JINR ACTIVITY IN FEL

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Abstract

Different methods for diagnostic of ultrashort electron bunches are developed at JINR-DESY collaboration within the framework of the FLASH and XFEL projects. Photon diagnostics developed at JINR-DESY collaboration for ultrashort bunches are based on calorimetric measurements and detection of undulator radiation. The MCP based radiation detectors are effectively used at FLASH for pulse energy measurements. The new MCP detector for X-ray beam diagnostic for XFEL is under development now in JINR. The infrared undulator constructed at JINR and installed at FLASH is used for longitudinal bunch shape measurements and for two-color lasing provided by the FIR and VUV undulators. The JINR also participates in development and construction of Hybrid Pixel Array Detector on the basis of GaAs sensors. The JINR in collaboration with IAP RAN and DESY (Zeuthen) develops a project of laser system based on Nd laser with pulse shaper for formation of quasi 3D ellipsoidal laser pulses applied for a prototype of XFEL gun.

FLASH MCP-BASED PHOTON DETECTOR

The free electron laser FLASH has been in operation at DESY since the year 2000 [1,2]. The electron energy now reaches 1 GeV, rms bunch length is 50 μm, the FWHM radiation pulse duration is about 30 fs, the normalized emittance is 2 π·mm·mrad, the bunch charge is 1 nC, the peak power is up to 1 GW, the peak brilliance is of 10^{28} ph/s/mrad2/mm2/(0.1%bw).

Successful operation of FLASH strongly depends on the quality of the radiation detectors. The key issues are: the wide wavelength range 6-100 nm, the wide dynamic range (from the spontaneous emission level to the saturation level), and the high relative accuracy of measurements which is crucial for detection of radiation amplification and characterization of statistical properties of the radiation.

The key FLASH photon detector developed by the JINR-DESY collaboration is a micro-channel plate (MCP) detector intended for pulse energy measurements [3-5]. The MCP detector is used for measurement of statistical properties of the radiation allowing determination of the pulse length. Key element of the detector is a wide dynamic MCP which detects scattered radiation from a target. With four different targets and MCPs in combination with optical attenuators, the present FLASH detector covers an operating wavelength range 6 -100 nm, and a dynamic range of the radiation intensities, from the level of spontaneous emission up to the saturation level of SASE FEL.

The gold target is perfect for the wavelength range above 10 nm, however its reflectivity falls dramatically for shorter wavelengths, and different targets and geometries of the detector are used. We added three more targets to gold mesh: two iron meshes, and one copper mesh. This helps us to operate the detector in a range below 10 nm.

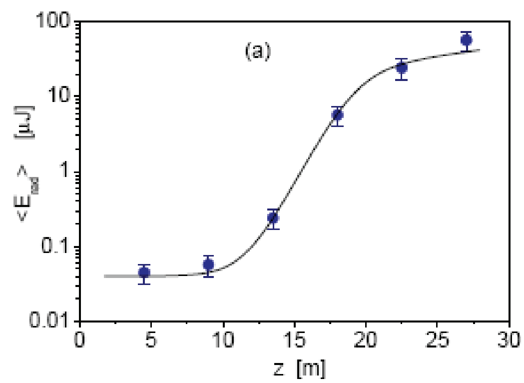

Figure. 1: Measured average energy in the radiation pulse versus the undulator length.

For tuning SASE at very short wavelengths we use movable MCPs directly facing photon beam. Light intensity variation by a factor of 50 is controlled by a mechanical attenuator of light located in the target unit. To have full control of light intensity in a wide range we installed a side MCP which detects radiation reflected by the iron mirror. The mirror serves for two purposes. One is to deflect the photon beam off- the axis, which allows placing the MCP in better background conditions.

The dependence of the measured average energy in the FLASH radiation pulse on the undulator length is shown in Fig. 1. In the saturation regime the average pulse energy is 40 μJ and the wavelength is 13.7 nm.

DEVELOPMENT OF XFEL MCP

The developed XFEL MCP-based detector consists of four main elements: attenuator, frequency filter, MCP equipped with anode as pulse energy monitor, and MCP imaging detector as a viewer of photon beam image (Fig.2). Frequency filter selects frequencies near the required harmonic of the radiation (fundamental, or higher). Technical realization of frequency filter and attenuator depends on the wavelength of interest. For operating wavelength band below 0.4 nm (fundamental harmonic of SASE1 and SASE2) Si (111) crystal (Bragg reflection) is used as a frequency filter, and attenuation is

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performed by a metallic films (Be/Al/Ti). Simulated coordinate (x,z) distribution of 12.4 keV photons in SASE 1 is given in Fig.3. For wavelength above 0.4 nm (fundamental harmonic of SASE3) SiC/W multilayer mirror is used as a frequency filter and attenuation of the signal is performed by a plane SiC mirror in combination with metallic film attenuator. SiC plane mirror is installed in front of multilayer mirror thus protecting the latter one from strong synchrotron radiation background.

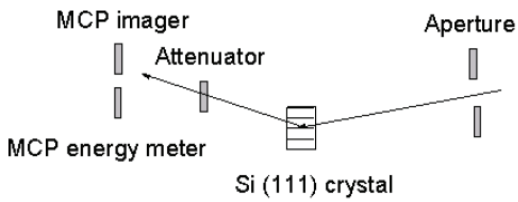

Figure 2: Schematic layout of the MCP-based photon detector at XFEL operating at wavelengths below 0.4 nm.

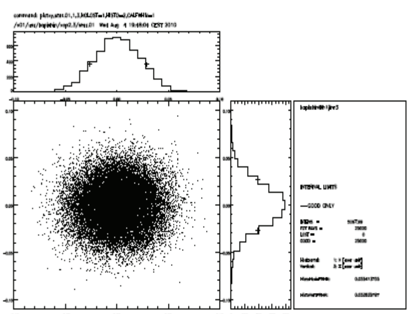

Figure 3: Simulated coordinate distribution of 12.4 keV photons in SASE 1 detected in the MCP imager plane.

FLASH FAR INFRARED UNDULATOR

The FLASH was equipped with an infrared electromagnetic undulator (Fig.4), tunable over a K–parameter range from 11 to 44, and producing radiation up to 200 μm at 500 MeV and up to 50 μm at 1 GeV [5-8]. The purpose of the device is two-fold: firstly, it is used for longitudinal electron bunch measurements, secondly, it is a powerful source of intense infrared radiation naturally synchronized to the VUV FEL pulses, as both are generated by the same electron bunches and being therefore well suited for precision pump-probe experiments.

The undulator was designed and constructed by JINR to the FLASH requirements [5-8]. The undulator period corresponds to 40 cm, the number of periods is 9, the magnetic field is varied in range of 0.1-1.1 T. Output undulator radiation has the following parameters: wavelength 5-200 μm, peak power 4 MW, micropulse energy 1 mJ, micropulse duration 0.5-6 ps. The spectrums of FLASH infrared undulator at different K-parameters are given in Fig.5.

Figure. 4: FLASH far infrared undulator constructed by JINR.

The energy radiated by the undulator is defined by the number of electrons per bunch N and a form-factor F(λ):

$$\varepsilon_{coh} = \varepsilon_e \times \left[N + N(N-1)\left|\bar{F}(\lambda)\right|^2 \right],$$

where ε_e is energy radiated by single electron. The form-factor is equal to $|F(\lambda)|^2 = \exp(-2\pi\sigma/\lambda)^2$ for Gaussian bunch with r.m.s. length σ. When the wavelength is longer than the bunch length, the coherent radiation dominates. Measuring the spectrum (Fig.5) that regime one can extract the form-factor and thus the charge distribution and the bunch leading spike length. The Gaussian fit (Fig.6) corresponds to the r.m.s. leading spike length of σ_{ls}= 12 μm.

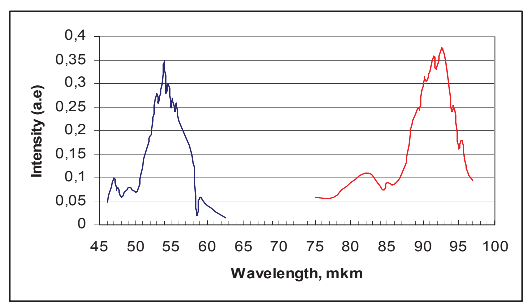

Figure 5: Spectrums of infrared undulator radiation.

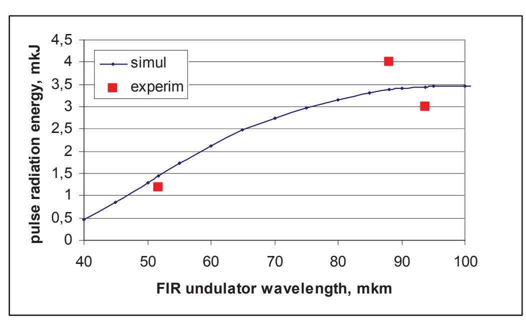

Figure 6: Dependence of the FIR undulator pulse radiation energy on the wavelength.

HYBRID PIXEL ARRAY DETECTOR

A bunched electron beam of extremely high quality is needed in the XFEL to get coherent radiation in subnanometer wavelength [10]. JINR in collaboration with Tomsk State University (TSU) and DESY design Hybrid Pixel Array Detector on basis of GaAs (Cr) detectors (Fig. 7) [11] in the frame work of the Russian-German project GALAPAD oriented on the development of the photon diagnostic systems. The technology of the pixel detector with resolution of 50 μm was developed on basis of the JINR-TSU GaAs (Cr) sensors and the Medipix (Swiss) chips. The peculiarity of the detector with Medipix chip that it measures the spectral characteristic of the X-ray radiation.

Figure 7: Spectrometric detector on basis of GaAs (Cr) pixel censor with 256×256 channels of 50 μm resolution and Medpix chip.

The sensitivity of GaAs detector is essentially improved in comparison with Si detector at photon energy larger 15 keV (Fig.8).

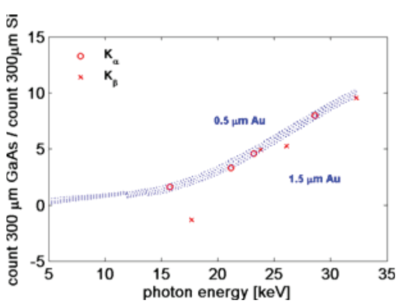

Figure 8: Dependence of ratio of counts in GaAs and Si detectors on photon energy.

FORMATION OF 3D ELLIPSOIDAL LASER PULSES

The JINR in collaboration with Institute of Applied Physics RAN and DESY (Zeuthen) develops a project of laser system based on Nd laser with pulse shaper for formation of quasi 3D ellipsoidal laser pulses applied for a prototype of XFEL gun. By optimization the main parameters of the XFEL photo injector one can simulate rather small projected normalized emittance: 0.46 mm mrad. Slice emittance of the bunch centre reduced in ~10% by applying an ellipsoid laser pulse [12]. Main reduction of the projected emittance (Fig.9) is due to significant decrease in head and tail slice emittance of the ellipsoid.

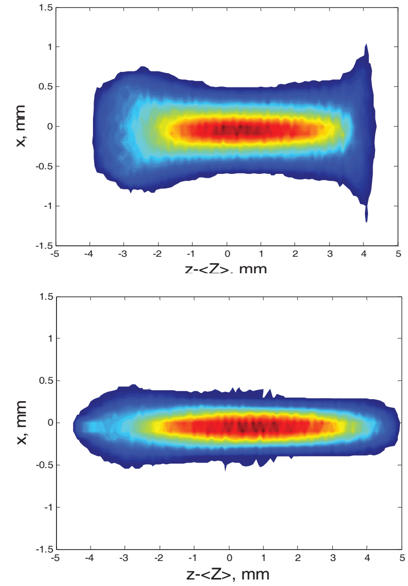

Figure 9: Transverse electron bunch shape for cylindrical (upper) and ellipsoid (down) laser shape pulses at a distance of 15 m [12].

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