X-Ray Refraction for Hard X-Rays XFEL Applications

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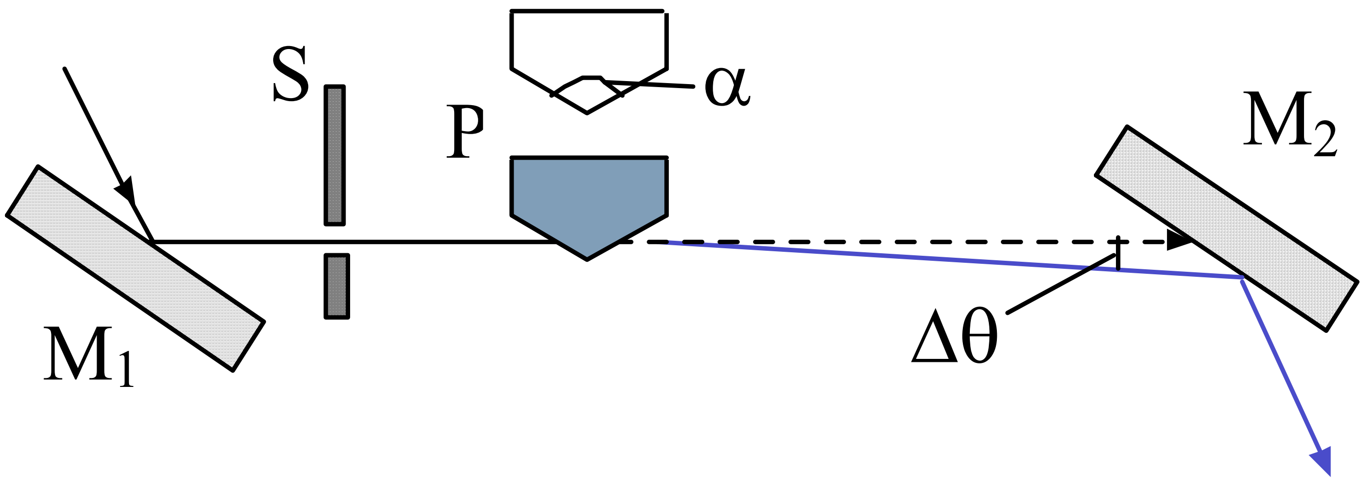
X-ray refractometry
Retrospective

B. Davis, C.M. Slack. “Measurement of the refraction of X-rays in a prism by means of the double crystal X-ray spectrometer”. Phys. Rev., v. 27, (1926) pp. 18-22.

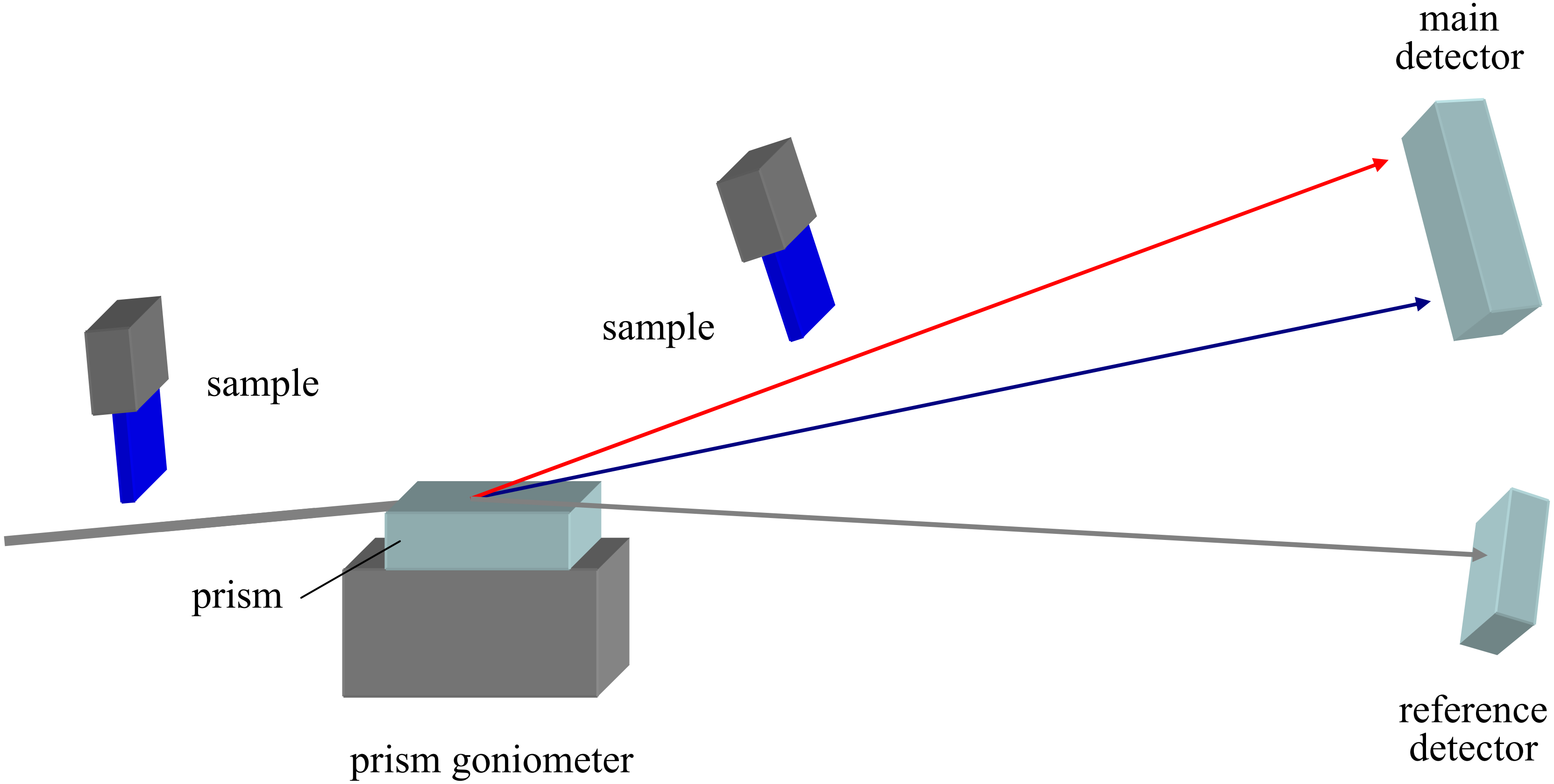


S – slit, P – prism, M_1, M_2 – crystal monochromators, Δθ –deviation angle, α – prism apex angle

α=160°-170°

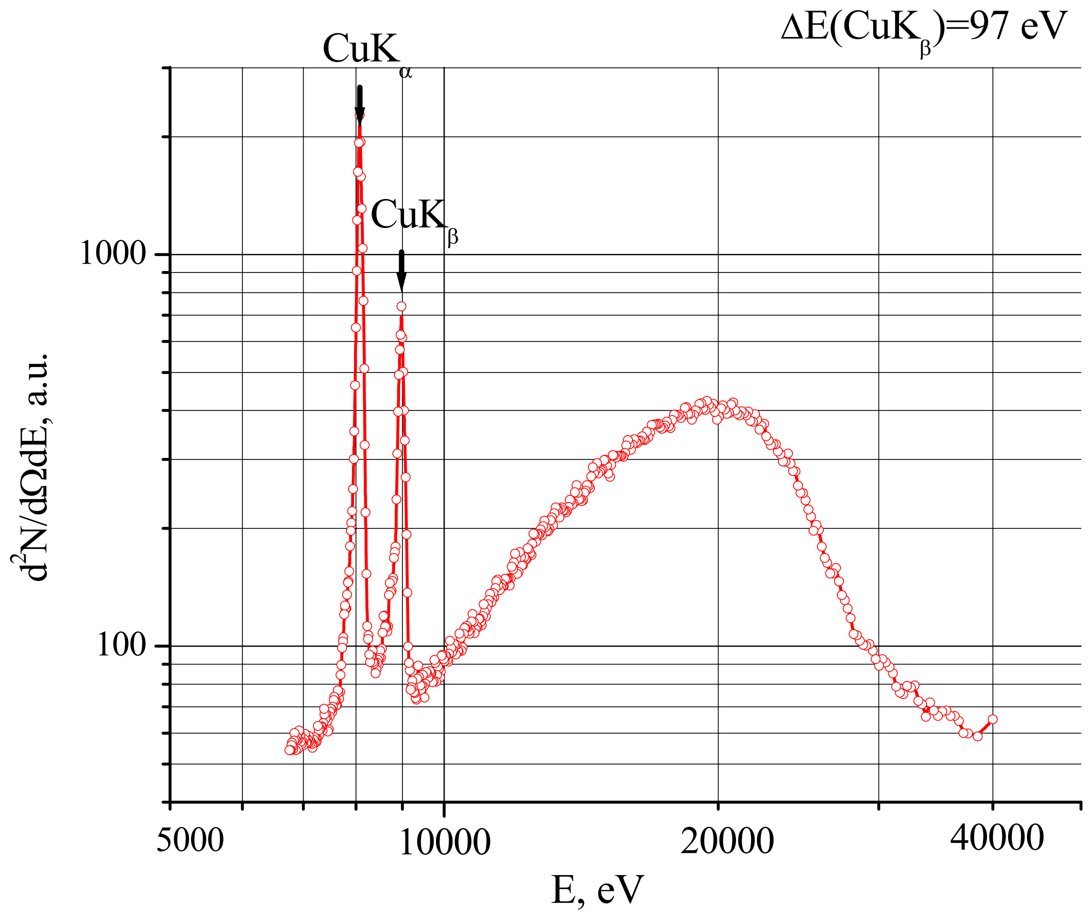
Δθ~10″

Prism spectrometer basic scheme



X-ray emission spectrum

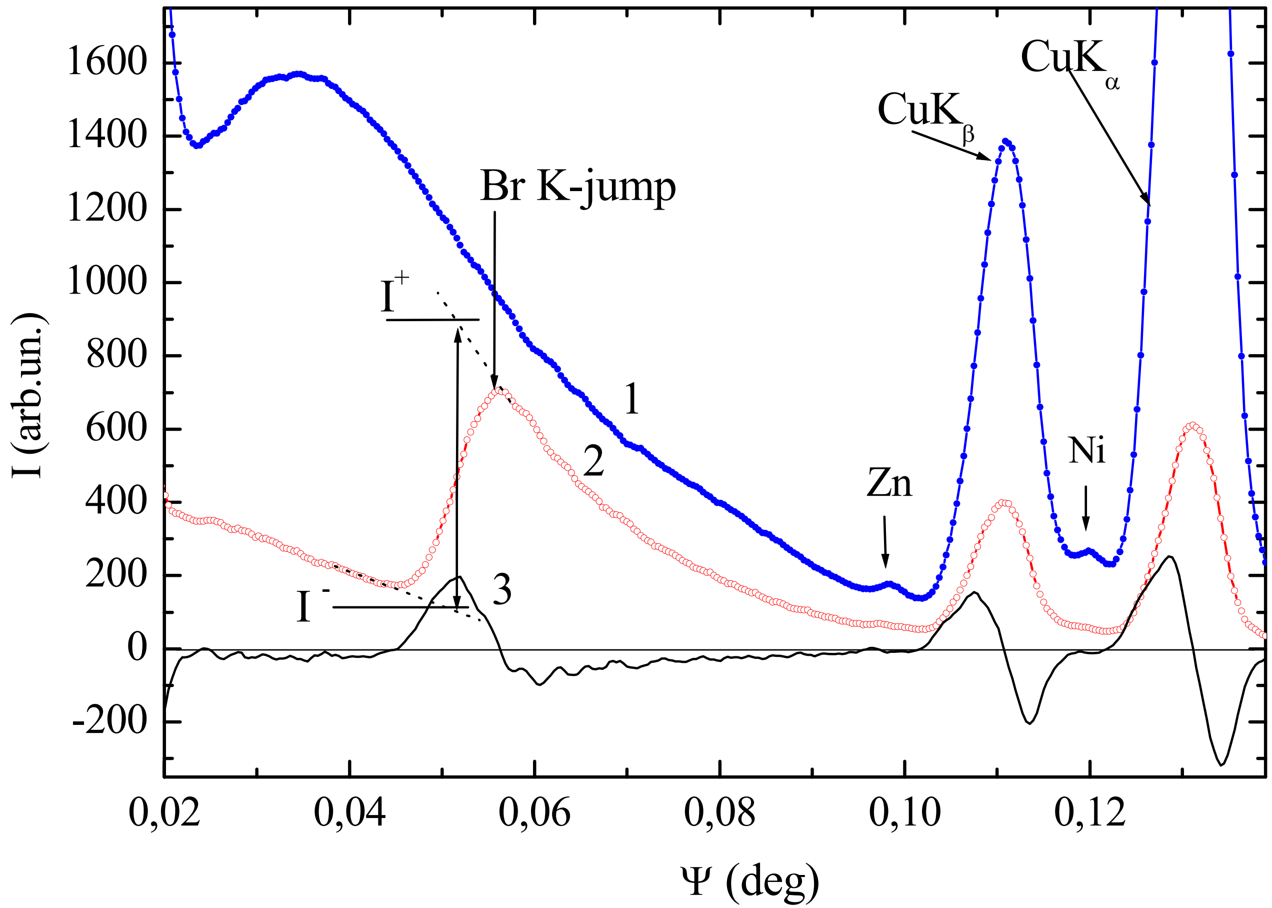
Cu-anode, U=40 kV, take-off angle 5,5°



X-ray prism spectrometry

X-ray emission (1) and absorption angle spectra (2)

(sample $C_{10}H_7Br$, 3 – normalized derivative of the curve 2)

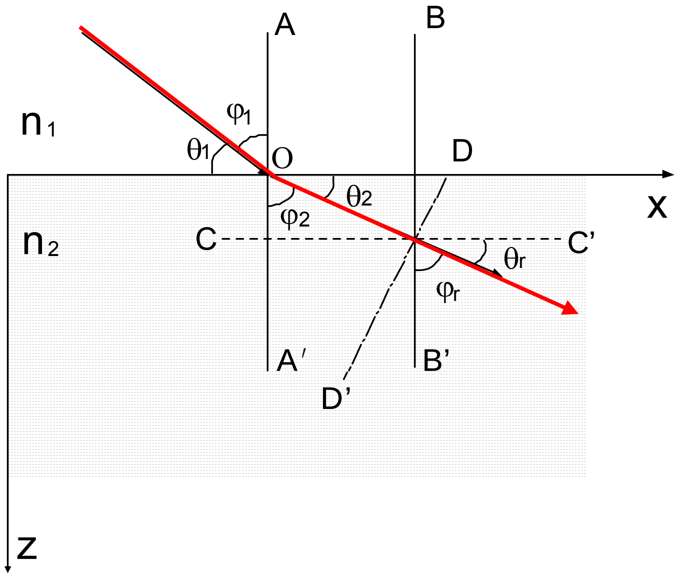


X-ray refraction and reflection at the flat boundary for media with complex index of refraction

Snell's law

$$\frac{n_1}{n_2} = \frac{\sin\varphi_2}{\sin\varphi_1}$$

$$n = 1 - \delta(E) - i\beta(E)$$



δ >> β

$$\Psi = \theta_1 - \theta_2 = \theta_1 - \sqrt{\theta_1^2 \pm 2\delta(E)}$$

angle of deviation

$\theta_1 \rightarrow \theta_c$ $\theta_1 \rightarrow 0$

singularity angles

$$r_{1,2} = \gamma \frac{k_1 - k_2}{k_1 + k_2}$$

reflectivity amplitude

k – wave vector, γ – surface roughness factor

Materials for X-ray refraction application at XFEL

Short list

Be, B, B_4C
Carbon modifications
- graphite
- amorphous C
- diamond

Very hard X-rays E>100 keV

substance	ρ, g/cm^3	δ x10^8	θ_c, mrad (″)	μρ, cm^{-1}
CoP	6,24	0,98	0,442 (91)	1,7
FeP	6,07	0,96	0,44 (90)	1,6
MnB_2	6,9	1,05	0,46 (95)	1,6
VN	6,13	0,95	0,44 (90)	1,4

Data for UK_β – spectral line (E=111 keV)

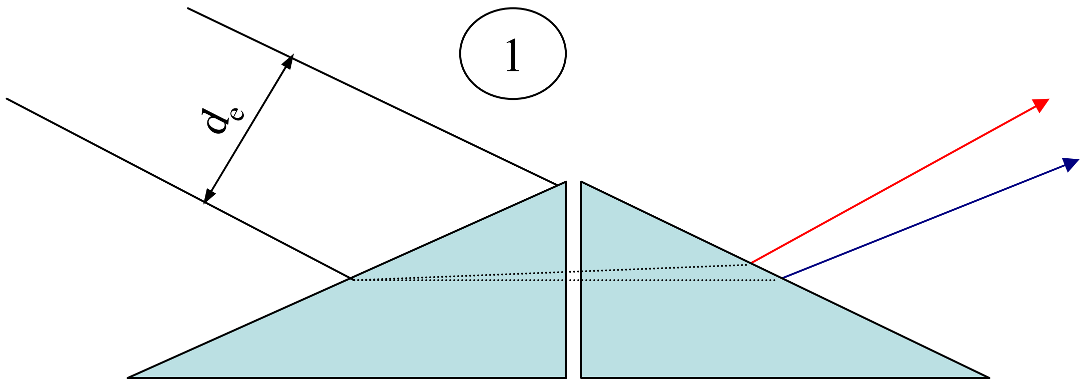
Monocrystal diamond properties

1. **Thermal conductivity, W/cm K**
   >100 (80 K)
   >20 (300 K)
2. **Atomic number, Z — 6**
3. **Density, g/cm^3 — 3,515**
4. **Linear expansion coefficient, K^{-1} — 9,1 10^{-7}**

Application energy range 5÷100 keV

Basic dispersion geometries

General features

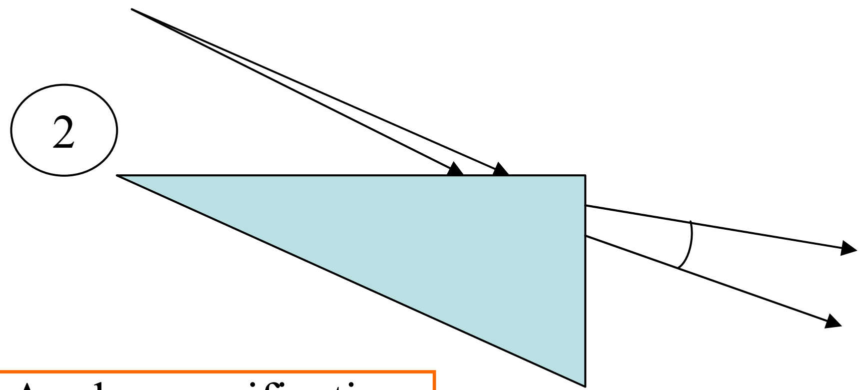


Prism refracting surface requirements

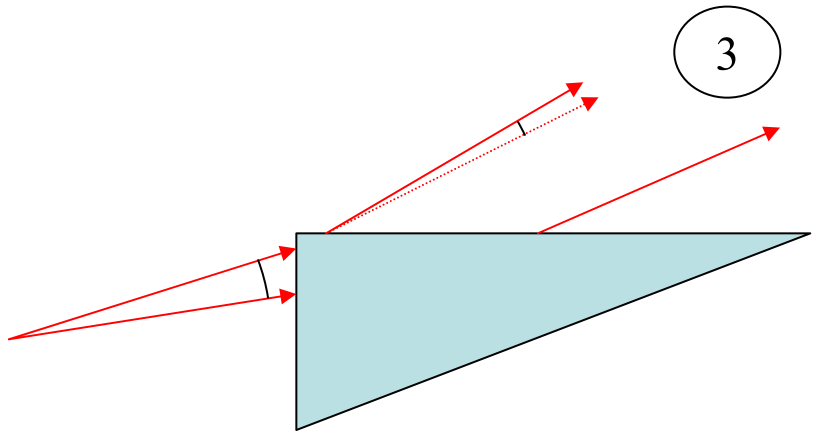
$\sigma < 1$ nm

$\Delta h < 10$ nm (L=1 cm)

Double deviation angle
Low-energy cut-off
Decreased aperture

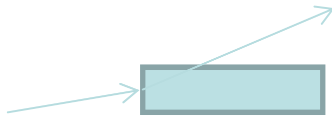


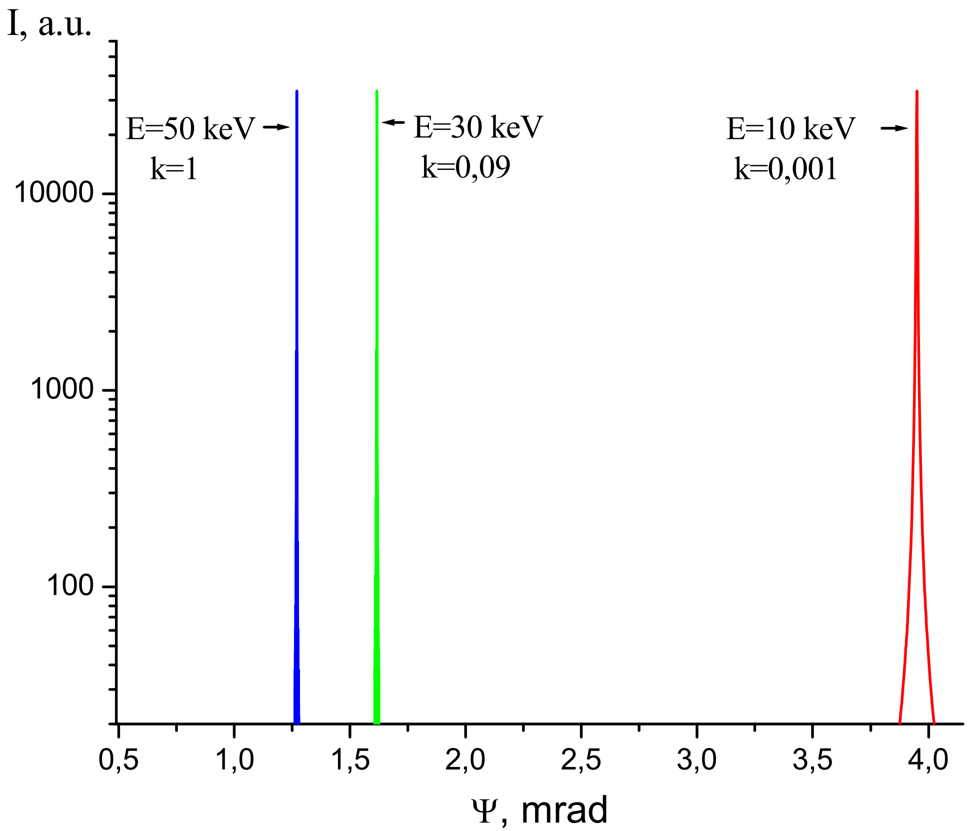
Angle magnification
Low-energy cut-off



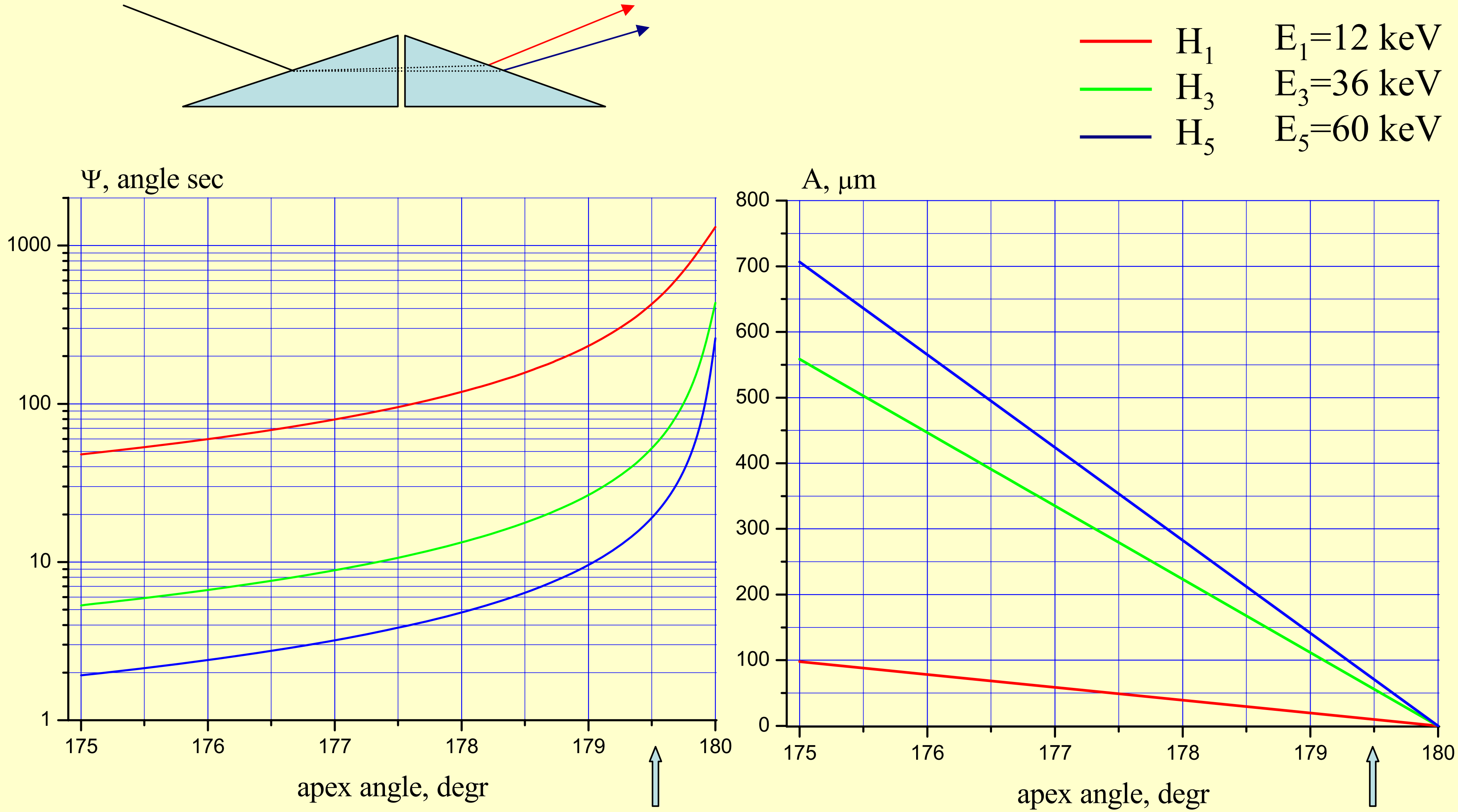
Angle demagnification
Unlimited energy range

XFEL harmonics determination by a diamond prism

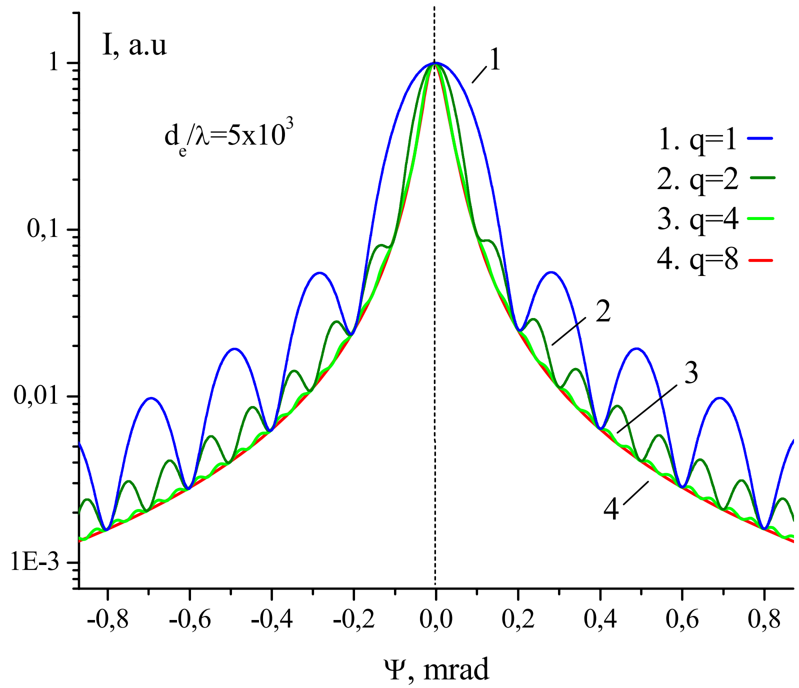


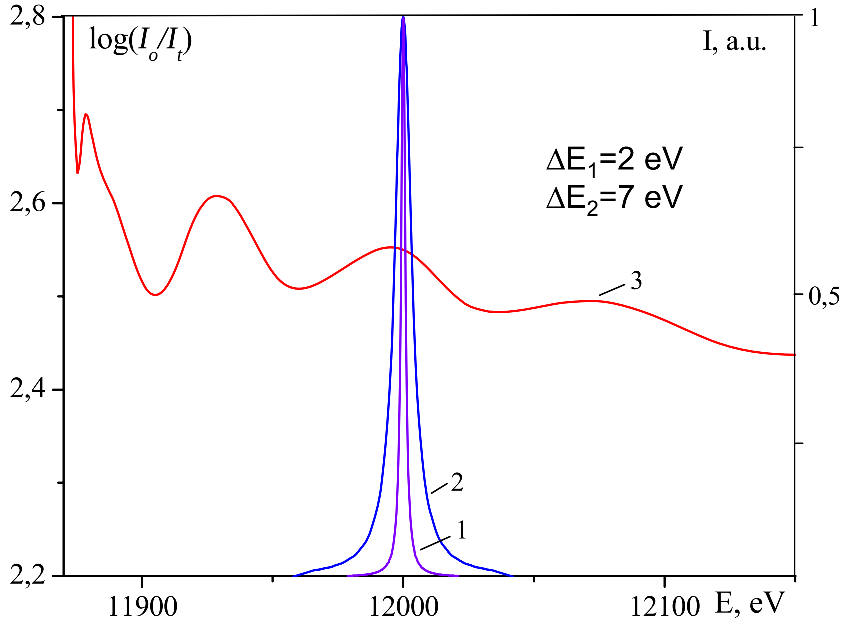


XFEL harmonics selection by a diamond prism



Influence of refracting face size
Interference pattern due to finite face size

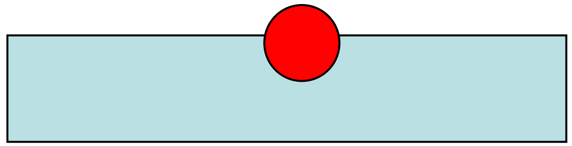




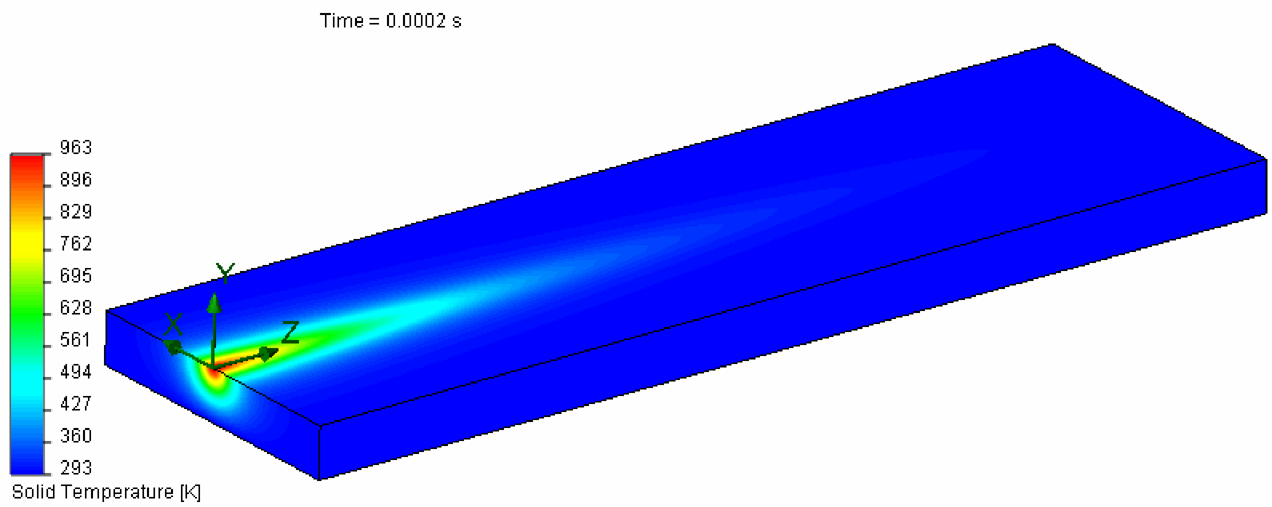
1- Be prism
2 – diamond prism
3 – As_2S_3 (XAFS database)

Heat transfer in the diamond prism

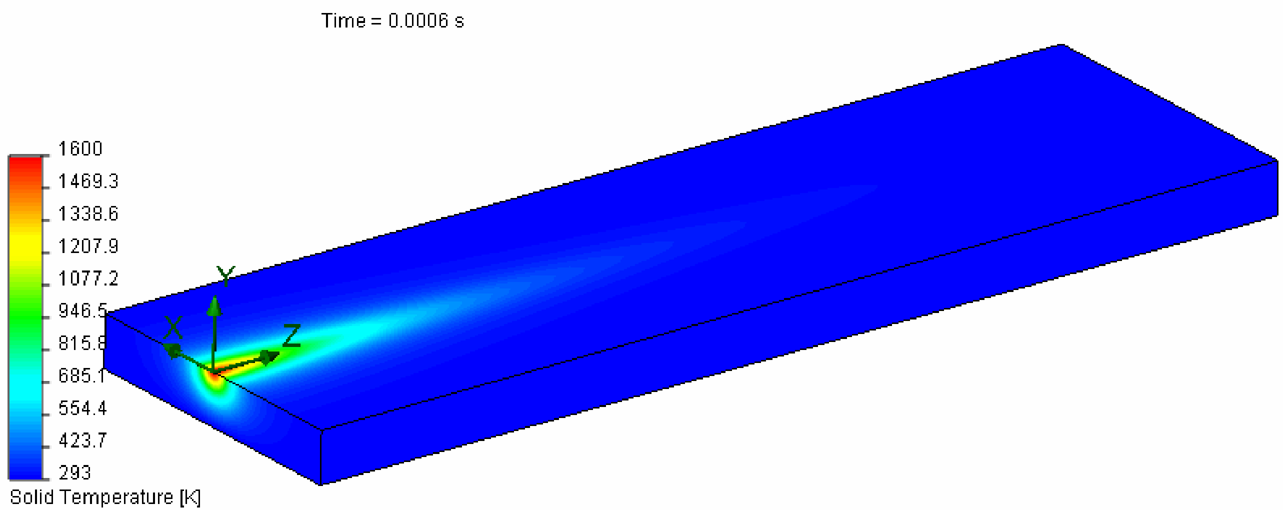
Radiation conditions
E=12 keV, N=10^{12} photon per pulse
Beam diameter 400 μm
Prism dimensions, mm: W x H x L
3 x 0,5 x 12   F=5 MHz

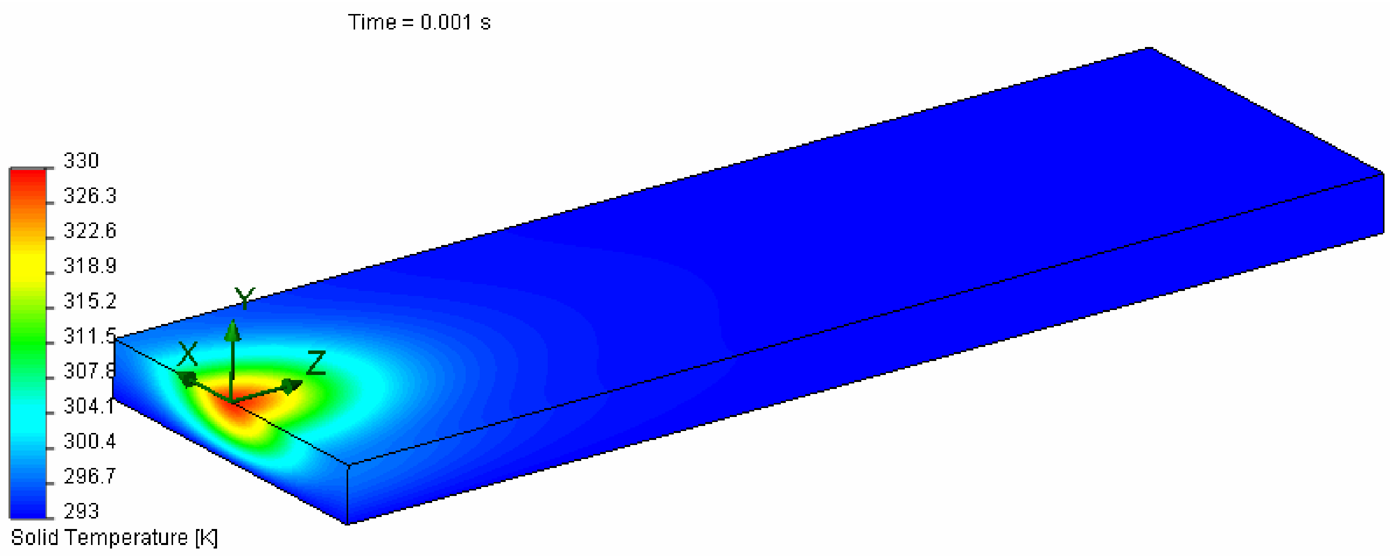


Room temperature, 293 K (20° C)

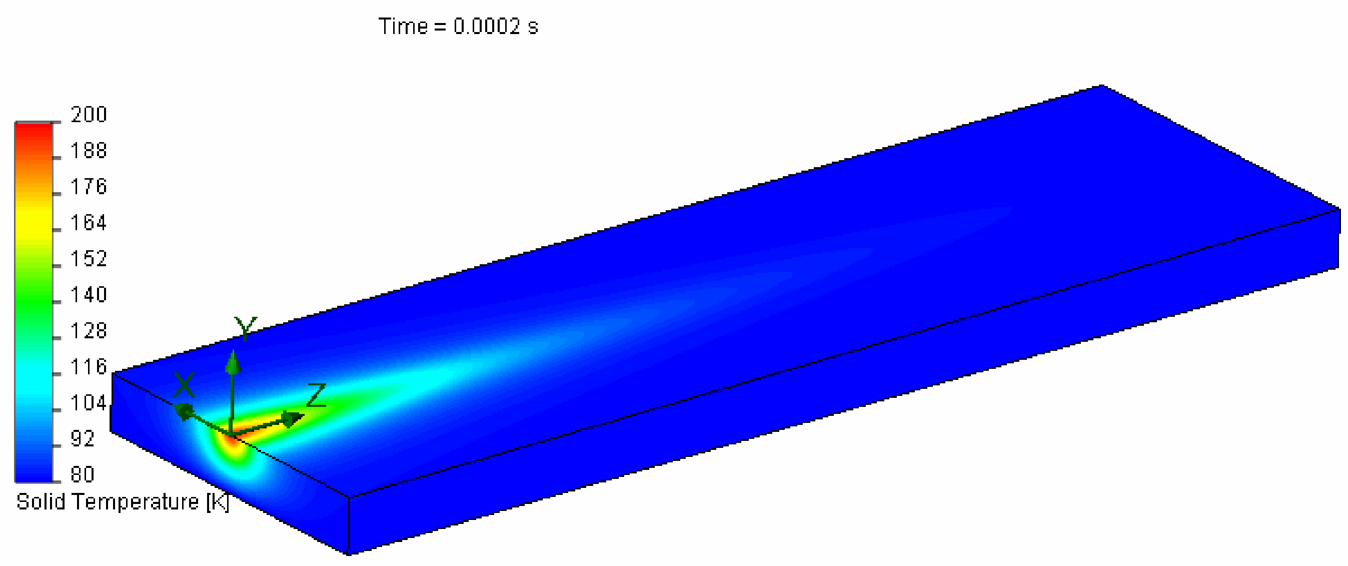


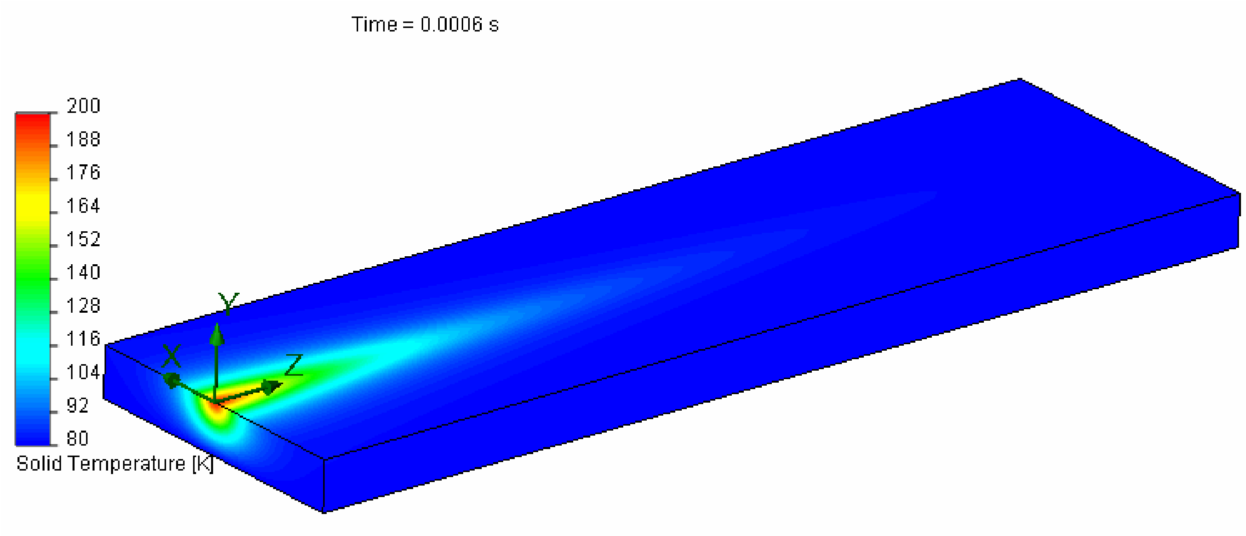
Heat transfer in the diamond prism at room temperature





Heat transfer in the diamond prism at liquid nitrogen temperature (80 K)





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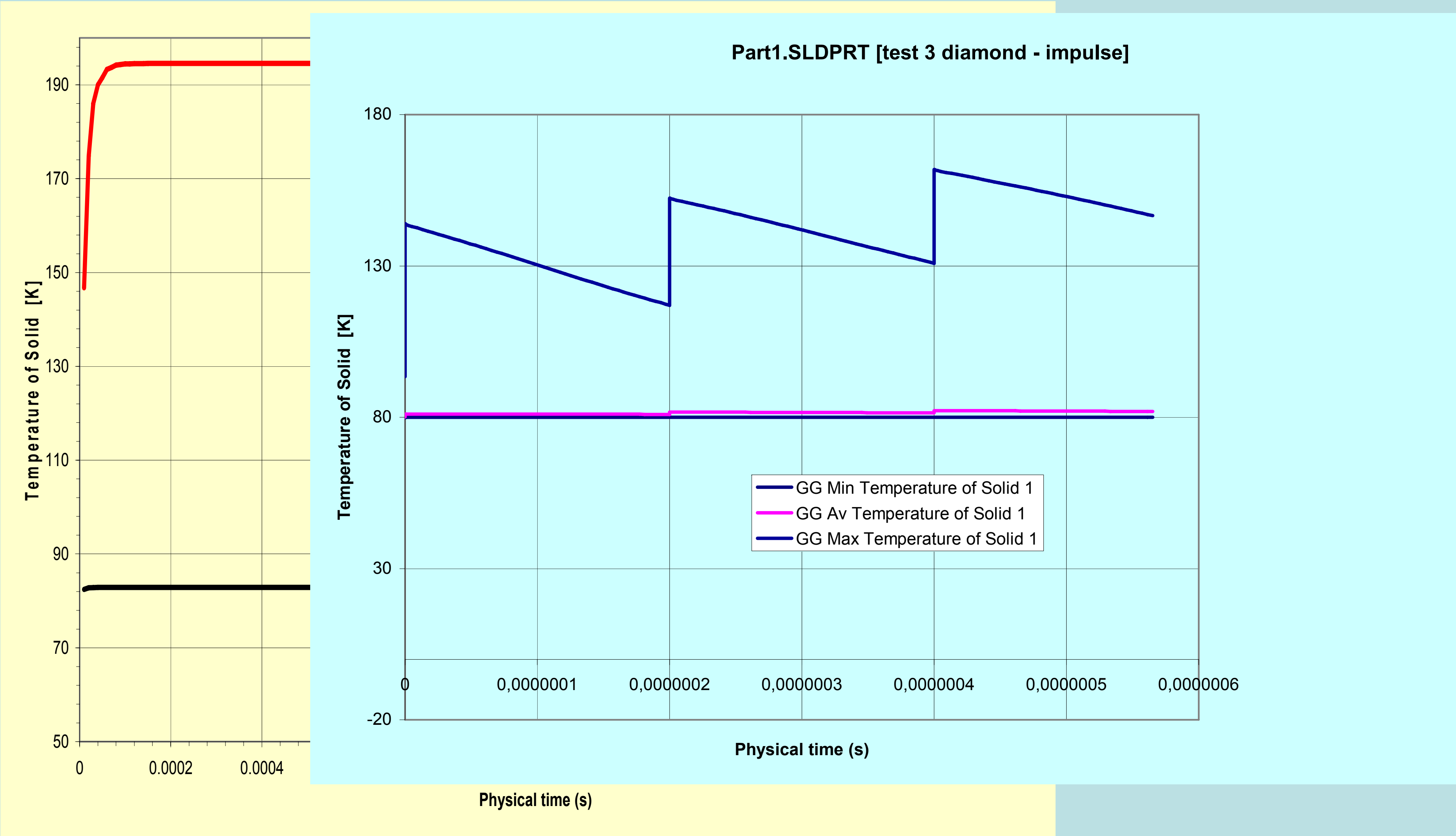
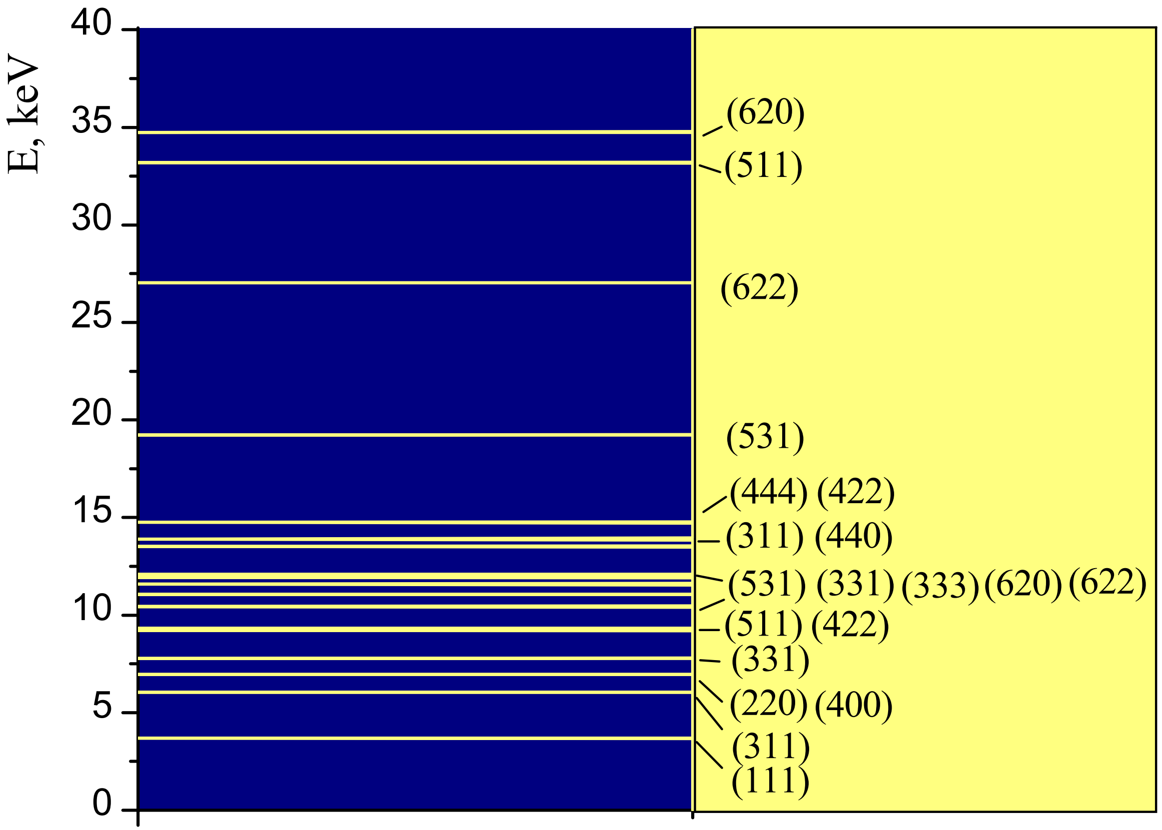
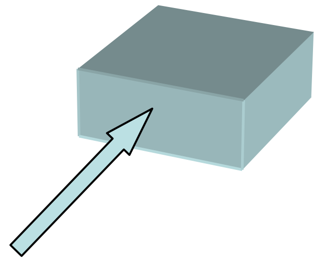


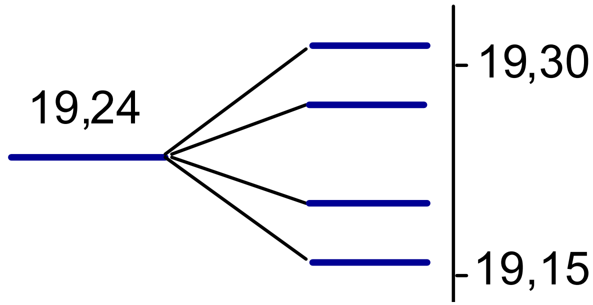
Diffraction effects

X-ray transmission spectra structure for monocrystal diamond in crystallographic direction [100]

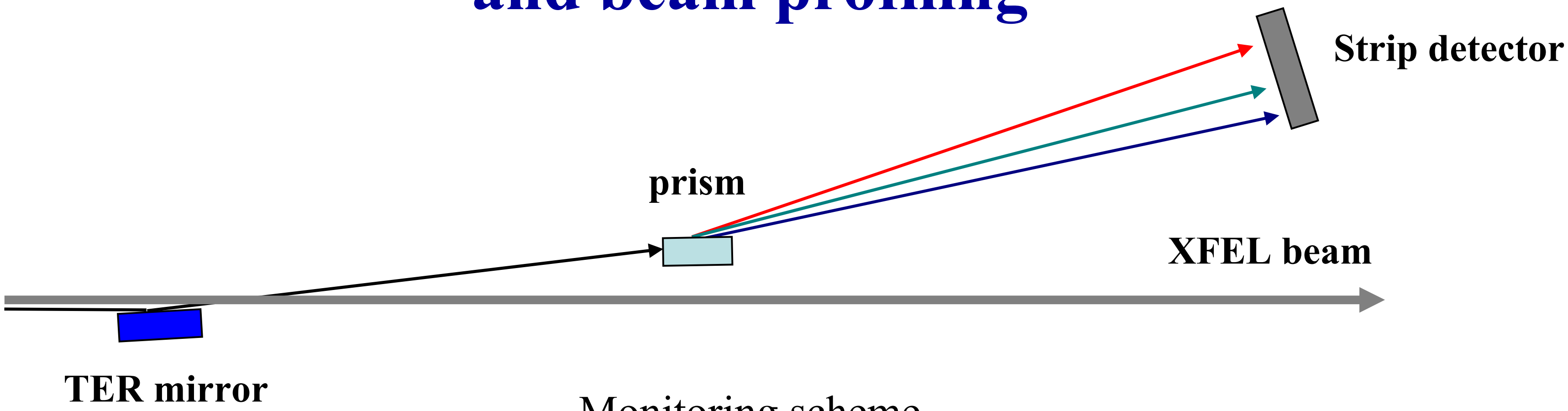




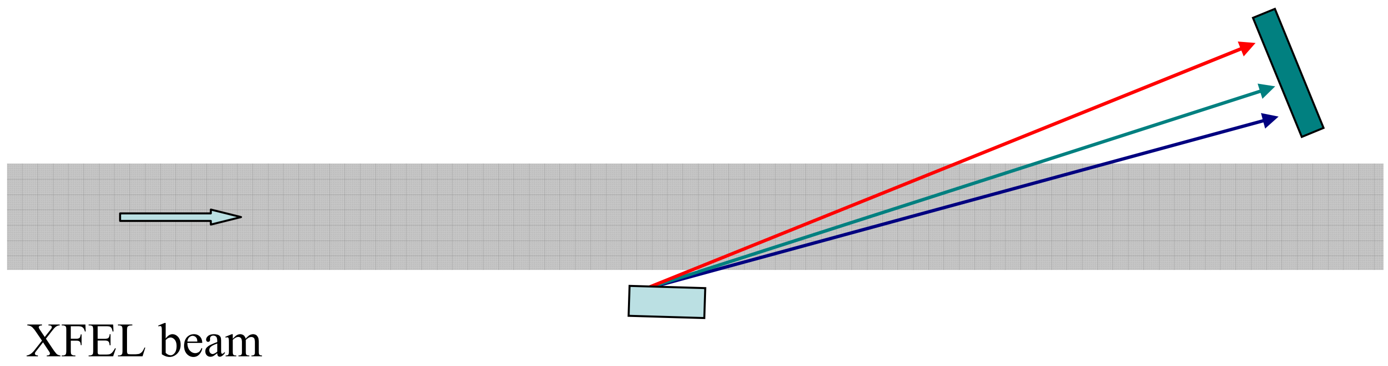
(531) reflex splitting
deviation Δϑ=6'



Beam harmonics monitoring and beam profiling

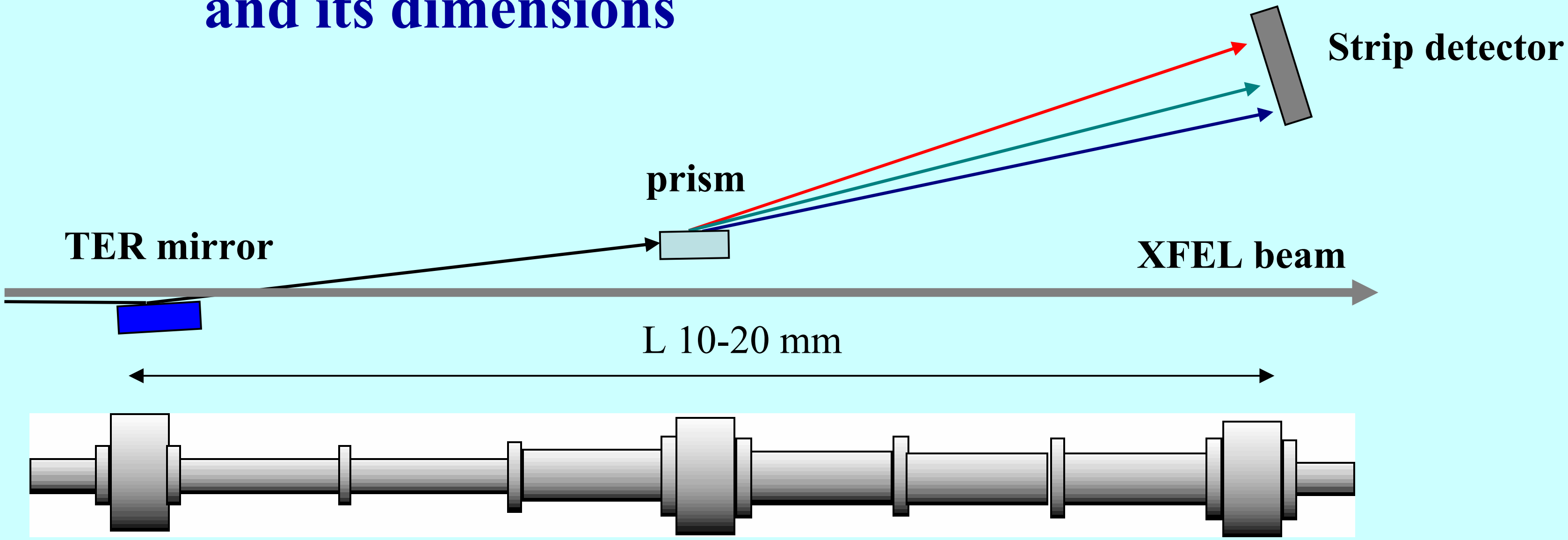


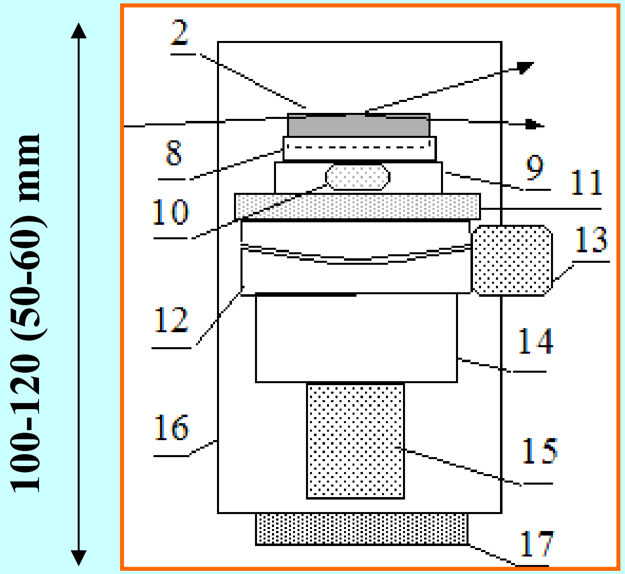
Monitoring scheme



Profiling scheme

Prism spectrometer general view and its dimensions



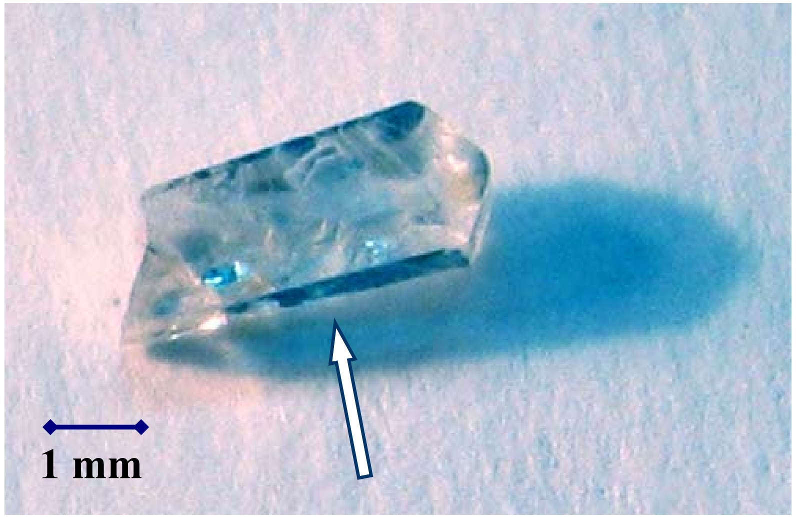


Prism adjustment system

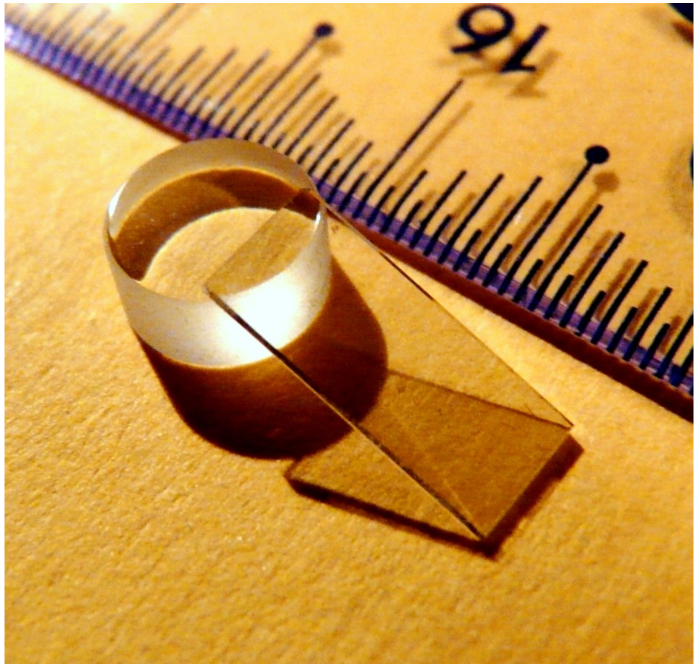
2-prism, 8-prism support, 9,10-cooler, isolator, 12-goniometer, 13,15 step motors,16-support,14,17- translation stages

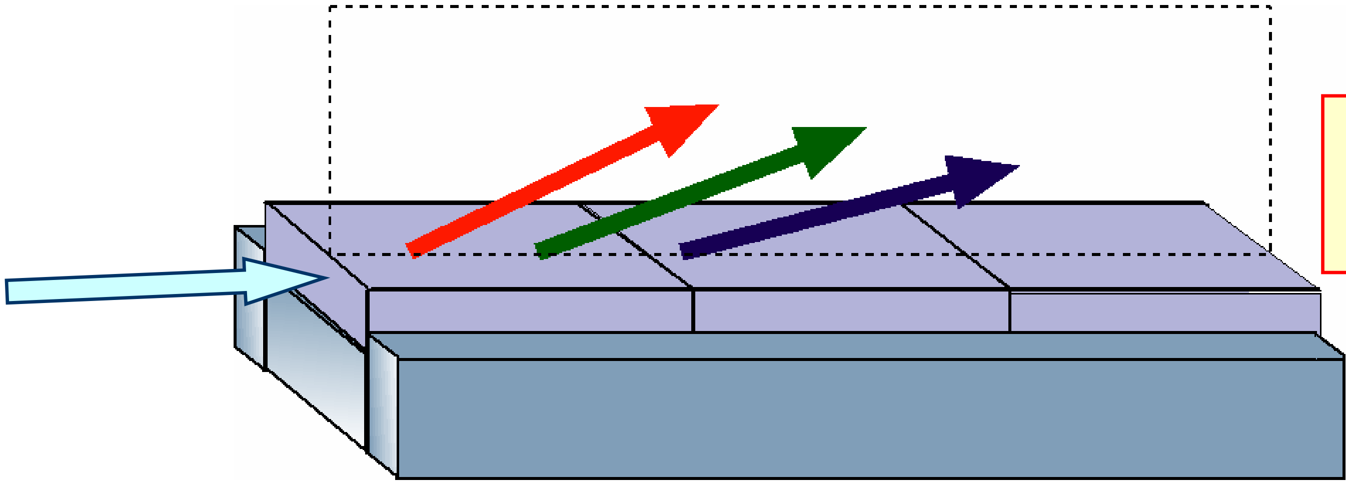
Prism technology achievements

2,5 mm refraction face



Large 10 mm refraction face





Mosaic structure prism with very large refraction and reflection face

Conclusions

Possible applications of prism refraction optics

- ♦ Investigation of absorption spectra including single-shot measurements
- ♦ Monitoring of XFEL harmonics and spontaneous radiation spectrum
- ♦ Space splitting of XFEL harmonics
- ♦ Selection of predetermined spectral bands

Thank you for attention