Parametric and characteristic X-ray radiation for diagnostics of interaction of ultra-relativistic particles with crystalline deflectors

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Abstract

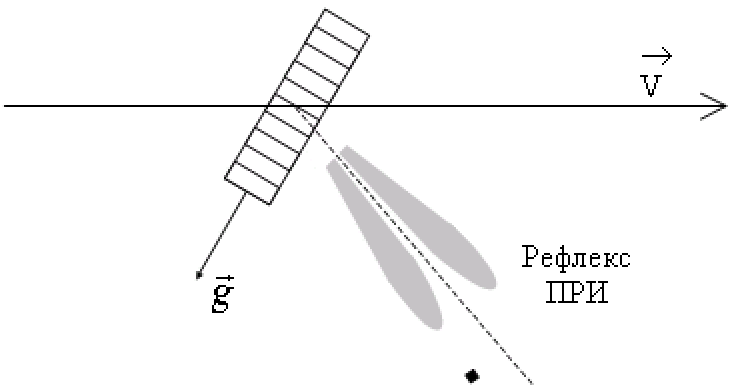
Usually, results of interaction of relativistic particles with a crystalline deflector are observed as a variation in the angular distribution of the particles. But for recent ten, the understanding of properties of X-ray radiation of relativistic particles moving in a bent crystal has bee developed. Some properties of the parametric X-ray radiation (PXR) emitted in a bent crystal were first considered in [1]. The application of the PXR for online diagnostics of the interaction of the beam with bent crystal was proposed in [2]. In [3], it was analyzed possibility to use PXR for control of the bent crystal degradation. Besides, characteristic X-ray radiation of crystal atoms were used for monitoring of number of electrons passed through crystalline target [4]. More recently, new experiments [5,6] were performed to study X-ray radiation excited by protons in crystalline and non-crystalline targets, but any manifestations of crystal curvature were not observed yet.

In present paper, we discuss different possibilities for application of parametric and characteristic X-ray radiation emitted from crystalline beam deflectors. Some peculiarities of X-rays emitted at different mechanisms of deflections, like channeling, volume reflection, and scattering on atomic rings are considered. Besides, applications of X-rays for monitoring of the beam intensity and for control of crystal alignment on a beam are discussed.

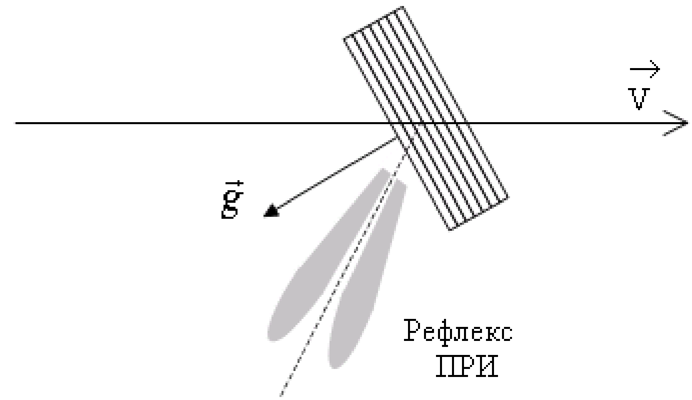
References

1. A.V. Shchagin, JETP Letters 80 (2004) 469-473.
2. A.V. Shchagin, J. Kharkiv Univ., Phys. Ser. “Nuclei, Particles Fields” 30 (2006) 35.
3. A.S. Gogolev, A.P. Potylitsyn, A.M. Taratin, Yu.S. Tropin, Nucl. Instrum. Methods B 266 (2008) 3876.
4. A.V. Shchagin, V.I. Pristupa, N.A. Khizhnyak, Phys. Lett. A148 (1990) 485-488.
5. W. Scandale et al. Phys. Lett, B701 (2011) 180-185.
6. A.G. Afonin at al., Problems of Atomic Science and Technology, Series “Plasma electronics and new methods of acceleration” №4(86) (2013) 315-319.

Common schemes for generation of PXR



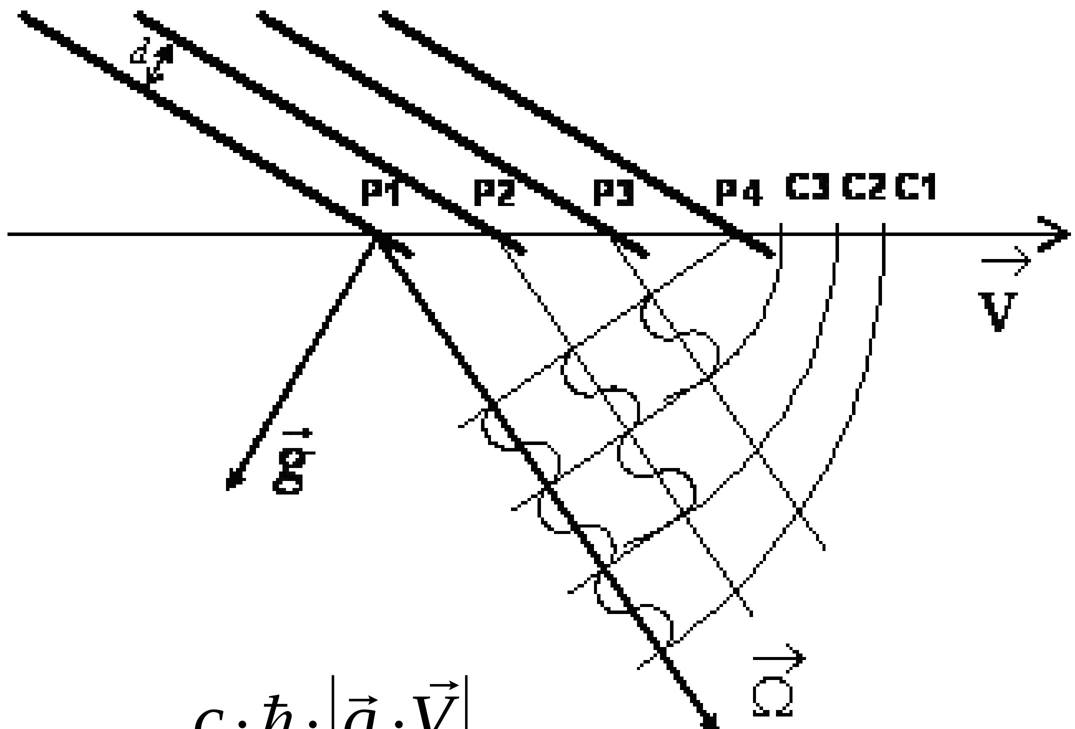
Laue geometry



Bragg geometry

The Huygens construction for generation of parametric X-ray radiation (PXR)

Proposed in: Shchagin A.V., Maruyama X.K. “Accelerator-Based Atomic Physics Techniques and Applications”, eds. S.M. Shafroth, J.C. Austin, AIP Press, New York, 279-307 (1997).



$$E_{CR} = \hbar \cdot \omega_{CR} = n_\lambda \cdot \frac{c \cdot \hbar \cdot \left| \vec{g} \cdot \vec{V} \right|}{c - \sqrt{\varepsilon_0} \cdot \vec{V} \cdot \vec{\Omega}}$$

Focusing of PXR **A.V. Shchagin JETP Letters 80 (2004)469-473.**

Huygens picture

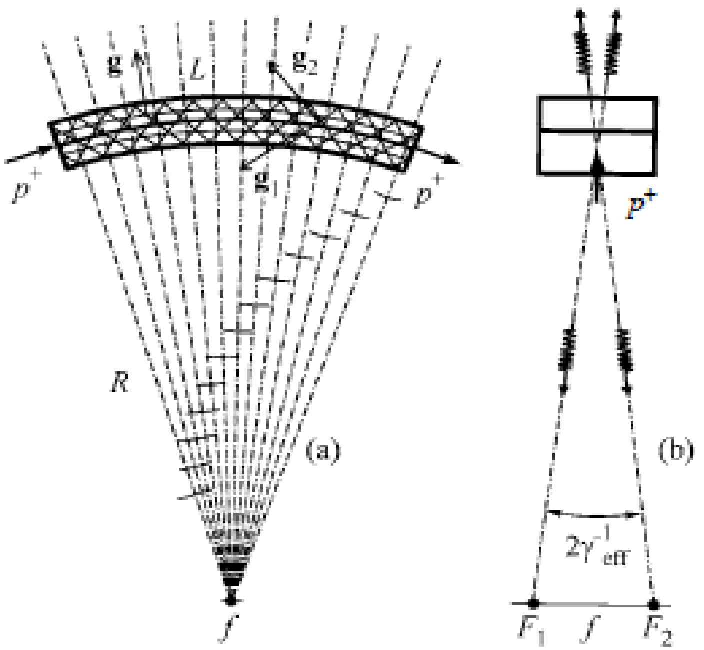


Fig. 1. Huygens picture and focusing PXRs emitted by channeled particles moving along a thin bent single-crystal plate: (a) side and (b) front views. The trajectory of a parti-

Properties of focused PXR

Radiation		CXR Si	PXR(400)	PXR(800)	PXR(12 00)
Polarization		No	Linear	Linear	Linear
E, keV		1.74	6.46	12.91	19.37
$(\Delta E/E)_{nat}$			$3.84 \cdot 10^{-9}$	$1.92 \cdot 10^{-9}$	$1.28 \cdot 10^{-9}$
$(\Delta E/E)_D$			$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$
T_e in Si, μm		13.3	37	270	865
Protons 70 GeV	γ_{eff}^{-1}	-	$1.42 \cdot 10^{-2}$	$1.36 \cdot 10^{-2}$	$1.35 \cdot 10^{-2}$
	$\Delta F, mm$	-	142	136	135
	$I, \frac{quanta}{cm^2 \cdot p^+}$	$1.65 \cdot 10^{-7}$	$9.56 \cdot 10^{-8}$	$1.86 \cdot 10^{-8}$	$1.55 \cdot 10^{-9}$
Protons 450 GeV	γ_{eff}^{-1}	-	$5.24 \cdot 10^{-3}$	$3.18 \cdot 10^{-3}$	$2.63 \cdot 10^{-3}$
	$\Delta F, mm$	-	52.4	31.8	26.3
	$I, \frac{quanta}{cm^2 \cdot p^+}$	$1.94 \cdot 10^{-7}$	$6.90 \cdot 10^{-7}$	$3.32 \cdot 10^{-7}$	$3.98 \cdot 10^{-8}$

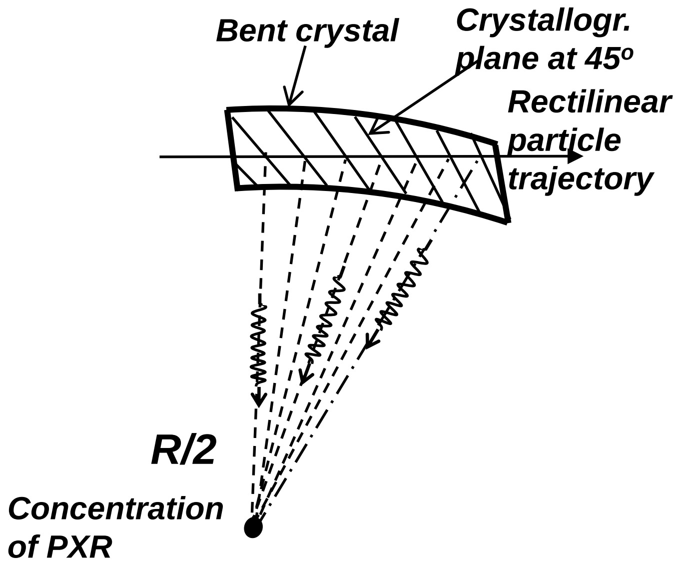
The application of PXR for online diagnostics of the beam and the bent crystal state was proposed in:

A.V. Shchagin, J. Kharkiv Univ., Phys. Ser. “Nuclei, Particles Fields” 30 (2006) 35.

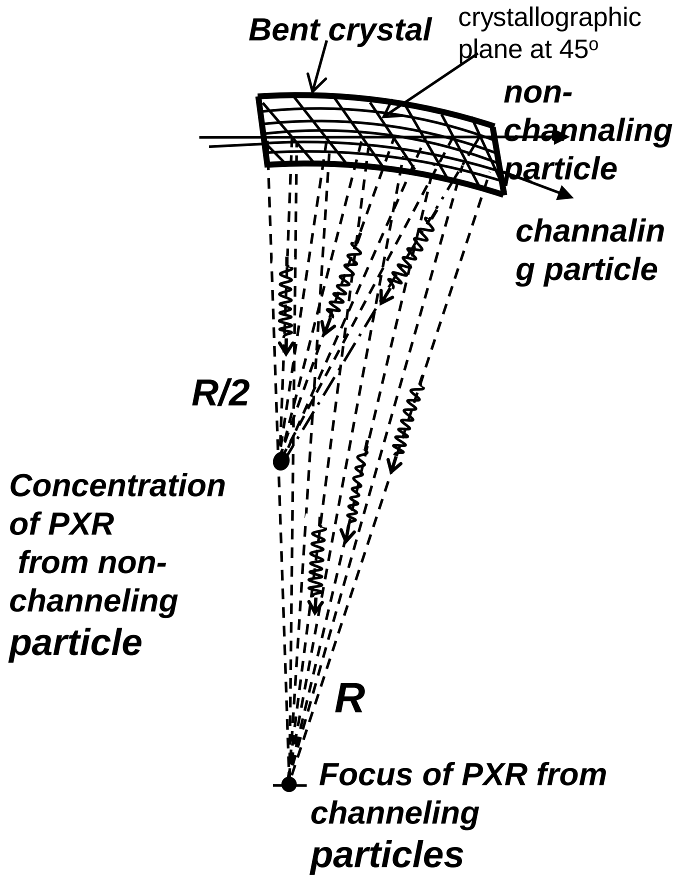
A.S. Gogolev, A.P. Potylitsyn, A.M. Taratin, Yu.S. Tropin, NIM B 266 (2008) 3876.

V. Guidi, A. Shchagin, in preparation

Concentration of PXR from particle moving rectilinearly (non-channeling case) through cylindrical bent crystal. The concentration is possible at arbitrary sign of the particle charge



PXR from channeling and non-channeling fractions of proton beams can be observed separately at distances R and R/2



Experiment in CERN Phys. Lett. B 701(2011)180

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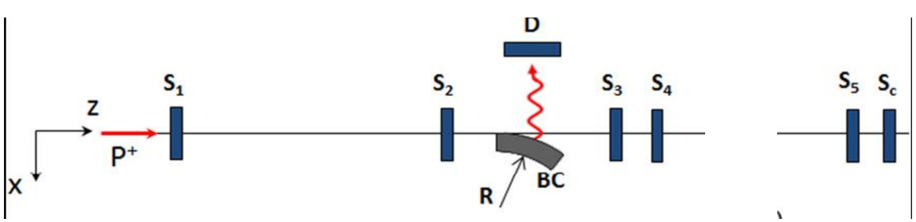
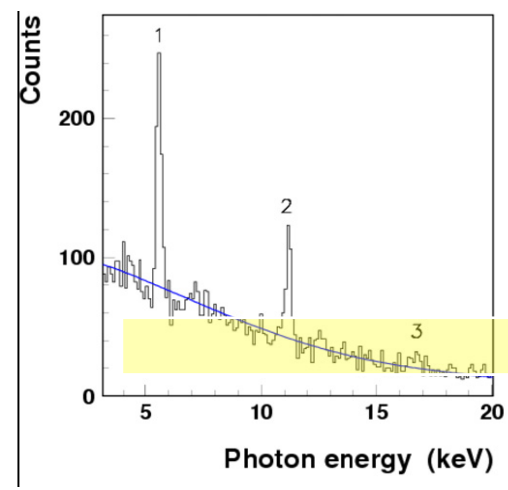
Observation of parametric X-rays produced by 400 GeV/c protons in bent crystals

W. Scandale[a,b], G. Arduini[a], R. Assmann[a], F. Cerutti[a], S. Gilardoni[a], J. Christiansen[a], E. Laface[a], R. Losito[a], A. Masi[a], E. Metral[a], D. Mirarchi[a], S. Montesano[a], V. Previtali[a], S. Redaelli[a], G. Valentino[a], P. Schoofs[a], G. Smirnov[a], L. Tlustos[a], E. Bagli[c], S. Baricordi[c], P. Dalpiaz[c], V. Guidi[c], A. Mazzolari[c], D. Vincenzi[c], B. Buonomo[d], S. Dabagov[d], F. Murtas[d], A. Carnera[e], G. Della Mea[e], D. De Salvador[e], A. Lombardi[e], O. Lytovchenko[e], M. Tonezzer[e], G. Cavoto[f], L. Ludovici[f], R. Santacesaria[f], P. Valente[f], F. Galluccio[g], A.G. Afonin[h], M.K. Bulgakov[h], Yu.A. Chesnokov[h], V.A. Maisheev[h], I.A. Yazynin[h], A.D. Kovalenko[i], A.M. Taratin[i,*], Yu.A. Gavrikov[j], Yu.M. Ivanov[j], L.P. Lapina[j], V.V. Skorobogatov[j], W. Ferguson[k], J. Fulcher[k], G. Hall[k], M. Pesaresi[k], M. Raymond[k], A. Rose[k], M. Ryan[k], O. Zorba[k], G. Robert-Demolaize[l], T. Markiewicz[m], M. Oriunno[m], U. Wienands[m], Yu.V. Efremov[n], S.R. Uglov[o], A.S. Gogolev[o]

Spectrum of X-ray radiation

Experimental setup





Experiment in Protvino, Russia

Problems of Atomic Science and Technology, Series “Plasma electronics and new methods of acceleration” №4(86) (2013) 315-319.

OBSERVATION OF PARAMETRIC X-RAY RADIATION EXCITED BY 50 GeV PROTONS AND IDENTIFICATION OF BACKGROUND RADIATION ORIGIN

A.G. Afonin[1], G.I. Britvich[1], Yu.A. Chesnokov[1], P.N. Chirkov[1], A.A. Durum[1], M.Yu. Kostin[1], A.V. Lutchev[1], V.A. Maisheev[1], A.A. Yanovich[1], A.V. Shchagin[2], V.I. Truten'[2], V.B. Ganenko[2], I.V. Kirillin[2], N.F. Shul'ga[2,6], A.S. Kubankin[3], N.N. Nasonov[3], A.P. Potylitsyn[4], A.S. Gogolev[4], S.R. Uglov[4], Yu.M. Cherepennikov[4], P. Karataev[5]*

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Experimental setup

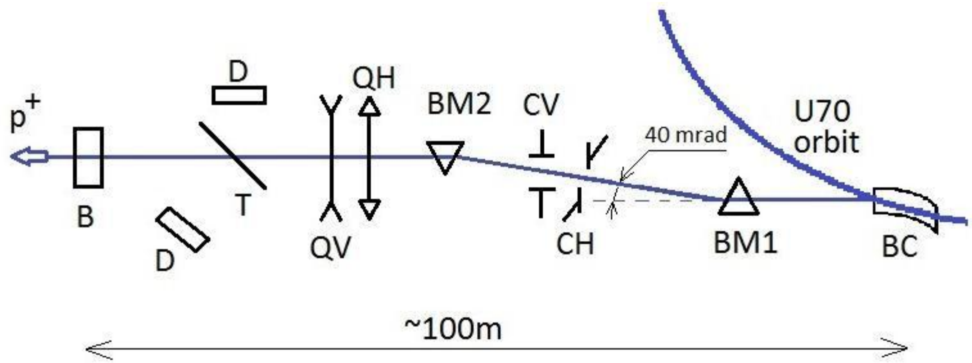


Fig. 1. The experimental layout at accelerator U70. The proton beam of energy 50GeV is extracted from the circle by a bent crystal BC. Then, the beam passes two bending magnets BM2, BM1, collimator C, target T. The number of protons in the beam is calculated by a scintillated counter B. The X-ray radiation and the background radiation is measured by the detector D that is shown in two positions.

Observation of parametric X-ray radiation

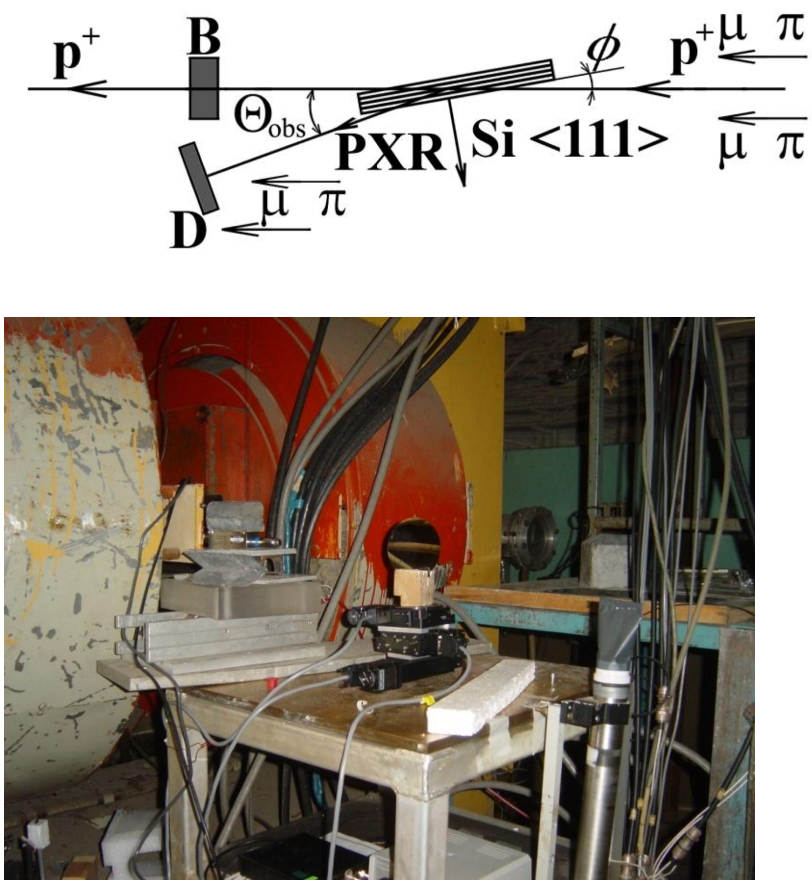


Fig. 5. The experimental setup for the PXR measurements

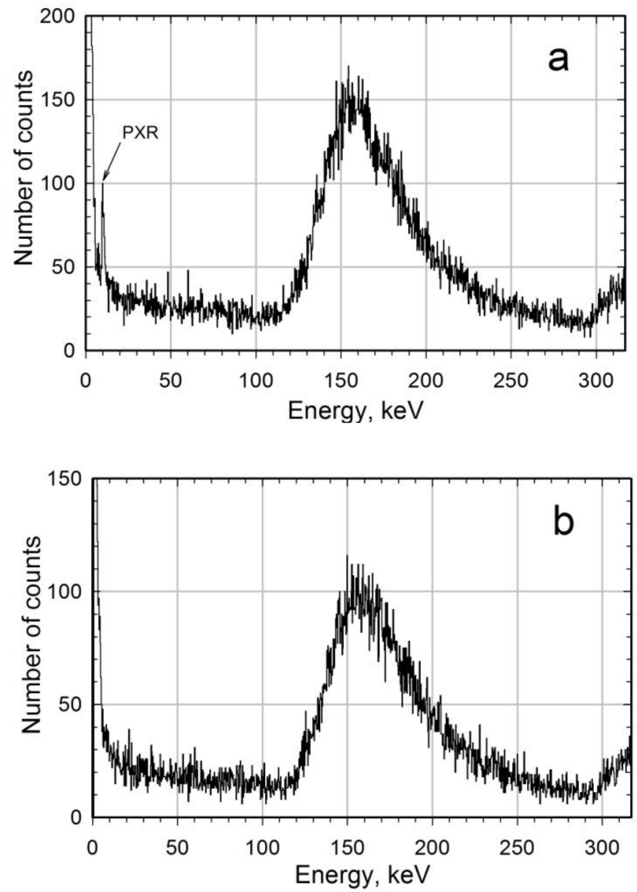
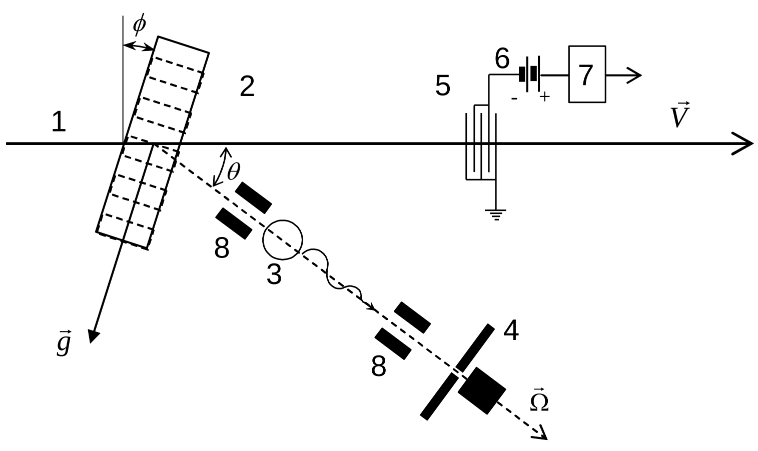


Fig. 6. Spectra without background subtraction measured when the PXR reflection is directed towards the detector (a) and when the PXR reflection is aligned aside from the detector (b). The arrow shows the PXR spectral peak

Simultaneously with PXR, the characteristic X-ray radiation is emitted from a crystal

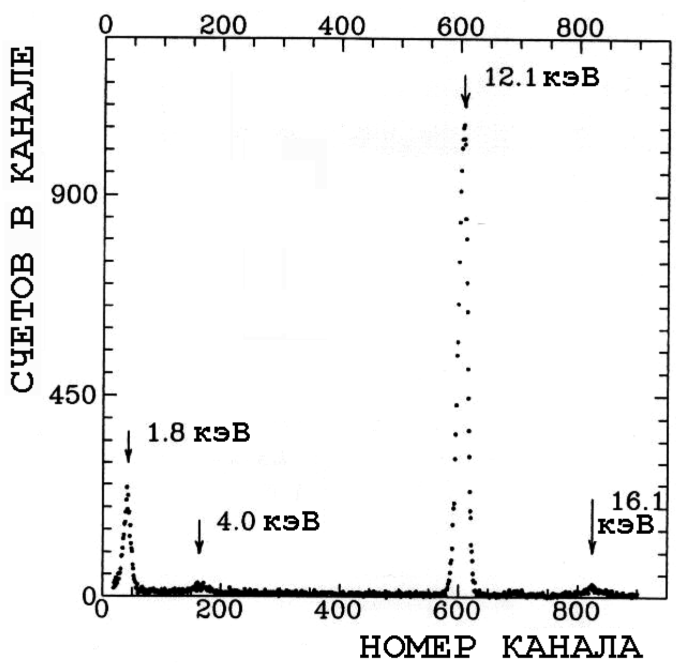
Example:

Experimental setup at electron beam energy 25 MeV



Spectrum of X-ray radiation from Si crystal at incident electron beam energy 25 MeV and the angle of crystal rotation 142.9 mrad

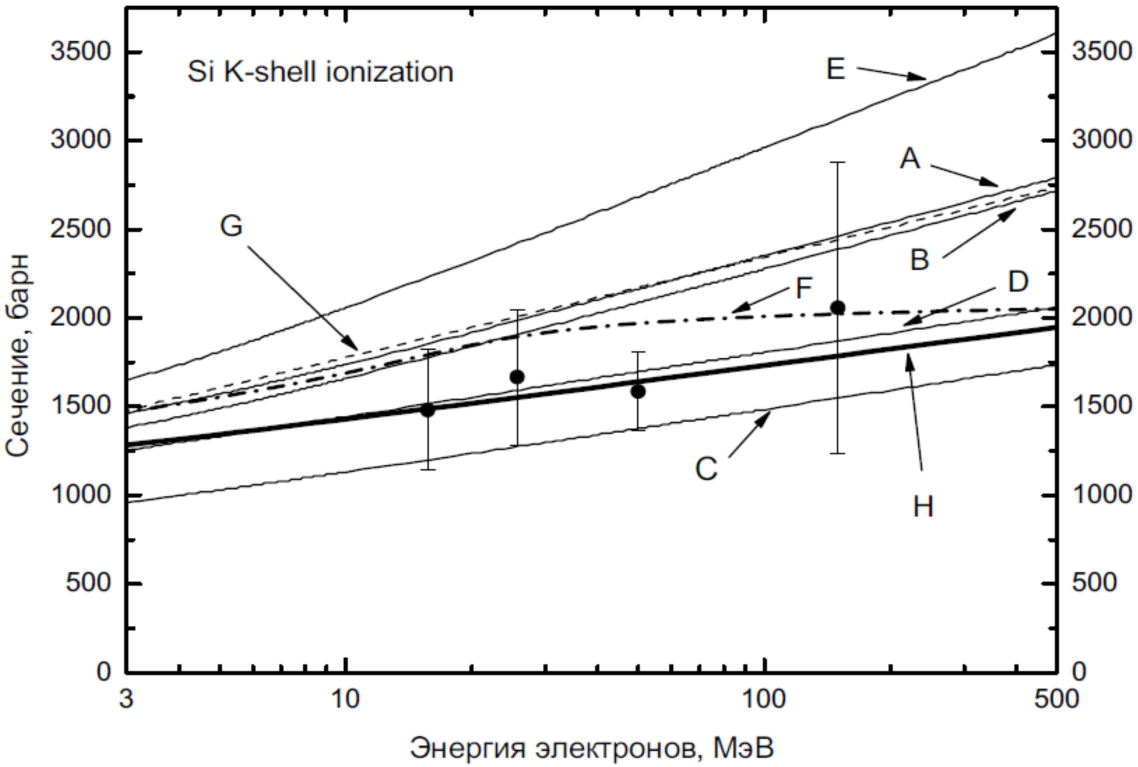
Shchagin A.V., Pristupa V.I., Khizhnyak N.A. Phys. Lett. A 148, 485-488 (1990).



Si K-shell ionization cross section by relativistic electrons

Shchagin A. V., Pristupa V. I., Khizhnyak N. A. NIM B, V.48, 1994, pp. 9-13.

A.V. Shchagin, V.V. Sotnikov. A formula for K-shell ionization cross section of Si atoms by relativistic electrons in a thin silicon layer. The Journal of Kharkiv National University No. 777, physical series “Nuclei, Particles, Fields”, Issue 2/34/, Kharkov, 2007, p. 97-101.



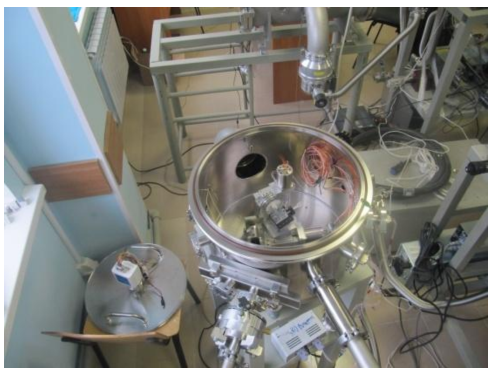
Line D:

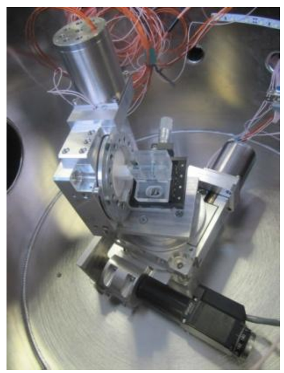
$$\sigma_K^{Si} = 134 \ln \gamma + 1025$$

Experimental perspectives

1. Vacuum goniometer can provide possibility for observation of characteristic X-ray radiation from Si crystal with energy 1.74 keV
2. Image plate would allow to observe angular distribution of PXR

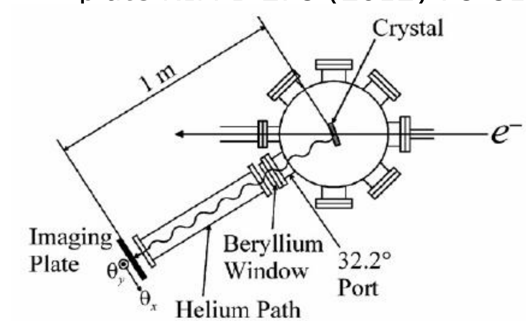
Preparation of vacuum goniometer in Belgorod radiation laboratory





Example of the Image plate application:

Y. Takabayashi, A.V. Shchagin. Observation of parametric X-ray radiation by an imaging plate NIM B 278 (2012) 78-81.



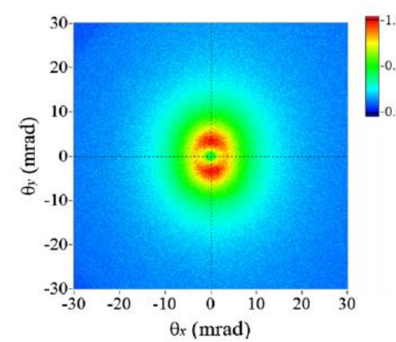
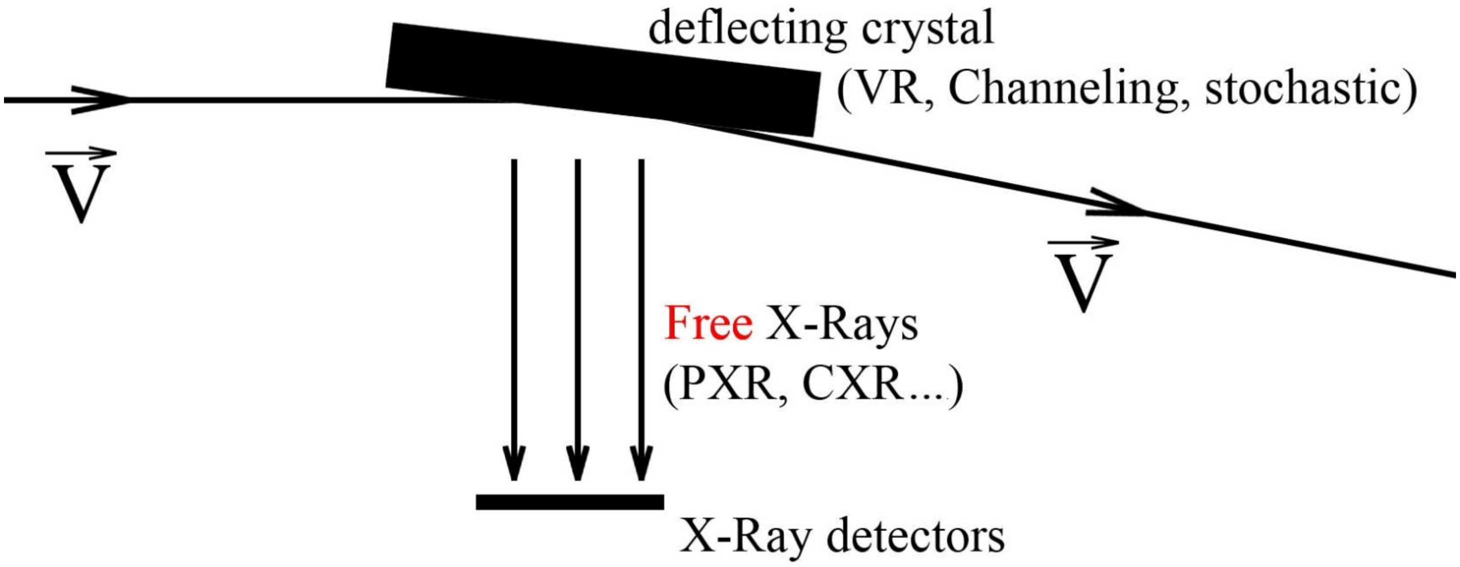


Fig. 2. Two-dimensional angular distribution in the PXR reflection observed with the imaging plate. The center of the PXR reflection (Bragg direction) is at $\theta_{x,y} = 0$.

Scheme of the diagnostics



The observation of PXR and CXR is the best way for online diagnostics of beam-crystal system

Thanks for attention