Gas Based Detectors for FEL Photon Diagnostics.

Kai Tiedtke

Satellite Workshop on Photon Beam Diagnostics, 29 Jan. 2015

HELMHOLTZ
GEMEINSCHAFT

DESY

Outline.

- Intensity and Beam Position Monitor (GMD) @ FLASH
- Gas-Monitor-Detector for hard X-Rays (XGMD)
  - Radiometric comparison of the XGMD prototype @ SACLA
  - Measurements of the absolute number of photon of LCLS hard X-ray line Brand - new
- Online spectrometer (OPIS)@ FLASH

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Requirements for Intensity and Beam Position Detectors .

- cover full dynamic range: ~ 6 - 7 orders of magnitude from spontaneous emission to SASE in saturation
- on-line pulse resolved detectors (non-destructive with respect to the beam)
- low degradation under radiant exposure by FEL beam with a peak power of few GW; high linearity
- ultra-high vacuum compatibility

No commercial detectors available!

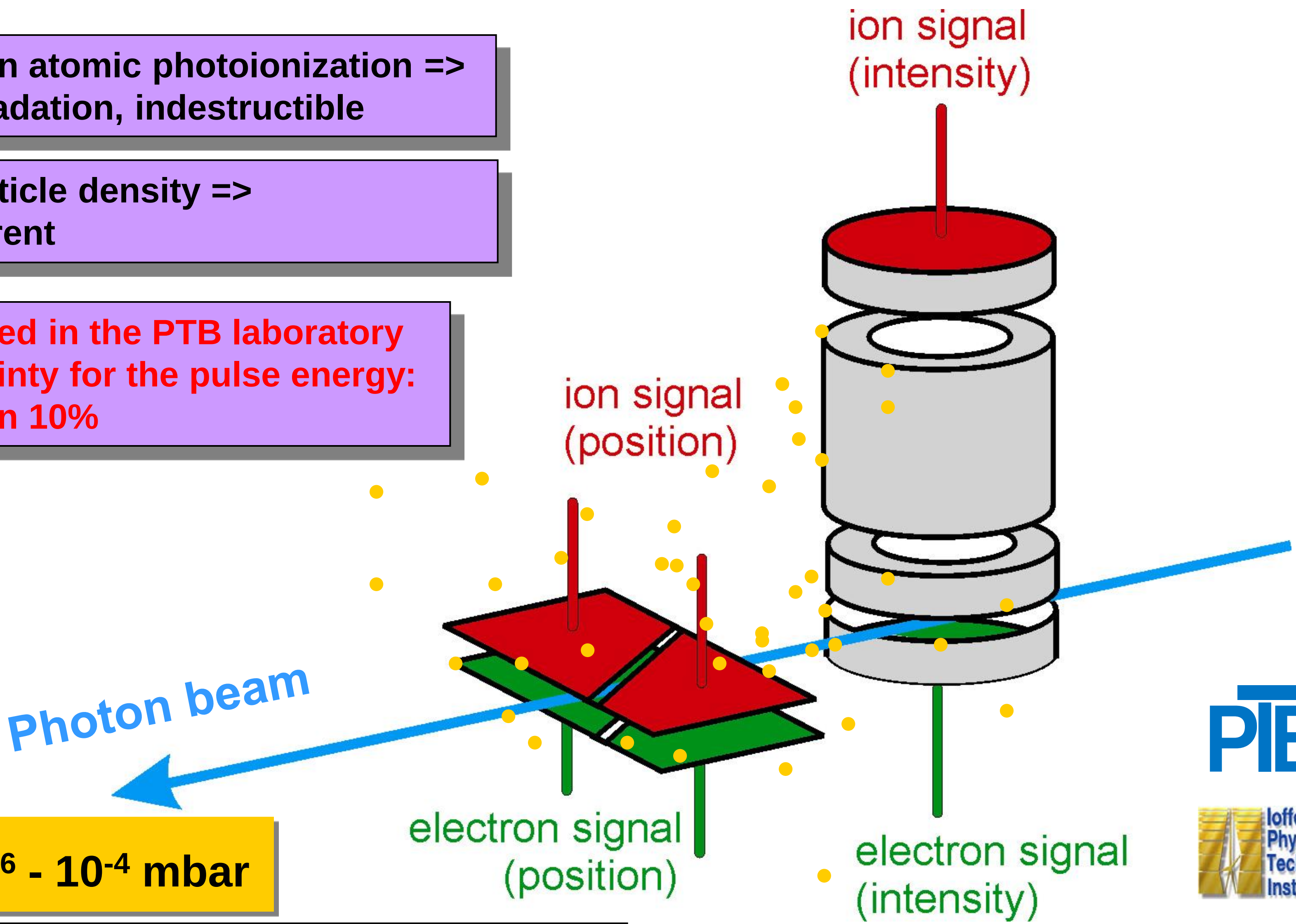
The *Atomic Photoionization Process* is a perfect candidate for non-destructive, pulse-resolved photon metrology tools.

Gas-monitor detectors for online intensity and beam position monitoring.

Based on atomic photoionization => no degradation, indestructible

Low particle density => transparent

Calibrated in the PTB laboratory
Uncertainty for the pulse energy: less than 10%



10^{-6} - 10^{-4} mbar

Reference number at the German Patent Office: 102 44 303

Equation behind the Gas-Monitor Detector.

Number of particles detected (electrons or ions). Average photoionization charge needed to evaluate.

Quantum Efficiency

$$N_{\text{particle}} = N_{\text{photon}} \cdot \sigma(\hbar\omega) \cdot z \cdot \eta \cdot n = N_{\text{photon}} \cdot Q.E.(\hbar\omega)$$

Cross Section

Atomic Gas Density (requires temperature and pressure info)

Detection Efficiency

Detector Acceptance Length

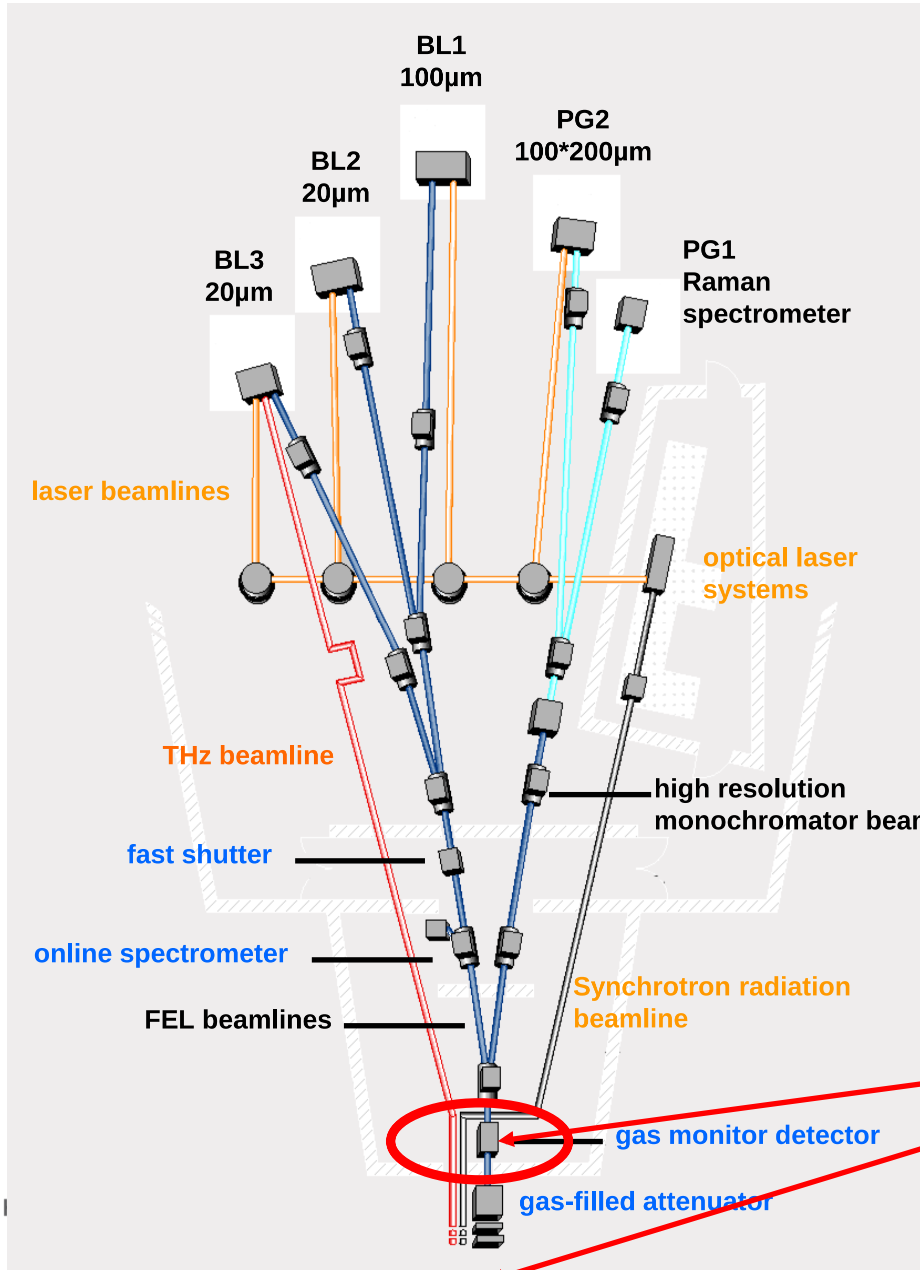
Charge accumulated by the detector

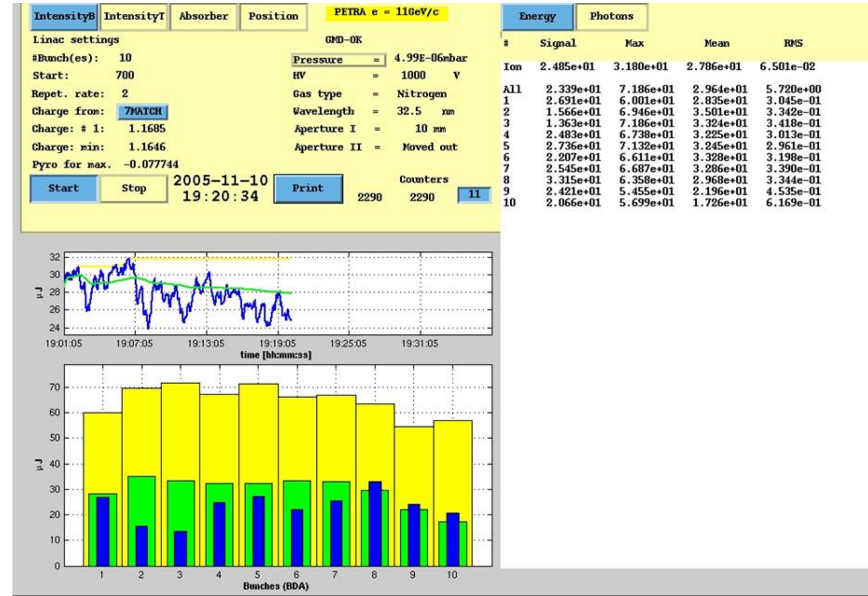
$$N_{\text{particle}} = \frac{Q}{e \cdot \gamma}$$

Elementary charge

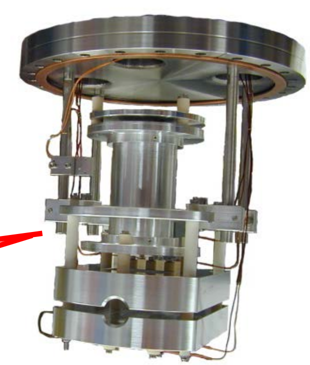
Mean ion charge

FLASH GMD for the EUV energy range

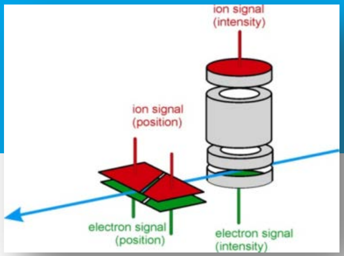




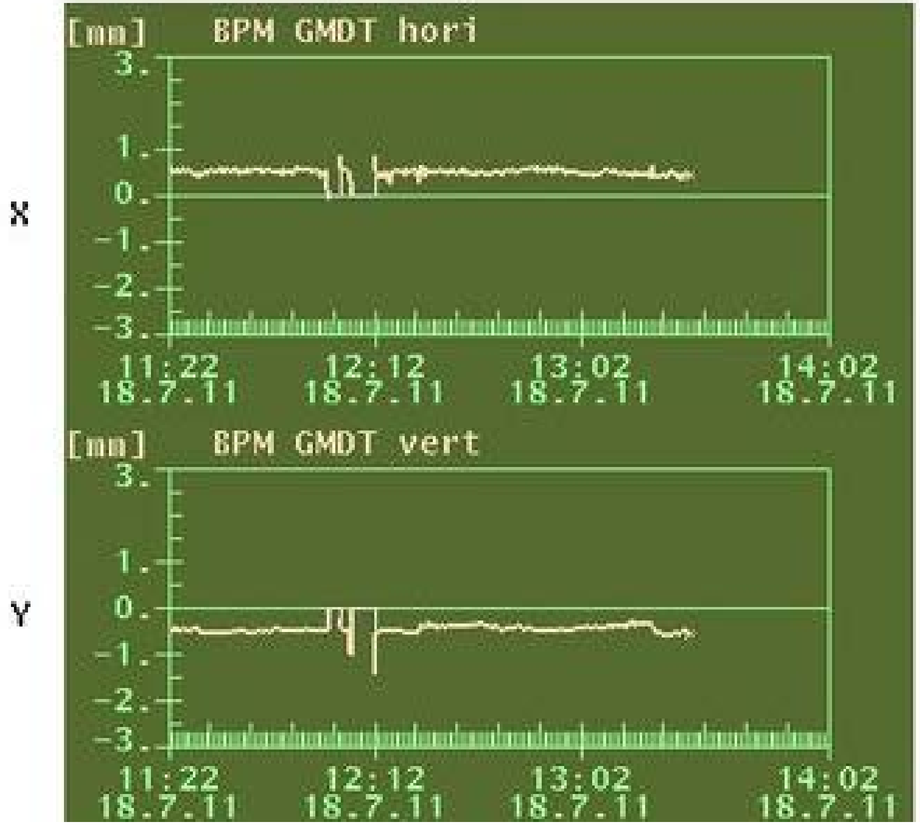
Two gas monitor detector sets: before and behind the gas attenuator

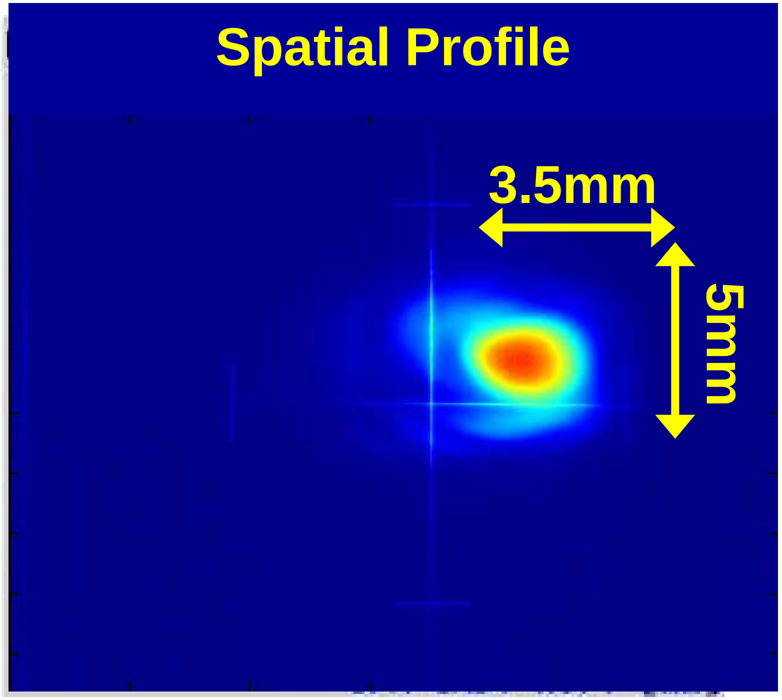


Beam position monitor



Accuracy for on-line measurements of relative beam positions: ~ 20 μm





The BPM information can be used for a machine feedback in order to stabilise the beam

Outline.

➢ Intensity and Beam Position Monitor (GMD) @ FLASH

see poster presented by A.A Sorokin

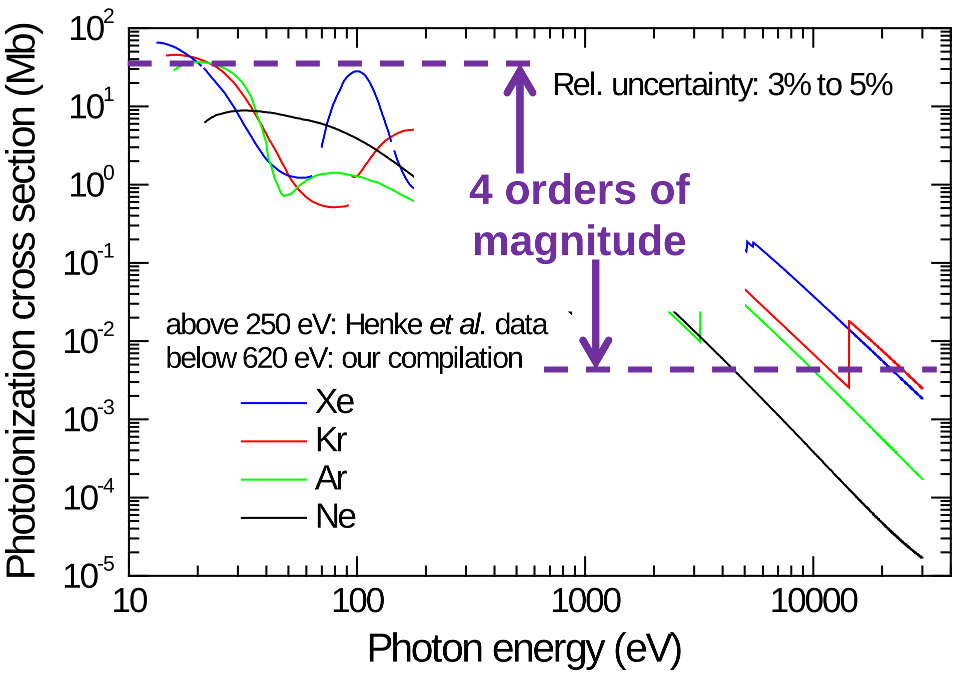
➢ **Gas-Monitor-Detector for hard X-Rays (XGMD)**

- **Radiometric comparison of the XGMD prototype @ SACLA**
- **Measurements of the absolute number of photon of LCLS hard X-ray line** Brand - new

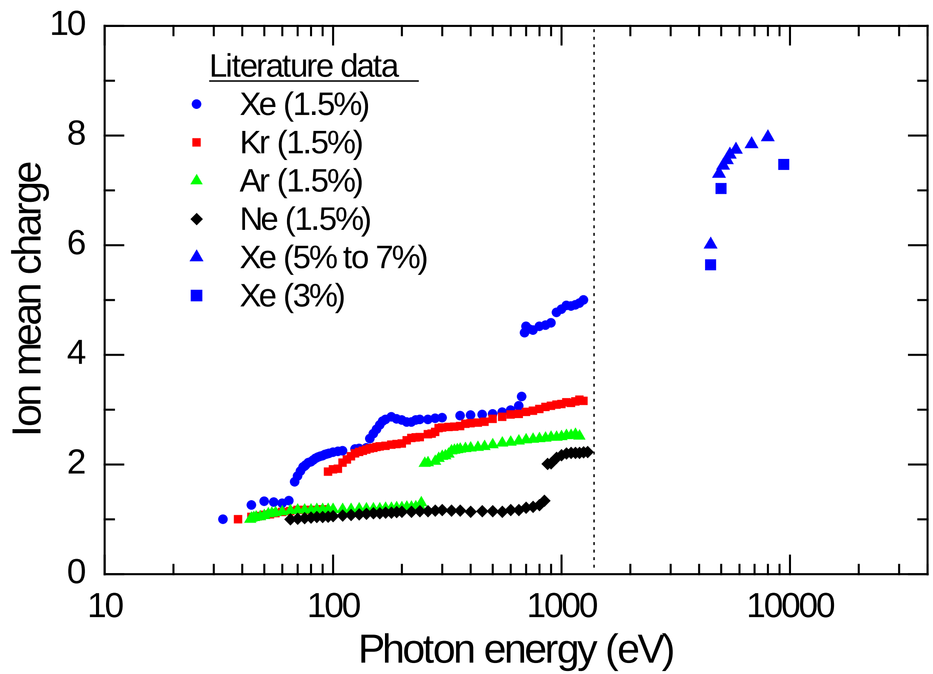
➢ Online spectrometer (OPIS)@ FLASH

Missing photoionization cross section data and ion mean charged values for the hard X-ray regime.

Total photoionization cross sections

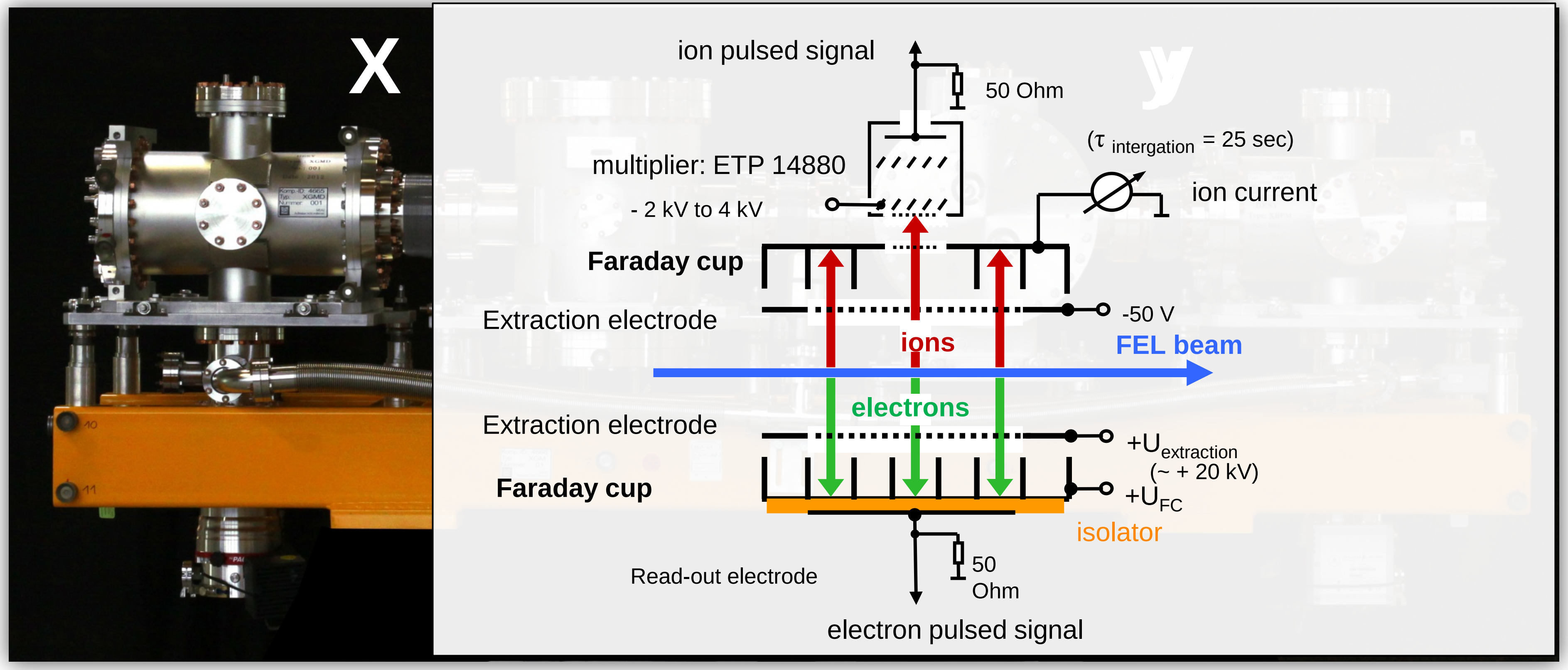


Ion mean charge



In the framework of a German–Russian BMBF project and in collaboration with the PTB we measured the photoionization cross sections and mean charge values up to 30 keV at the VUV undulator beamline of MLS, the four crystal monochromator beamline (FCM), and the BAM line in 2012.

3*rd* generation GMD for European XFEL and SwissFEL-
Intensity and beam position with an extended energy and dynamic range.



- Photon energy range: up to 20 keV
- Uncertainty for the pulse energy: <10 %
- Time resolution: < 200 ns
- Operating pressure: 10^{-6} mbar – 10^{-4} mbar
- Presently we are building 6 XGM for XFEL and 1 for PSI

- High extraction voltage of up to 20 kV has to be applied to prevent detection of highly energetic photoelectrons by the ion detector.

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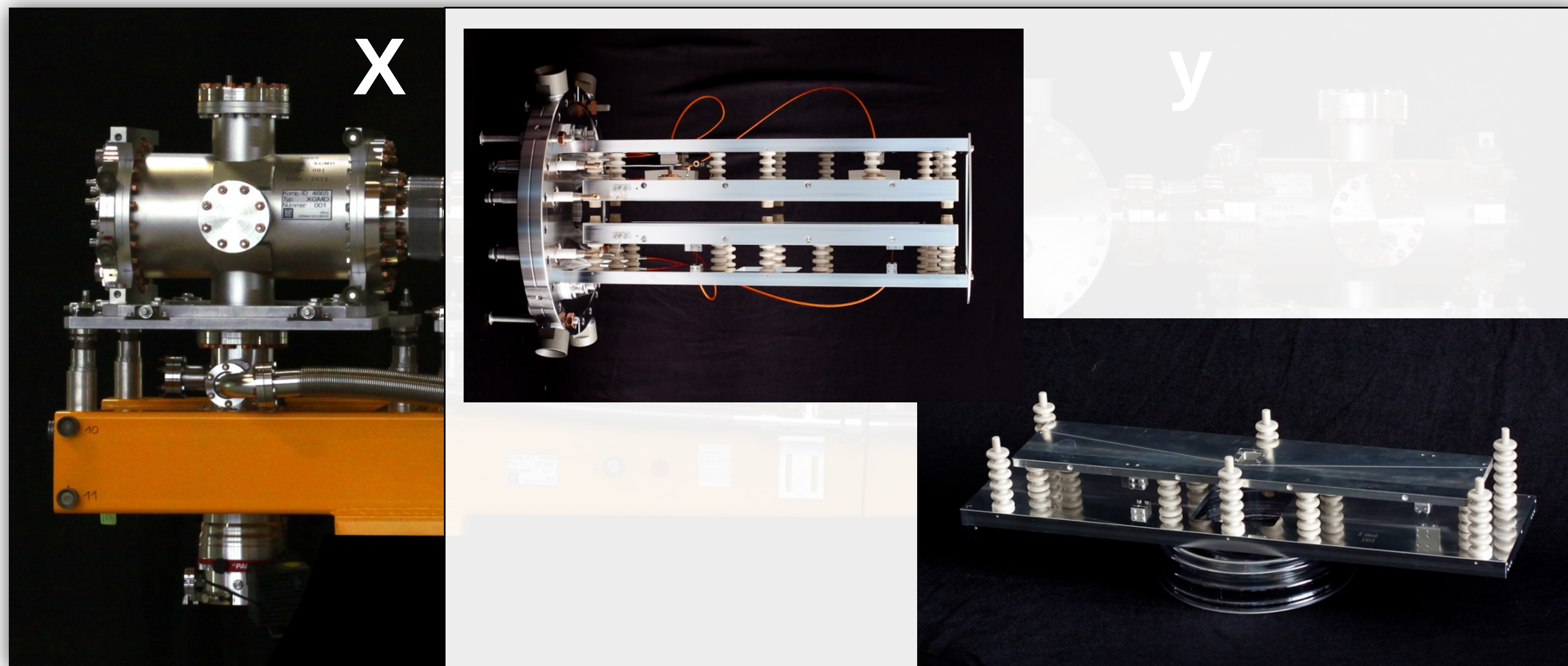

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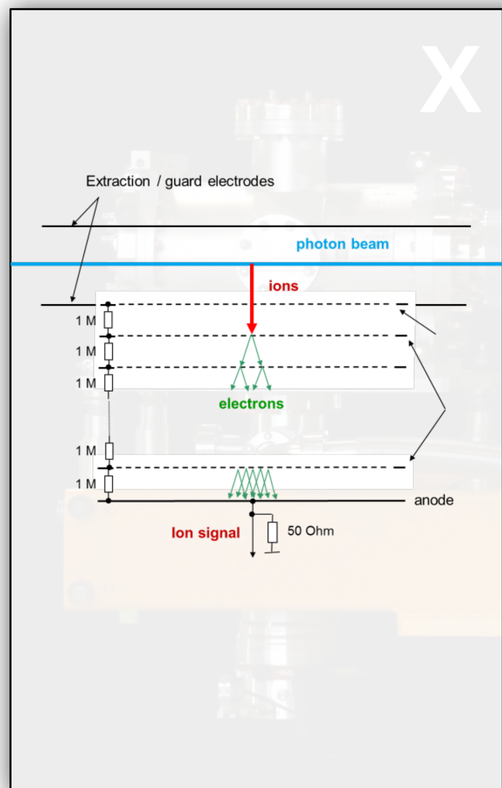
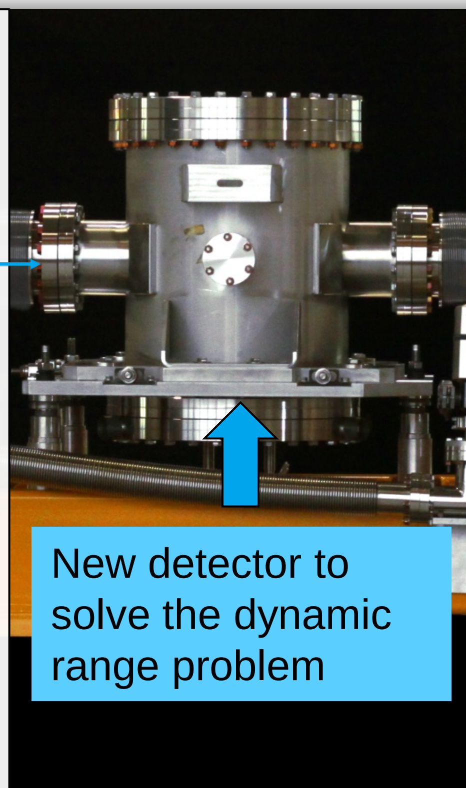
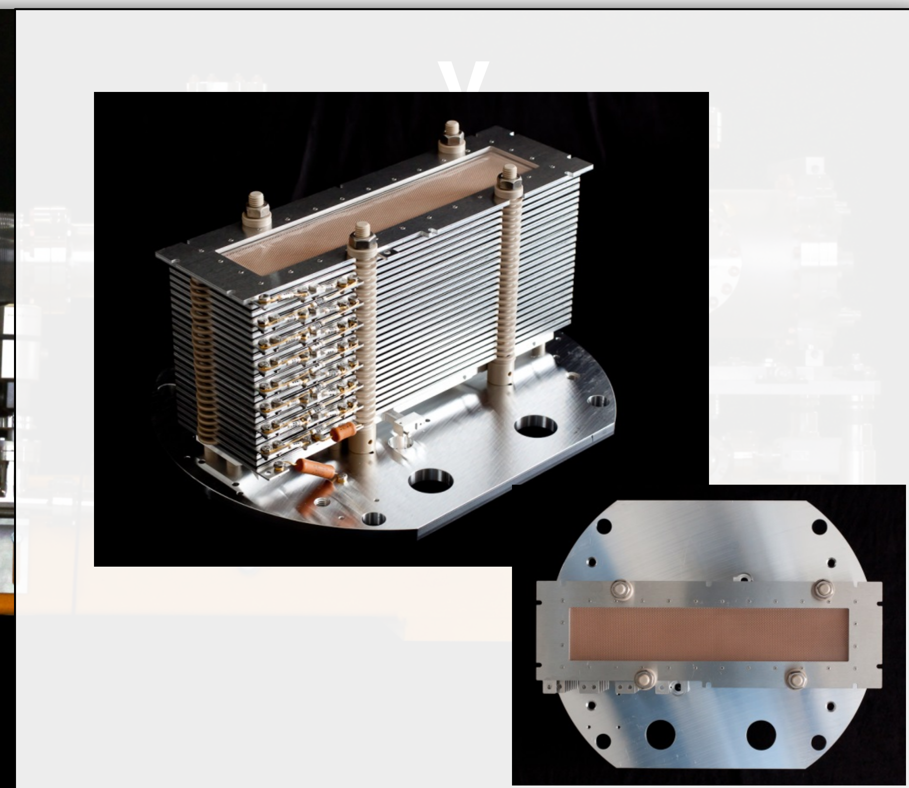


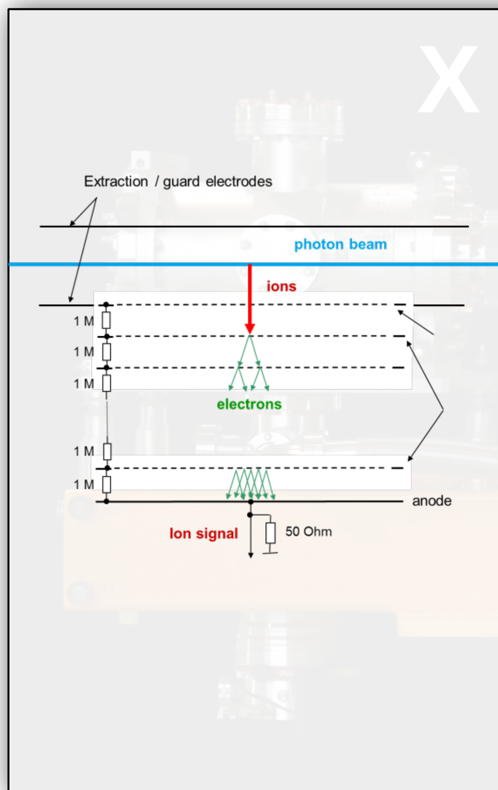


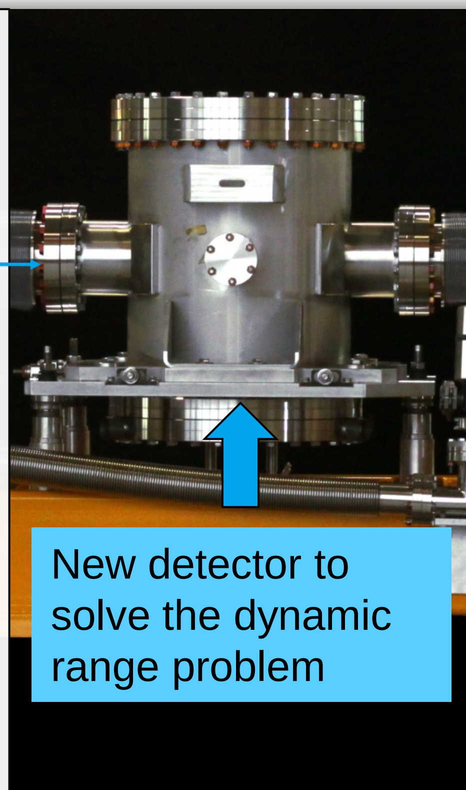


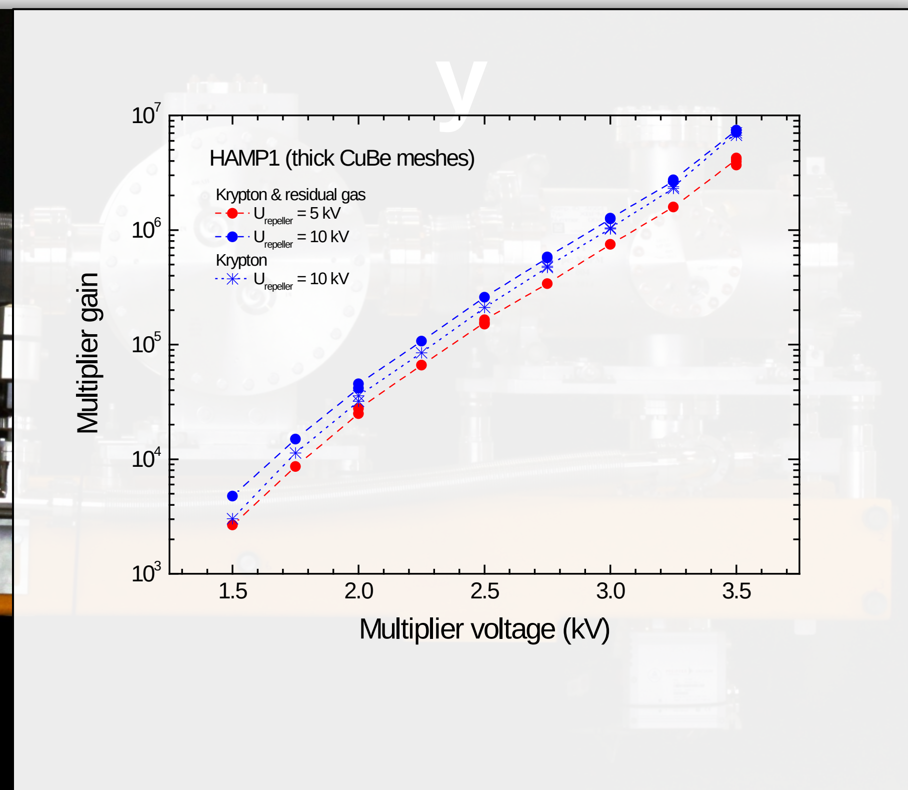
- It's a giant multiplier with 20cmx3cm open area
- CuBeO dynodes own design
- Gain: 10^7
- Split electrode to measure beam position
- Robust
- Operating pressure: 10^{-8} mbar – 10^{-4} mbar

- Relative uncertainty (pulse to pulse): < 1 % (for more than 10^{10} photon per pulse)

3*rd* generation GMD for European XFEL and SwissFEL- Intensity and beam position with an extended energy and dynamic range.







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Comparison between the XGMD pulse energy monitor with a cryogenic radiometer of AIST at SACLA

by DESY/PTB and RIKEN/AIST
November 21-23, 2011

Repetition rate : 10Hz
Pulse duration : 20fs
Peak power : 5GW

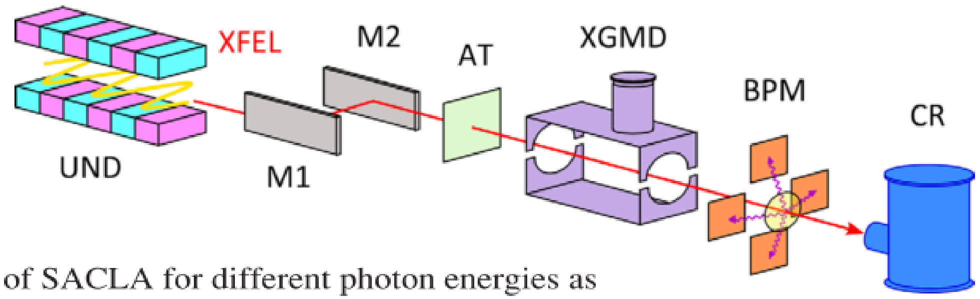


TABLE I. Average pulse energy of SACLA for different photon energies as measured with the CR and the XGMD and calibration coefficient of the SACLA BPM.

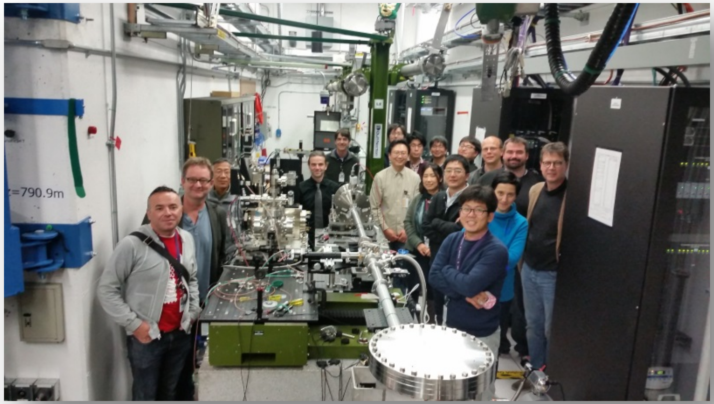
Photon energy (keV)	Average pulse energy (μJ) CR	Average pulse energy (μJ) XGMD	XGMD to CR measurement ratio	BPM spectral responsivity (μC/J)
4.4	32.26 ± 0.35	32.9 ± 2.0	1.020 ± 0.061	7.07 ± 0.21
5.8	104.2 ± 1.3	106.6 ± 6.1	1.023 ± 0.060	19.69 ± 0.73
9.6	95.3 ± 2.3	93.9 ± 6.1	0.985 ± 0.068	22.68 ± 0.79
13.6	42.2 ± 1.1	40.8 ± 2.9	0.967 ± 0.072	13.59 ± 0.80
16.8	0.96 ± 0.03	...	...	9.36 ± 0.58

XGMD : uncertainties ~6%
Radiometer : uncertainties 1.1%~3.1% - operated by liquid helium at 4.2K

M. Kato, T. Tanaka, T. Kurosawa, N. Saito, M. Richter, A.A. Sorokin, K. Tiedtke, T. Kudo, K. Tono, M. Yabashi, T. Ishikawa, *Pulse energy measurement at the hard x-ray laser in Japan,* Appl. Phys. Lett. 101, 023503 (2012)

Measurements of the absolute number of photon of LCLS hard X-ray line

by DESY/PTB and LCLS/AIST
January 21-24, 2015



Measurement of the absolute number of photon of LCLS pulses with an XGMD

In-house Development

Sanghoon Song
Hard X-ray department

ENERGY Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Collaboration

SLAC

- Aymeric Robert
- Sanghoon Song
- Marcin Sikorski
- Roberto Alonso-Mori
- Diling Zhu
- Yiping Feng
- HXR staff
- Gabriella Carini : Detector
- Stefan Moeller : SXR
- Mark Hunter : CXI
- Hae Ja Lee : MEC

XGMD

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- Mathias Richter :PTB Mathias.Richter@ptb.de

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- Owada Shigeki: RIKEN SPring-8 osigeki@spring8.or.jp
- Tanaka Takahiro: AIST takahiro-tanaka@aist.go.jp
- Kato Masahiro: AIST masahiro-katou@aist.go.jp

Measurements of the absolute number of photon of LCLS hard X-ray line

by DESY/PTB and LCLS/AIST
January 21-24, 2015

Goal

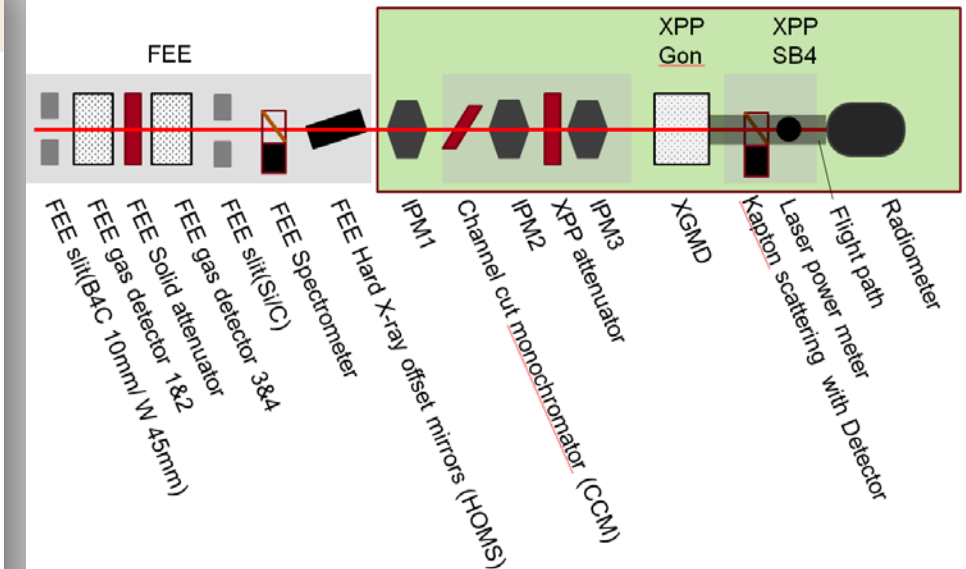
SLAC

Evaluate the absolute number of photon of LCLS hard X-ray line as a function of X-ray energy and operation mode of the machine

1. Transmission of the hard X-ray line (HOMS, other)
2. Cross Calibration of various Intensity monitor (XGMD, Radiometer, IPM, kapton monitor, laser power meter)
3. Brilliance

Experiment setup

SLAC



Measurements of the absolute number of photon of LCLS hard X-ray line – Preliminary results

by DESY/PTB and LCLS/AIST
January 21-24, 2015

9.0 keV

	9.0 keV (mJ)	9.0 keV (photons/pulse)
E(XGMD), mJ	1.03	7.14E+11
E(gas), mJ	2.30	1.60E+12
T, %	45%	
T(estimated), %	46%	
ratio(T/Testimated)	0.97	

Run	1st try	T (%)		XGMD (uJ)	C (uW)		after correcting factor (/120*1.37), uJ	Ratio (XGMD/C)
170	Vac+Kapton	4.1	XPP att	36.5	3090		35.28	1.03
171	Vac+Kapton	1	XPP att	7.25	660		7.54	0.96
172	Vac+Kapton	2	XPP att	15	1300		14.84	1.01
173	Vac+Kapton	3	XPP att	22.4	1920		21.92	1.02
174	Vac+Kapton	5	XPP att	52.1	4380		50.01	1.04
175	Vac+Kapton	6	XPP att	65.1	5470		62.45	1.04
176	Vac+Kapton	7.5	XPP att	83.3	7020		80.15	1.04
177	Vac+Kapton	9.1	XPP att	107.5	8960		102.29	1.05

6.0 keV

	6 keV (mJ)	6 keV (photons/pulse)
E(XGMD), mJ	0.246	2.56E+11
E(gas), mJ	1.42	1.48E+12
T, %	17.3%	
T(estimated), %	16.3%	
ratio(T/Testimate	1.06	

correction factor for 6 keV

1.00/(gasTransmission('Air',0.116,6)*Transmission('C*',100e-6*2,6)*Transmission('C22H10N2O5',75e-6*2,6,1.4))Out[120]: 3.01698544545632

Run	condition	T (%)		XGMD (uJ)	C (uW)		after correcting factor (/120*3.01	Ratio (XGMD/C)
185	Vac+Kapton	100	XPP att	245.6	9300		233.82	1.05
186	Vac+Kapton	52	XPP att	120.7	4820		121.18	1.00
187	Vac+Kapton	28	XPP att	50.8	2250		56.57	0.90
188	Vac+Kapton	15	XPP att	25.5	1340		33.69	0.76
189	Vac+Kapton	7.7	XPP att	15.5	1000		25.14	0.62
190	Vac+Kapton	4	XPP att	7.5	690		17.35	0.43
191	Vac+Kapton	2	XPP att	3.2	530		13.33	0.24
192	Vac+Kapton	28	XPP att	50.8	1700	add C* window, 3.84	54.40	0.93

Contribution from higher harmonics

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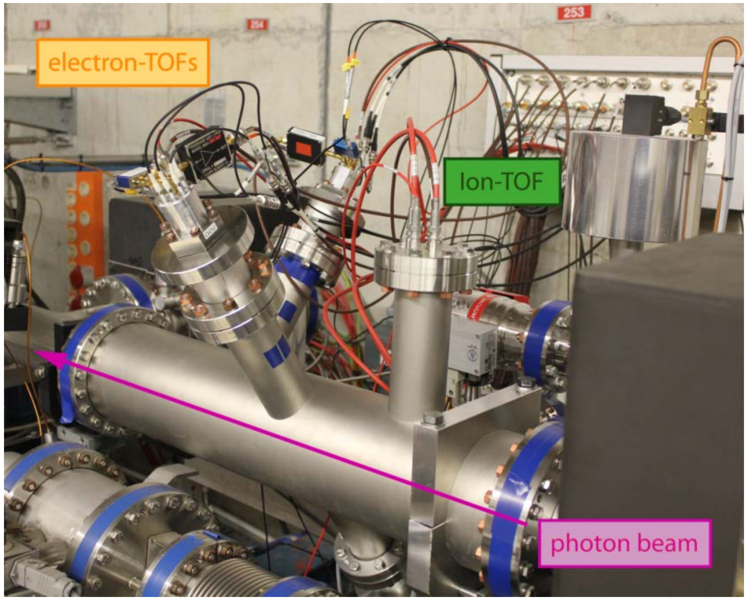
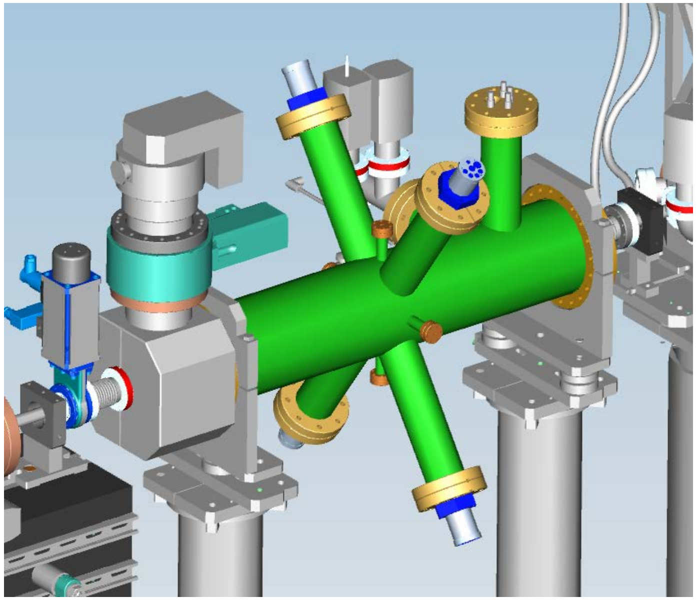
see poster presented by M. Braune

Online Photoionization Spectrometer.

One can use the Ion and Electron TOF data
to pinpoint the photon energies.





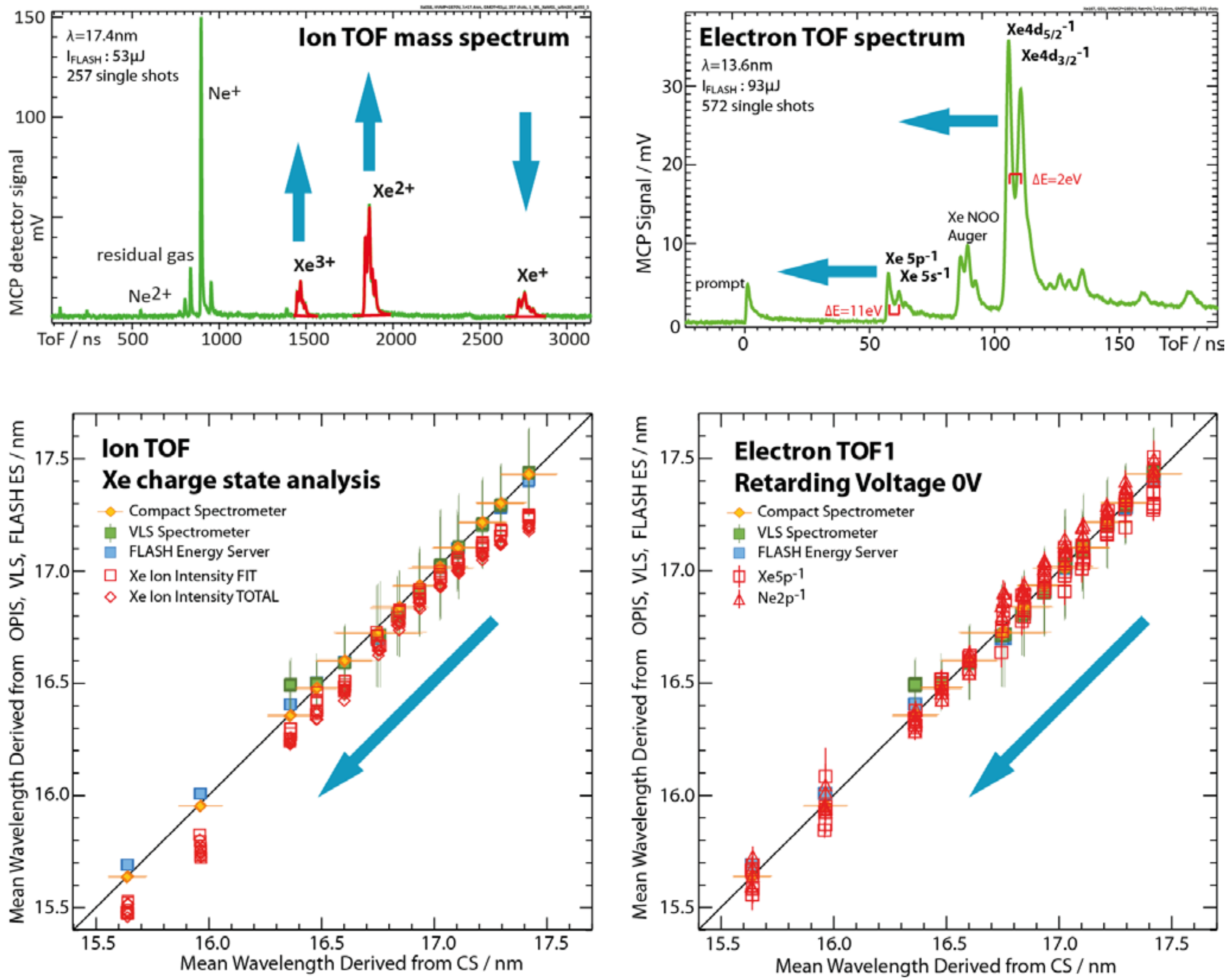
1 Ion time-of-flight spectrometer
open multiplier detector
electric fields (1-2kV) to extract photoions

4 Electron time-of-flight spectrometers
micro channel plate detectors

µ-metal chamber
$p_{target} < 3 \cdot 10^{-7}$hPa

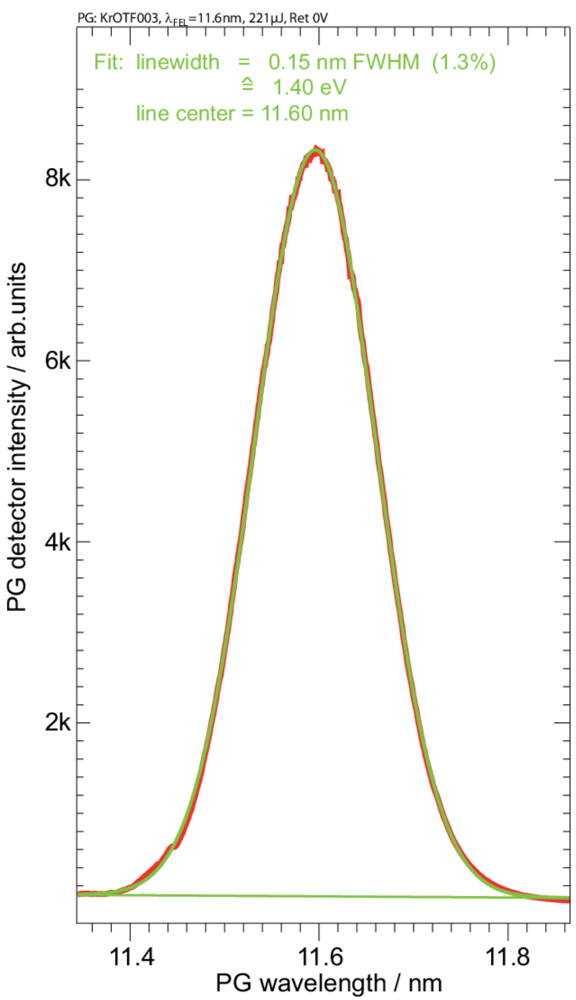
Transmission: ~100%
Signal recording by fast digtizers
Capable of multi-bunch operation

OPIS wavelength measurement: center wavelength.

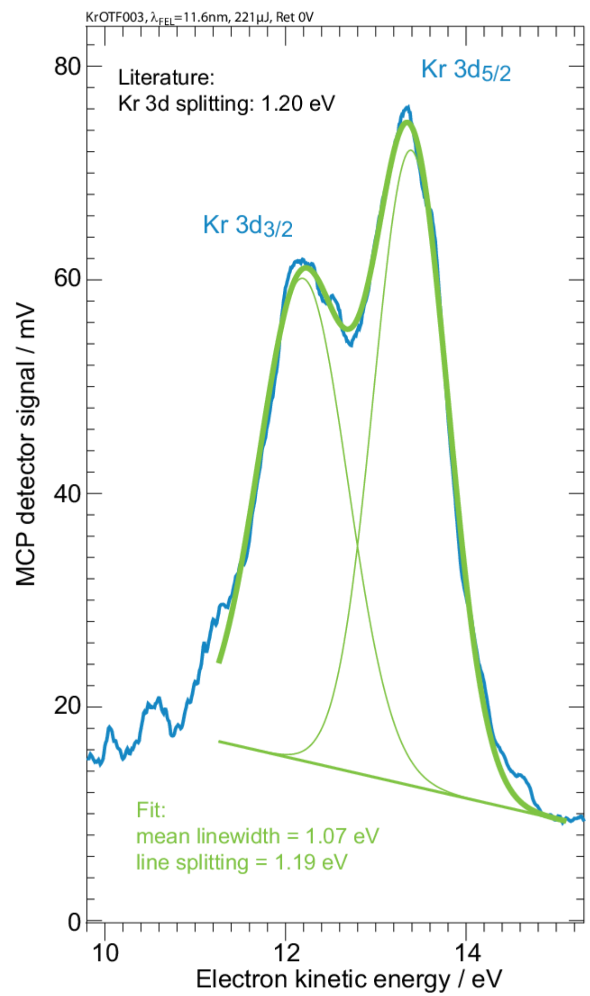


OPIS wavelength measurement: spectral width.

PG Spectrometer



OPIS: Kr



- Spectral width can be deduced from lines in the energy-converted photoelectron spectra
- So far, information about the spectral distribution is limited

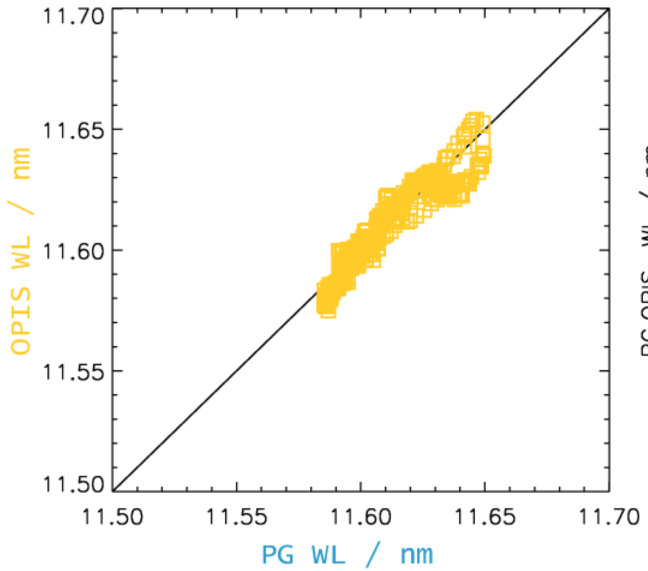
OPIS: …towards single-shot measurements.

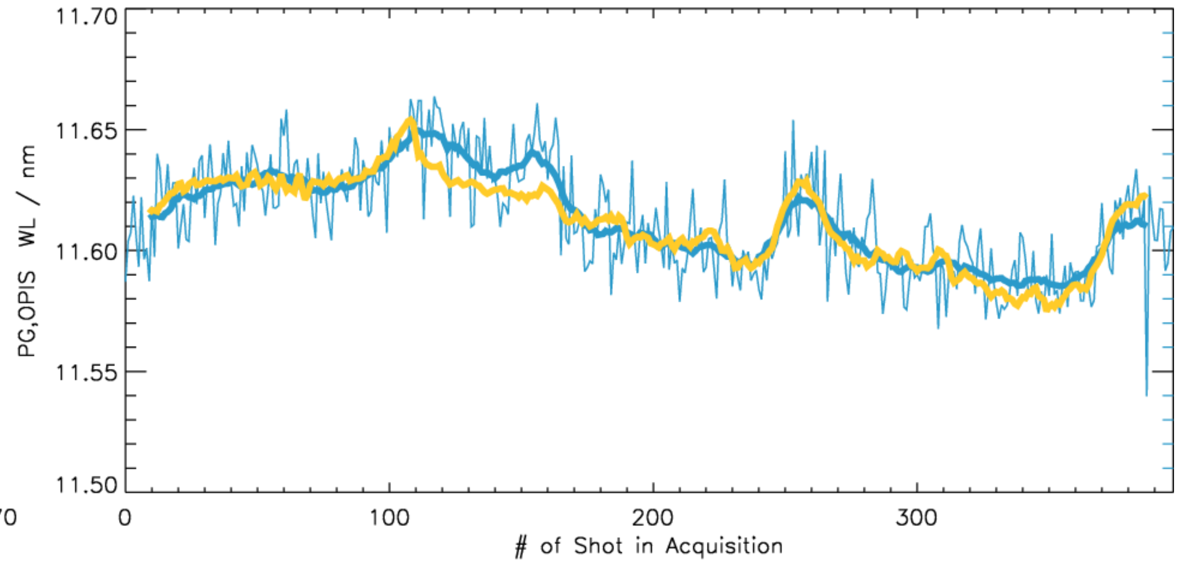
OPIS, PG measurements with Xe @ 11.60nm (25V retarding)
400 shots = 40 seconds

Compare moving average of 20 FEL shots:
PG : mean value of 20 single shot WL-values
OPIS: WL determination from 20-shot average spectrum

Including OPIS correction by $\Delta\lambda = -0.028$nm
derived from Auger line analysis

OPIS measurements reproduce wavelength fluctuations within
$\Delta\lambda = 0.01 - 0.02$ nm





A Final Comparison (for FLASH)

	E-TOF	I-TOF
Speed of measurement	Single shot capability (good signal quality conditions needed)	Single shot capability throughout the FLASH wavelength range
Uncertainty of wavelength measurement	0.05 nm Intrinsic calibration by means of Auger lines	0.1nm -0.4 nm due to the uncertainty of partial cross section data?
Expected “bonus” information	Spectral distribution Higher harmonics	-
Robustness	Sensitive to electric and magnetic fields, beam stability	Like a rock

Conclusions

The XGM pulse energy monitor:

- Perfect agreement with cryogenic radiometer in the hard X-ray regime
- HAMP multiplier provides a huge dynamic range
- we already started the assembly of 7 devices for XFEL and SwissFEL

The OPIS Online spectrometer :

- characterized and calibrated in the whole wavelength range of FLASH during the last year
- Reliable spectrometer for FLASH 2

But we have to…

- improve its shot-to-shot capabilty

Acknowledgments

Many thanks to:

PTB *A. Gottwald, M. Krumrey, and M. Richter*

Ioffe Physico-Technical Institute *S. Bobashev*

SwissFEL P. Juranic, L. Pattey, and R. Abela

SACLA M. Yabashi, K. Tono, T. Kudo, and T. Ishikawa

LCLS A. Robert, S. Song, M. Sikorski, R. Alonso-Mori, D. Zhu, Y. Feng, G. Carini, S. Moeller, and M. Hunter

AIST: N. Saito, M. Kato, T. Tanaka, and T. Kurosawa

and our collaborators from the European XFEL company who funded parts this work

European XFEL S. Molodtsov, T. Tschentscher, J. Grünert, W. Freund, and J. Buck

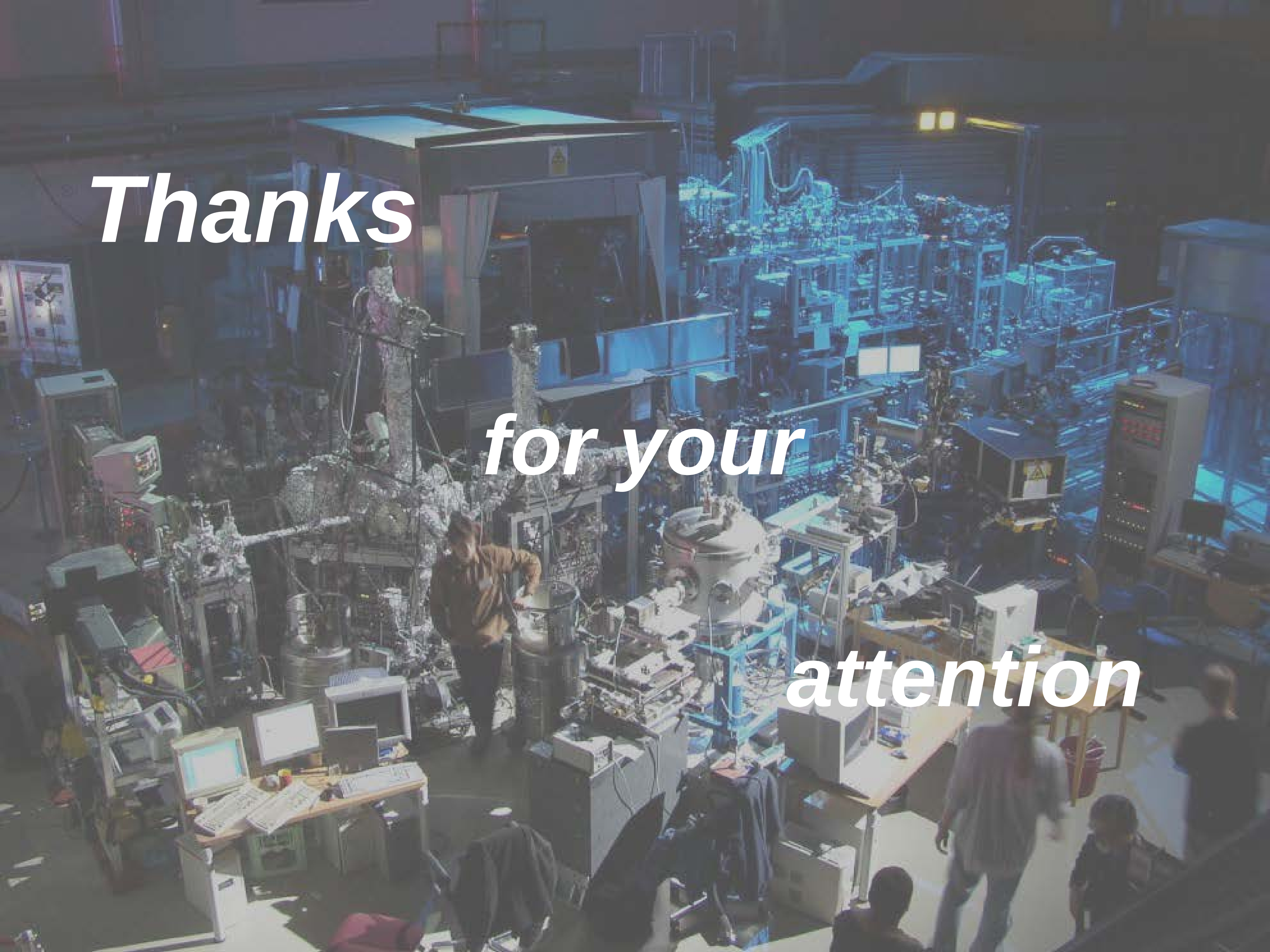
Acknowledgments

Many thanks to:

DESY Crew:

A. A. Sorokin, H. Kühn, S. Bonfigt, M. Brachmanski, P. Bonfigt,

M. Braune, L. Tiedtke, F. Jastrow, S. Kreis, Y. Bican, and B. Keitel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