Photon Diagnostics at the Free Electron Laser FLASH

Dr. Ilka Mahns

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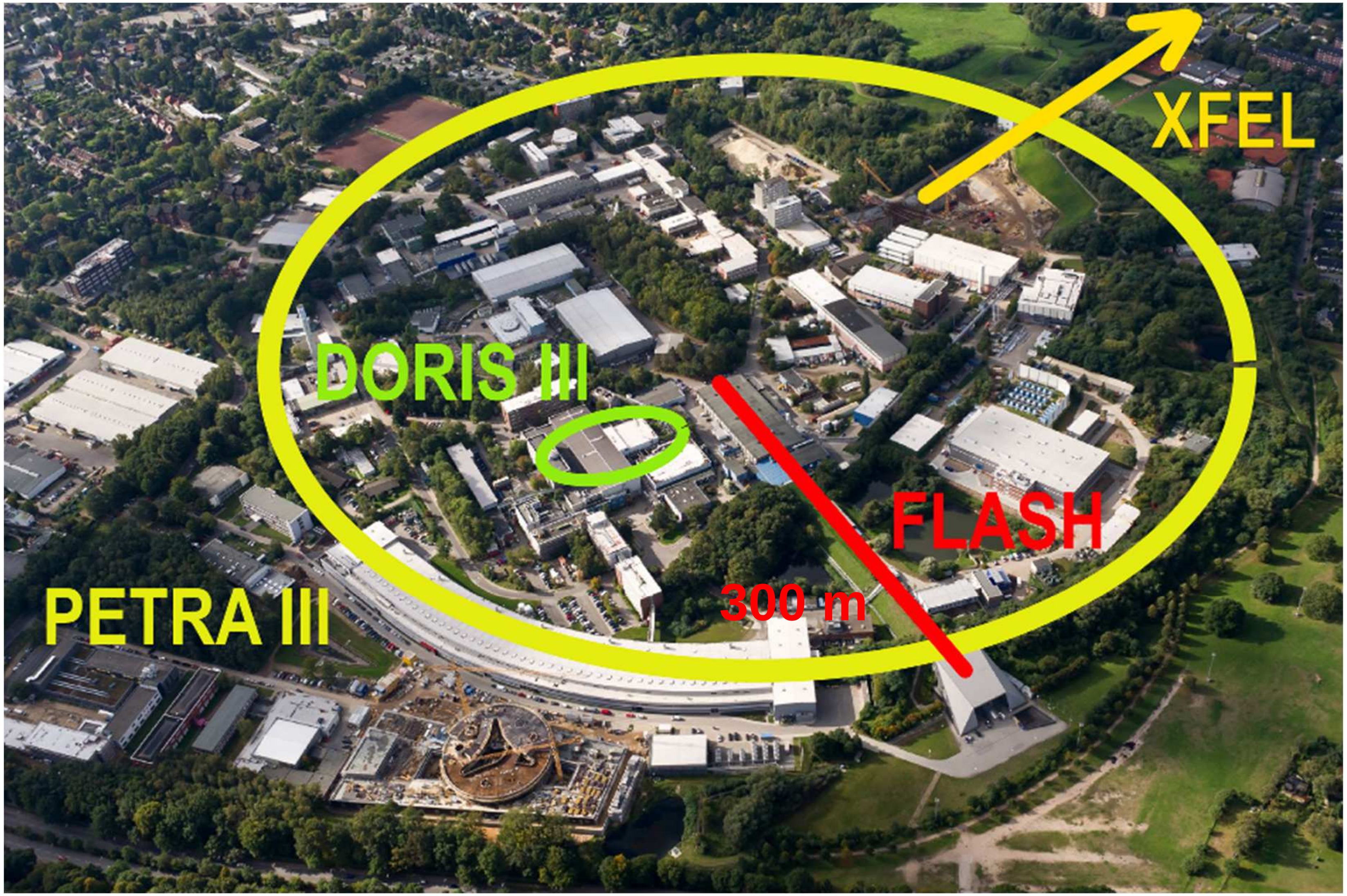
HELMHOLTZ | ASSOCIATION

DESY

Outline.

- Photon Beam Transport and Layout of the Facility
- Photon Beam Properties
- Diagnostics Tools
  - Intensity
  - Beam Position
  - Intensity Profile on the Sample / Focus Size
  - Spectral Distribution
- Summary and Outlook

FLASH = Free-electron LASer in Hamburg.

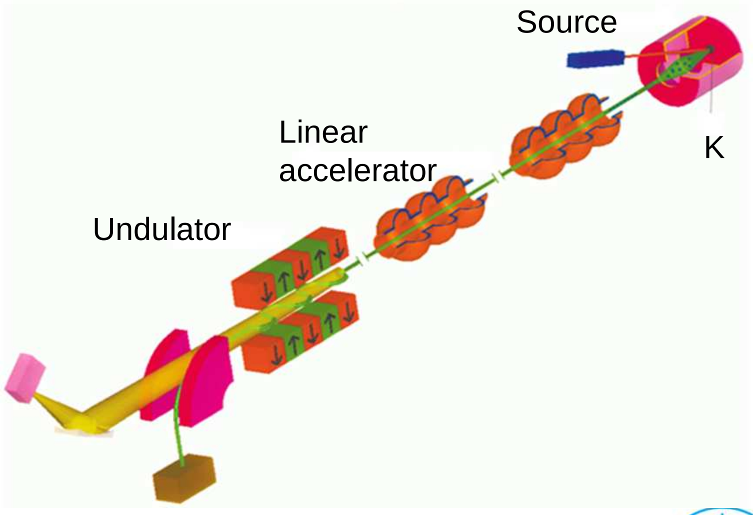


LINAC driven **SASE** free electron laser

FLASH Undulators.

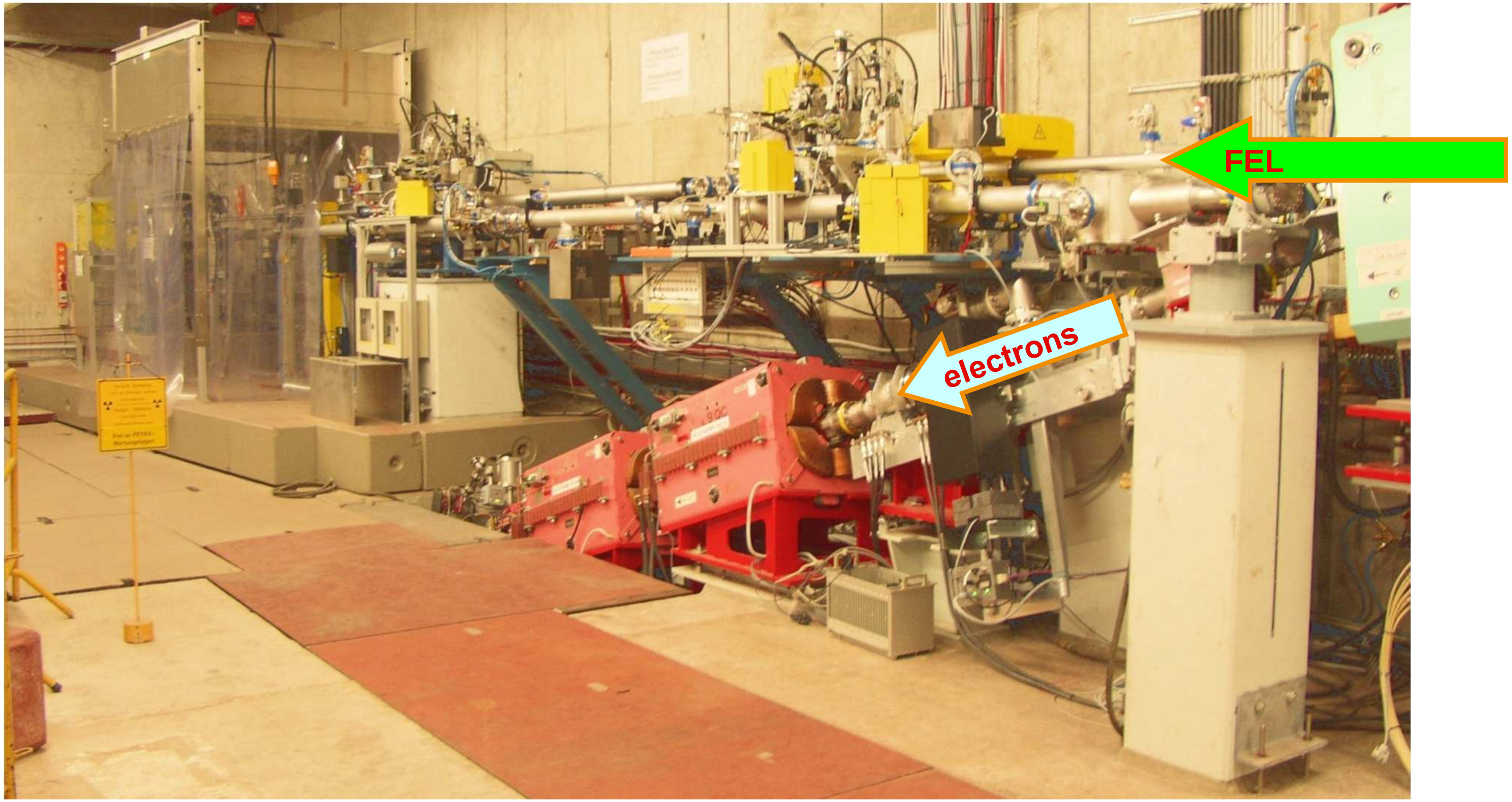
- 6 undulator modules (4.5 m each)
- Gap height: $g = 12$ mm (fixed)
- Period: $\lambda_u = 27$ mm
- Peak magnetic field: $B_0 = 0.47$ T

Wavelength tuning by changing electron beam energy



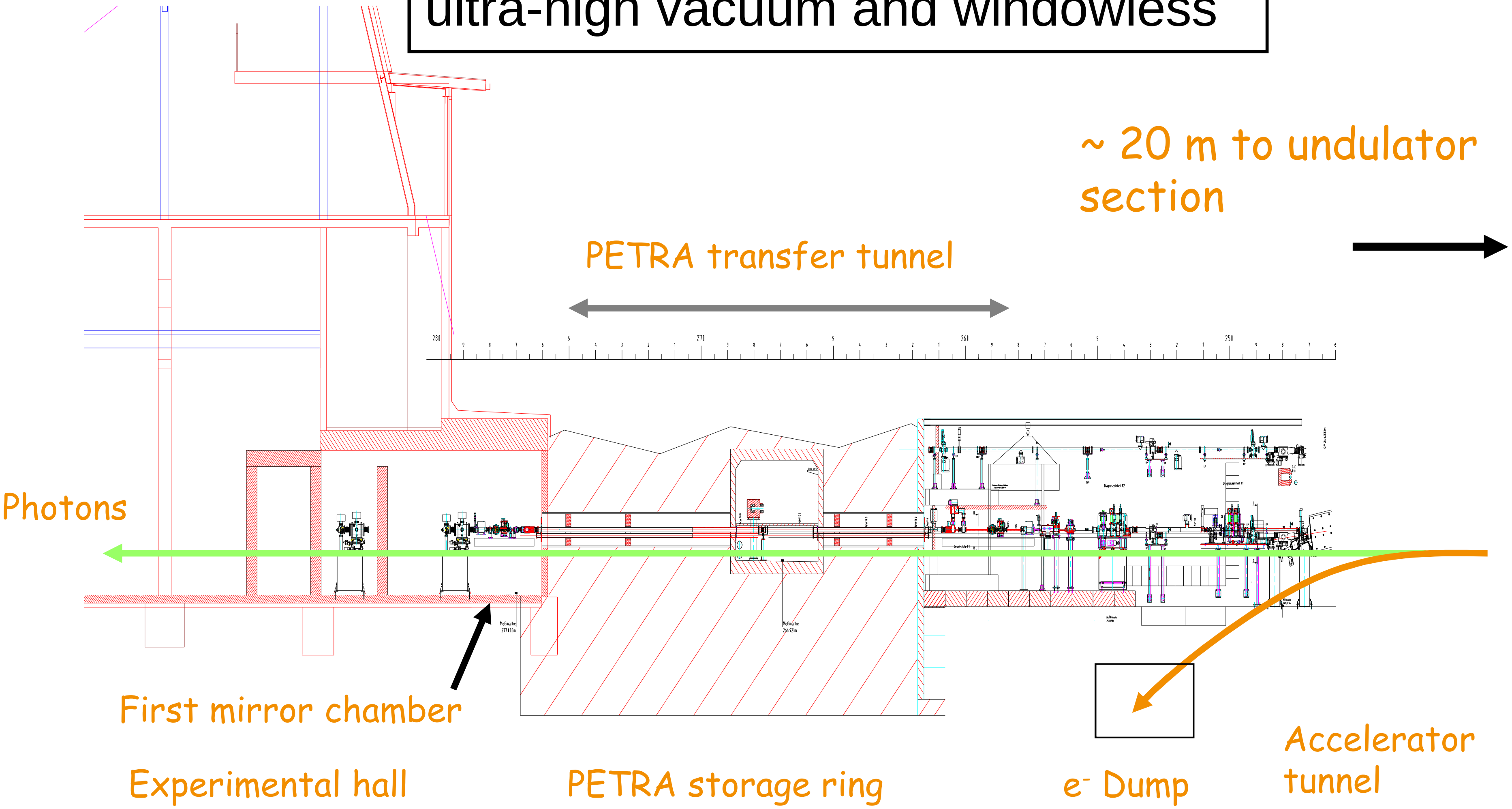
FLASH Beam Dump.

Start of the photon beam transport

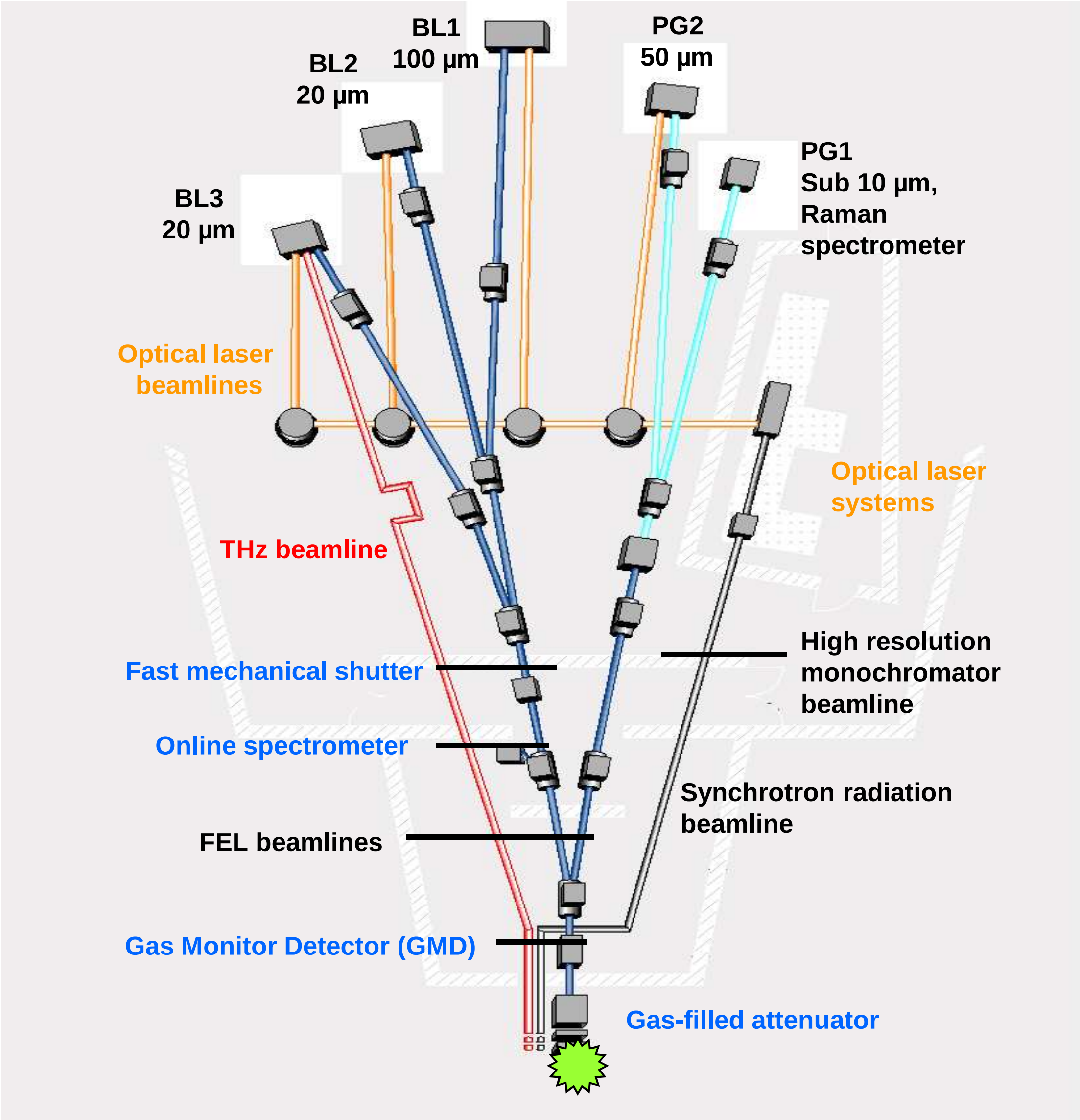


Photon Beam Transport.

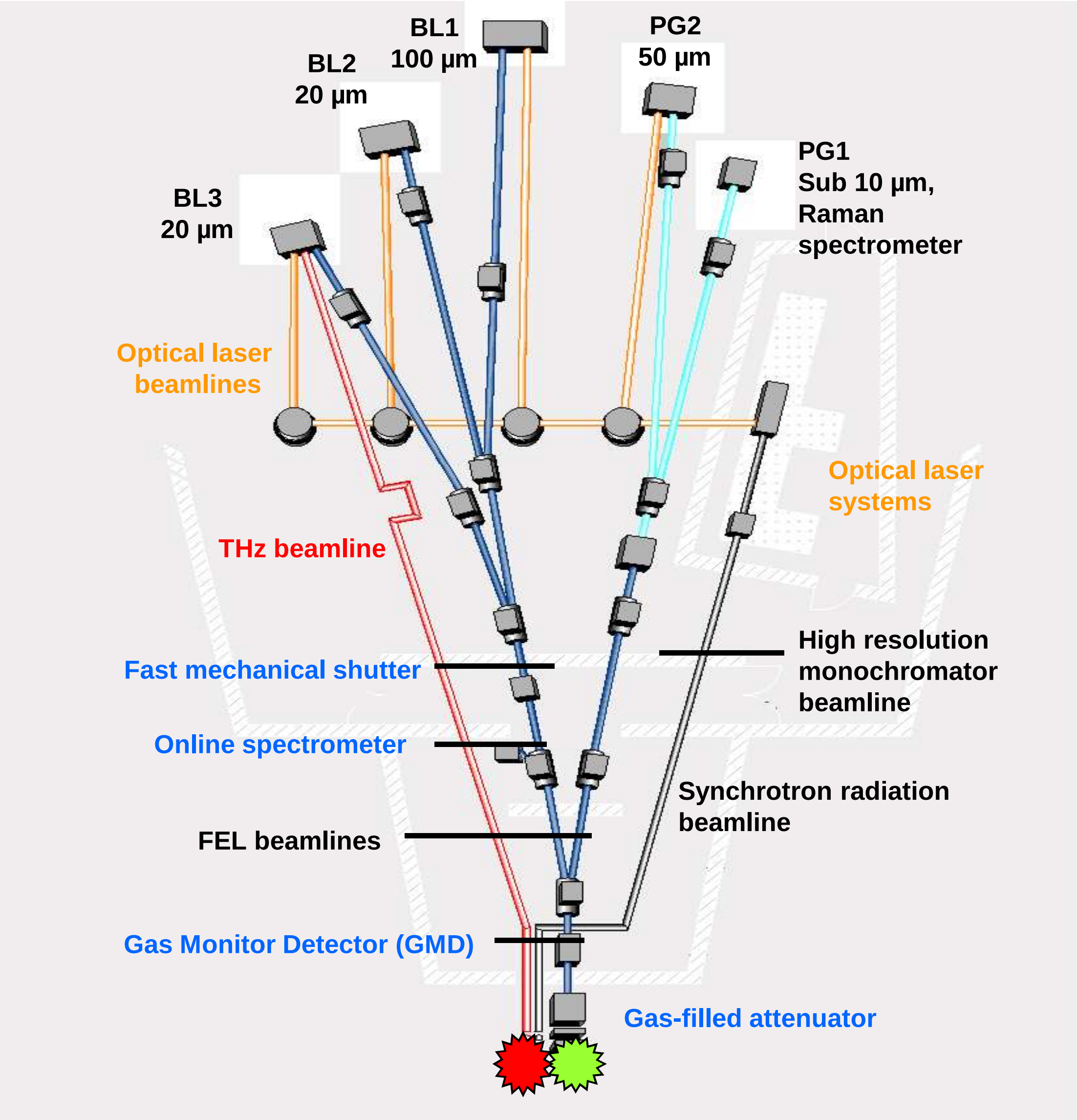
ultra-high vacuum and windowless



Experimental Area of FLASH.



Experimental Area of FLASH.



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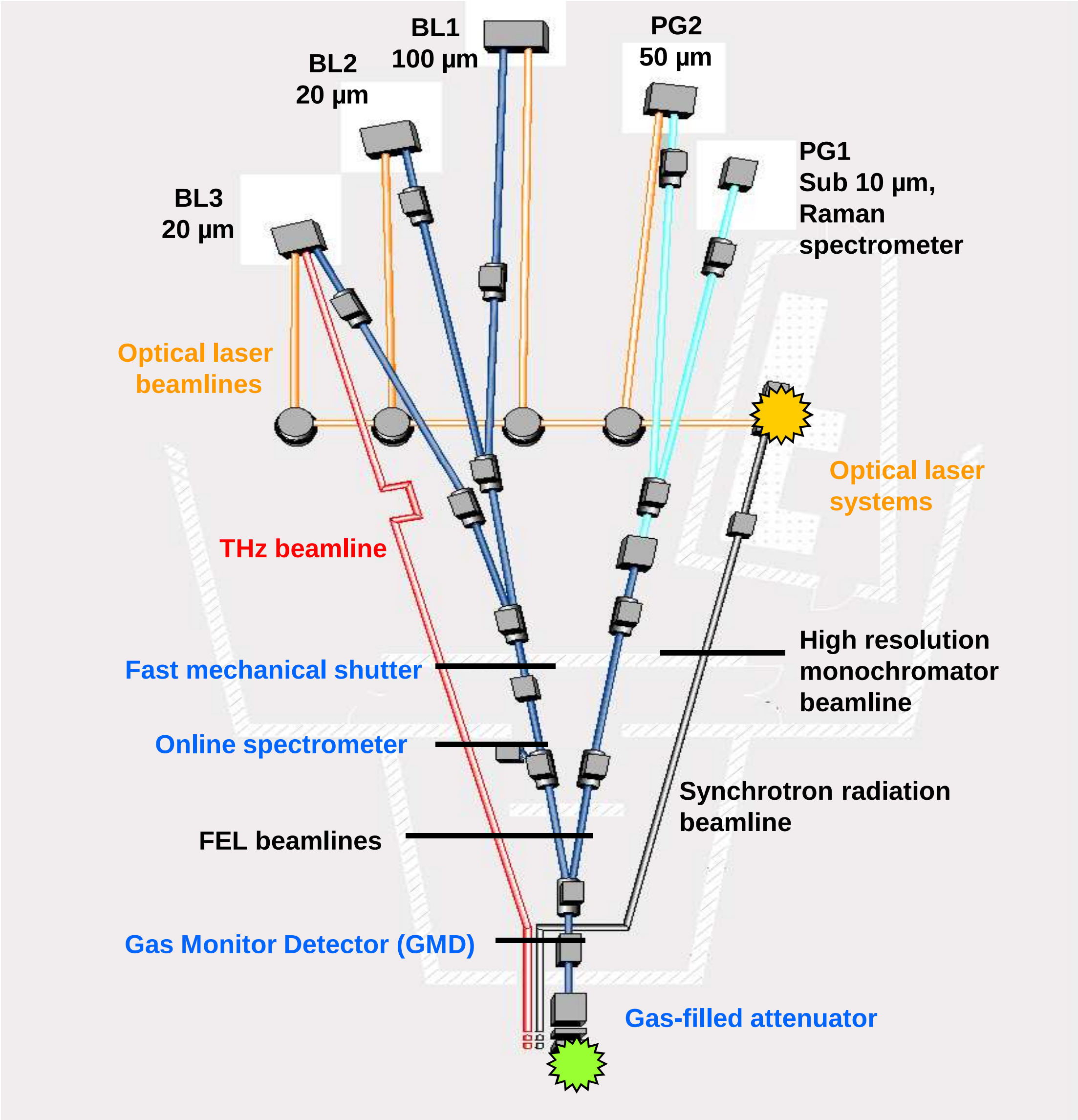
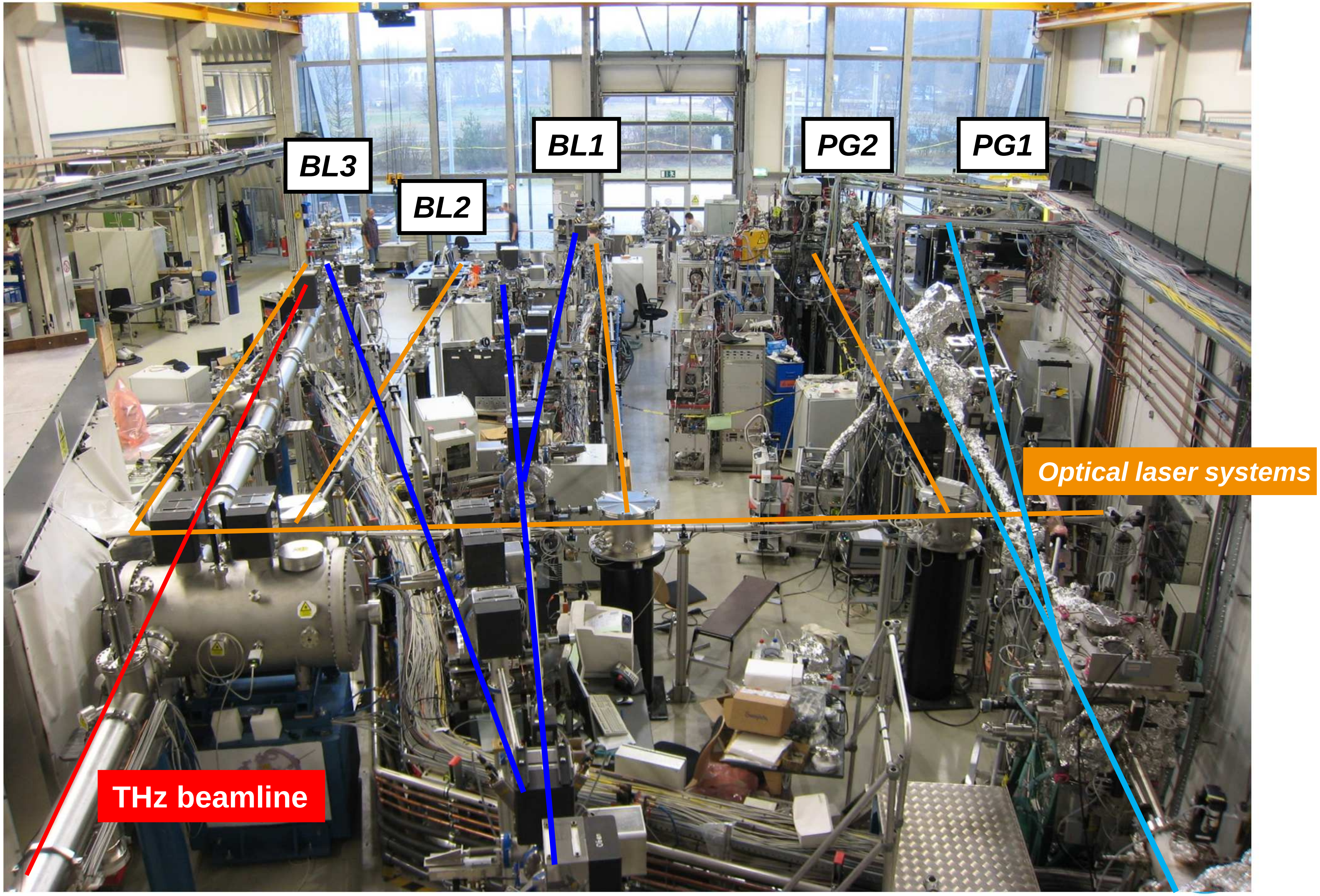


FLASH Experimental Hall.



- Photon Beam Transport and Layout of the Facility
- **Photon Beam Properties**
- Diagnostics Tools
  - Intensity
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  - Intensity Profile on the Sample / Focus Size
  - Spectral Distribution
- Conclusion and Outlook

FLASH Properties.

- Wavelength tunability! (< 5 nm – 60 nm)
- FEL harmonics down to X-ray

  (at 5 nm → 3rd = 1.7 nm, 5th = 1 nm)
- Narrow bandwidth (0.5 – 1%)
- Coherence
- Femtosecond pulses (10 – 100 fs)

→ Study of time dependent processes (realized as *pump and probe* - experiments)

100 fs (femtoseconds) correspond to a distance of 30 µm at the speed of light (≃ 300.000 km/s), i.e. the width of a hair!!

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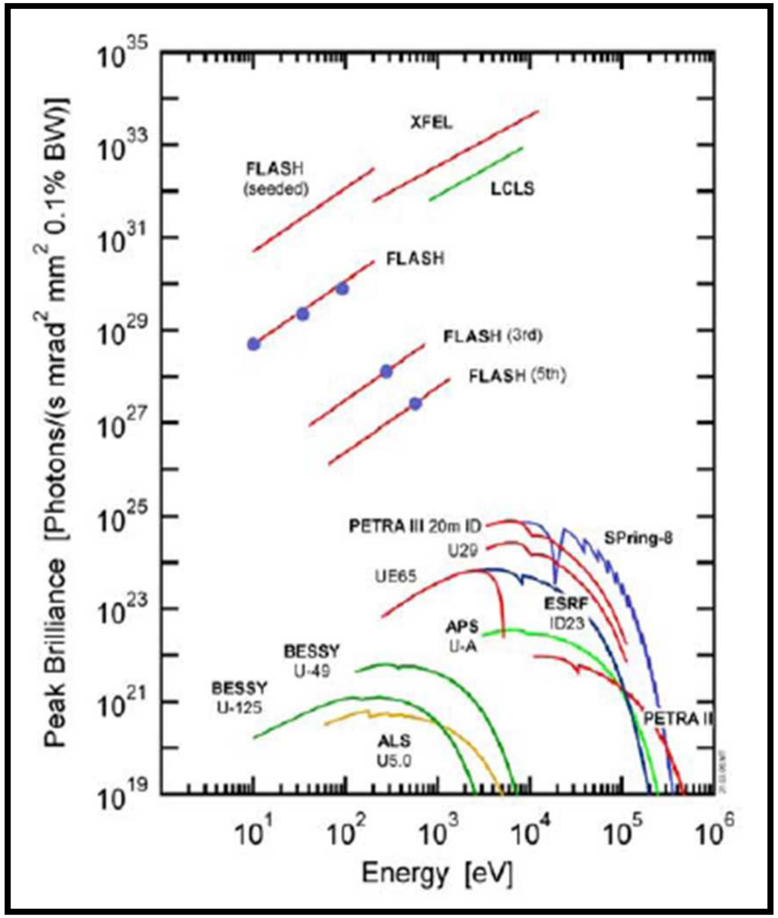
- Coherence
- Femtosecond pulses (10 – 100 fs)
- High intensity (GW peak power)



Focused to 1 μm²
→ extreme power density of 10^{16} W/cm² can be achieved to study nonlinear effects, plasma physics, etc.

peak brilliance

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Diagnostic Tools.

What kind of diagnostic tools do user need to make efficient use of FELs?

➢ Intensity	Gas-Monitor Detectors (GMD)
➢ Beam position	GMD Split Electrodes
➢ Intensity profile on the sample / Focus size	Wave Front Sensor
➢ Spectral distribution	Photoelectron spectra

Due to the SASE specific shot-to-shot fluctuation the users need most this information for every single pulse => online, non-destructive

The *Atomic Photoionization Process* is a perfect candidate for non-destructive, pulse-resolved photon metrology tools.

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Requirements for Intensity Detectors.

- Cover full dynamic range: ~ 7 orders of magnitude from spontaneous emission to SASE in saturation
- On-line detectors (non-destructive) for single-pulse measurements (response < 100 ns)
- Low degradation under radiant exposure
- Ultra-high vacuum compatibility

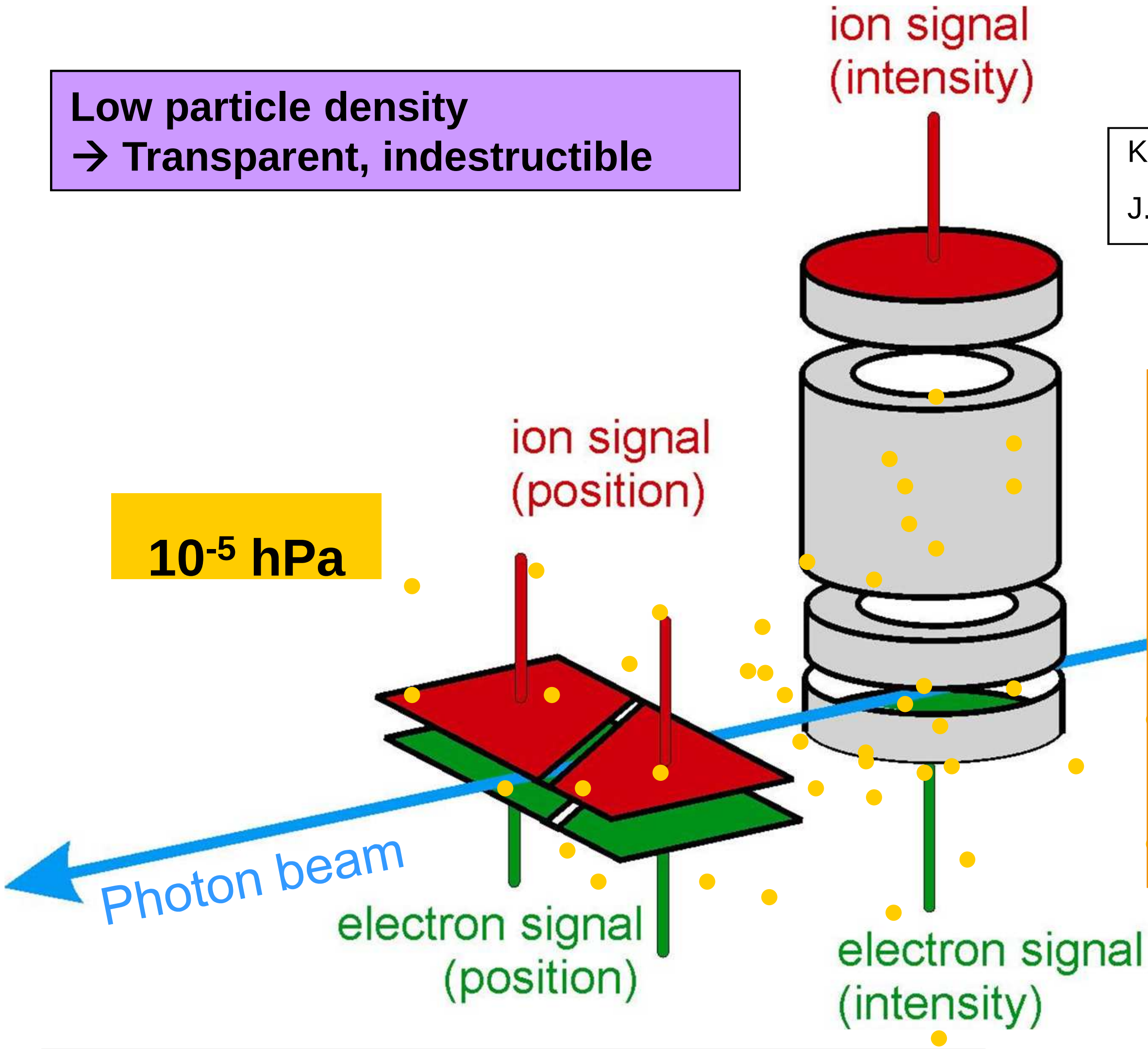
No commercial, calibrated detectors available!

Gas-Monitor Detectors for Online Intensity and Beam Position Monitoring.

Low particle density
→ Transparent, indestructible

K. Tiedtke et al, *Gas-detectors for X-ray lasers*, J. Appl. Phys. **103**, 094511 (2008)

10^{-5} hPa



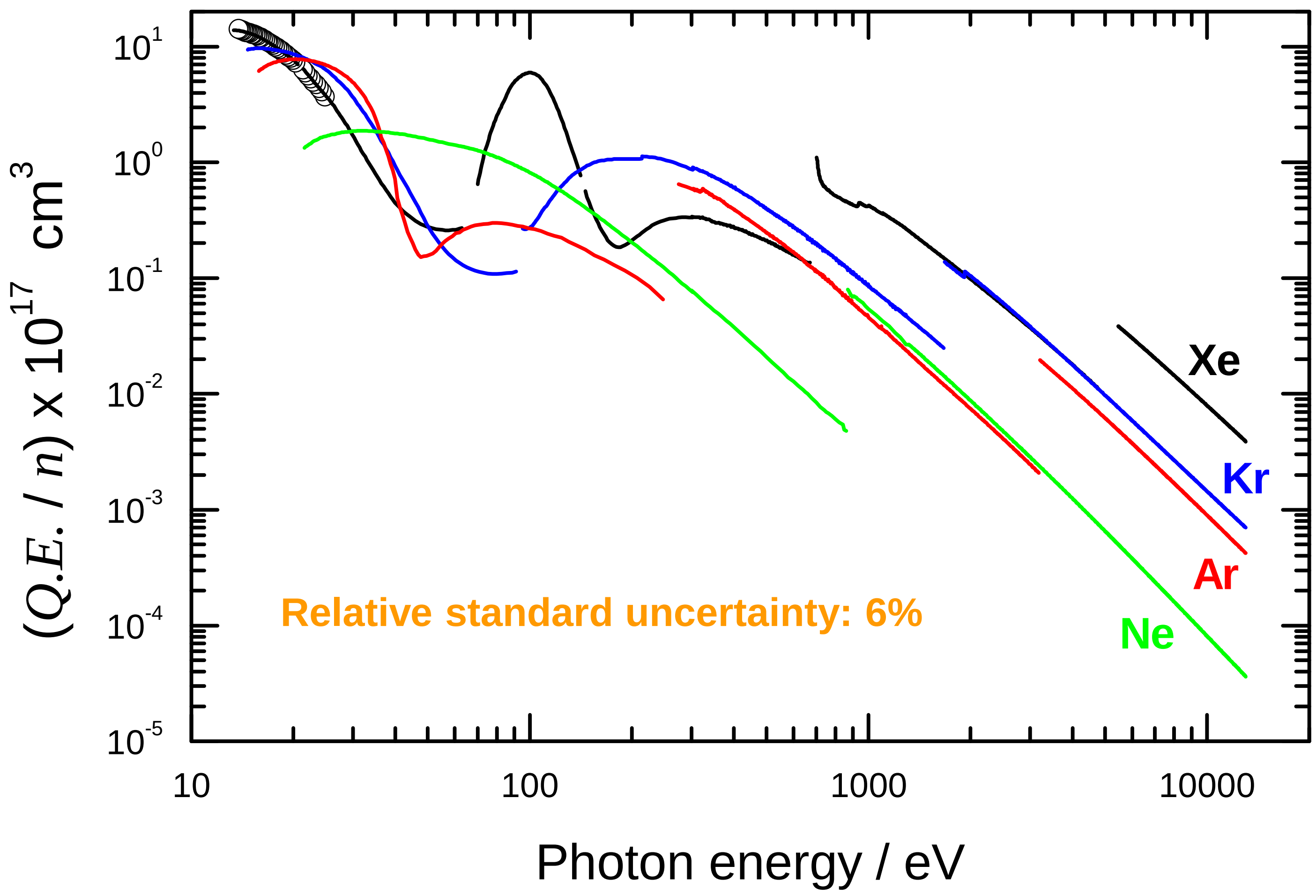
Single photoionisation:

$$N = N_{ph} \times n \times \sigma \times l$$

N = *N*umber of electrons or ions
N_{ph} = Number of photons
n = Target density
σ = *P*hotoionisation cross section
l = *L*ength of interaction volume

Reference number at the German Patent Office: 102 44 303

Quantum Efficiency of the GMD.

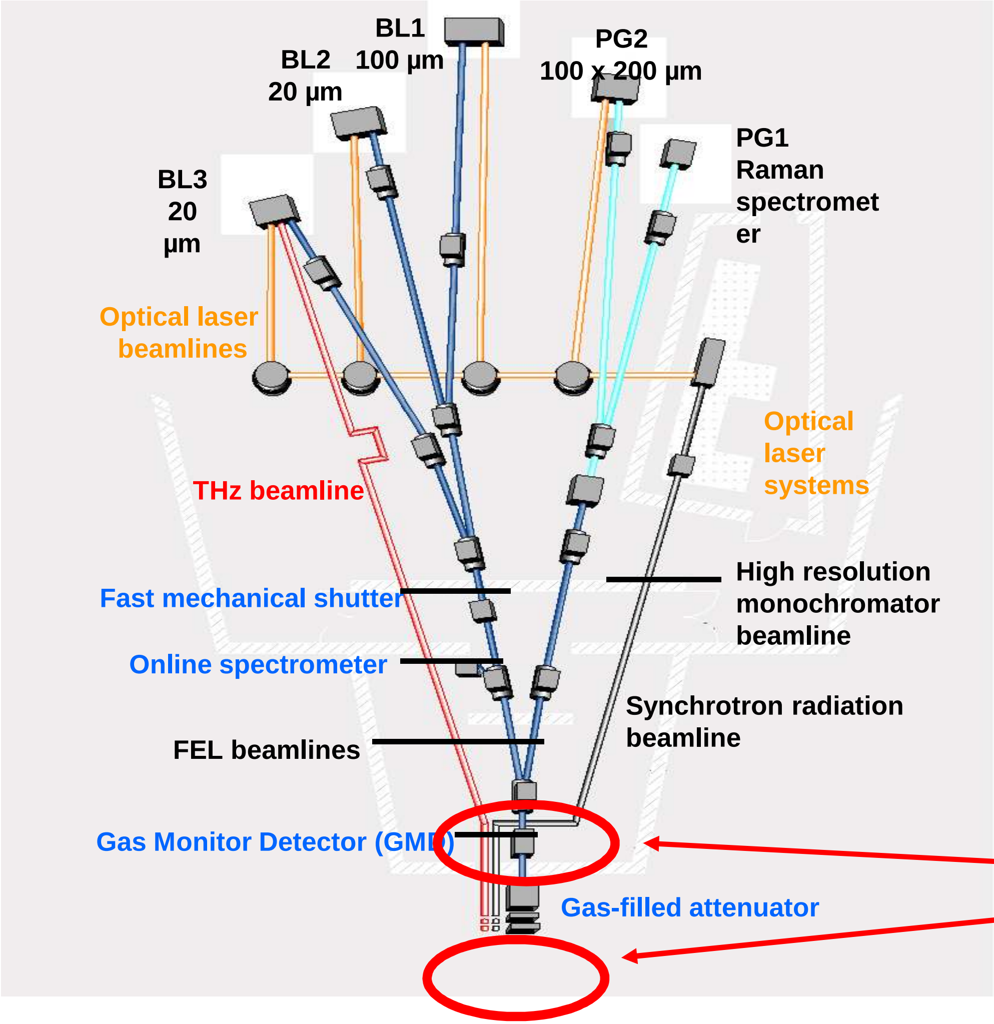


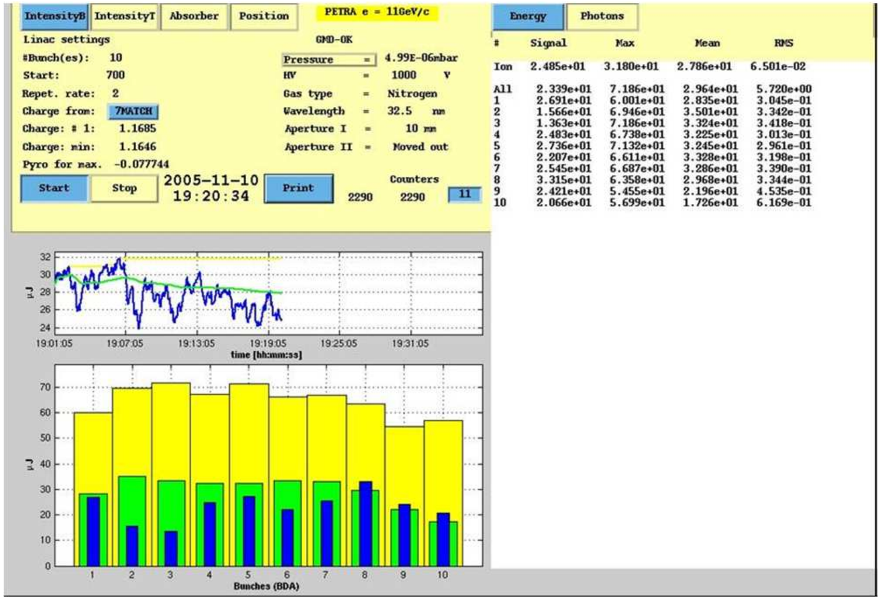
To determine the pulse energy on a shot-to-shot basis we need….

- Pressure and temperature → gas density
- Kind of gas and wavelength → cross section
- Calibrated ion current (electrometer)
- Integrated electron peaks (fast integrator → fast ADC)
- Bunch pattern (rep. rate, number of bunches in the train)
- Information about bunch loses
- Evaluated data must be correlated with “machine time stamp” and saved to the DAQ system
- In addition, machine operators need status information about gas attenuator, apertures, and beam shutter

All these things have to be remotely controlled, easy to handle, and reliable over years!

FLASH GMD.





Two gas monitor detector sets: before and behind the gas attenuator

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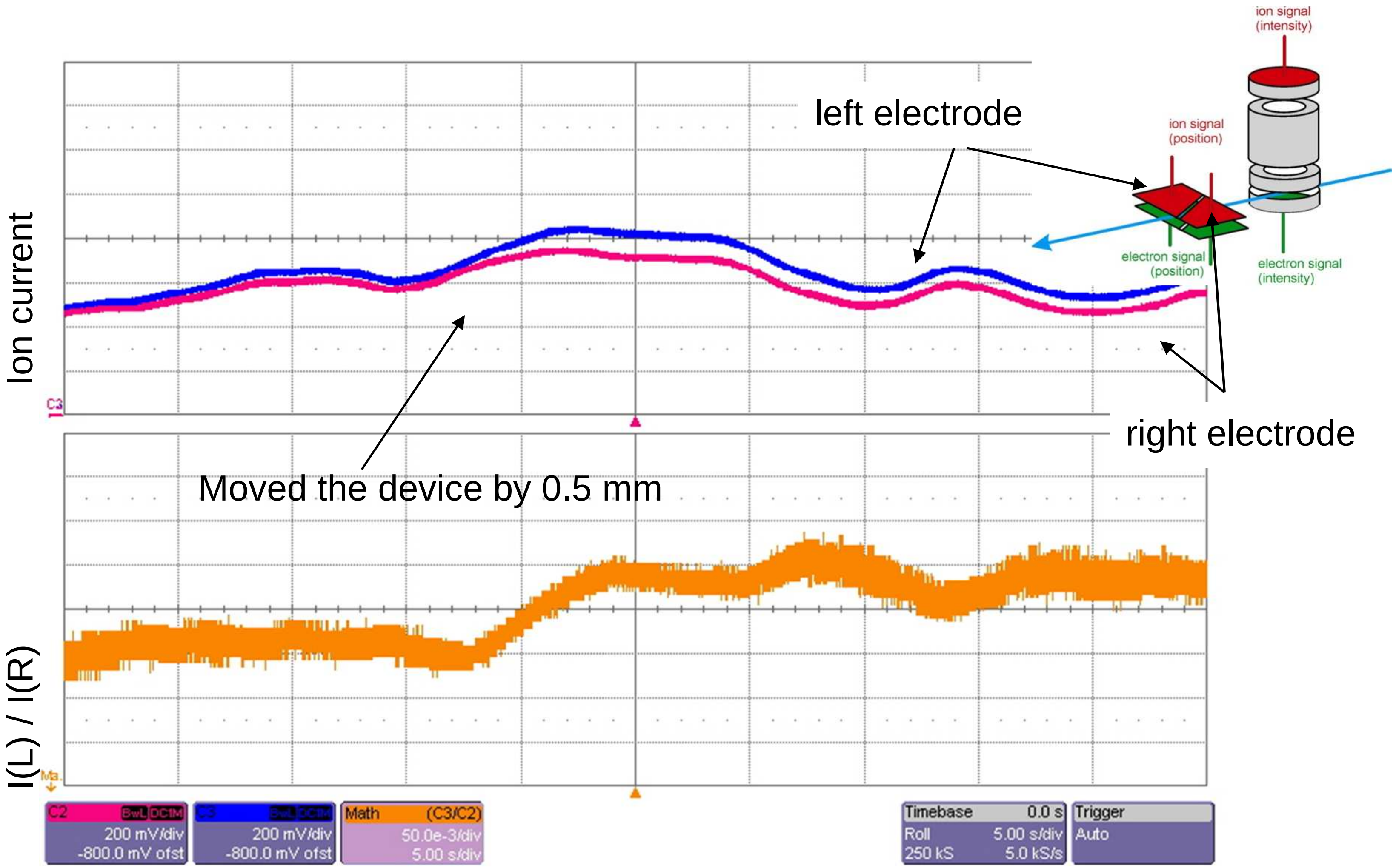
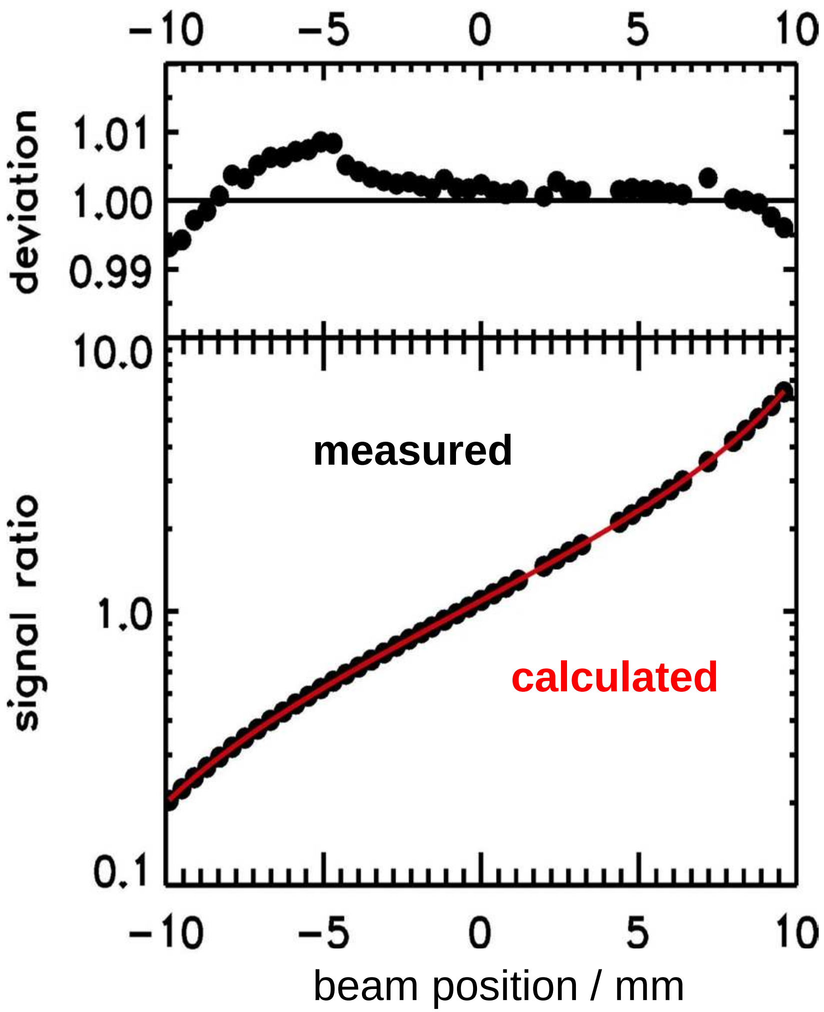
Beam Position Monitor (Split Electrodes).



Calibration Measurements of the BPMs.



- Accuracy for on-line measurements of relative beam positions: ~ 20 µm
- Two gas-monitor detector sets, which are 20 m apart, allow on-line monitoring of the angle: ~ 1 µrad

Ioffe Physico-Technical Institute

PTB

DESY

➢ Photon Beam Transport and Layout of the Facility

➢ Photon Beam Properties

➢ **Diagnostics tools**

- Intensity
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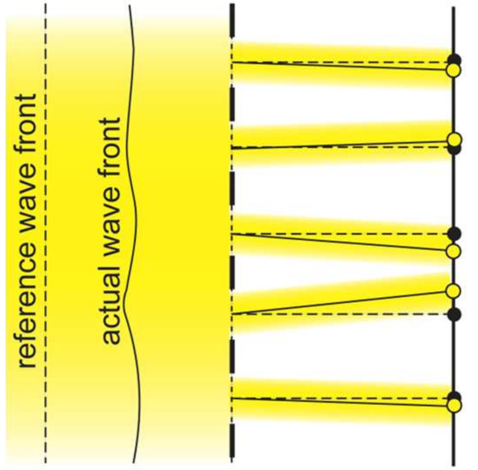
➢ Conclusion and Outlook

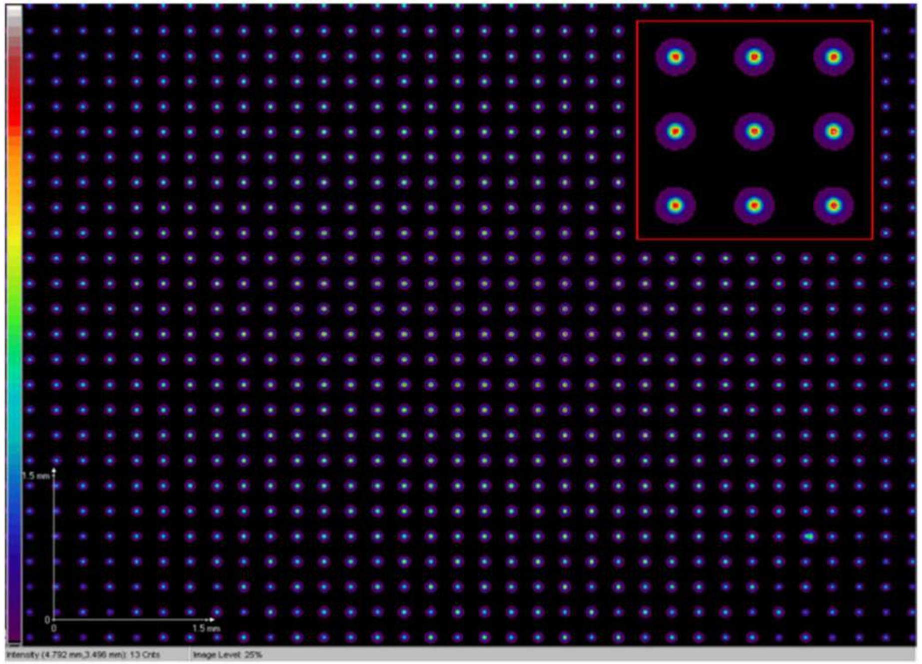
Wave Front Sensor Principle.

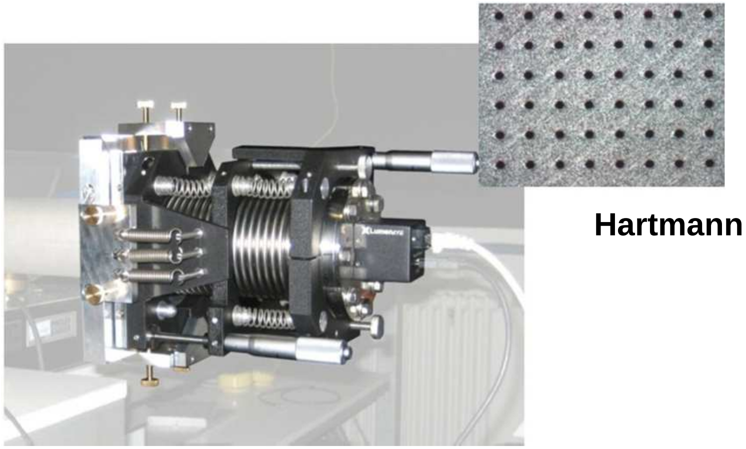
Collaboration with Laser Lab Göttingen



→ The actual beam is compared to a perfect spherical wave.

Reference spot pattern





Hartmann plate

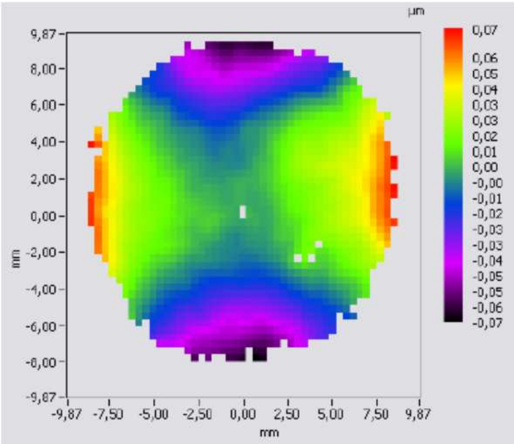
Capabilities

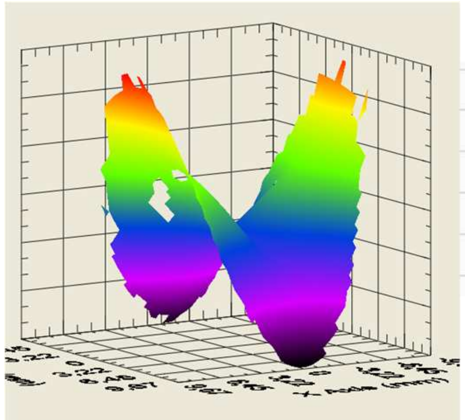
- Accuracy approx. λ/15 PV for EUV
- Wave front reconstruction
- Zernike coefficients

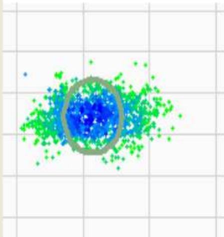
Wave Front Measurements for Optics Adjustment.

Before adjusting ellipsoidal mirror of BL2

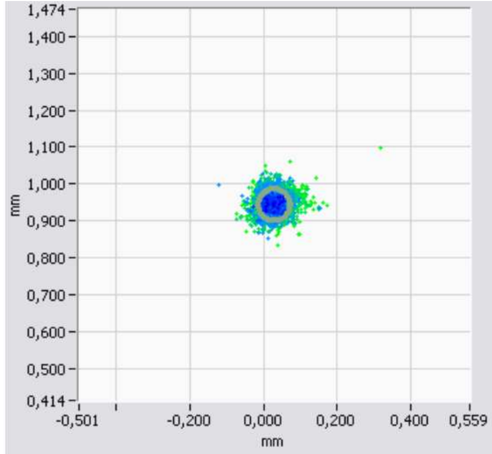
Collaboration with Laser Lab Göttingen







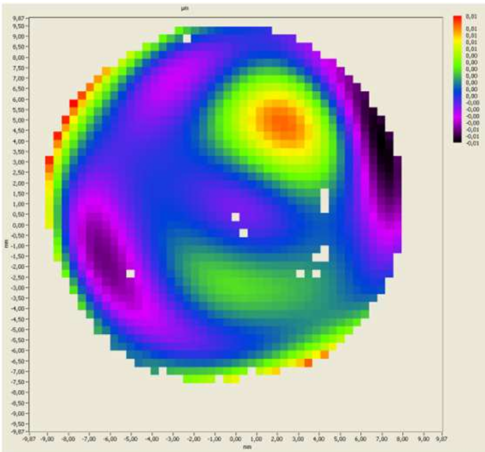
radius 87.8 µm
@ 50 mm defocus

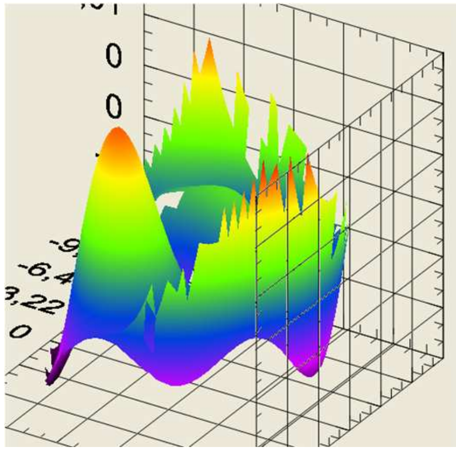


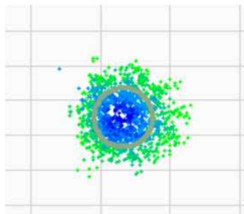
Rotation: 0 Yaw: 0 **PV: 110 nm RMS: 22 nm @ 27 nm → λ/1**

radius 42.3 µm @ focus

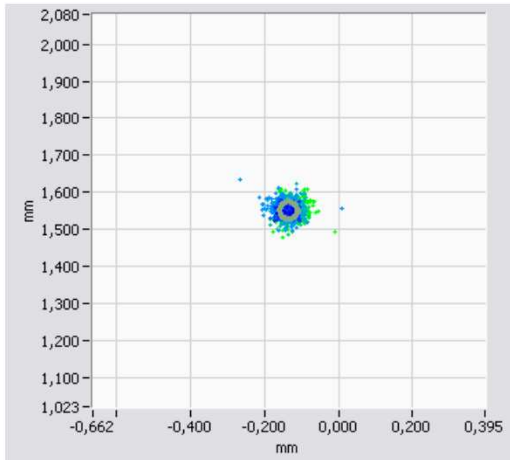
After adjustment of BL2







radius 84.1 µm
@ 50 mm defocus



radius 24.1 µm @ focus

Rot: 45000 Yaw: -0.01 **PV: 18 nm RMS: 3 nm @ 27 nm → λ/9**

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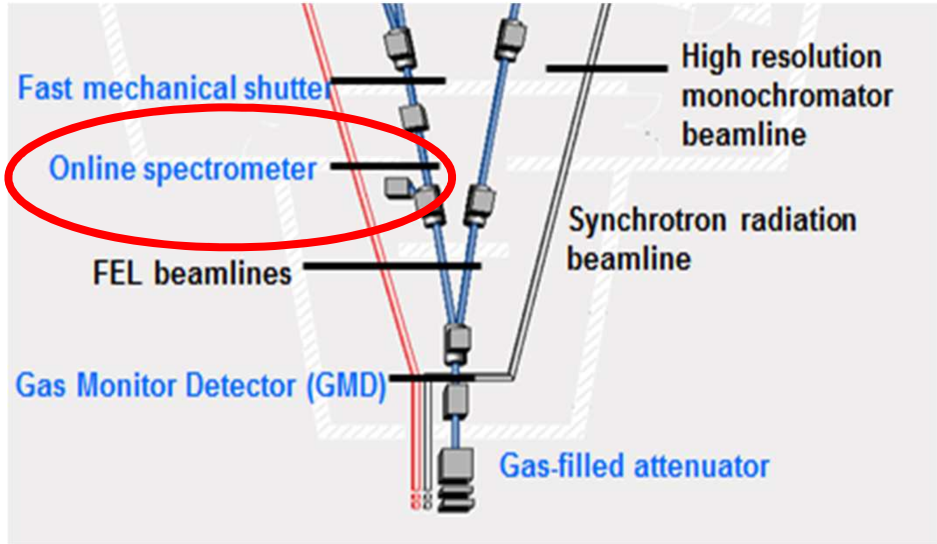
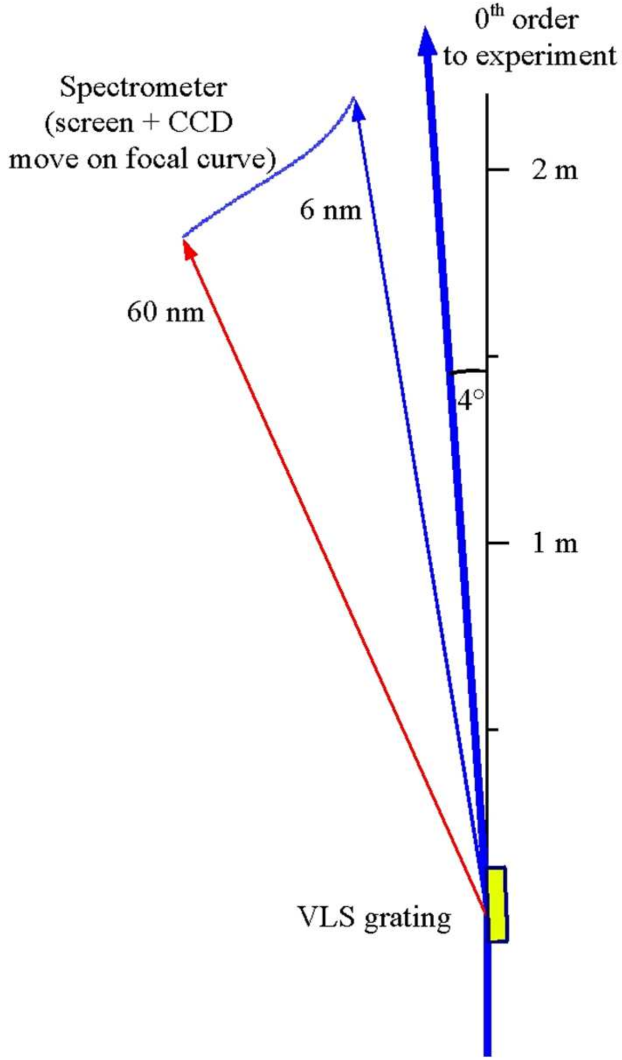
VLS online Spectrometer – Spectral Distribution.

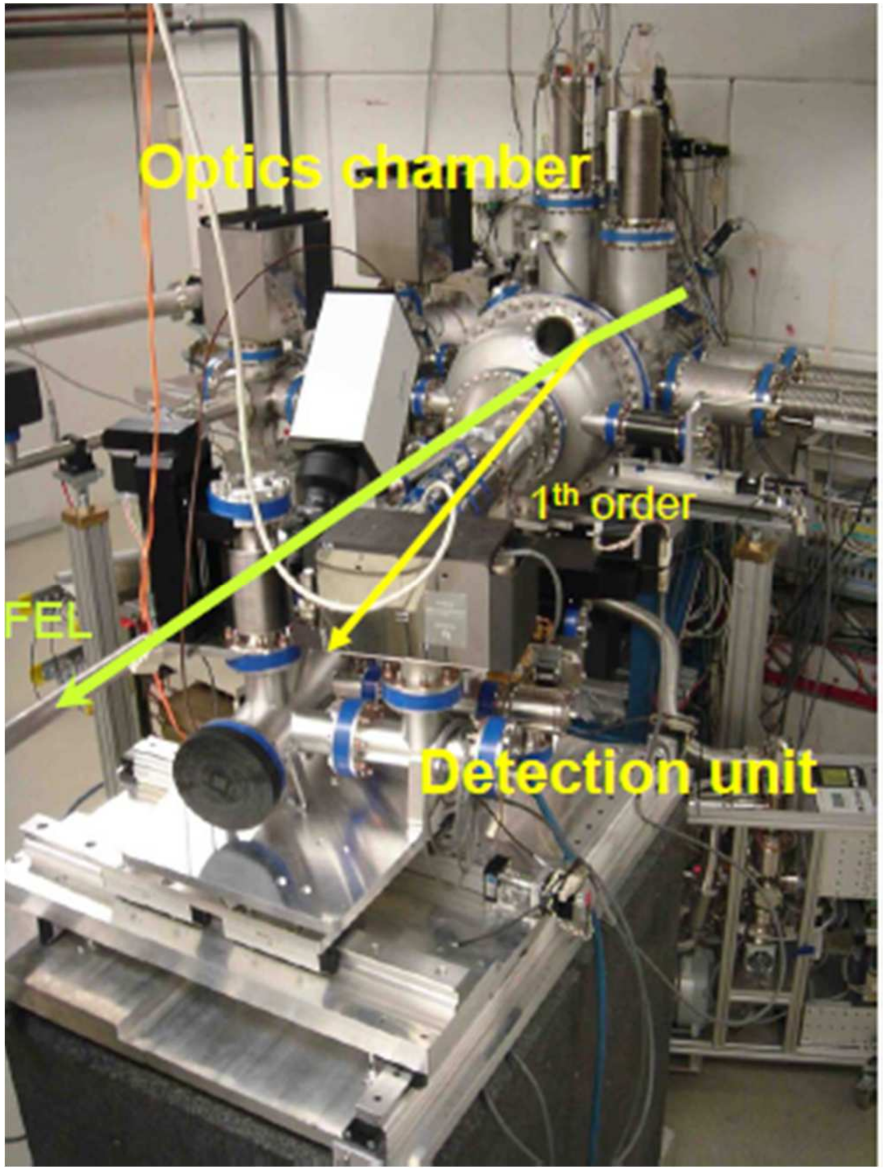
Variable Line Spacing grating spectrometer

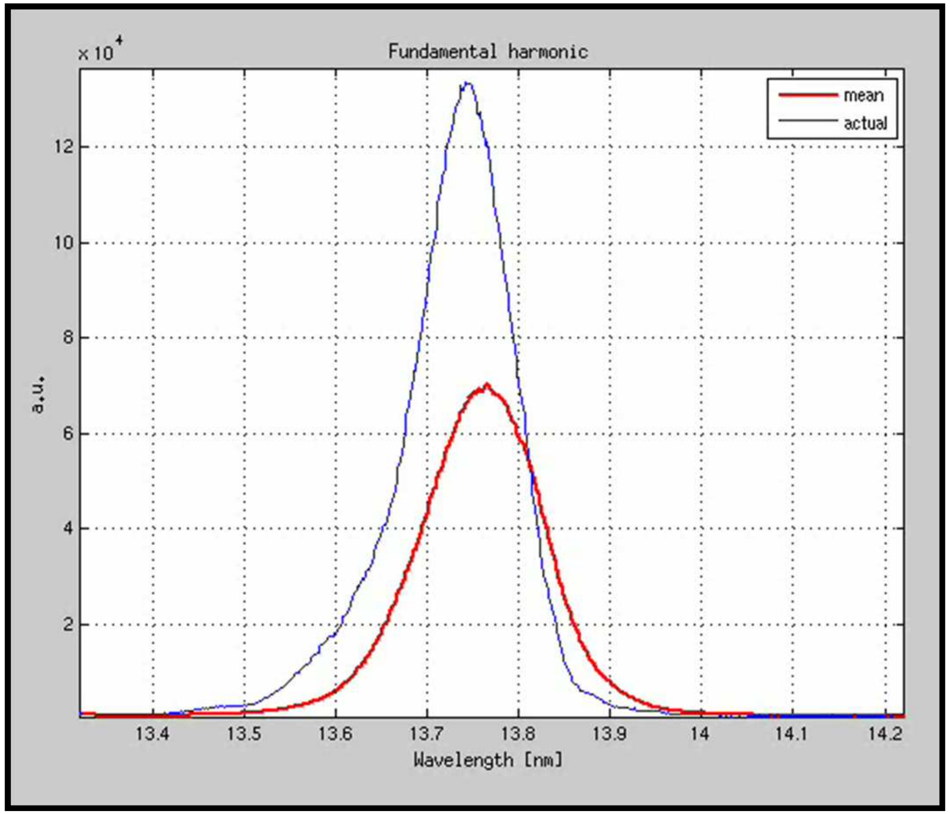




Collaboration with: BESSY, R. Reininger (SAS), F. Quinn (CLRC) et al.

VLS Spectrometer at FLASH – Pulse Duration.





Pulse length τ_{rad}:

$\tau_{rad} \cong 2\pi^{1/2} / (\Delta\omega)_{FWHM}$

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Conclusions.

The essential techniques for FEL beam diagnostics at FLASH are available:

- GMD detector for intensity measurements
- GMD splits electrodes for beam position determination
- Technique to determine the lateral distribution in the focus with the Hartmann wave front sensor
- VLS spectrometer to figure out the spectral distribution

Outook.

- Development of a new generation of GMDs for higher photon energies (hard X-ray FELs like XFEL)

→ High photon energy

→ Low quantum efficiency

→ Low ionization ratio

→ Low intensity signal

→ Ideas:

  → Increasing of the length of the detector

  → Higher pressure

  → Different gases

- Round Robin Tests of the X-GMD at SACLA (Japan) and LCLS (USA)
- Implementation of GMDs in other FELs

The FLASH Team.

W. Ackermann, G. Asova, V. Ayvazyan, A. Azima, N. Baboi, J. Bähr, V. Balandin, B. Beutner, A. Brandt, A. Bolzmann, R. Brinkmann, O.I. Brovko, M. Castellano, P. Castro, L. Catani, E. Chiadroni, S. Choroba, A. Cianchi, J.T. Costello, D. Cubaynes, J. Dardis, W. Decking, H. Delsim-Hashemi, A. Delserieys, G. Di Pirro, M. Dohlus, S. Düsterer, A. Eckhardt, H.T. Edwards, B. Faatz, J. Feldhaus, K. Flöttmann, J. Frisch, L. Fröhlich, T. Garvey, U. Gensch, Ch. Gerth, M. Görler, N. Golubeva, H.-J. Grabosch, M. Grecki, O. Grimm, K. Hacker, U. Hahn, J.H. Han, K. Honkavaara, T. Hott, M. Hüning, Y. Ivanisenko, E. Jaeschke, W. Jalmuzna, T. Jezynski, R. Kammering, V. Katalev, K. Kavanagh, E.T. Kennedy, S. Khodyachykh, K. Klose, V. Kocharyan, M. Körfer, M. Kollewe, W. Koprek, S. Korepanov, D. Kostin, M. Krassilnikov, G. Kube, M. Kuhlmann, C.L.S. Lewis, L. Lilje, T. Limberg, D. Lipka, F. Löhl, H. Luna, M. Luong, M. Martins, M. Meyer, P. Michelato, V. Miltchev, W.D. Möller, L. Monaco, W.F.O. Müller, O. Napieralski, O. Napoly, P. Nicolosi, D. Nölle, T. Nunez, A. Oppelt, C. Pagani, R. Paparella, N. Pchalek, J. Pedregosa-Gutierrez, B. Petersen, B. Petrosyan, G. Petrosyan, L. Petrosyan, J. Pflüger, E. Plönjes, L. Poletto, K. Pozniak, E. Prat, D. Proch, P. Pucyk, P. Radcliffe, H. Redlin, K. Rehlich, M. Richter, M. Roehrs, J. Roensch, R. Romaniuk, M. Ross, J. Rossbach, V. Rybnikov, M. Sachwitz, E.L. Saldin, W. Sandner, H. Schlarb, B. Schmidt, M. Schmitz, P. Schmüser, J.R. Schneider, E.A. Schneidmiller, S. Schnepp, S. Schreiber, M. Seidel, D. Sertore, A.V. Shabunov, C. Simon, S. Simrock, E. Sombrowski, A.A. Sorokin, P. Spanknebel, R. Spesyvtsev, L. Staykov, B. Steffen, F. Stephan, F. Stulle, H. Thom, K. Tiedtke, M. Tischer, S. Toleikis, R. Treusch, D. Trines, I. Tsakov, E. Vogel, T. Weiland, H. Weise, M. Wellhöfer, M. Wendt, I. Will, A. Winter, K. Wittenburg, W. Wurth, P. Yeates, M.V. Yurkov, I. Zagorodnov, K. Zapf

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Thanks for your attention!