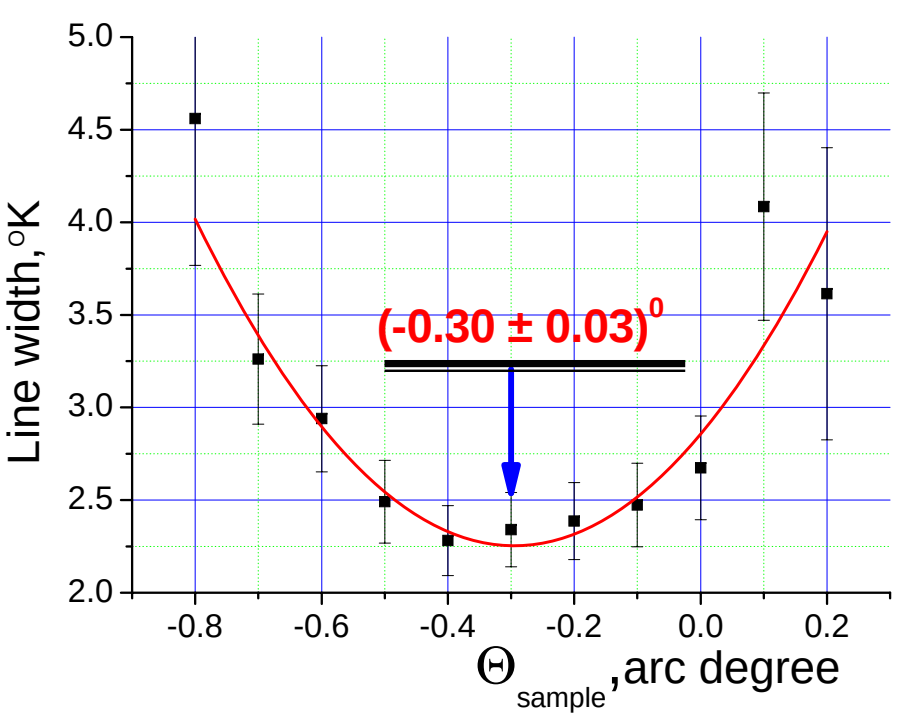
To get the accuracy

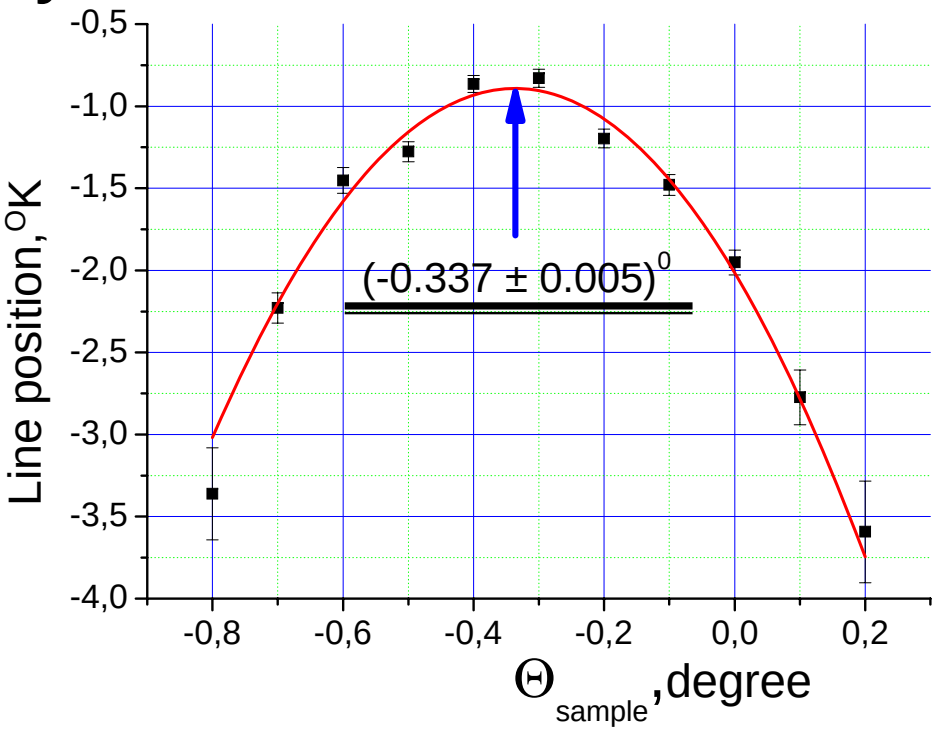
$\sigma(\Delta d/d)\sim 10^{-6}$ we need angular crystal alignment

$\sim 0.05^0$

Crystal angular alignment

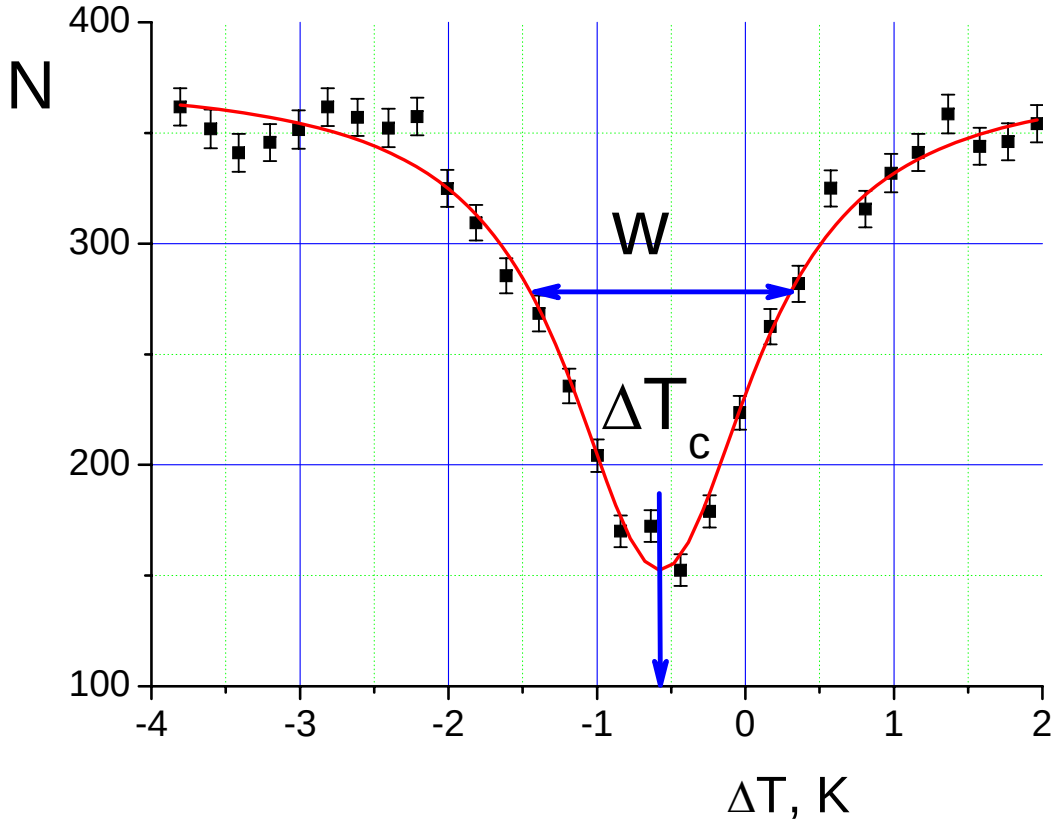
- Minimal width of two crystal line





For the presented case the systematic for **Δd/d** due to not exact crystals angular alignment ~ $\sigma(\Delta d/d)_{syst} \approx 2.5\ 10^{-7}$

Example of two crystal line ("good")



$W_T=(1.54 \pm 0.07)^0K$

$\Delta T_c=(-0.520 \pm 0.015)^0K$

$W_d=(2.1 \pm 0.1)10^{-5}$

$W_d(theory) \approx 2 \cdot 10^{-5}$

$\Delta d/d=(-73 \pm 2(stat))10^{-7}$

Both crystals (sample and analyzer) are perfect but have different interplanar distance

$\Delta d/d \sim 10^{-5}$

Sample was synthetic
Analyzer was natural

??

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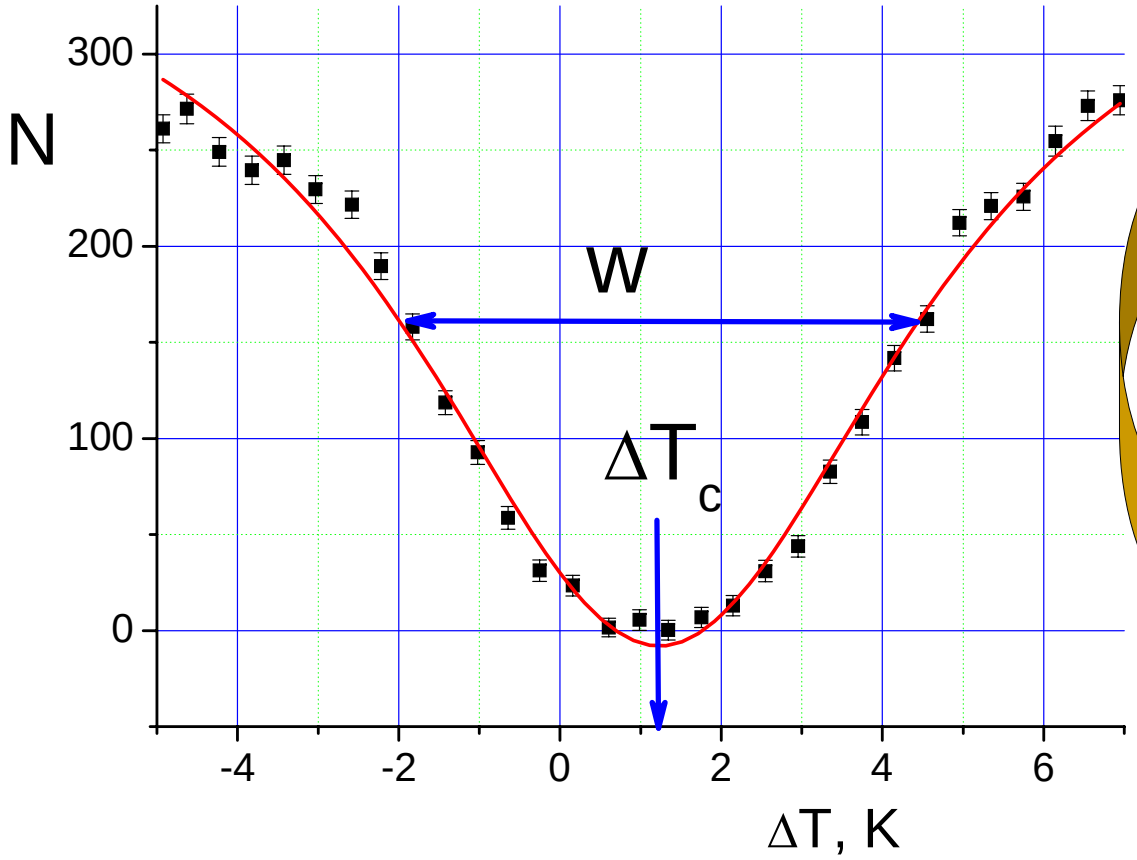
Example of two crystal line ("bad")



$W_T=(7.67 \pm 0.25)^0K$

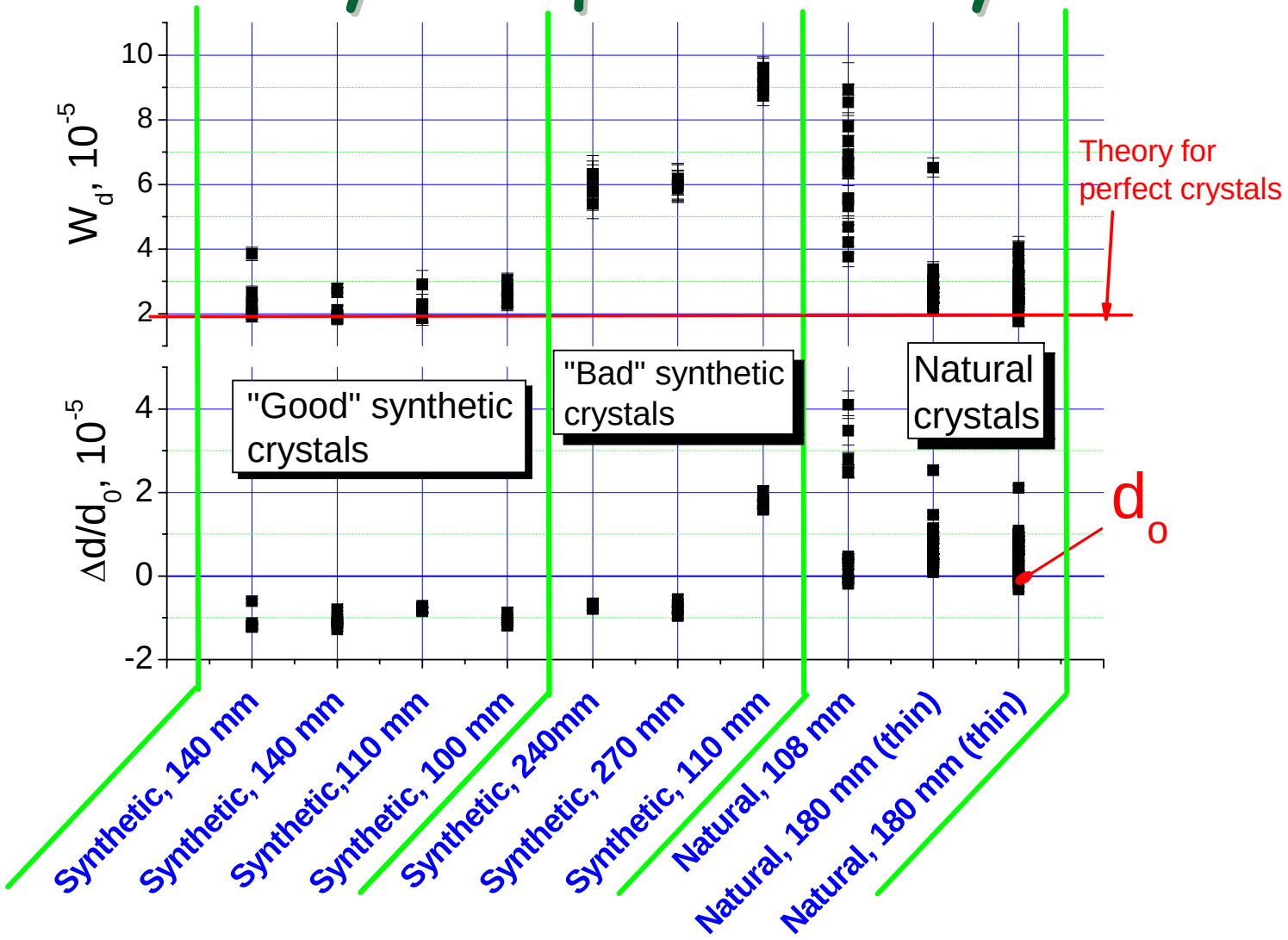
$\Delta T_c=(+1.23 \pm 0.02)^0K$

$W_d=(10.7 \pm 0.4)10^{-5}\approx$

$\approx 5 \cdot W_d(theory)$

$\Delta d/d=(173 \pm 3(stat))10^{-7}$

Summary of quartz crystals



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Summary of quartz crystals

	Description	$W_{\Delta d/d}$, 10^{-5}	$\Delta d/d$, 10^{-5}
1	Synthetic, 140x140x35mm^3	2.0 – 2.7	-(1.3 – 1.0)
2	Synthetic, 240x160x40mm^3	6	-(0.8 – 0.7)
3	Synthetic, 270x148x40mm^3	6	-(0.9 – 0.6)
4	Synthetic, 140x140x35mm^3	2.0 – 2.6	-(1.3 – 1.0)
5	Natural, 180x130x8mm^3	2.2 – 3.0	+(0.2 – 1.2)
6	Synthetic, 110x40x14mm^3 (“bad”)	8.8 – 9.5	+(1.6 – 1.8)
7	Synthetic,110x40x18mm^3 (“good”)	1.9 – 2.2	-(0.9 – 0.8)
8	Natural, 108x85x143mm^3	3.5 – 8.0	+(0.0 – 3.0)
9	Natural, 180x118x8mm^3 (analyzer)	1.9 – 3.2	-0.5 – +0.5
10	Synthetic, 100x100x30mm^3	2.4 – 2.7	-(1.2 – 1.0)

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Summary

- The backscattering method to test the crystal quality was developed
- Low requirement for the preliminary angular alignment (~0.5^0) due to large Bragg width for $\pi/2$ reflex
- The crystals can be measured without preliminary preparation (cutting off, polishing and …)
- The tested crystal thickness is limited only by the neutron absorption, so for quartz and silicon crystals we test up to 50 cm.
- The accuracy of measurements can be $\Delta d/d \sim 10^{-7}$ relatively to reference crystal