



Automatic gain adjustment and calibration of intensity monitors for sFLASH

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Abstract

Direct seeding is intensively studied at FLASH facility. This project (sFLASH) challenges the researchers to establish six-dimensional overlap between electron bunch and seeding laser pulse. In order to accomplish this task, several diagnostic blocks are used. One of them is the photon diagnostic branch, which is used for monitoring of the radiation (intensity, statistical properties). It includes 3 micro-channel plates (MCP), which are used to detect XUV radiation in a wide range of intensity. The dynamic range of MCP can be modified by application of appropriate voltage to electrodes. My purpose is to automatize the adjustment of the gain, using the calibration formula, determined by previous summer students.

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1 Introduction

The FEL (Free Electron Laser) produces intense radiation by means of a relativistic beam of electrons. The electrons pass through an undulator, where they perform a sinusoidal trajectory. The undulator radiation in forward direction is described by formula

$$\lambda_{ph} = \frac{\lambda_u}{2\gamma^2} \left(1 + \frac{K^2}{2}\right) \quad (1)$$

where λ_{ph} is the wavelength of the emitted radiation, λ_u is the period of the undulator, γ is the ratio between total energy and rest energy of the electron.

Self-Amplified Stimulated Emission (SASE) occurs, when an electron beam with a sufficient electron density interacts with electromagnetic field created via spontaneous emission of undulator radiation (Fig. 1). In the undulator the electrons, which are in phase with electromagnetic field, are retarded and the electrons, which are in opposite phase, are accelerated. This leads to micro-bunching of the uniform electron cloud in discs with a distance of λ_{ph} between them (Fig. 2). Therefore electrons begin to radiate coherently, which leads to an exponential growth of radiation intensity.

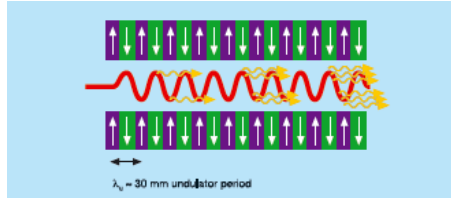


Figure 1: Self-Amplified Stimulated Emission in an undulator results from interaction of electrons with spontaneous radiation they emit.

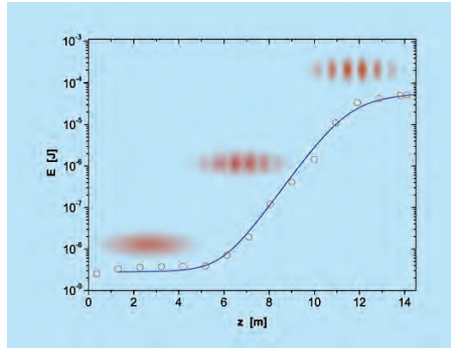


Figure 2: Micro-bunching (real number of micro-bunches is around 10^5) and exponential growth of radiation power. [1]

The FEL radiation pulse consists of a large number of wavepackets. Within one wavepacket the radiation is transversely and longitudinally coherent, but the wavepackets are completely uncorrelated due to the start-up from shot noise: since the electron

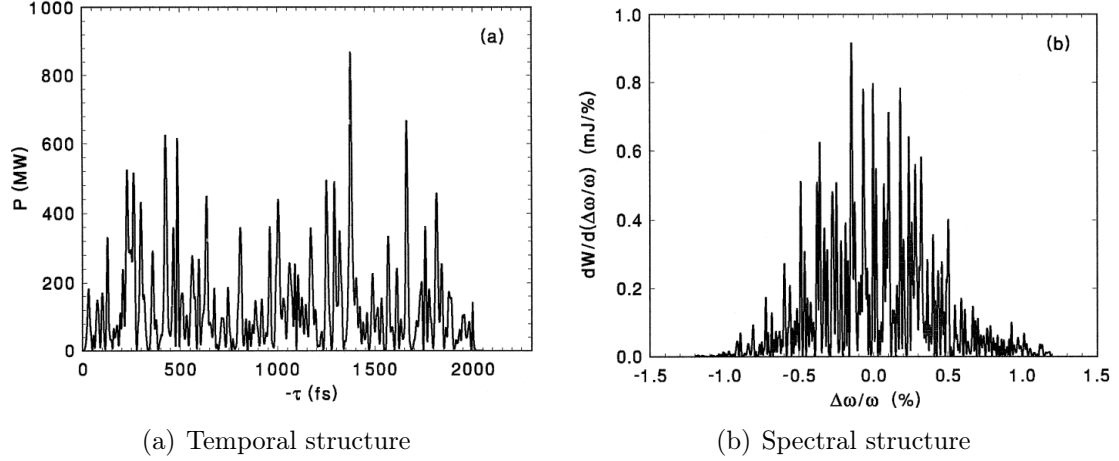


Figure 3: Properties of a pulse produced in SASE regime [2] p. 395

bunch consists of discrete charges, the charge density exhibits fluctuations which are random in time and space (Fig. 3). As a result, the radiation produced by such a beam has a ‘spiky’ spectrum (Fig. 3(b)). In order to improve the longitudinal coherence, one can use a seeding laser. It is obvious that the seeding laser should provide stable pulses and the intensity should be higher than noise from spontaneous radiation.

2 FLASH facility

The FEL user facility in Hamburg FLASH consists of accelerator modules, which accelerate electrons to the energy of 1.2 GeV, and a 27 m long fixed-gap undulator (Fig. 4). The electrons are produced in an electron gun by means of a laser-driven photoinjector. The bunch charge is usually 0.5 nC. The bunch compressors are used to increase the peak current up to 1000 A or more. As a result, femtosecond pulses with average energy of 70 μ J and the peak energy of 130 μ J are delivered [1].

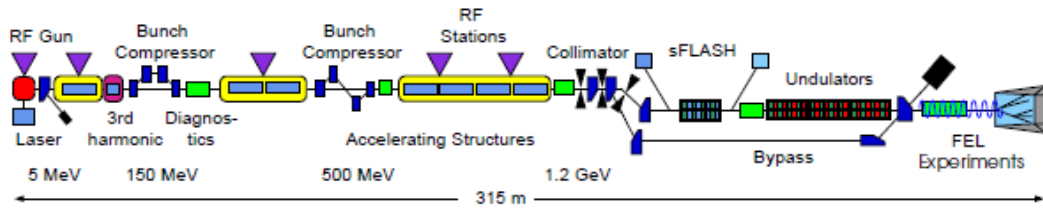


Figure 4: FLASH layout.

3 sFLASH Experiment

Currently FLASH is operated in the SASE regime. An experiment for direct seeding is set up (sFLASH) upstream of the existing SASE undulators. The sFLASH experiment allows seeding FLASH externally with higher harmonics of an optical laser (800 nm). As a result, longitudinal coherence will be improved, which is highly required in precise pump-probe experiments. The radiation from high harmonic generation (HHG) is injected into the accelerator upstream of the undulators. For the experiment the 21st harmonic (38 nm) is used, delivering energy pulses in the nJ range [3].

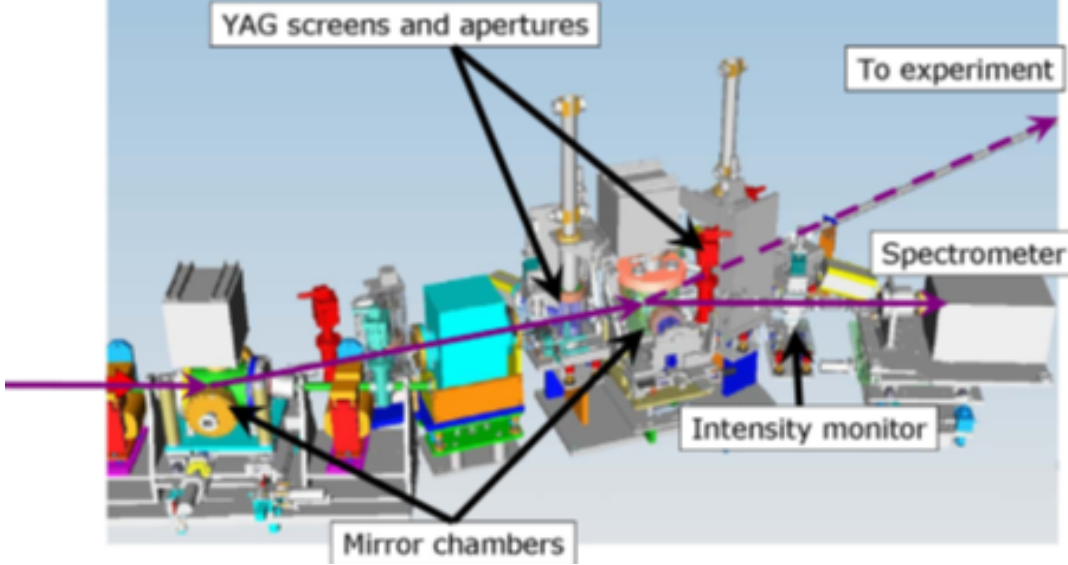


Figure 5: Layout of the diagnostic branch. [3]

The electron beam is bended in a small magnetic chicane, then, due to a mirror triplet, the synchrotron radiation is extracted from the electron beamline. Then, the photon beam passes a transversal diagnostic unit equipped with a Ce:YAG screen, observed by two cameras, and different apertures. The switching mirror reflects the photons either towards the diagnostic branch equipped with an intensity monitor and an XUV spectrometer or towards an experimental hutch (Fig. 5), adjacent the FLASH tunnel.

3.1 sFLASH diagnostic branch

Diagnostics of the intensity of FEL radiation is carried out with three MCP detectors, which measure the intensity of light scattered from a gold mesh, tilted by 45° with respect to the incoming beam. One MCP detects scattered photons perpendicular to the incoming beam, and other two MCPs measure the intensity of the light scattered at small or large angles with respect to the incoming radiation (Fig. 6(a) and Fig. 6(b)).

The MCPs used in the sFLASH experiment consist of a plate with an array of small channels, which act as continuous dynode-photomultipliers. All MCPs have two

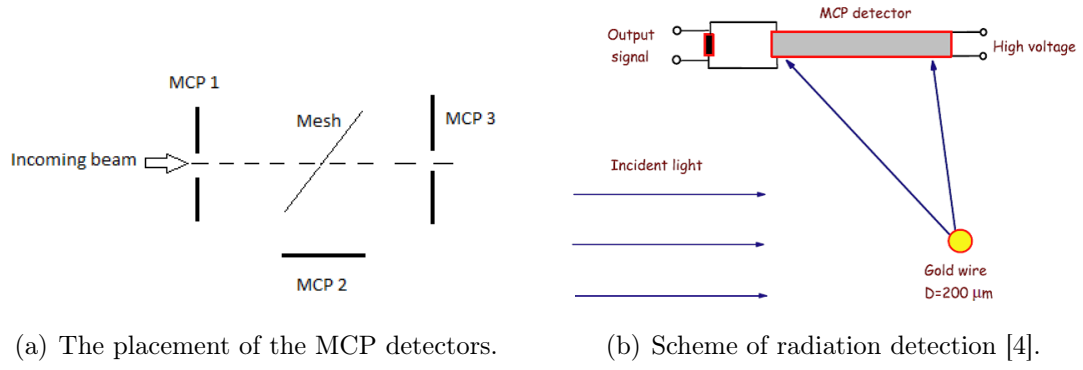


Figure 6: Nondestructive beam monitoring.

stages (chevron shape). The gain of the MCP can be changed in a wide range, applying different voltage to it. Thus, a wide range of radiation intensities is covered, from the level of spontaneous emission or HHG radiation up to the saturation level of SASE or the seeded FEL. The signal from the MCP is amplified in an amplifier, stretched, and then converted into a digital signal in an ADC. The ADC output, read from the DOOCS server looks like the plot in Fig. 7.

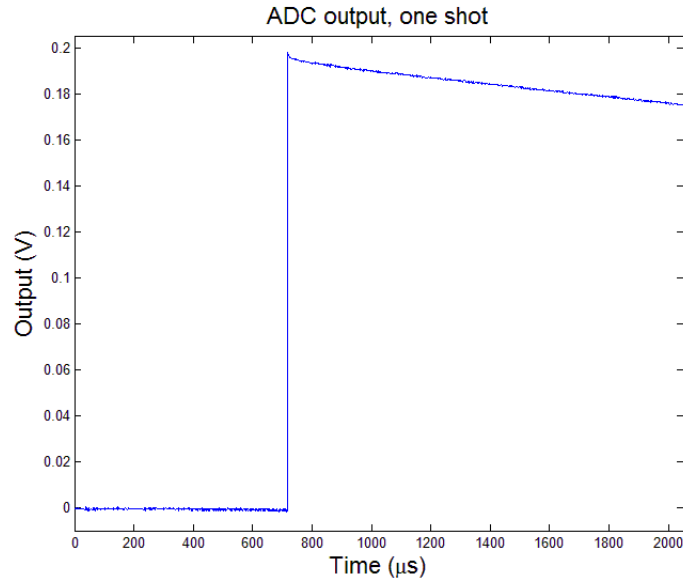


Figure 7: Shape of the signal from MCP.

4 Processing the MCP output

The signal is the pulse that appears at 700 μs (see Fig. 7). It is proportional to the intensity of the incoming beam. There is a background signal before the pulse and an

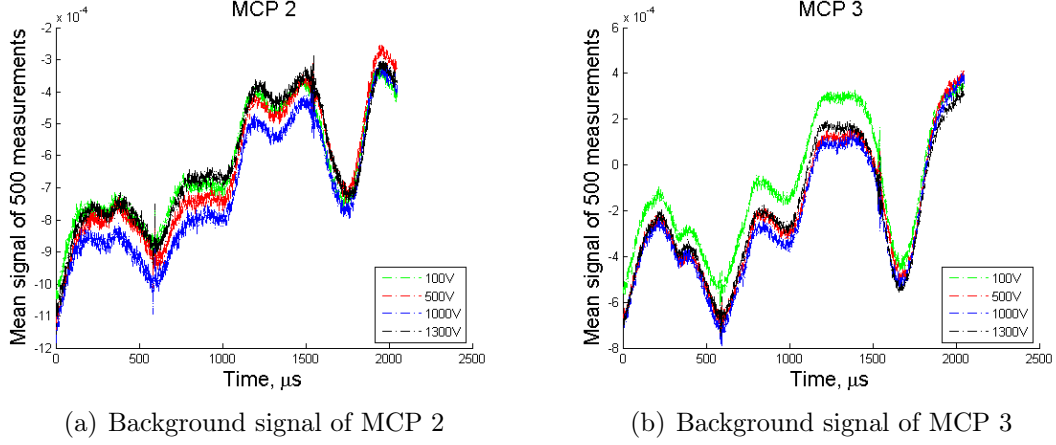


Figure 8: The mean background signal of 500 shots at different applied voltage.

exponential decay after, caused by the signal stretcher (Fig. 8).

An important feature is the nearly exponential dependence of the signal from the high voltage applied to MCP. The plot from Fig. 9 in semi logarithmic scale is almost linear, which proves the former supposition. For an absolute calibration one needs to know the MCP gain function, namely the dependence of the MCP gain for different high voltages. One can fit the MCP gain using the function:

$$G = \exp(a + b \cdot V + c \cdot V^2 + d \cdot V^3) \quad (2)$$

where G is the gain (amplification coefficient of the MCP), V is voltage and a, b, c, d are the polynomial parameters [4].

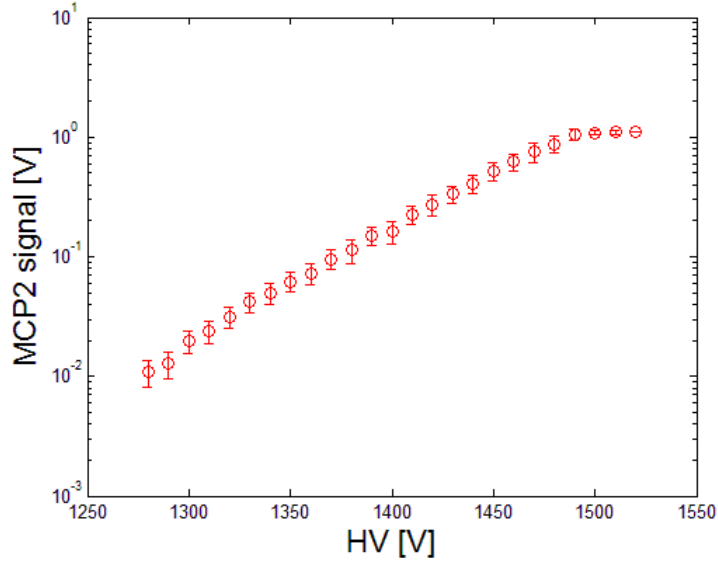


Figure 9: The output of MCP 2 at an input intensity of about 50 pJ.

Due to the saturation of ADC at 1.1 V, the exponential law 2 is not applicable anymore for MCP output, higher than 1 V. The noise prevents the measurement of low signal. My aim was to automatize the process of reaching the optimal voltage, applied to the MCPs by means of a user-friendly MATLAB program.

5 Description of the program

The program consists of 6 or 7 functions (in dependence of the method, used to calculate the output of the MCP). The most important functions are:

- *MCP_gain_control*
- *change_HV*
- *check_to_change_HV*
- *check_signal*

The main function *MCP_gain_control* sets the values of the voltage, which is applied to the MCP. These values were taken from the report of the previous summer student Marek Oja:

```
HV = [670 710 790 870 1050 1120 1190 1200 1250 1350 1450 1500 1550 1600
1650 1700 1750 1800];
```

In order to set the voltage, appropriate for the incoming intensity, a *while* loop was chosen. It has a timeout (1 min by default), but usually the best voltage value is found much faster (less than 20 sec for stable beam). The information about the MCP output is displayed in MATLAB Command Window after each iteration. In case the signal is not detected even at the highest voltage, the program asks for stopping and returning with an error, or proceeding for 1 min. Message boxes with information about exceeding the calibration range are provided. The subfunction *SetHV* gathers all the required commands for setting the voltage to a predefined value. The function *change_HV* executes the change of the voltage. A *while* loop with temporal constraints waits before the voltage reaches the set value with an accuracy of 1 V. A wait bar monitors this process. This function can be used in other programs where the voltage is changed often. More robust usage of *change_HV* is after an investigation of the experiment setup by means of the function *check_to_change_HV*:

```
check_message = check_to_change_HV(HV);
if strcmp(check_message{1}, '')
err = change_HV(MCP_HV_set_DOOCS, MCP_HV_read_DOOCS, HV);
```

Check_to_change_HV function returns two types of error messages: *err1* are the obstacles that prevent any photon to hit the detector. *err2* restricts to detect the radiation from HHG only. The function *check_signal* determines whether the signal

from the MCP is detected or not; if detected, it is assessed with 3 qualifiers: 'low', 'in range' and 'saturated'. The limit of detection is defined to be 5σ of the standard deviation of the background signal of one channel ($4 \cdot 10^{-4}V$). The boundaries of the desired signal range are taken from the interval, where nearly linear dependence of the signal from high voltage in logarithmic scale occurs ($0.05 \div 0.7V$). Two methods for MCP output calculation are available: taking the background signal or not. In the first method, the background signal is taken at the beginning and then it is subtracted from the MCP output. In the second method, the differential of the MCP output is taken. As a result a function, which resembles a delta function is obtained (Fig. 10), where the pulse height corresponds to the MCP signal:

```
differential_of_signal = diff(mean_signal);
```

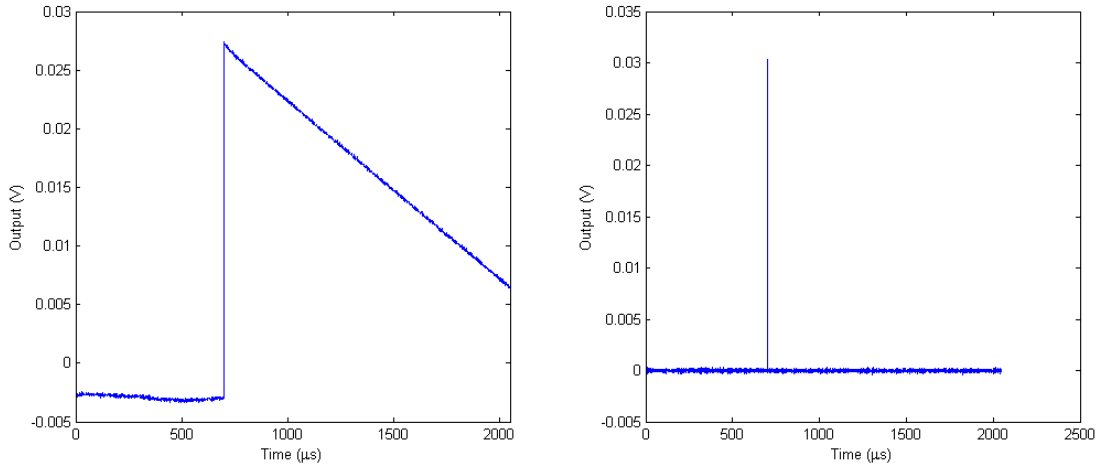


Figure 10: The output of MCP 3 (average of 10 shots) and the output differential.

The signal and its information are transferred to *MCP_gain_control*, where the voltage is increased or decreased in dependence of the qualifier.

6 MCP gain function

As mentioned above, the MCP output is proportional to the intensity of the incoming beam and exponentially dependent of the applied voltage (Equ. 2). Hence,

$$s = \frac{\varepsilon}{\varepsilon_0} \cdot G \quad (3)$$

where ε is the energy, $\frac{1}{\varepsilon_0}$ is a normalizing factor, s is the MCP output and G is the gain. In order to do an absolute calibration of the MCP, the gain function G and normalizing factor are to be calculated. Because G is an exponential function, it was decided to take as many as possible data for the fitting. The measurements for each MCP, using

voltages with narrow spans between (10 V) were done. For covering a larger range of high voltages, 3 different incoming energies were used: full flux from HHG, about 1/4 of the full flux (Al-filter) and 1/12 of full flux. The results of the measurements are presented in Fig. 11.

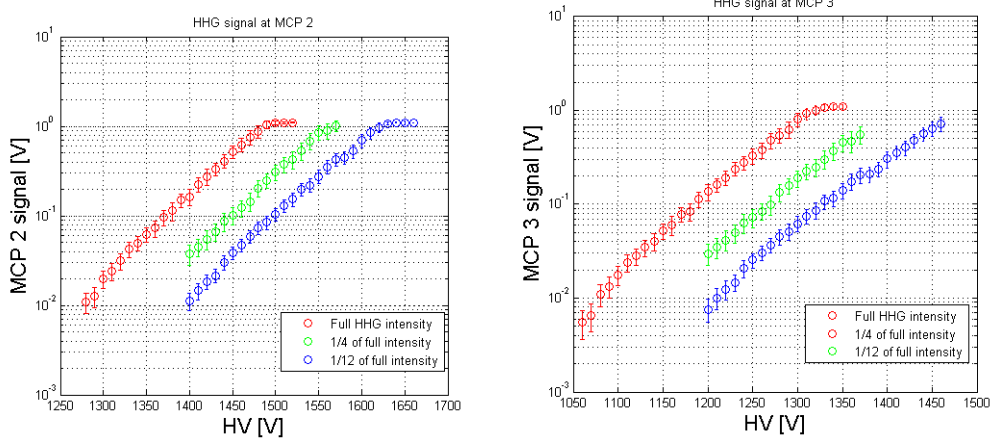


Figure 11: The results of the measurements for MCP 2 and MCP 3.

These data were used for determination of the gain function. The data with saturated signal were neglected. The data for fitting to the gain function G were found, using formula: $G = \frac{\varepsilon_0}{\varepsilon} \cdot s$, where $\frac{\varepsilon_0}{\varepsilon}$ is 1, 4.7 ± 0.4 , 3.0 ± 0.3 for each measurement. The result is in the Fig. 12.

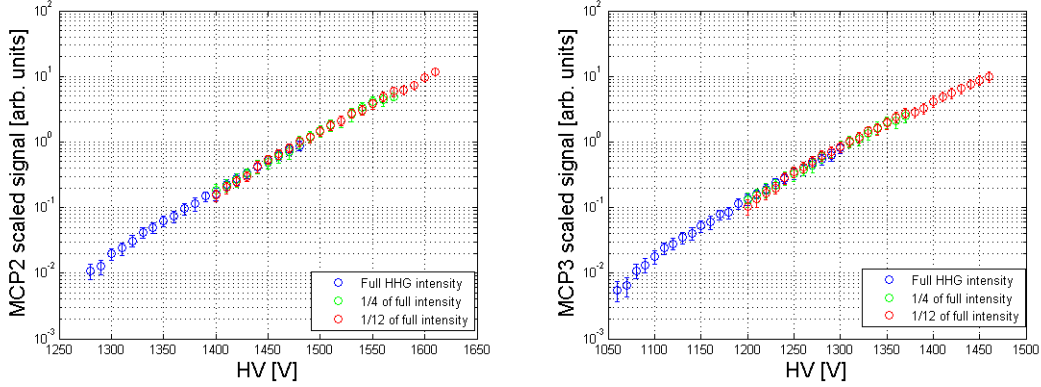


Figure 12: The data, used in the fitting to the gain function.

The results of the fitting with 3 parameters for MCP 2 and MCP 3 are shown in Fig. 13 and 14.

The result from the fitting with 4 parameters (used in [4]), shows that parameter $d = 2.8 \cdot 10^{-37}$ can be neglected. Therefore, only the quadratic polynomial in the exponent is used. ε_0 is the energy from the HHG source, which reaches the mesh. Taking into account the energy losses on the mirrors, $\varepsilon_0 = 50 \pm 20$ pJ. The absolute calibration will

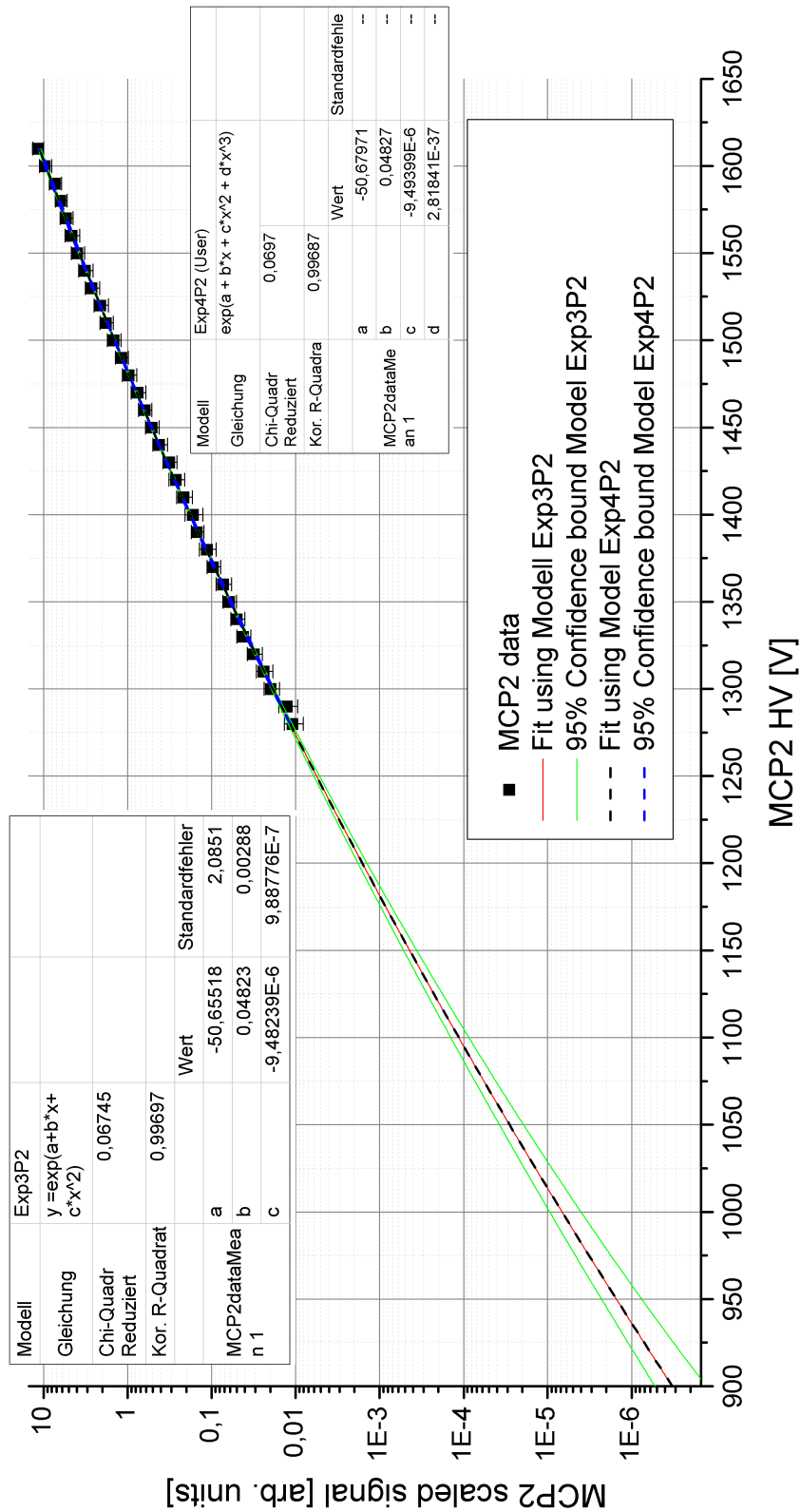


Figure 13: The results of the 3 and 4-parameter fitting for MCP 2.

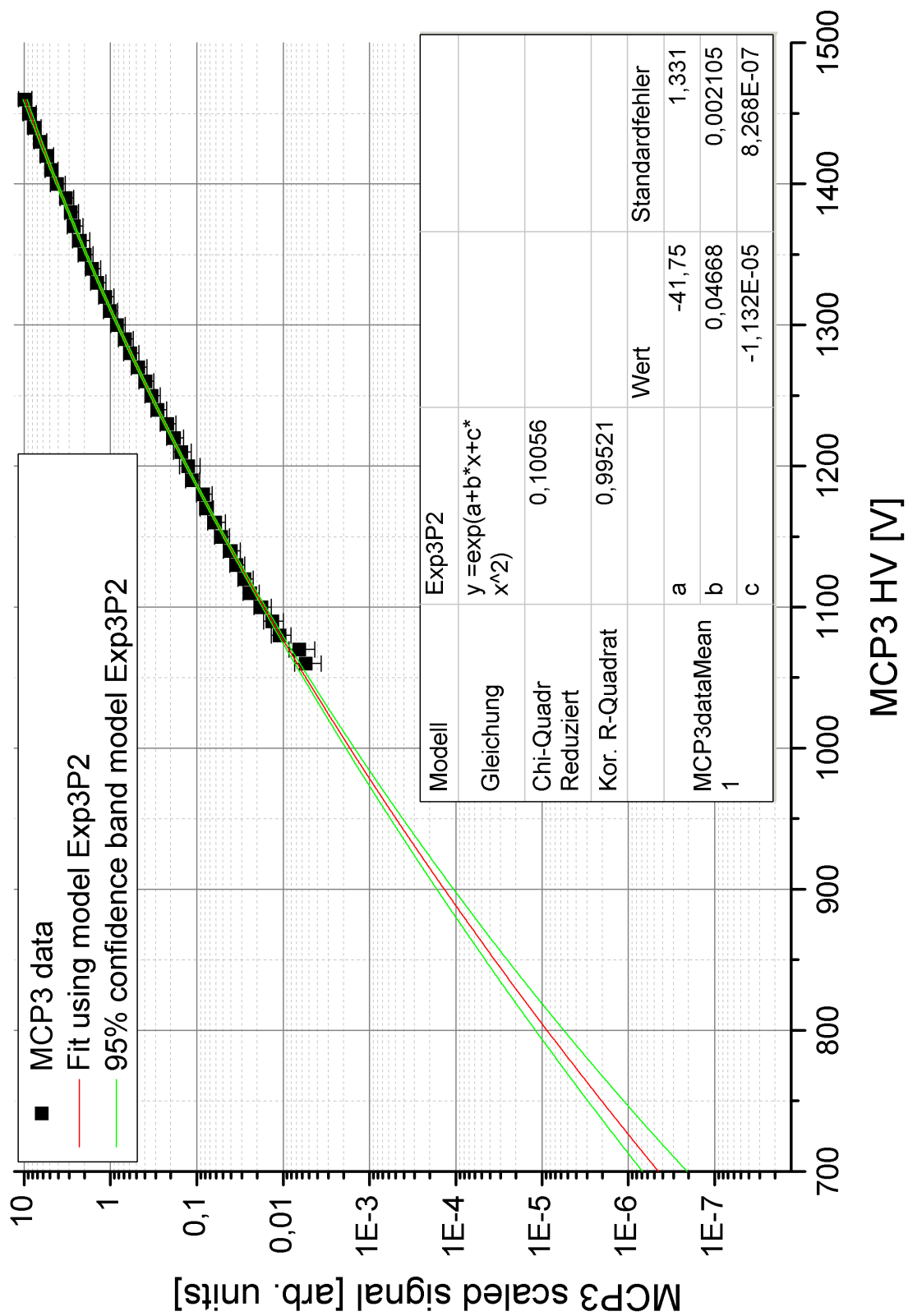


Figure 14: The results of the 3-parameter fitting for MCP 3.

be used for determination of energy pulses in μJ from SASE or seeded radiation, after the automatic gain adjustment provided by *MCP_gain_control* function.

7 Outlook

Program for adjusting the gain of the MCPs was tested on the BKR computer. Next step is building a graphical interface, which will deliver the energy value of synchrotron radiation in real time. For this purpose the absolute calibration function will be used along with the *MCP_gain_control* function. For testing the obtained calibration function, one should do more measurements. Special attention should be paid for the behaviour of the gain function in high energy regime.

References

- [1] <http://flash.desy.de/>
- [2] E.L. Saldin et al. *Statistical properties of radiation from VUV and X-ray free electron laser*. // Optics Communications 148 (1998). P. 383-403
- [3] J. Bödewadt et al. *sFLASH - First results of direct seeding at FLASH*. // Proceedings of FEL2010, Malmö, Sweden
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