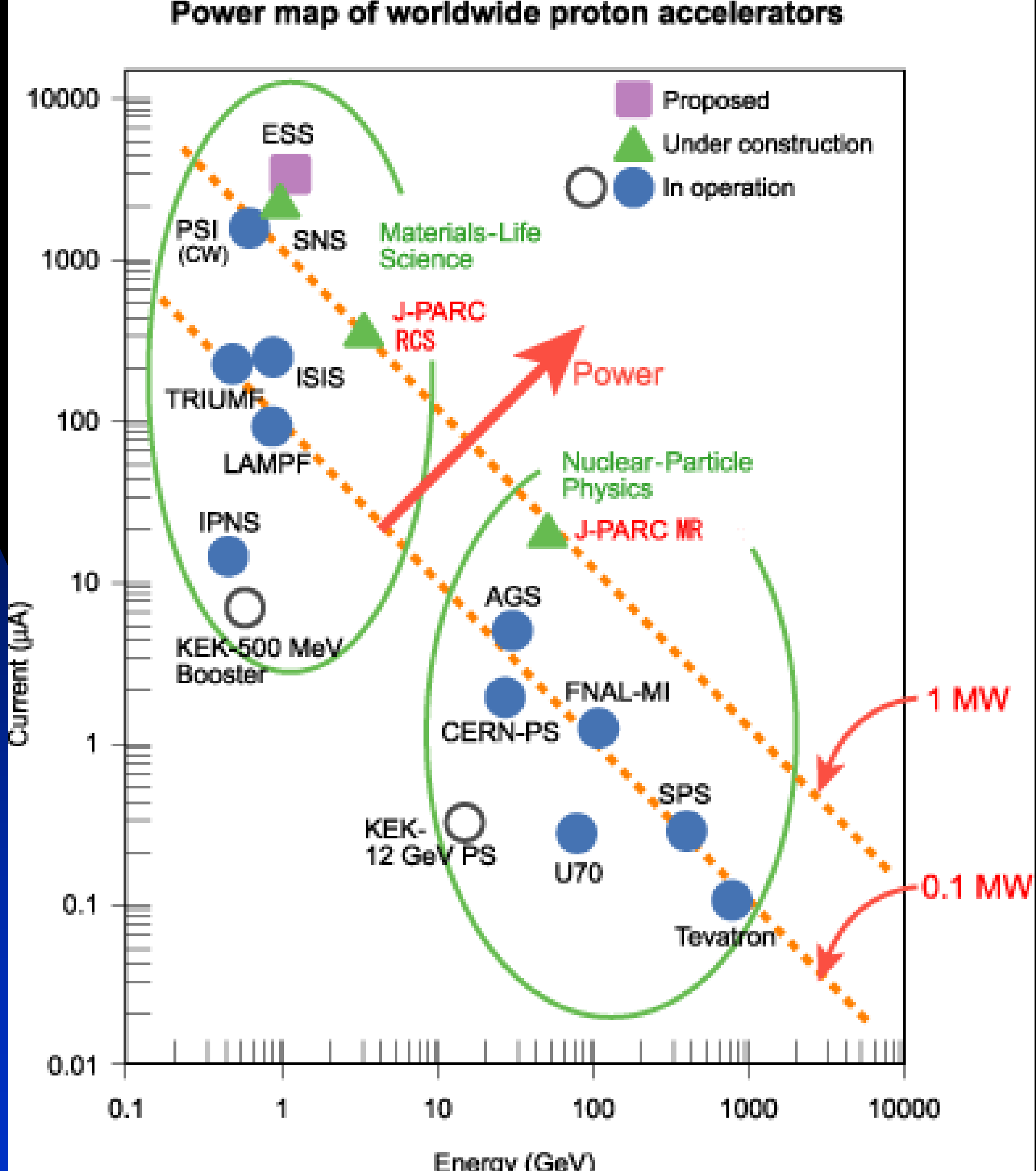
METHOD OF CRYSTAL DEFLECTOR MONITORING

A.S. Gogolev
A. P. Potylitsyn
A.M. Taratin



http://j-parc.jp/Acc/en/gaiyoE.html

Purpose:

- Development of a crystal deflector monitoring technique based on parametric x-ray radiation.

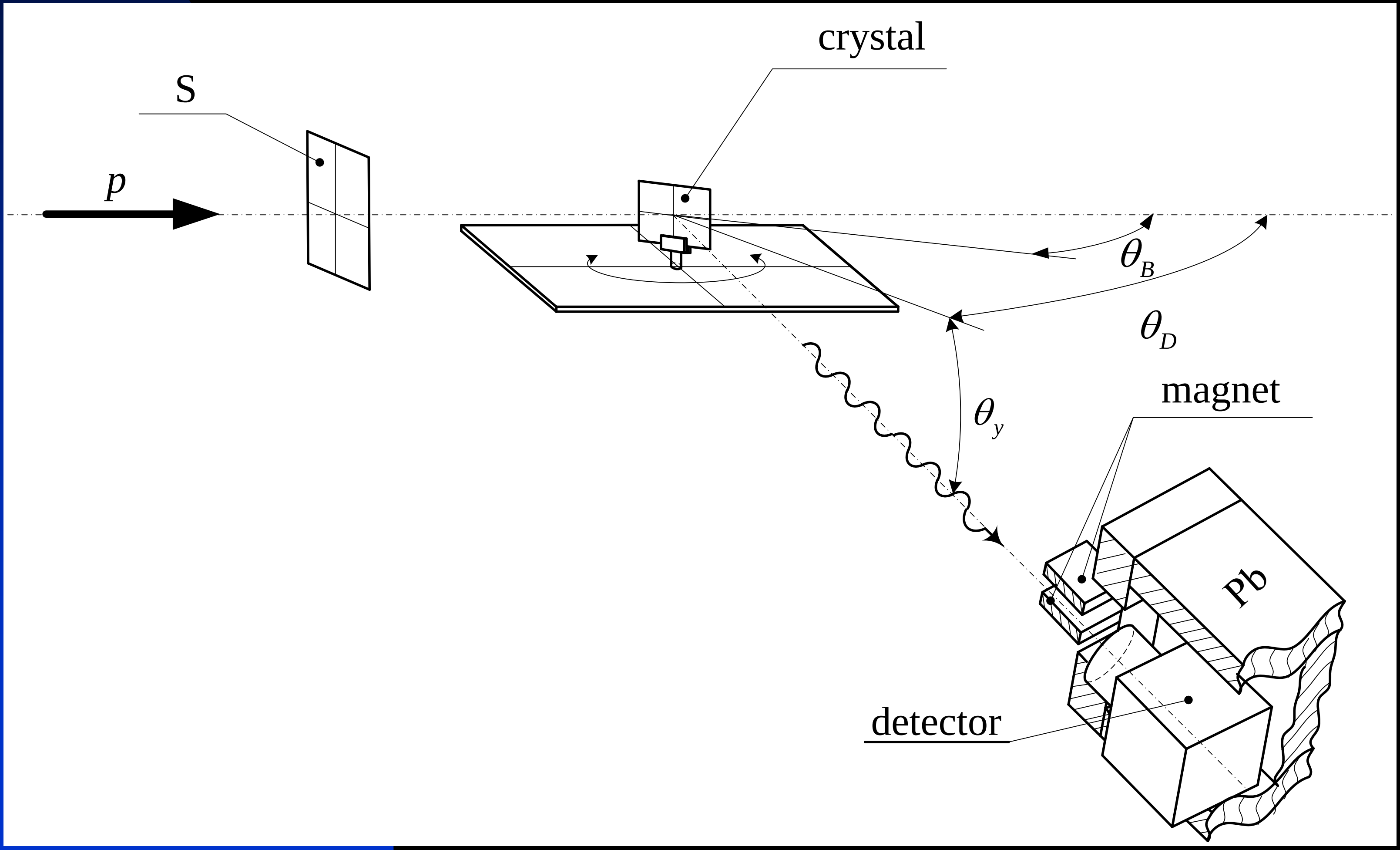
Problems:

- Parametric x-ray radiation (PXR) generation process modelling of particles in the bent crystals based on kinematic theory.
- Check of an offered method experimentally.

PXR **generation** process

PXR relates to a class of polarization radiation which do not depend on mass of an initial particle are determined by its velocity and charge only.

PXR can be considered as the process of the diffraction of virtual photons connected with Coulomb field of a fast charged particle on crystal planes, and its transformation into real X-rays.



PXR yield

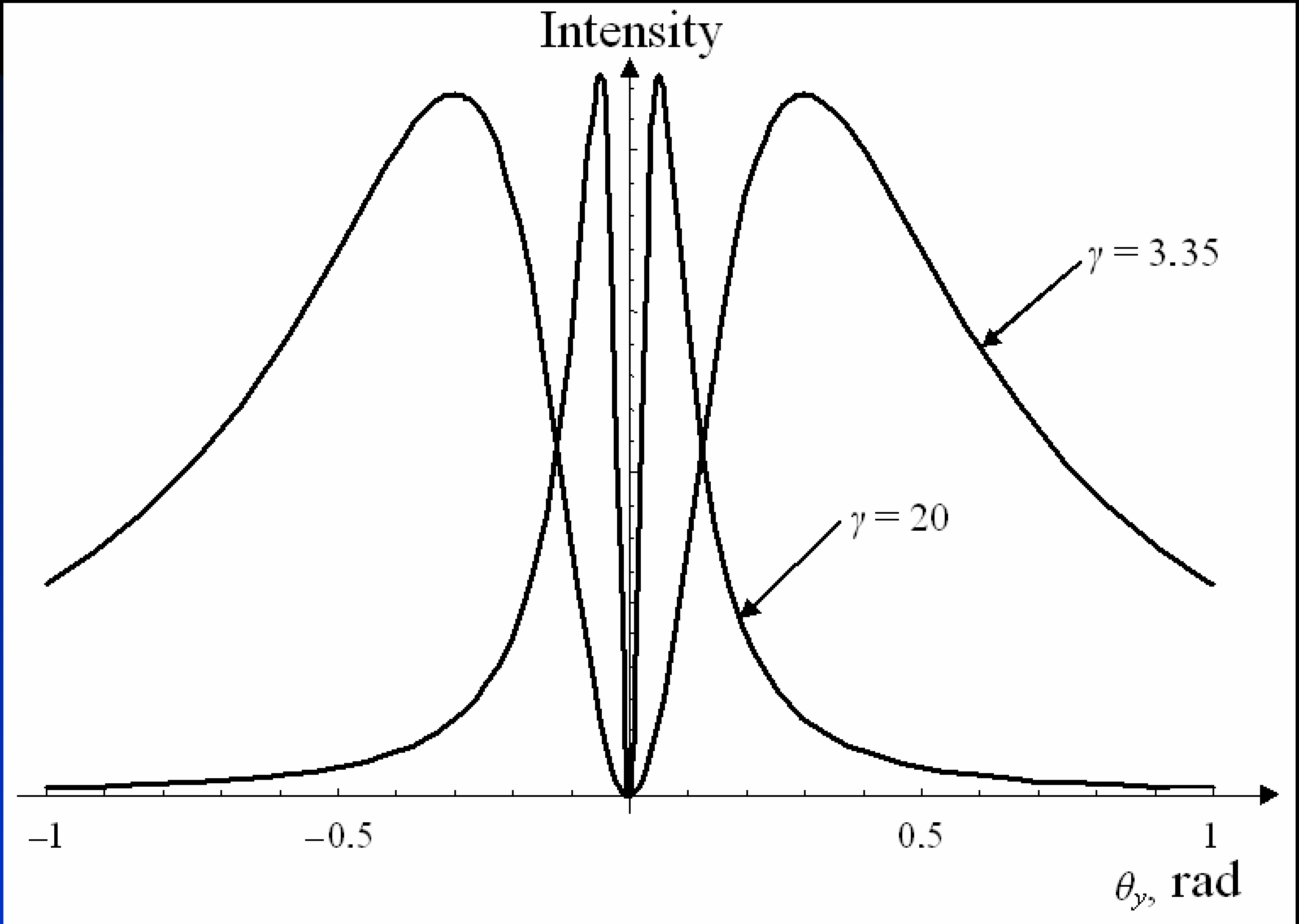
Angular distribution of PXR can be written down in a general view the following way [H. Nitta. Phys. Lett. A 158 (1991) 270]:

$$\left(\frac{dN}{dld\Omega}\right)_i = \frac{Z^2\alpha}{2\pi\hbar}\sum_g \frac{(\omega/c)^3\left|\chi_g\right|^2}{\beta(1-\sqrt{\varepsilon}\mathbf{\beta}\cdot\mathbf{n})}\sum_\alpha\left[\frac{(\sqrt{\varepsilon}(\omega/c)\mathbf{\beta}-\mathbf{g})\cdot\mathbf{e}_{\mathbf{k}\alpha}}{\mathbf{k}_g^2-(\omega/c)^2}\right]^2$$

.

where Z – charge of a incident particle, α – fine structure constant, **g** – reciprocal lattice vector, **n** – unit vector at direction of PXR photon, **β** – normalized electron speed vector, $\beta = v/c$, c – velocity of the light, ε – permittivity of the crystal matter, $\omega = \mathbf{g}\,\boldsymbol{\beta}/(1 - \sqrt{\varepsilon}\,\boldsymbol{\beta}\,\mathbf{n})$ – photon energy, ω_p – crystal matter plasmon energy, γ – Lorentz-factor, $\mathbf{e}_{\mathbf{k}\alpha}$ – unit vector of polarization, $\mathbf{k}_g = \mathbf{k} + \mathbf{g}$.

Angular distribution of PXR

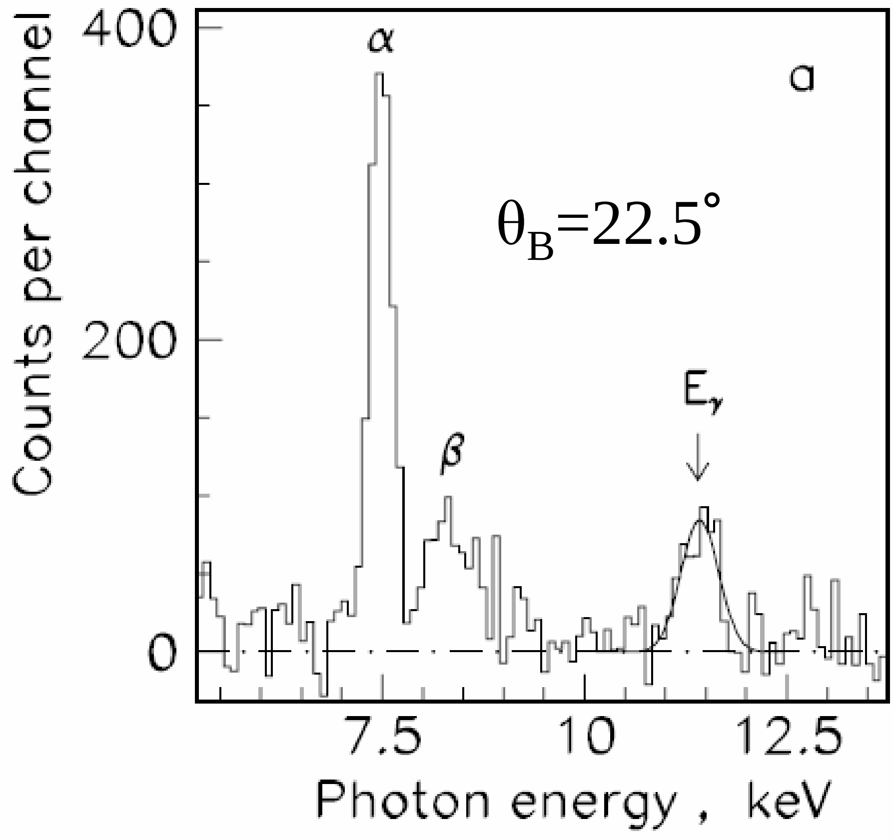


PXR from relativistic electrons in crystals has been investigated theoretically and experimentally at different electron energies.

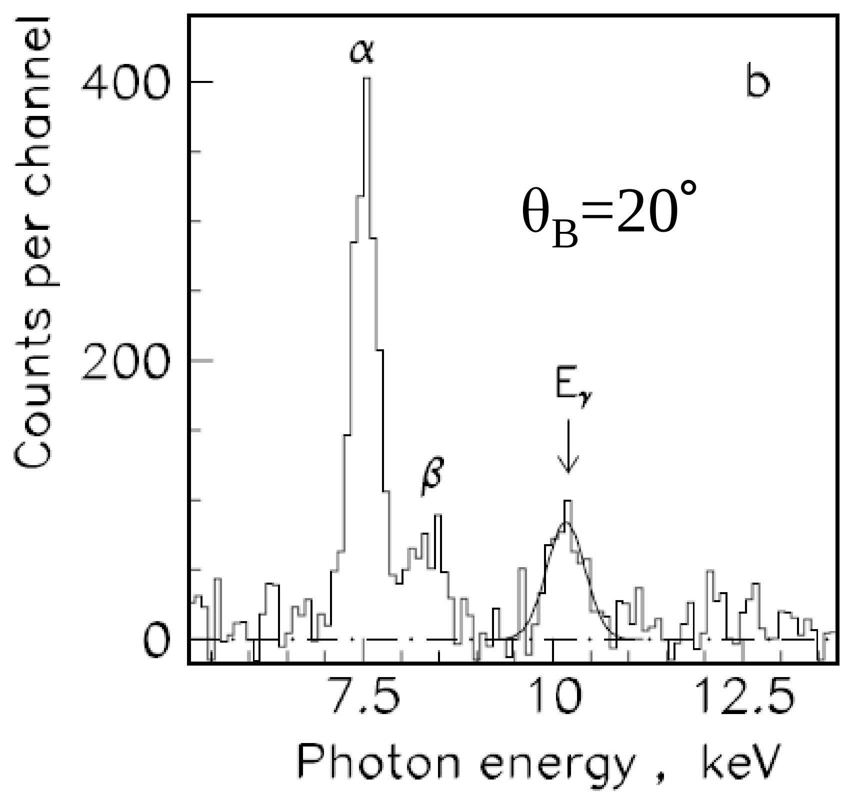
First experiment with the aim of PXR observation from heavy charged particles has been carried out on the 70-GeV proton beam at IHEP [V.P. Afanasenko, V.G. Baryshevsky, R.F. Zuevsky et al., Phys. Letters A170, 315 (1992)].

One year ago the results of the first experimental observation of PXR from protons in a silicon crystal were presented. The experiments were carried out on the 5-GeV proton beam extracted from the Nuclotron at the Laboratory of High Energies, JINR (Dubna) [Yu.N. Adischev, S.V. Afanasiev, V.V. Boiko et al., JETP Letters, 2005, V. 81, № 6, p. 305].

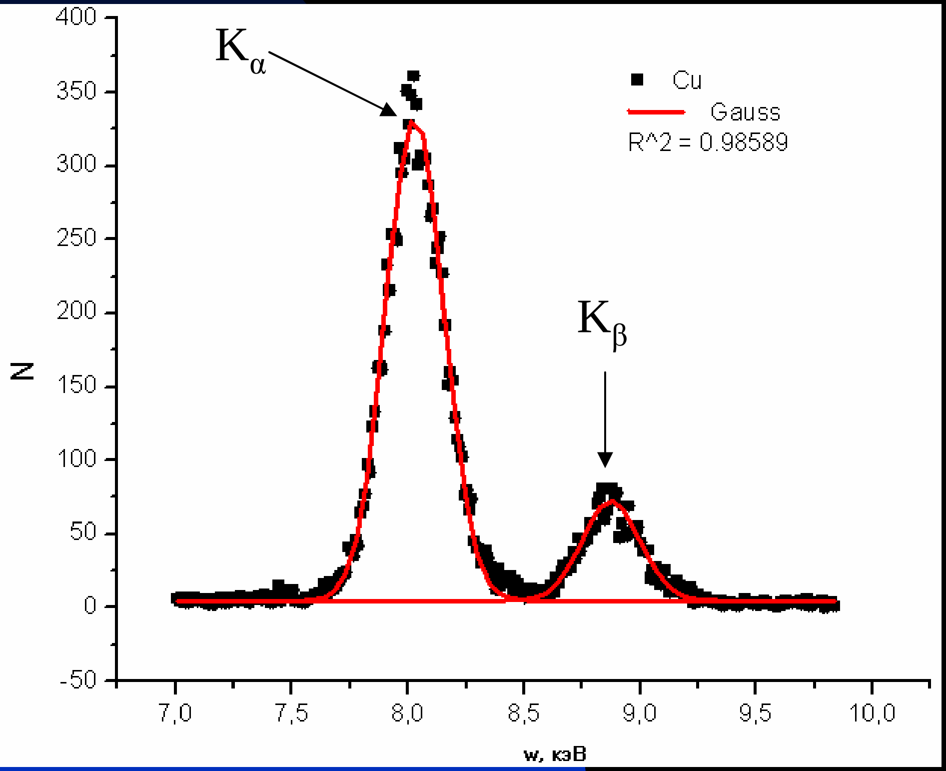
Results of the experiments



$dN/d\Omega \sim 10^{-6}$ photons/(proton·sr)



Characteristics of the detector



Spectrum of copper characteristic radiation

$$I_t^\alpha = 15,44 \cdot 10^{-3}$$
$$I_t^\beta = 3,24 \cdot 10^{-3}$$
$$I_e^\alpha = 12,28 \cdot 10^{-3}$$
$$I_t^\beta / I_t^\alpha = 0,2098$$
$$I_e^\beta = 2,52 \cdot 10^{-3}$$
$$I_e^\beta / I_e^\alpha = 0,2052$$

The FWHM of the measured 8.046-keV K_α line was equal to 320 eV (sigma = 136 eV).

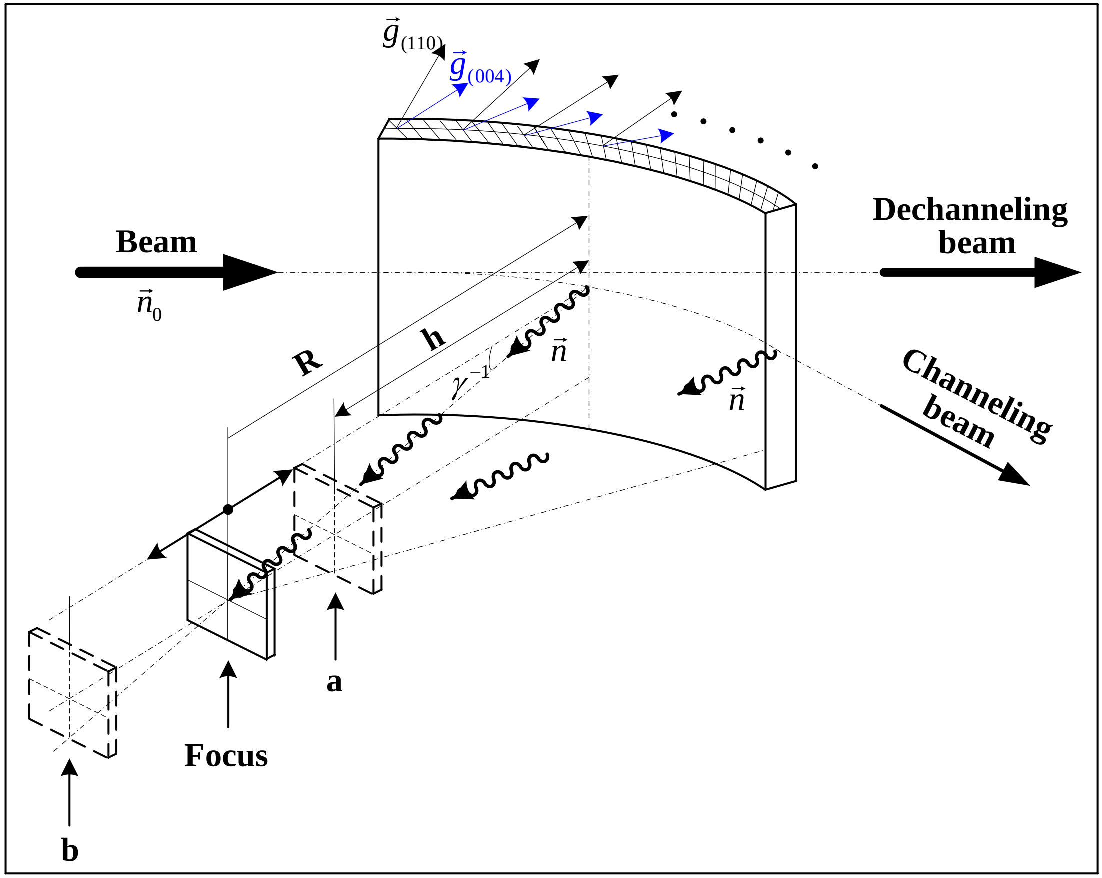
Many PXR experimental researches showed that kinematic model is valid for description of observable PXR properties generated in thin straight crystals. Thus, at first approximation it's possible to use this model for simulation of PXR yield from the bent crystal. Let us consider a bent crystal as a set of *n* the straight samples tilted by angle α/n relative to each other. Then PXR yield from all crystal can be presented as superposition of separate samples contributions using the following formula:

$$\frac{dN}{dLd\Omega} = \sum_{i=1}^{n} \left(\frac{dN}{dld\Omega} \right)_i$$

EXPERIMENTAL SCHEME

The 50 GeV proton beam is deflected by Si crystal, which it is cut out along planes (110).

Optimal bending radius of the deflector for the beam extraction is equal to 5 R_c, here R_c is the critical radius of channeling. For silicon crystal (110) $R_c \approx E/6$ [cm], E – proton energy in GeV. So almost optimal deflector bend radius of crystal is about R = 40 cm. Let us choose R = 50 cm and h = 40 cm deflector distance (see fig.). For deflection at angle α = 0.1 rad deflector length had to be L = 5 cm. For slight angular divergence beam extraction efficiency is about 20%. Let us choose

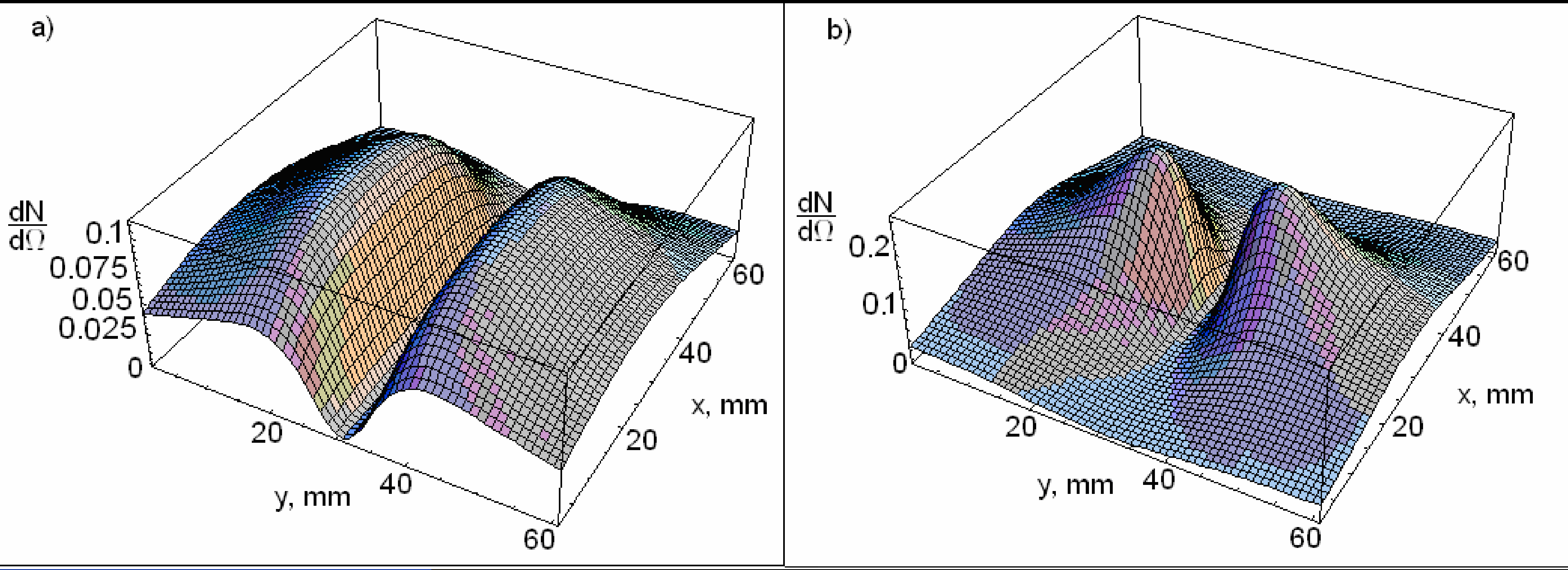


deflector height and width to be equal to 1 cm and 0.1 cm, correspondingly.

X-ray emission is measured by semiconductor detector with sensitive area ~ 10 mm^2 and resolution ~ 100 eV.

Spectral-angular distribution of radiation generated by the proton crossing (100) planes tilted by 45˚ relative to deflecting silicon crystal planes (110) is calculated using the developed approach. PXR photons are concentrated at the optical focus of bent crystal surface. The focusing effect allows considerably reduce a time of measurements due to statistics increased. Spectral line width of PXR has the minimum if X-ray detector was placed in the focus. PXR line width depends on crystal curvatures.

[A.V. Schagin, JETP Letters, 2004, V. 80, № 7, p. 535]



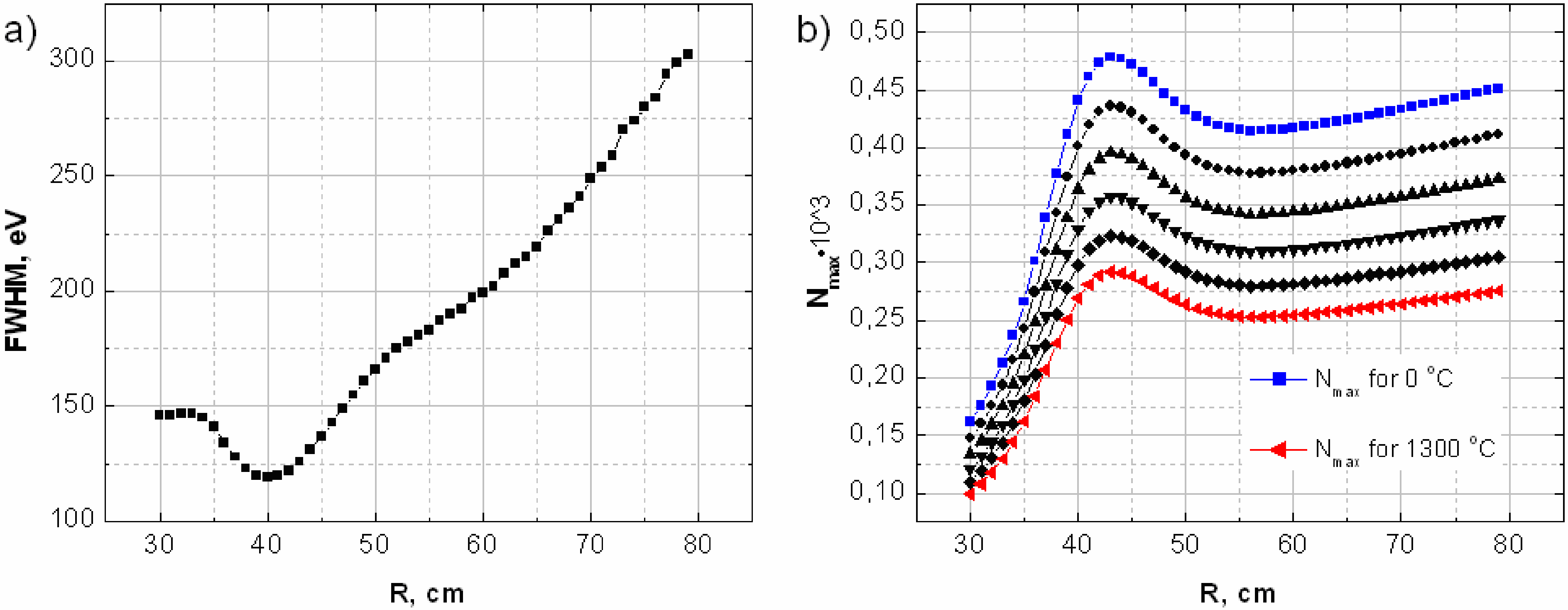
PXR angular distribution of (100) planes: a) from straight crystal with length 5 cm; b) from bent crystal with length 5 cm and bending radius R = 50 cm. Distance to the detector plane is 50 cm.

For the choosen geometry PXR line width for which average energy is equal to 6.5 keV. This value was calculated with taking into account energy resolution of the detector (~ 100 eV). PXR angular density $dN/d\Omega$ in focus point has been equal to 0.25 photon/sr/p_c for channeling protons. For particles passing through a crystal without a deflection just along the initial direction the focusing also is observed but it is caused not by changing of observation angle as in channeling fraction beam the case but by changing of Bragg angle, and the PXR angular density in focus was equal to 0.06 photon/sr/p_d.

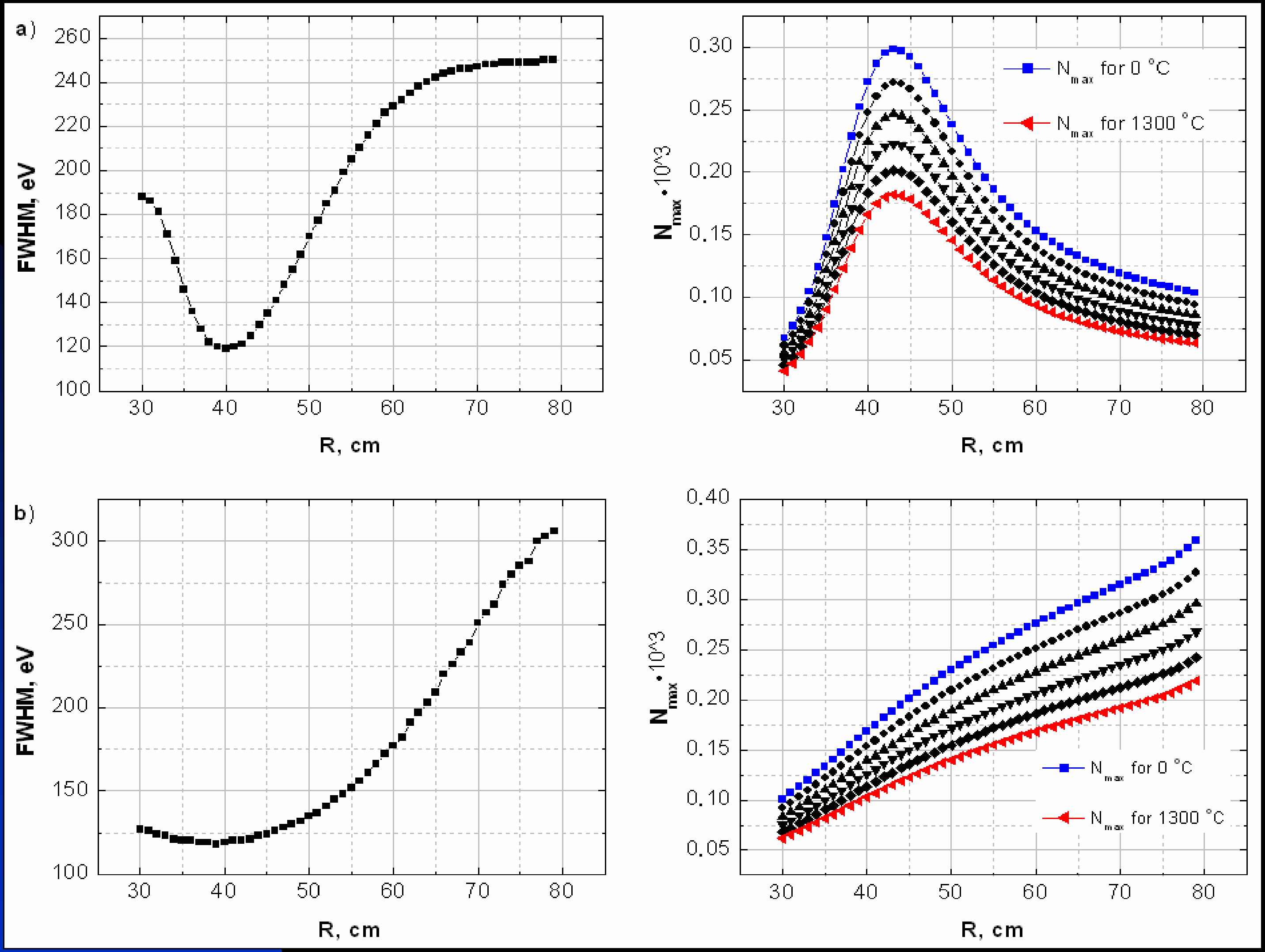
During simulation the approximation that 20 % of particles were deflected at the angle 0.1 rad by silicon deflector with length 5 cm was used. At this stage we consider that dechanneling beam fraction i.e. 80 % particles passes through the crystal along the initial direction .

The extraction of 1% particles from halo of JPARC beam will provide intensity of PXR about 10^5 photons/second to detector with $d\Omega = 4\cdot10^{-6}$.

FWHM of detector equal to 100 eV

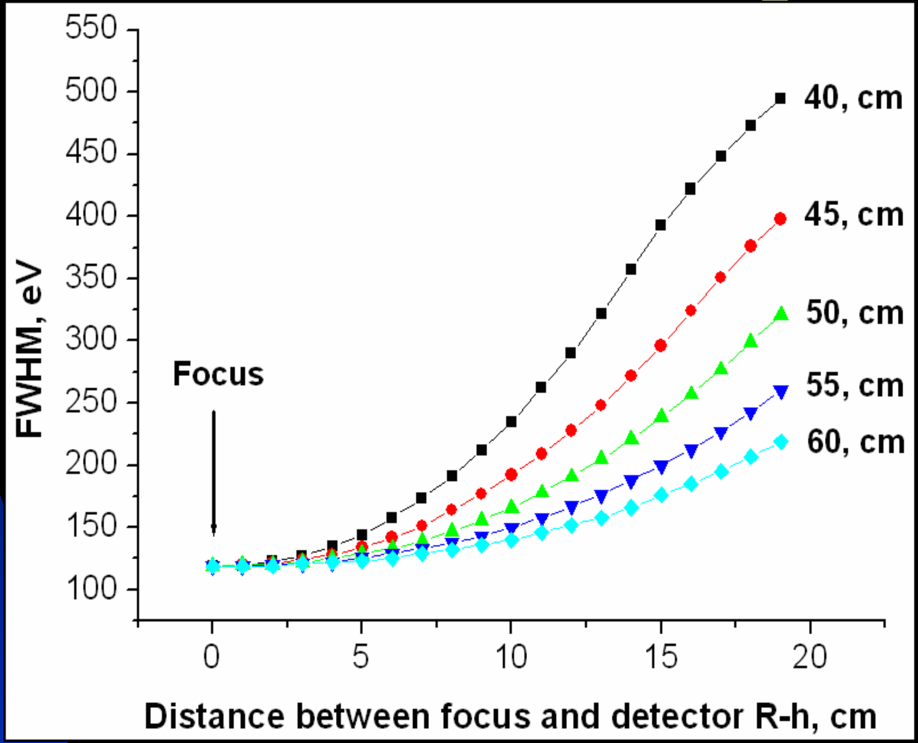


Dependences on deflector radius: a) FWHM of PXR; b) PXR line intensity.



Contributions of a beam separate fractions to the general dependence FWHM and PXR line intensity : a) channeling; b) dechanneling.

Dependence of PXR line width on detector positions for different deflector bending radius



If it is necessary to have more exact information about deflector bending radius one can carry out a few additional measurements of PXR lines for various positions of the detector on an optical axis of deflector

SUMMARY

- We propose to use PXR as a diagnostics tool for on-line monitoring of a quality and parameters of crystal deflector.
- The PXR spectral line width allows to estimate a curvature radius of deflector.
- Degradation of line intensity may be used for determination of deflector temperature and/or radiation damage.

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