Influence of crystals mosaicity on observed characteristics of X-ray emission along the propagation velocity of fast electrons in thick tungsten crystals

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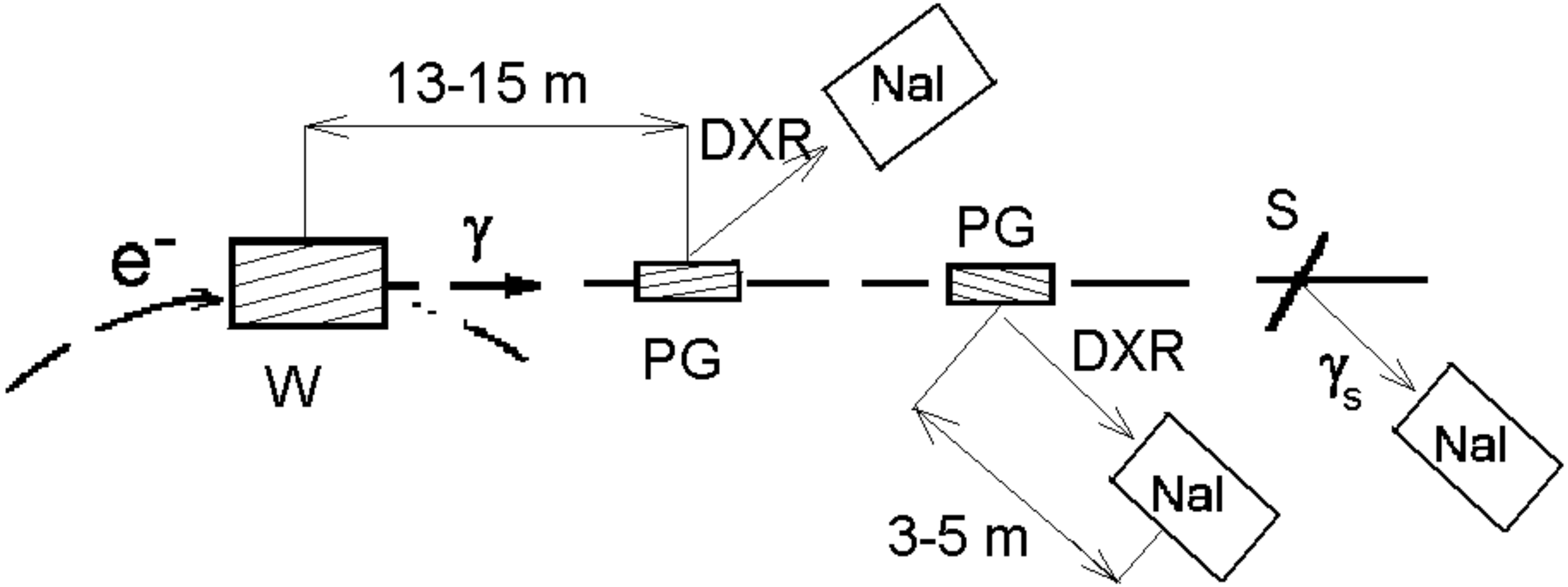
Mosaic crystal classification in accordance with R. James,

“The optical principles of the diffraction of X-rays”, London, 1958.

Class a – size of blocks > primary extinction length.
Class b – size of blocks < primary extinction length
These crystals have high X-ray reflectivity and widely use in experimental physics (monochromators, X-ray telescope an so on)
Class α - blocks are nearly parallel each other.
Secondary extinction effect is vary large.
Class β - blocks have very wide distribution.
Secondary extinction effect is rather small.
aα - perfect crystal
bβ - ideal mosaic crystal (typical example -HOPG with large characteristic mosaicity angle)
Extinction length depends on photon energy and the diffraction order, therefore the same crystal may belong to class a or b in the dependence of experimental conditions.

Experimental setup and condition

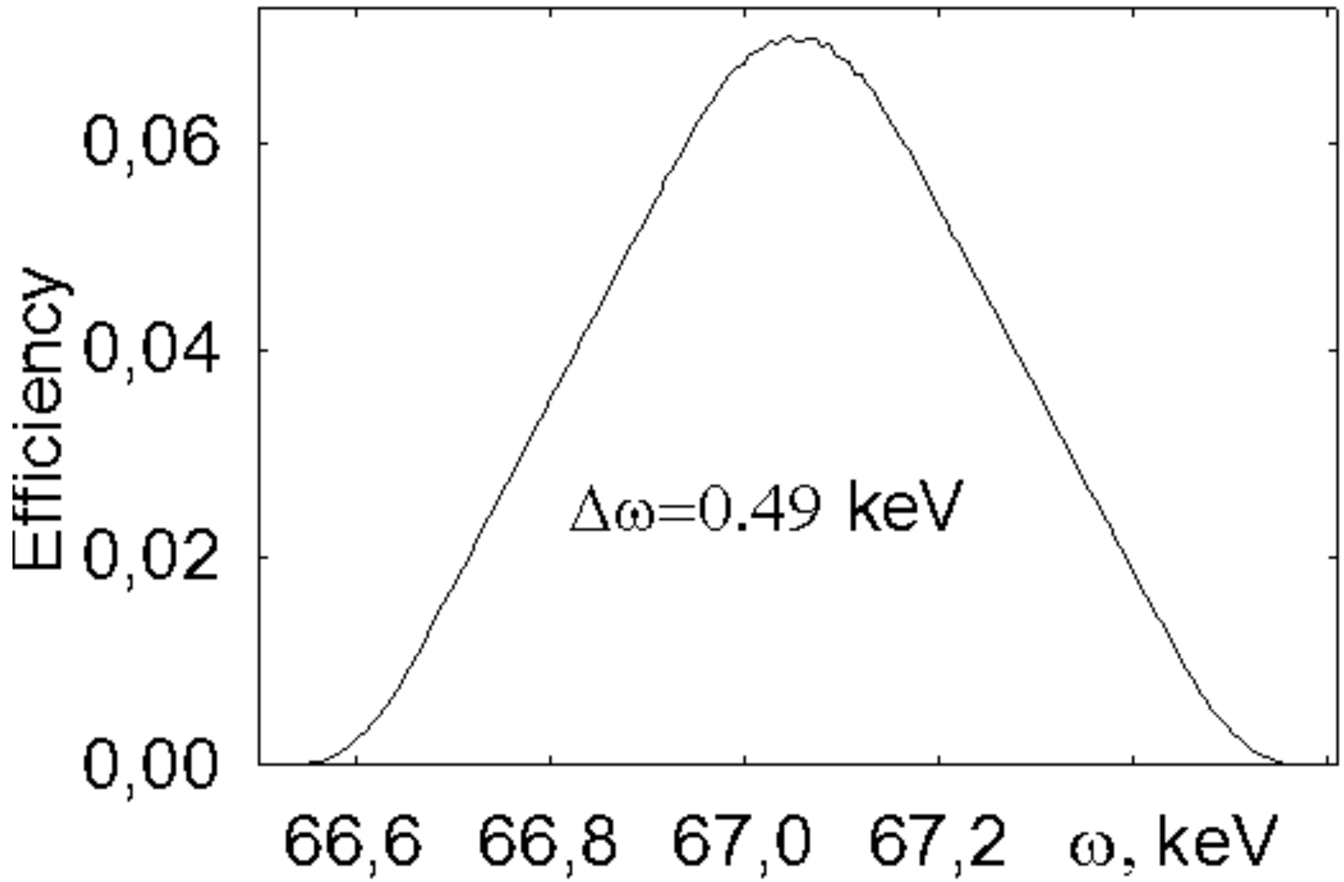
E=500 MeV, W <111>, T=0.41 mm, σ~ 0.2 mrad,



Distance between both crystals and NaI detectors is about 18 m, therefore we have obtained satisfactory difractometers characteristics: $\Delta\omega/\omega$ ~0.6%−1%, ε~0.5%−7%

Difractometer efficiency

PG crystal 2.5x22.5x6.5 mm, σ~4 mrad, Θ=3.16º, ω~ 67 keV



ω=40 keV – $\Delta\omega$ ~ 0.276 keV,

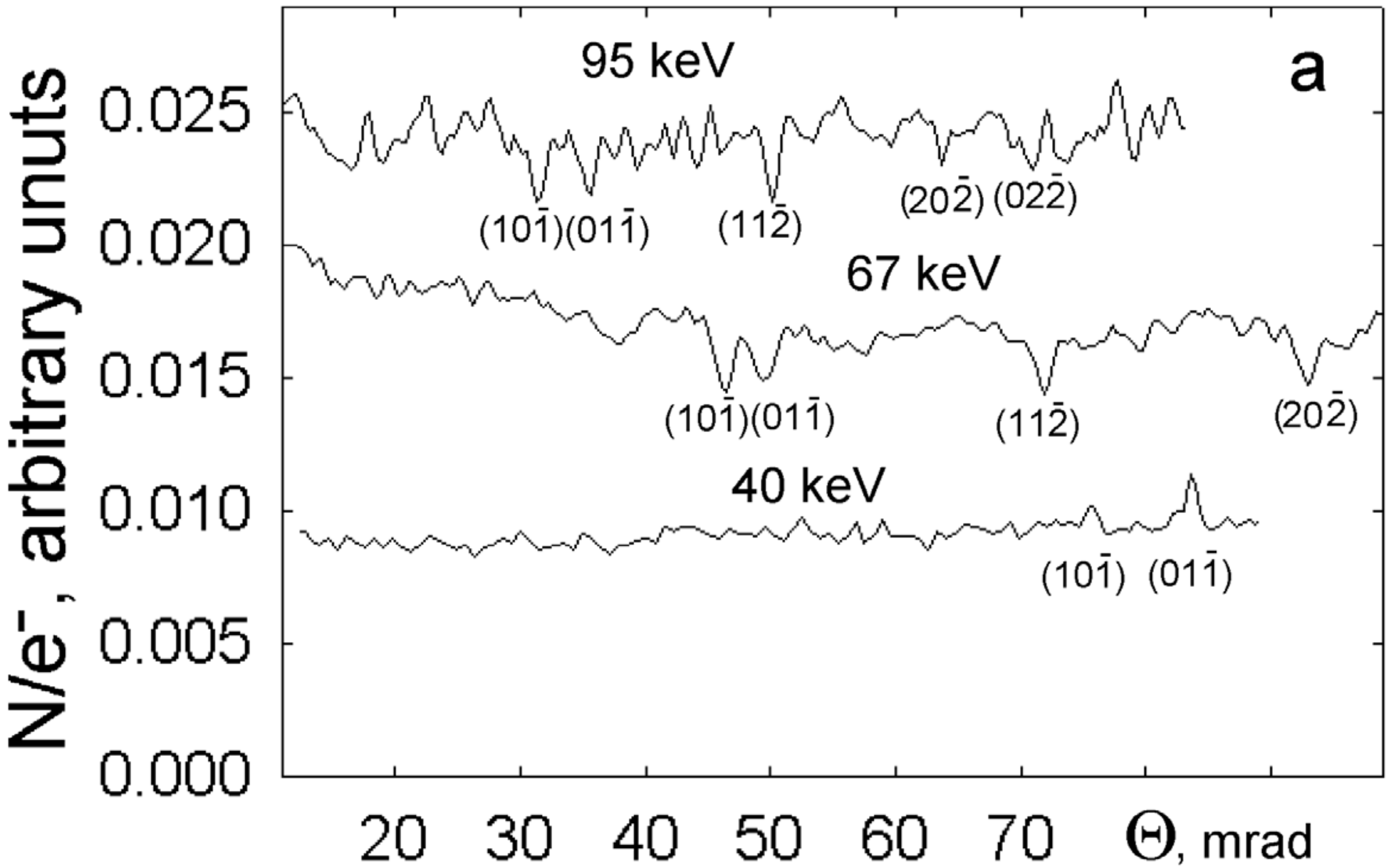
ω=28.3 keV, $\Delta\omega$~0.172 keV

Measured and calculated photon yield for disoriented tungsten crystal

ω, keV	Y_{exp}, photon/electron	Y_{calc}, photon/electron	Y_{exp}/Y_{calc}
28.3	$(1.16 \pm 0.05) \cdot 10^{-9}$	$1.27 \cdot 10^{-9}$	0.96
40	$(2.0 \pm 0.1) \cdot 10^{-9}$	$2.13 \cdot 10^{-9}$	0.95
67	$(14.78 \pm 0.7) \cdot 10^{-9}$	$15.5 \cdot 10^{-9}$	0.95
80	$(0.40 \pm 0.02) \cdot 10^{-9}$	$0.36 \cdot 10^{-9}$	1.1
96	$(5.1 \pm 0.3) \cdot 10^{-9}$	$5.15 \cdot 10^{-9}$	0.99
120	$(3.6 \pm 0.4) \cdot 10^{-10}$	$3.47 \cdot 10^{-10}$	1.04

Bremsstrahlung contribution:
28.3 keV~20%; 40 keV~70%, 67 keV~99.5%

Diffraction measurements

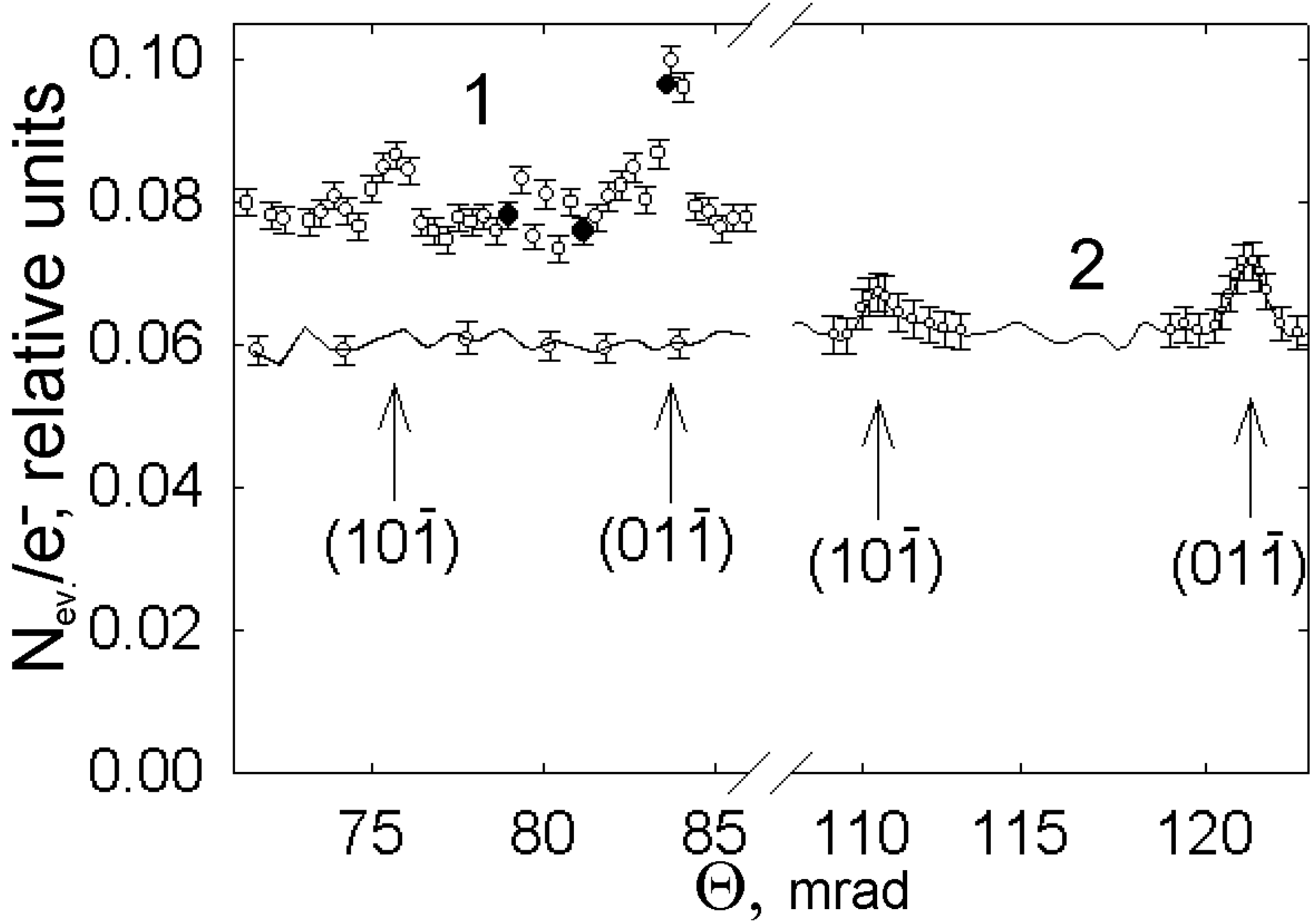


Depth of the hollows ~10-15%, full width ~2-2.5 mrad

Wee have seen influence of weak planes as (112) and (220) too.

For similar strong planes the left hollow is deeper than right one.

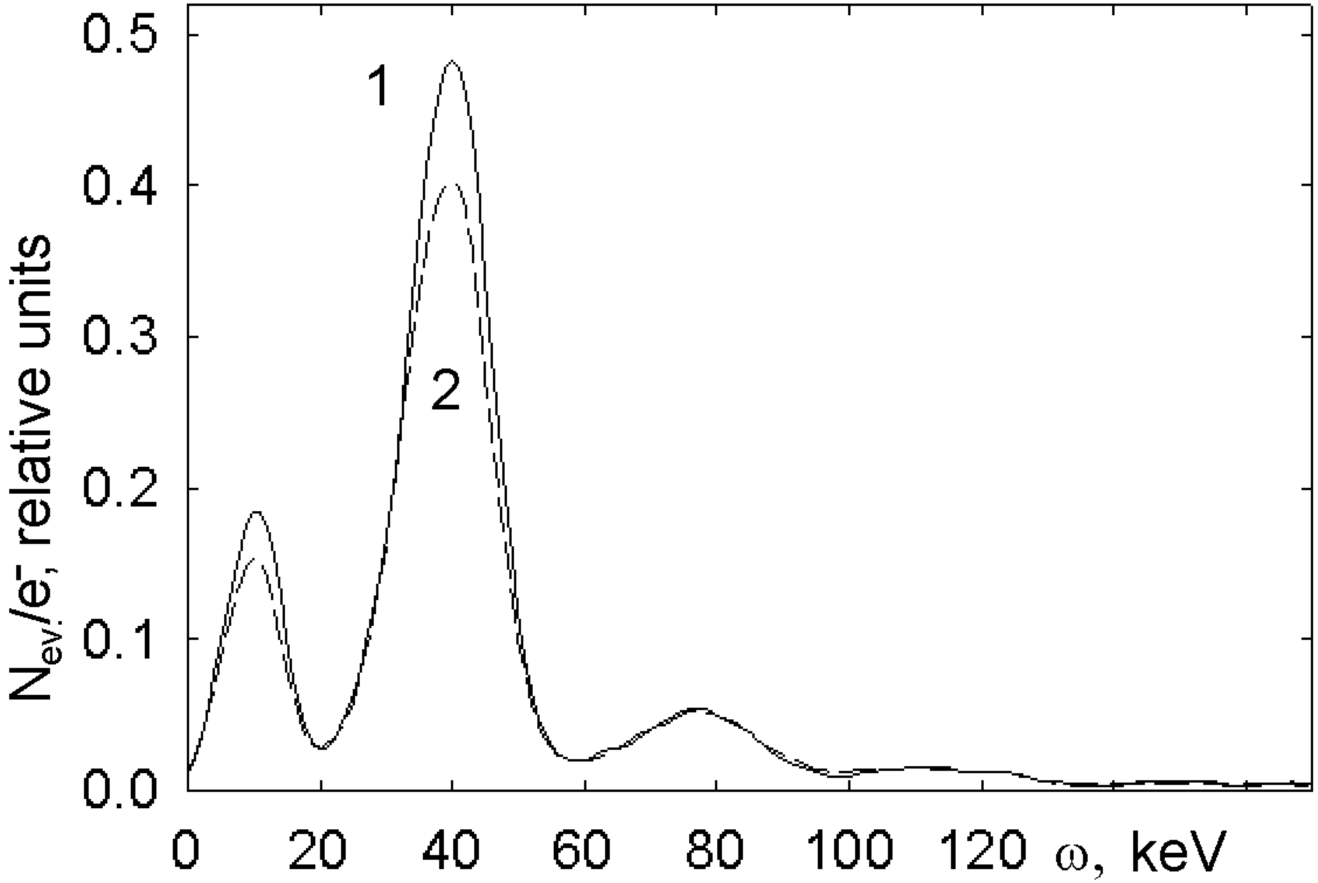
FPXR measurements



Left peaks are greater than right one.

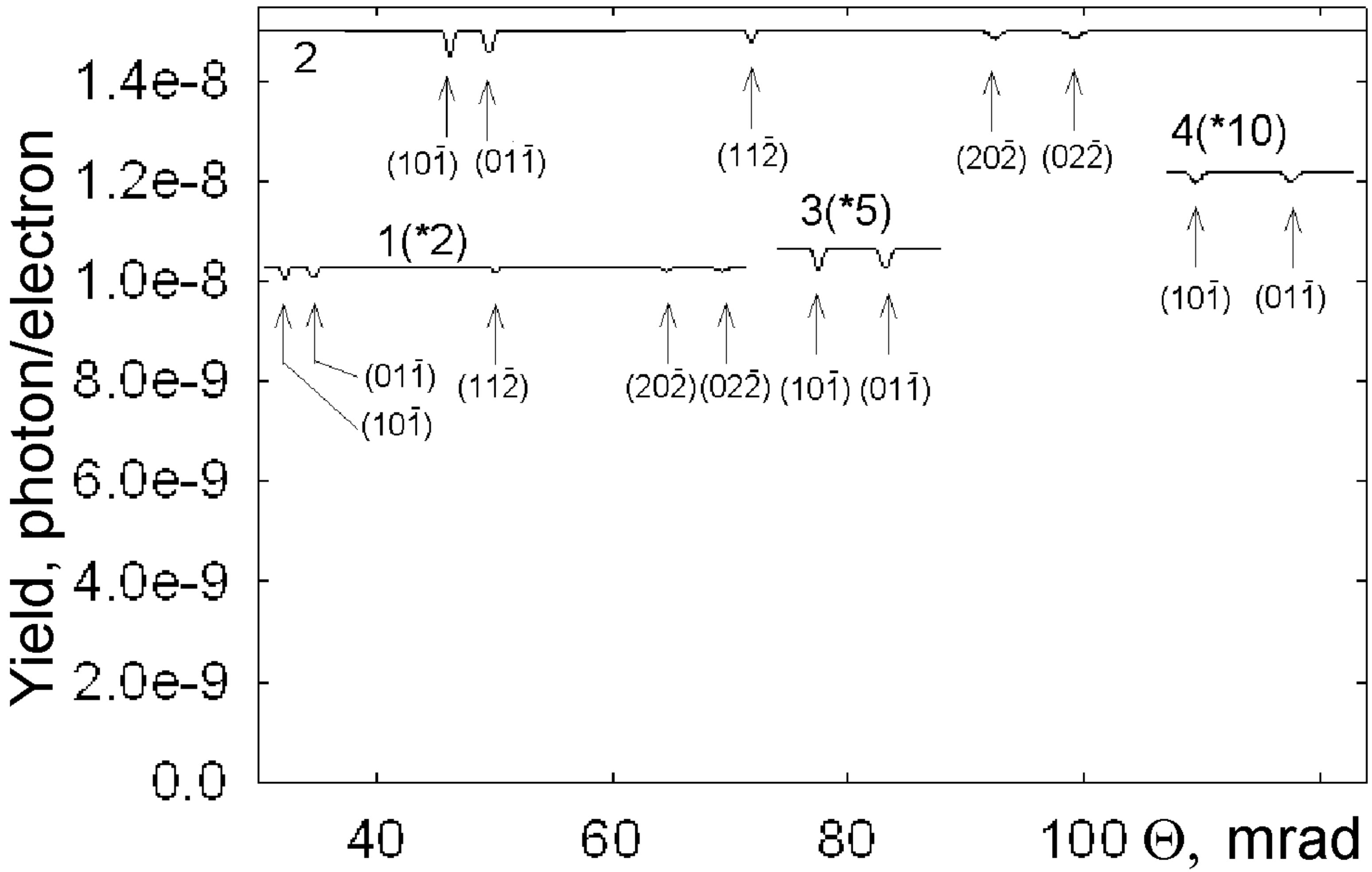
FPXR yield ~30% from BS+TR one for 40 keV and ~ 15% for 28 keV

Spectra measurements



Θ, mrad	Y_1, ev./e$^-$	Y_2, ev./e$^-$	Y_3, ev./e$^-$	Y_4, ev./e$^-$
83.7	$(1.44\pm0.01)\cdot10^{-9}$	$(1.71\pm0.02)\cdot10^{-10}$	$(4.7\pm0.1)\cdot10^{-11}$	$(2.7\pm0.4)\cdot10^{-11}$
81.3	$(1.26\pm0.01)\cdot10^{-9}$	$(1.82\pm0.02)\cdot10^{-10}$	$(4.8\pm0.1)\cdot10^{-11}$	$(2.7\pm0.2)\cdot10^{-11}$
79.3	$(1.25\pm0.01)\cdot10^{-9}$	$(1.82\pm0.02)\cdot10^{-10}$	$(4.6\pm0.1)\cdot10^{-11}$	$(2.6\pm0.2)\cdot10^{-11}$

Calculation of diffracted photon yield for a perfect tungsten crystal

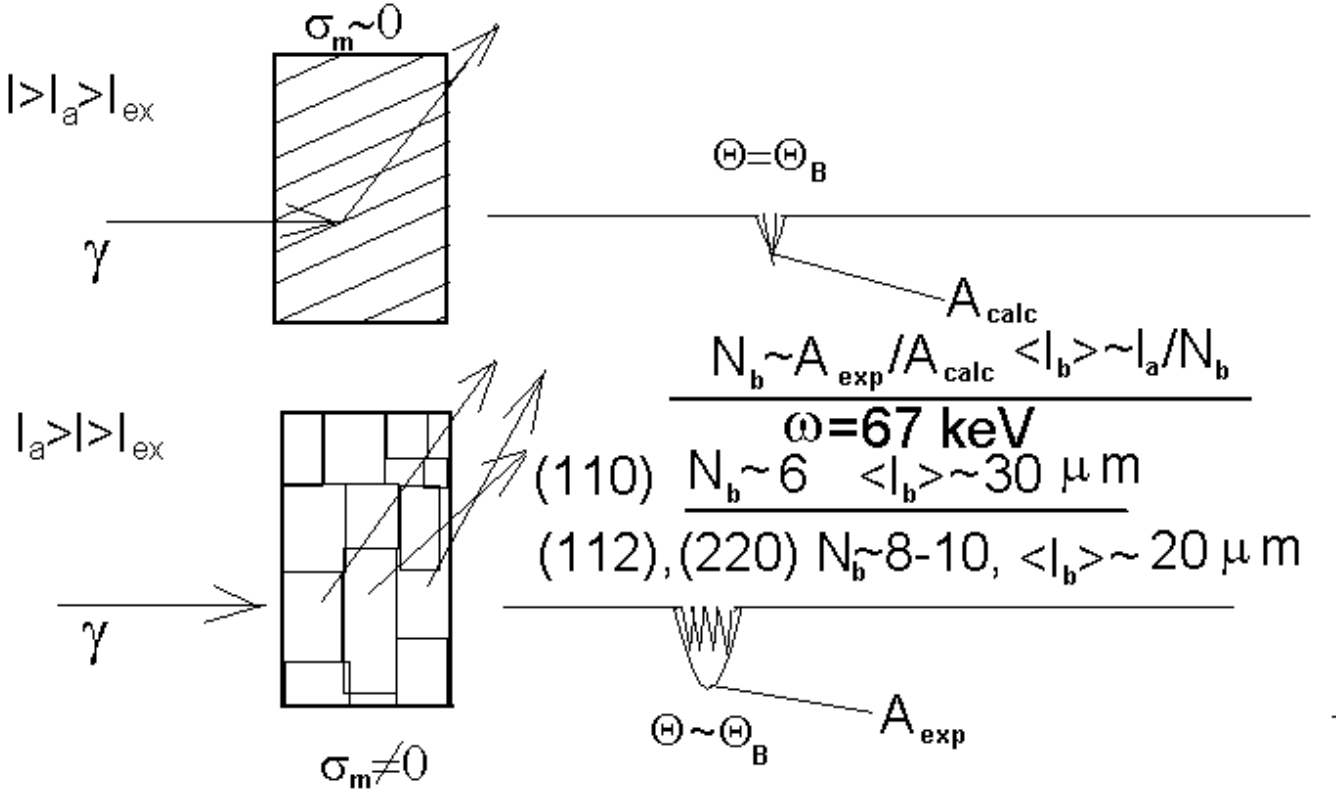


1 - ω= 96 keV, 2- ω=67 keV, 3- ω=40 keV, 4-ω=28 keV

Full width ~ 1- 1.5 mrad. Depth of the hollows:

ω=96 keV~2% , ω=67 keV~3%, ω=40 keV~4.5%. ω=28 keV~1.5%.

Determination of the average blocks size and estimation of FPXR yield for a perfect W crystal



ω=40 keV l_a~48 μm A_{calc}~4.5% A^{est}_{exp}~12% Y^{tot}_{FPXR}~1.5 Y^{exp}_{FPXR}

Here we have two mechanisms: FPXR with a narrow peak and BS diffraction suppression with a gap. We may estimate the BS suppression contribution using a blocks numbers. For Mainz experiment this correction is about 10% or less because of smaller bremsstrahlung contribution (~30% instead of ~70% at Tomsk)

Where size of the blocks may be important?

1) Large an electron energy where a characteristic length (coherent length or dechanneling one) becomes comparable with a block size.
2) For channeling radiation and synchrotron like radiation of high energy electrons the influence of the blocks size is rather small because the particle emits photons on small parts of its trajectory.
3) Coherent bremsstrahlung (coherent pair production) takes place when the particle (photon) moves along straight line in the crystal. If the coherence length will be less than a block size we should observe CB (CPP) suppression. It is possible that this effect had been observed earlier for CPP in PG crystals (block size~1-5 μm):

   Berger C. et al. PRL 1970 V. 25, P.1366, Eisele R.L. et al..//NIM 1973 V. 113, P. 489. In both papers coherent effect was about 1.5-2 times less than it was predicted by ordinary CPP theory.

   We didn’t see any contradictions with the theory for a PG crystal and electrons and photons energy of 900 MeV and 60-300 MeV, respectively (C.Yu. Amosov, et al. // NIM B119 (1996), P. 103., Correction –I.E. Vnukov // Izv. Vysh. Uch. Zav. 2002, V.45, No.9, P.66(in Russian)).
4) Positron production in thick tungsten crystals if blocks size will be about 1 μm or less. Wide positron theta-scan in <u>all published experimental works</u> clearly shows that some part of positrons is generated by CB photons.
5) Hard X-ray and γ-astronomy. Here we need mosaic crystals with size of the blocks less than primary extinction length an a rather small mosaicity angle.

For this aim we need crystals of bα.class

Conclusion

1) The measurement results of the X-ray yield in the experiments in Tomsk and Mainz are caused by the competition between two mechanisms: forward PXR and bremsstrahlung diffraction in mosaic crystals of aα class. For a perfect tungsten crystal FPXR yield should be larger on 10% for Mainz experiment and about 50% for Tomsk one.

2) Information about average blocks size can be obtained from the comparison of the measured diffraction suppression of radiation emission with the calculated or measured one for a perfect crystal. It may be done for substantially lower electrons energies. We need a rather long distance in order to use monochromators with a perfect or mosaic crystal.

3) In mosaic crystals with the increasing of the electrons (photons) energy the suppression of coherent radiation (coherent pair production) yield should be observed due to the finite dimension of microblocks in comparison with the radiation formation length, that may be important for the development of crystal positron injectors for linear electron-positron colliders of the next generation and future experiments for higher particles (photons) energies.

E=500 MeV, W, <111>, T=1.7mm, σ~0.5 mrad