Induced Parametric Beam Instability in Conditions of Grazing Geometry

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FORMULATION

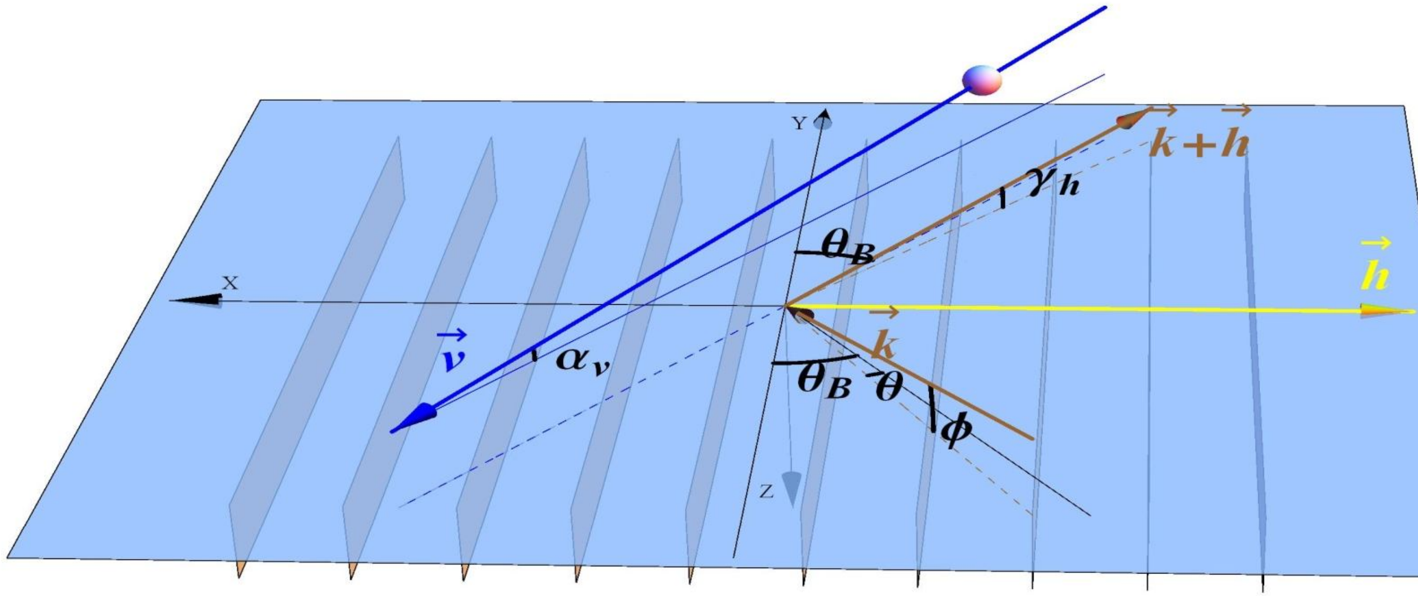
Parametric x-rays (PXR) – this is mechanism of the quasi-monochromatic x-rays generation as a result of relativistic electron interaction with the periodic field of a crystalline target.

Theoretical prediction - **40 years ago** (Minsk, Erevan)
First experiments – **25 years ago** (Tomsk, Minsk)

Wide practical application of the effect is limited by followed factors:
1) Crystal target damage due to increasing beam current
2) Absorption of the radiation in a crystal target
3) Problems of implementation of coherent generation (free electron laser - FEL).

Motivation of the Contribution: Discussion of basic idea and evaluation of the **PXR-FEL** parameters

DIFFRACTION GEOMETRY – GID PXR



V.G. Baryshevsky // Doklady AN SSSR **299**(6) (1988) 1363

GID PXR - BASICS

Electromagnetic field outside a crystal in the GID conditions include three waves, i.e. incident, diffracted, and specular

$$\mathbf{E}^{(-)}_{\mathbf{k}\omega}(\mathbf{r}) = \sum_{s=\sigma,\pi} \{\mathbf{e}_{\mathbf{k}s} e^{i\mathbf{k}\mathbf{r}} + \mathbf{e}_{\mathbf{k}_R s} R e^{i\mathbf{k}_R\mathbf{r}} + \mathbf{e}_{\mathbf{k}_h s} H e^{i\mathbf{k}_h\mathbf{r}}\}$$

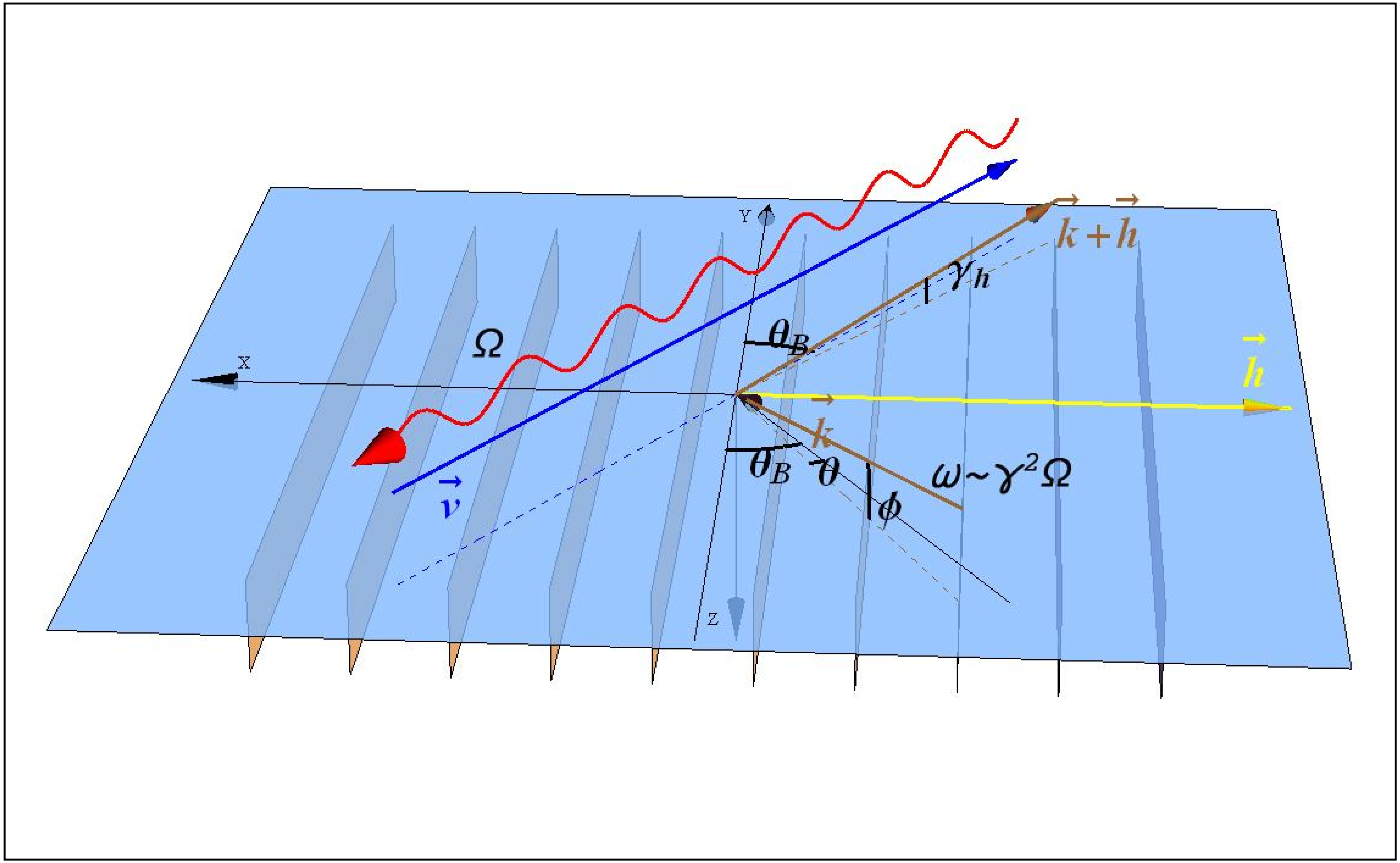
$$\mathbf{k}_R = \{\mathbf{k}_{||}, -\mathbf{k}_{\perp}\}; \mathbf{k}_h = \{\mathbf{k}_{||} + \mathbf{h}, \omega\gamma_h\}$$

GID PXR permits overcome issues with a target damage and radiation absorption (**J. Appl. Phys. 38 (2007) 135**).

To provide that essential to fulfill conditions:

$$z_0 < \lambda\gamma; \quad \gamma = \frac{E}{mc^2}$$

GID PXR INDUCED BY OPTICAL LASER



GID PXR INDUCED BY OPTICAL LASER

(RREPS-2009)

Angular distribution of x-ray quanta:

$$\frac{\partial^2 N^{(s)}}{\partial\theta\partial\varphi} = \frac{\alpha}{2\pi c^2} L_c \frac{\omega}{c} \left| H^{(s)}(\theta,\varphi) \left[\mathbf{u} - \mathbf{v}_0 \frac{\mathbf{k_h u}}{\Omega(1+\beta)} \right] \mathbf{e}_{\mathbf{k_h},s} e^{i\omega\gamma_h z_0} \right|^2 \frac{1}{1 + \frac{\mathbf{k}\,\mathbf{v}_0}{c}}$$

Kinematical conditions for photons:

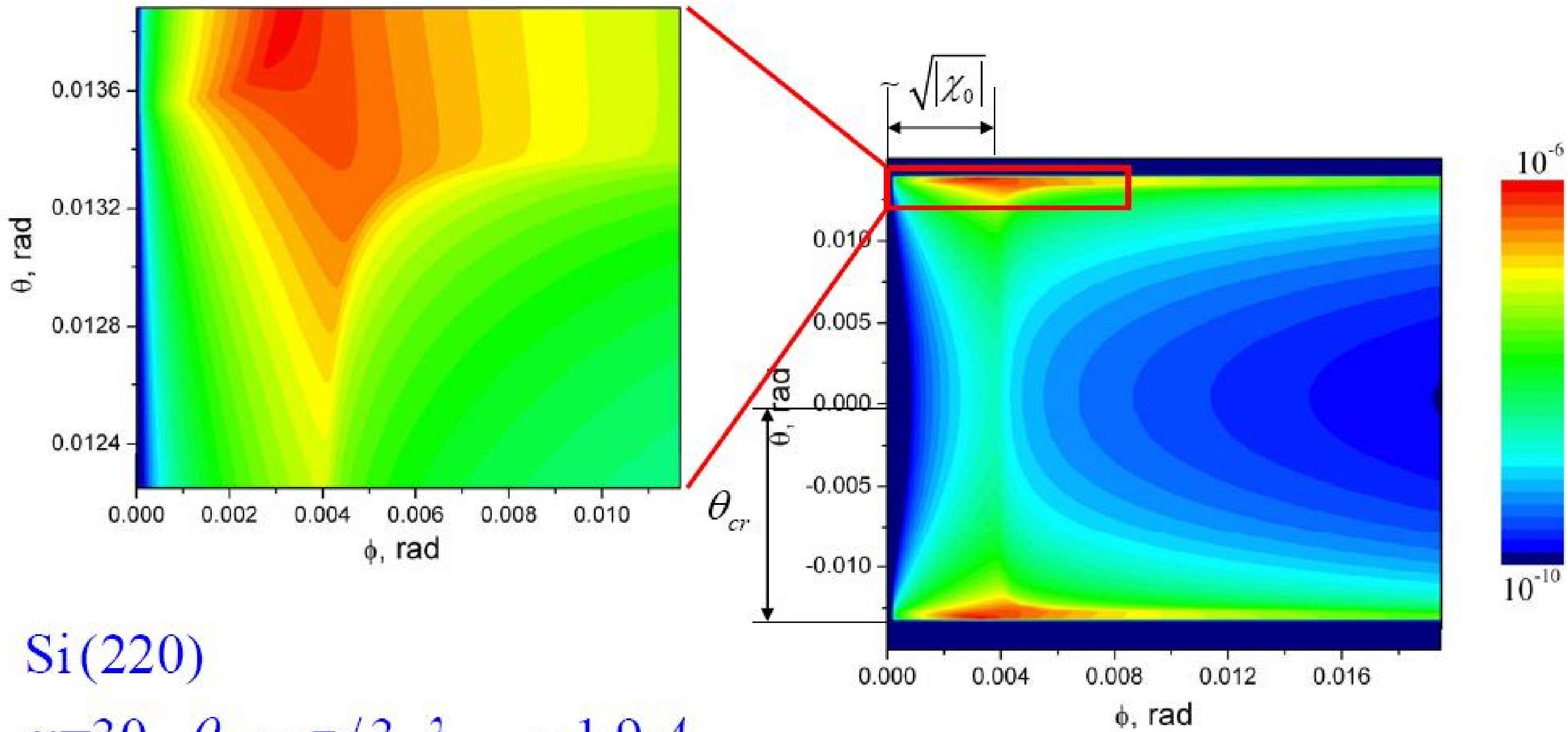
disp: $\omega^2 = \mathbf{k}_h{}^2$ $\qquad$ $\omega\gamma_{\mathrm{h}} = -\sqrt{\omega^2 \mathrm{Sin}(\varphi)^2 - \mathrm{h_x}{}^2 + 2\,\mathrm{hx}\,\omega\,\mathrm{Cos}(\varphi)\,\mathrm{Sin}(\theta_{\mathrm{B}}+\theta)}$

$\int \mathrm{dt} \to \delta(\omega + \mathbf{k}_h\mathbf{v} - \Omega(1+\beta))$ $\qquad$ $\omega = \dfrac{\mathrm{h_x}\beta\mathrm{Sin}(\theta_{\mathrm{B}}) + \Omega(1+\beta)}{1 - \beta\mathrm{Cos}(2\theta_{\mathrm{B}}+\theta)\,\mathrm{Cos}(\varphi)}$

Intensity is independent on z_0 while

$$\theta < \theta_{cr} \sim \sqrt{2\left(\frac{\Omega(1+\beta)}{\omega_B} - \frac{1}{2\gamma^2}\right)}$$

ANGULAR DISTRIBUTION



Si(220)

$\gamma=30,\ \theta_B=\pi/3, \lambda_{\text{x-ray}}=1.9\,A$

$z_0=10^4\text{A}, L_c=1\text{ cm}, \lambda_{\text{laser}}=1.026\,\mu m, W_{\text{laser}}=1\,MWt, D_{\text{focal laser}}=50\,\mu m$

$$Q=\int d\varphi d\theta N_{\mathbf{n}} \sim 10^{-11}\, photon/electron$$

MECHANISMS OF FEEDBACK

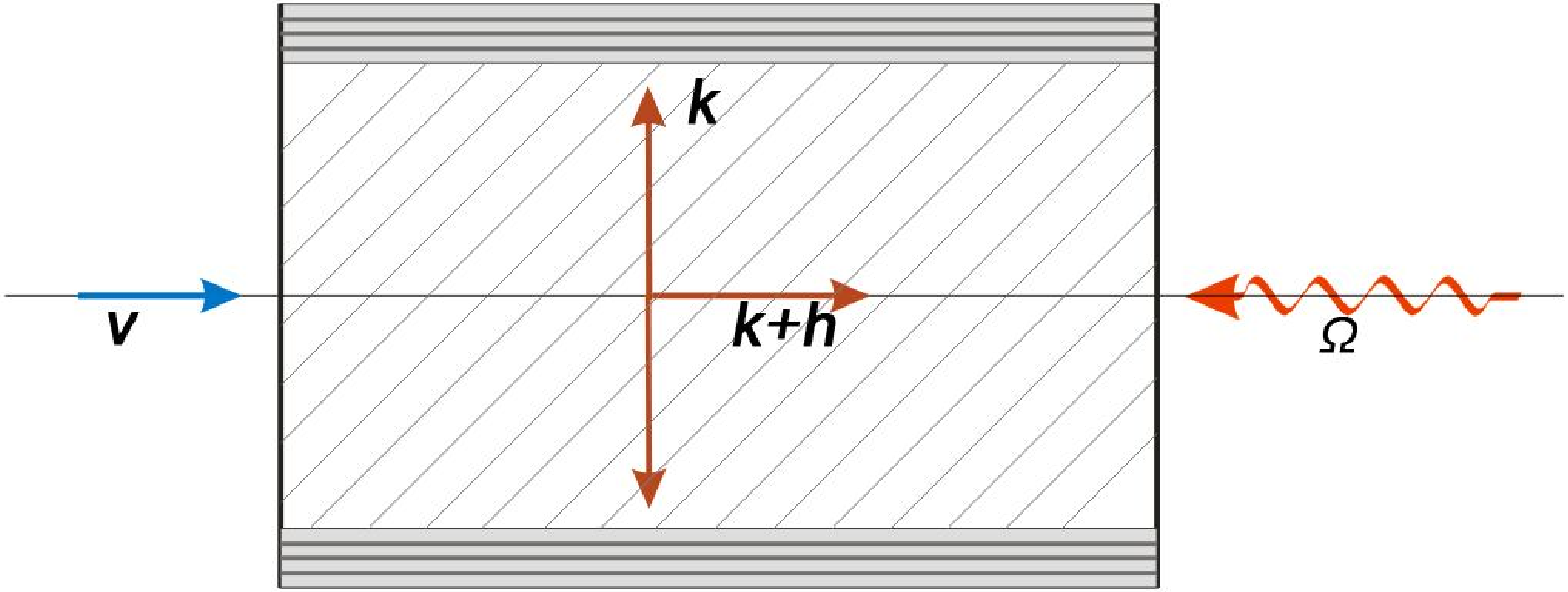
Intensity of the spontaneous radiation is **limited**.
Further enhancement of the spectral density is possible using self-amplification on the expense of electron beam modulation at the feedback presence **(SASE).**

Two basic mechanisms of SASE:
1. Single-pass regime at undulator – operated in XFELs located at synchrotrons of 3rd and 4th generation
2. Distributed feedback (on the use of linear or cavity resonators) – operated in micro-wave generators

For PXR firstly was proposed in **Phys. Lett. 102A (1984) 141** (was demonstrated at INP Minsk – for the microwave range).
For the XFEL -

R. Colella and A. Luccio, Opt. Commun. **50**, 41 (1984).
K. Kim, Y. Shvyd'ko, and S. Reiche, Phys. Rev. Lett. **100**, 244802 (2008).

FEEDBACK FOR FEL PXR-GID



Wave **k** stands for the confinement of the radiation field inside the resonator;

Wave **(k+h)** – for the beam modulation.

Resonator may be implemented using a diamond crystal:

K. Kim, Y. Shvyd'ko, and S. Reiche, Phys. Rev. Lett. **100**, 244802 (2008).

EVALUATION OF THE GAIN (1)

V. Baryshevsky, I. Feranchuk, A. Ulyanenkov. Parametric X-Ray Radiation in Crystals, Springer, 2005, Pages 151-152: Expression for the Gain (G)

$$G \approx \left(\frac{4\pi e^2}{m\gamma^3} |\chi_h| \rho_B \omega^2 a^2\right)^{1/4} cm^{-1}; \;\; \hbar = c = 1$$

ρ_B − Electron beam density

$a = \dfrac{eE_0}{m\Omega}$ − Parameter determining interaction between wave and electron

EVALUATION OF THE GAIN (2)

$\rho_B \approx 3\,10^6\ cm^{-3}; \gamma \approx 10^2;$

$L_{imp} \approx 10^4\,cm; \omega = 5\ keV;$

Electron beam

A 70 Mev racetrack microtron

V.I. Shvedunov[1], A.N. Ermakov[1], I.V. Gribov[1], E.A. Knapp[1], G.A. Novikov[1], N.I. Pakhomov[1], I.V. Shvedunov[1], V.S. Skachkov[2], N.P. Sobenin[3], W.P. Trower*, V.R. Yajlijan[1]

Nuclear Instruments and Methods in Physics Research A 550 (2005) 39–53

$I_L \approx 8.6\,10^{22}\ W m^{-2};$

$L_F \approx 5\,cm; a \approx 0.2$

Laser beam

Modelling properties of hard x-rays generated by the interaction between relativistic electrons and very intense laser beams

Alexandru Popa

J. Phys. B: At. Mol. Opt. Phys. **42** (2009) 025601 (9pp)

$$G \approx 0.4\ cm^{-1};$$

$$\text{for}\quad \omega \approx 2\,keV; \chi_h \approx 10^{-5}$$

CONCLUSION

In order to understand the possibility of the GID PXR FEL implementation, it is needed to perform followed experiments:

1. **Experimental observation of the spontaneous GID PXR at the Compton backscattering of the optical laser beam**
2. **Experimental verification of the SASE effect for GID PXR**

(i.e. observation of nonlinear dependence of the radiation intensity upon the beam current)

THANK YOU
FOR YOUR ATTENTION!