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The quest for perfect beam transport systems and photon diagnostic tools: Highlights of WP7

In order to give you an idea about the motivation for our WP7 activities let's summarize:

- the features of Free Electron Lasers and
- the resulting requirements to perform experiments at such kind of machine

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  - **wavelength tunability ! (4.1nm – 50)**
  - **narrow bandwidth (0.5-1%)**
  - **coherence**
  - **femtosecond pulses (10 - 200fs)**
    ➔ Study of time dependent processes

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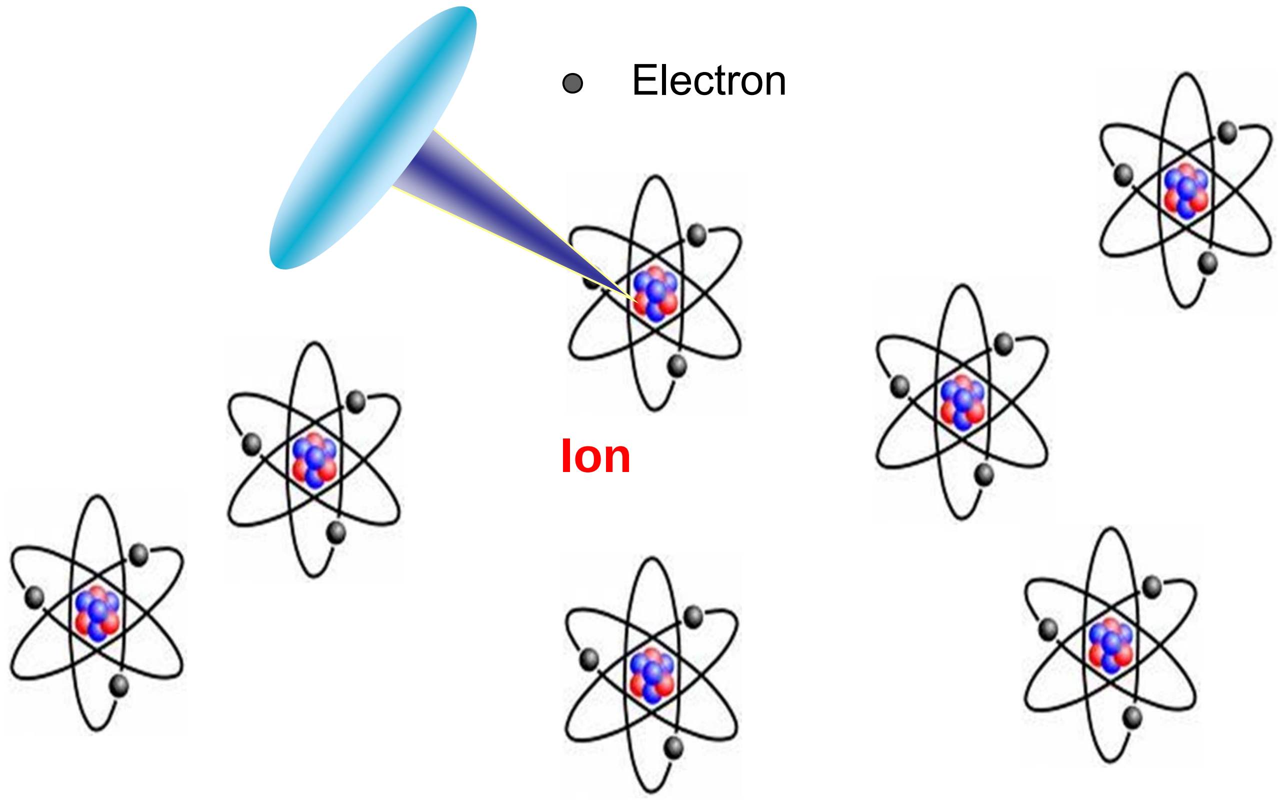
  - **narrow bandwidth (0.5-1%)**
  - **coherence**
  - **femtosecond pulses (10 - 200fs)**
  - **high intensity (> 5 GW peak power)**

focused to 1μm^2 => extreme power density of 10^{16} W/cm^2

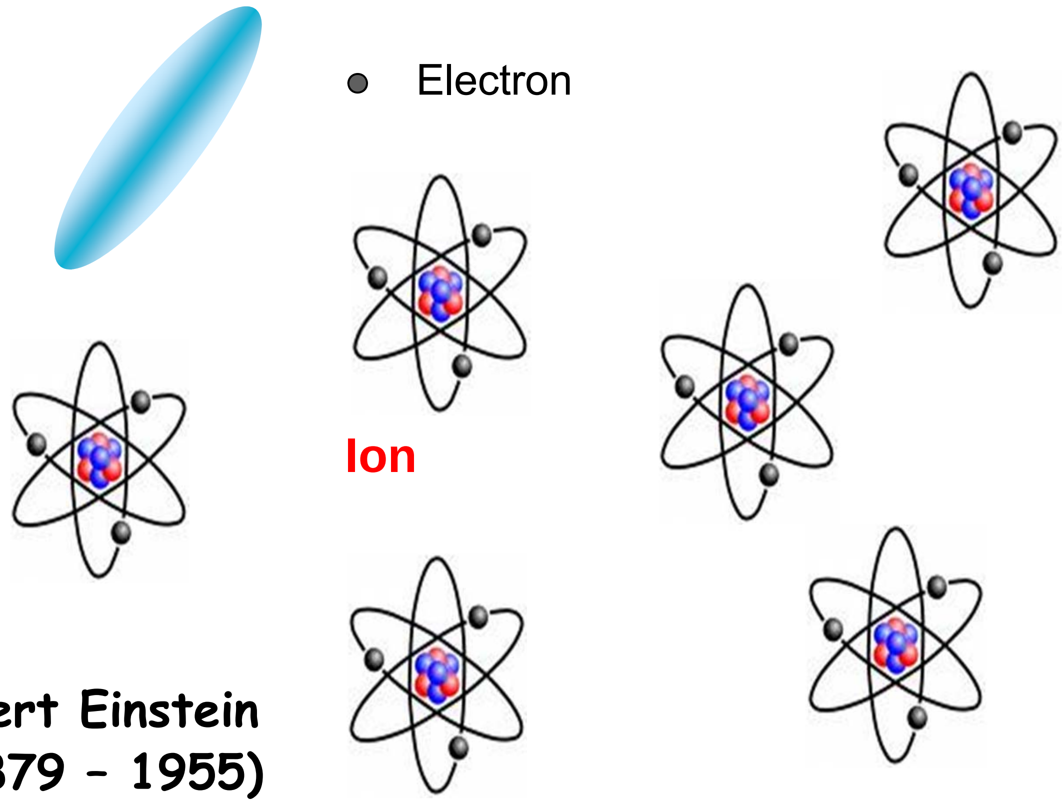
Let's consider a simple experiment…

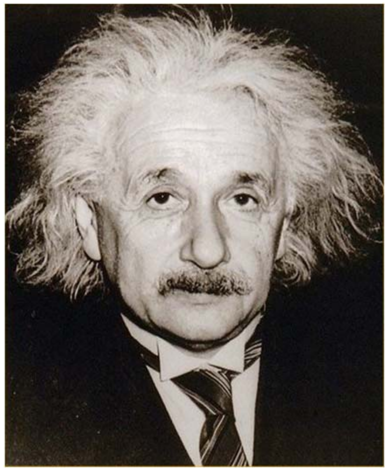
- Focus the FEL photon beam as far as possible
- Place a simple target in the focus like noble gas atoms and
- Let's have a look to what extend the atoms will be ionised



One might think that this a boring experiment…

classical photoelectric effect





Albert Einstein (1879 – 1955)

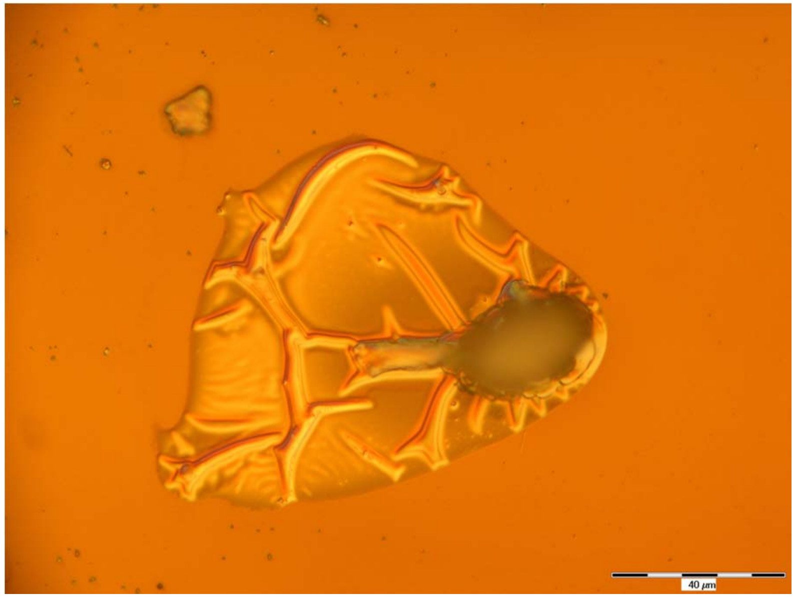
Before we can perform such an experiment…

one has to build an appropriate beamline and diagnostic tools.

That means we have to transport and to focus the FEL pulse onto the sample, but:

Damage studies of optical components

• What kind of mirrors shall we choose to withstand the high peak power?



Courtesy of R. Sobierajski et al.

Before we can start an experiment…

That means we have to transport and to focus the FEL pulse onto the sample, but:

• What kind of mirrors shall we choose to withstand the high peak power?

• What is the minimum length for all distributing mirrors and how perfect the shape has to be in order to avoid any degradation of the photon pulses?

Damage studies of optical components

Metrology of optics to minimize slope errors

Simulation of the FEL radiation transport (Wavefront propagation)

Before we can start an experiment…

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That means we have to transport and to focus the FEL pulse onto the sample, but:

• What kind of mirrors shall we choose to withstand the high peak power?

• What is the minimum length for all distributing mirrors and how perfect the shape has to be in order to avoid any degradation of the photon pulses?

• How can we minimize the focus size and what kind of tool can we use to characterize the focus (a CCD camera would be immediately destroyed) ?

Damage studies of optical components

Metrology of optics to minimize slope errors

Simulation of the FEL radiation transport (Wavefront propagation)

Development of diagnostic tools to characterize the wavefront / focus

Damage studies

In order to solve these problems WP7 brought together experts from all these different disciplines:

1) Thus, we supported an experimental campaign to study the damage thresholds of optical coatings. Here, also colleagues from LCLS, SCSS and XFEL are involved and these studies are still ongoing

Talk by *Jerome Gaudin*

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Talk by *Bernd Schäfers*

Metrology

order to solve these problems WP7 brought together experts from all these different disciplines:

2) We initiated a (real) start-to-end simulation of an existing beamline including not only the lasing process but also the photon beam transport and the imperfectness of the mirrors. The latter have been defined by the metrology labs.

3) Different methods have been developed to characterize the wavefront/focus at the end station.
These results have been used to benchmark the different simulation codes.

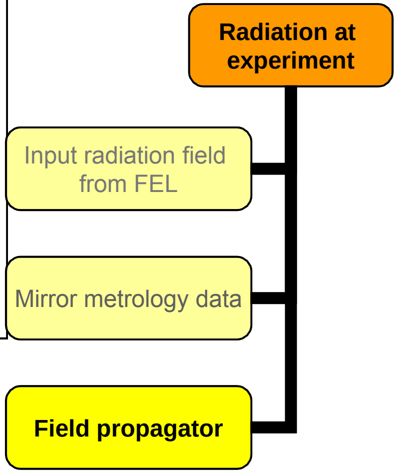
Start-to-end simulation

Wavefront characterizatio n

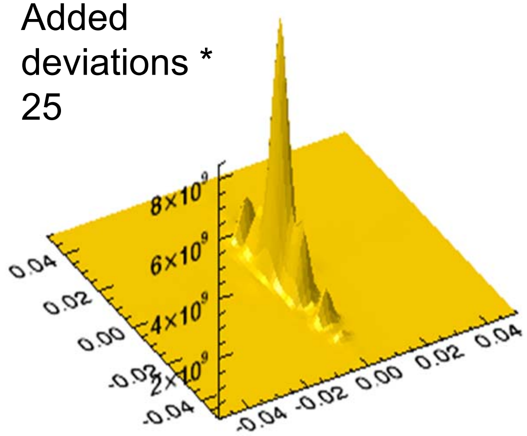
First results of S2E simulations of BL2 at FLASH

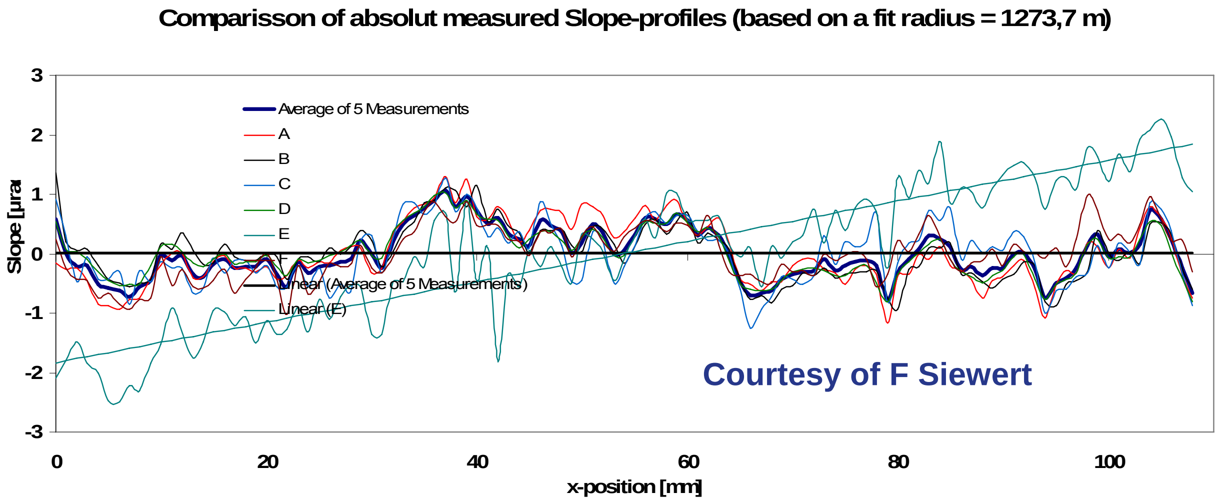
presented by Marion Bowler on the annual meeting in 2009

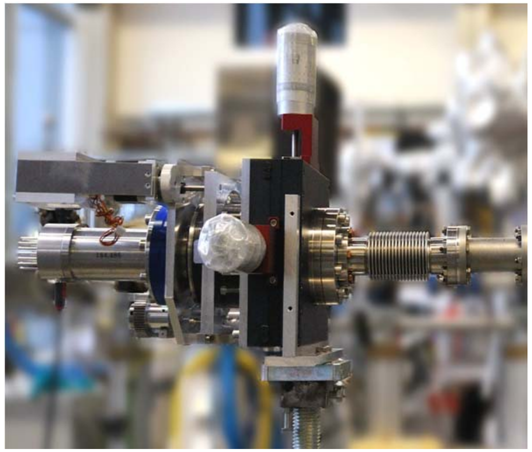
- Start to End simulations of BL2 at FLASH.
- Input field from Genesis 1.3, calculated by DESY (B Faatz)
- Metrology data from BESSY (F Sievert)
- Propagation using new code FOCUS



Added deviations * 25







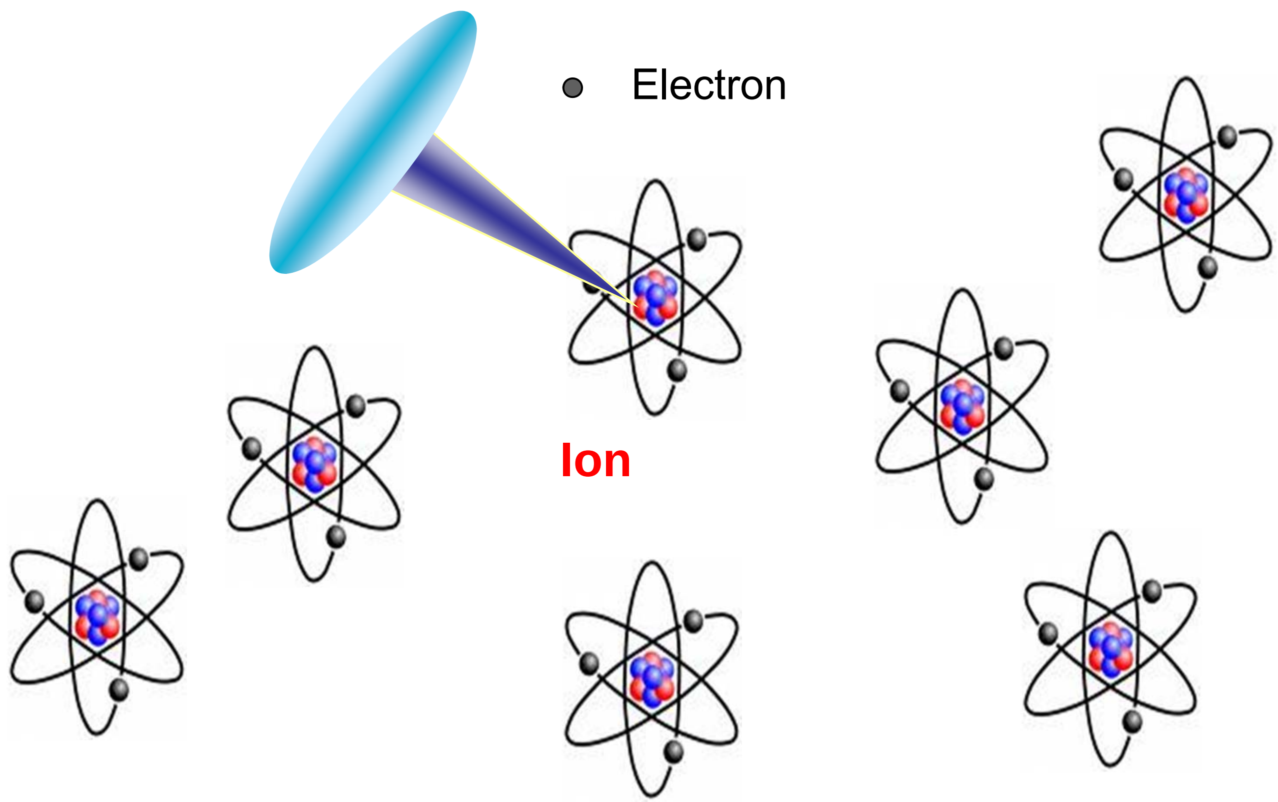
New wavefront sensor

WP3 activity: Wavefront propagation workshop

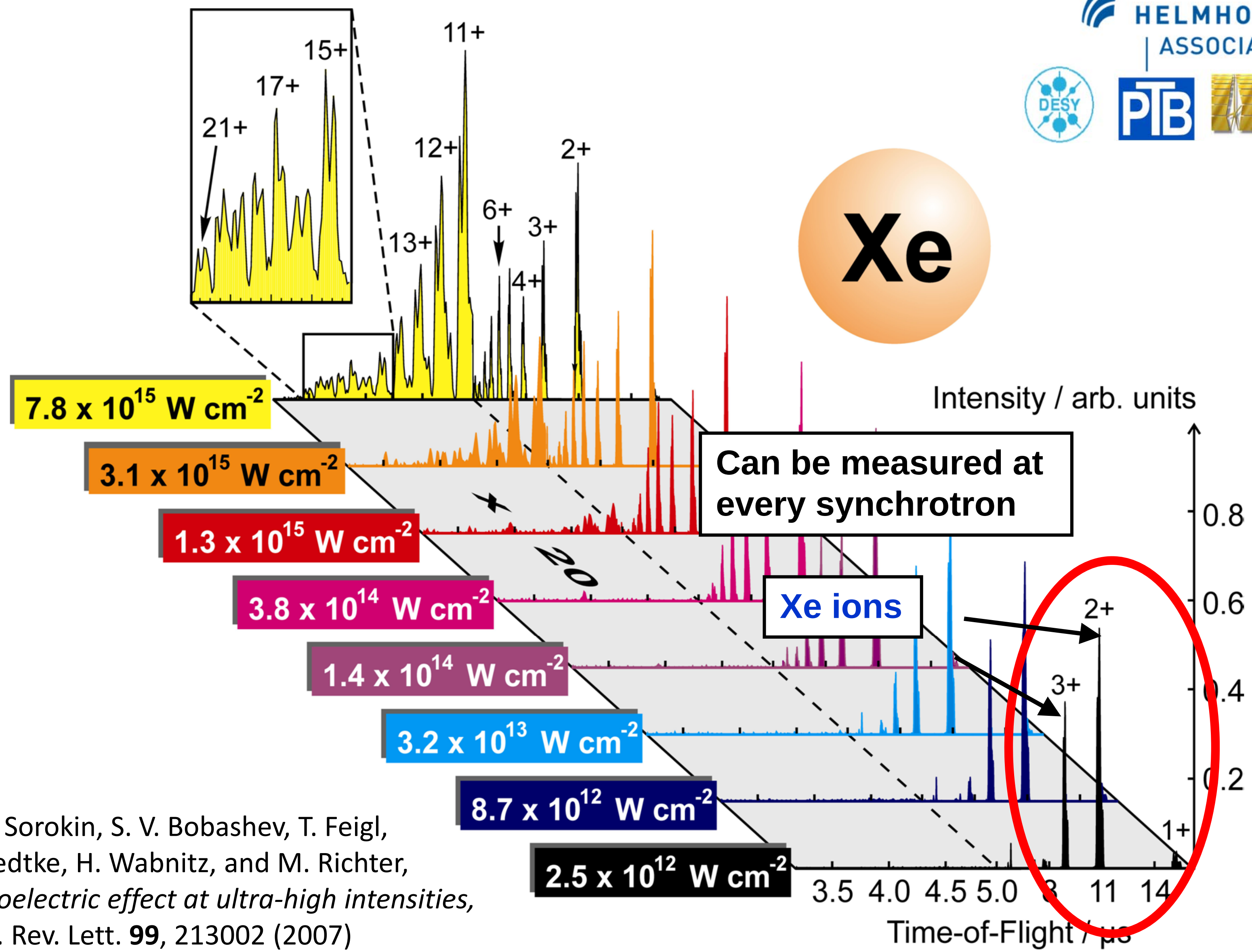
on 1st July 2009 at Daresbury Laboratory

Let's come back to our simple experiment…

- Focus the FEL photon beam as far as possible
- Place a simple target in the focus like noble gas atoms and
- Let's have a look to what extend the atoms will be ionised



Multiple Ionization of Xenon in the EUV.



A. A. Sorokin, S. V. Bobashev, T. Feigl,
K. Tiedtke, H. Wabnitz, and M. Richter,
Photoelectric effect at ultra-high intensities,
Phys. Rev. Lett. **99**, 213002 (2007)

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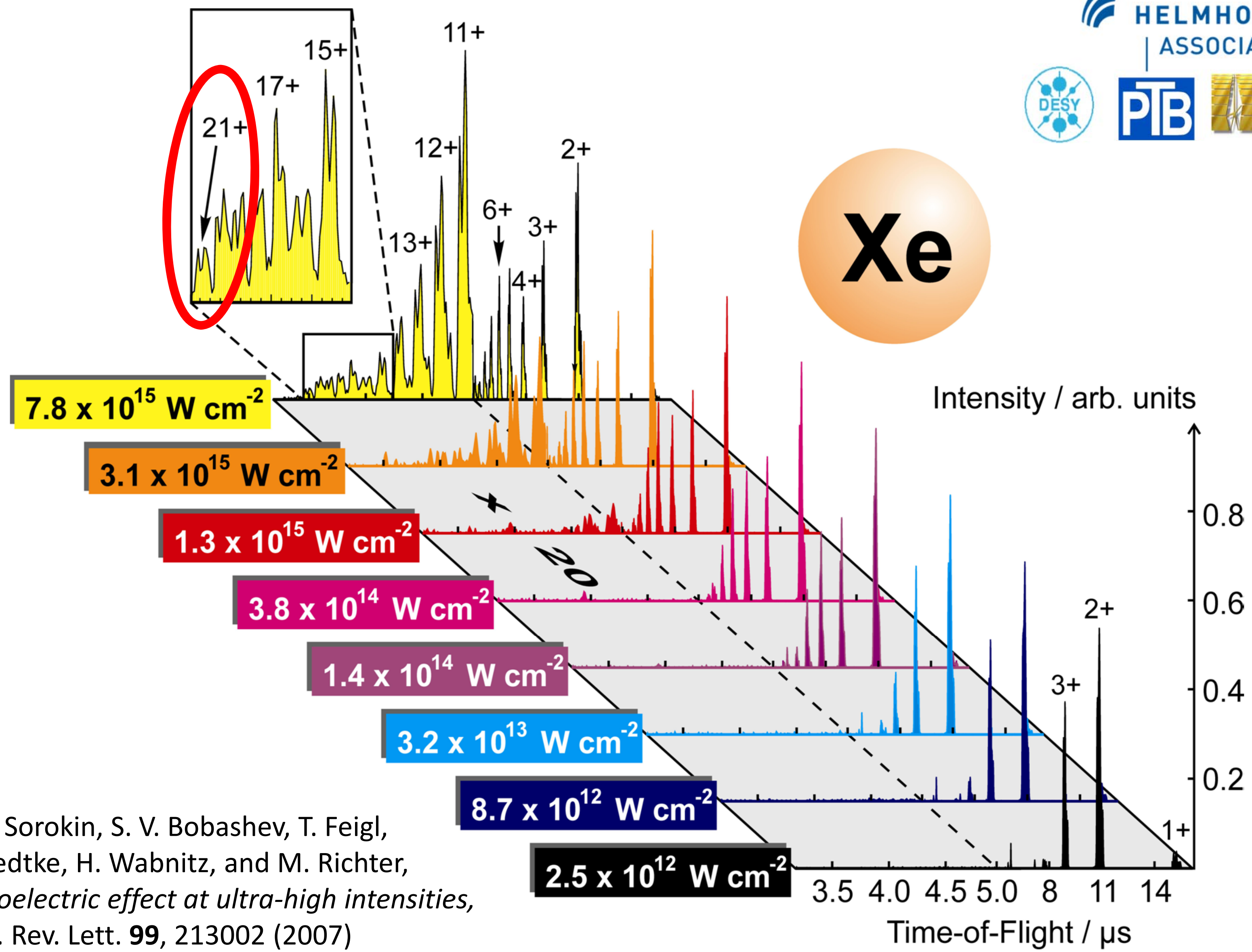

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Multiple Ionization of Xenon in the EUV.

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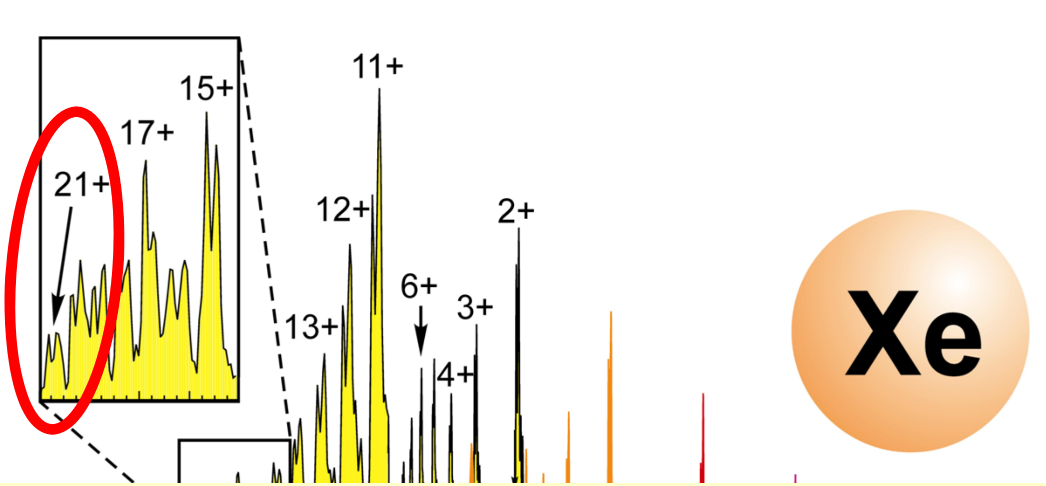
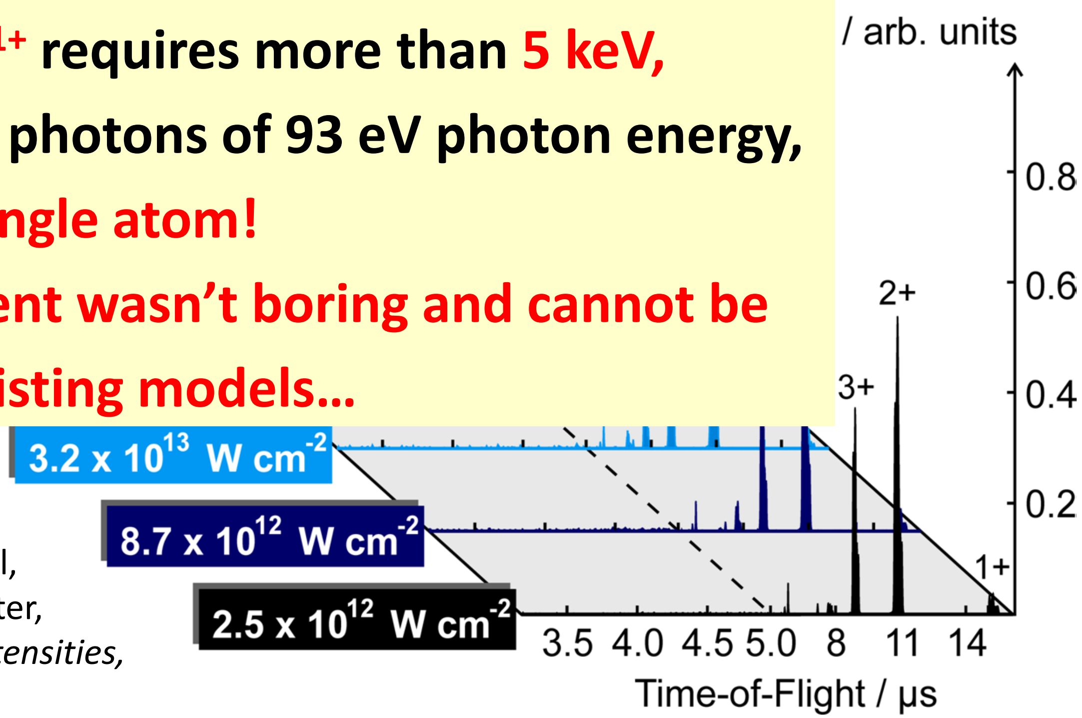
HELMHOLTZ ASSOCIATION

DESY PTB Ioffe Physico-Technical Institute



The generation of Xe^{21+} requires more than 5 keV,
i.e. more than 57 EUV photons of 93 eV photon energy,
to be absorbed by a single atom!
It seems this experiment wasn't boring and cannot be easily explained by existing models…



A. A. Sorokin, S. V. Bobashev, T. Feigl, K. Tiedtke, H. Wabnitz, and M. Richter, *Photoelectric effect at ultra-high intensities*, Phys. Rev. Lett. **99**, 213002 (2007)

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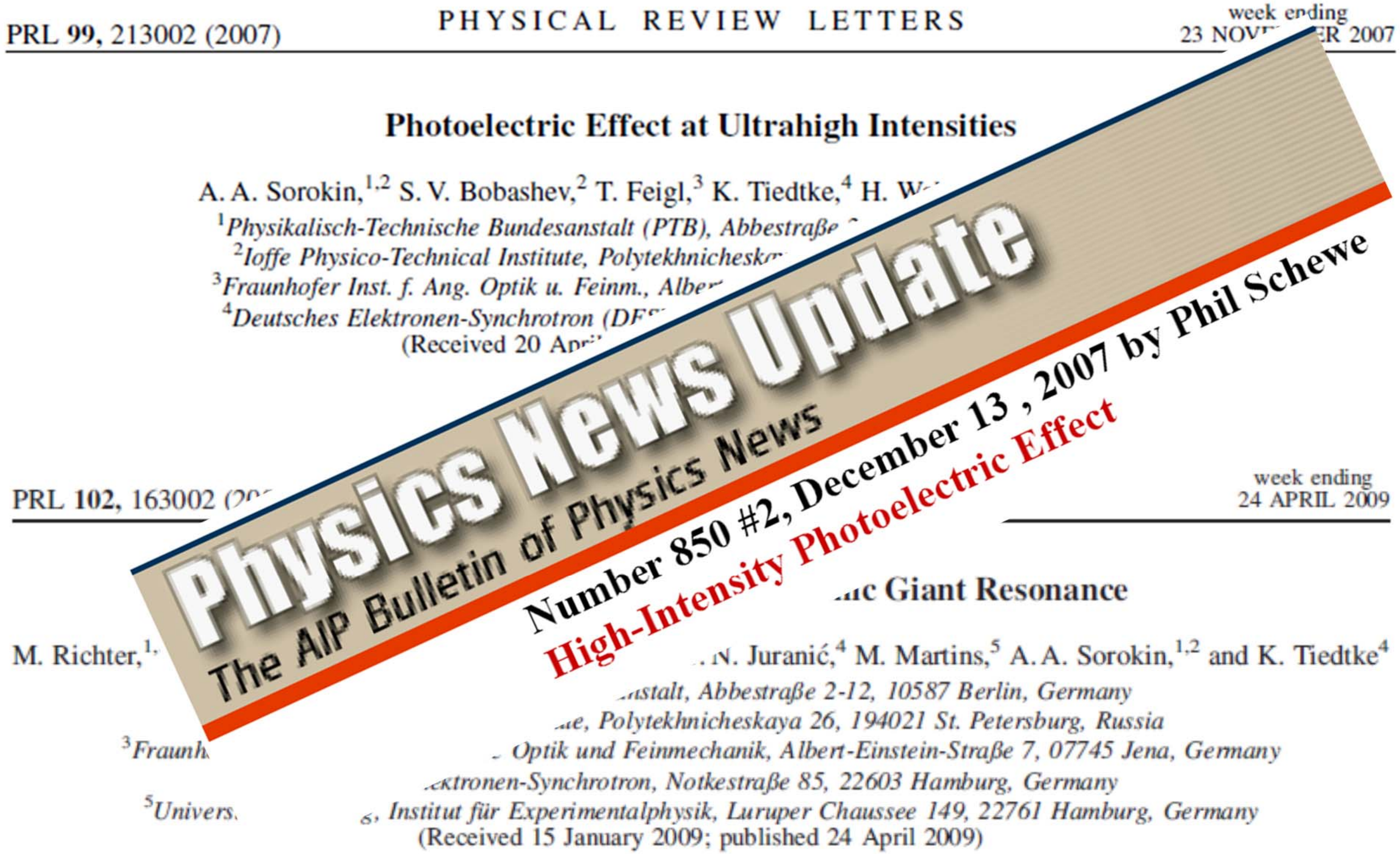

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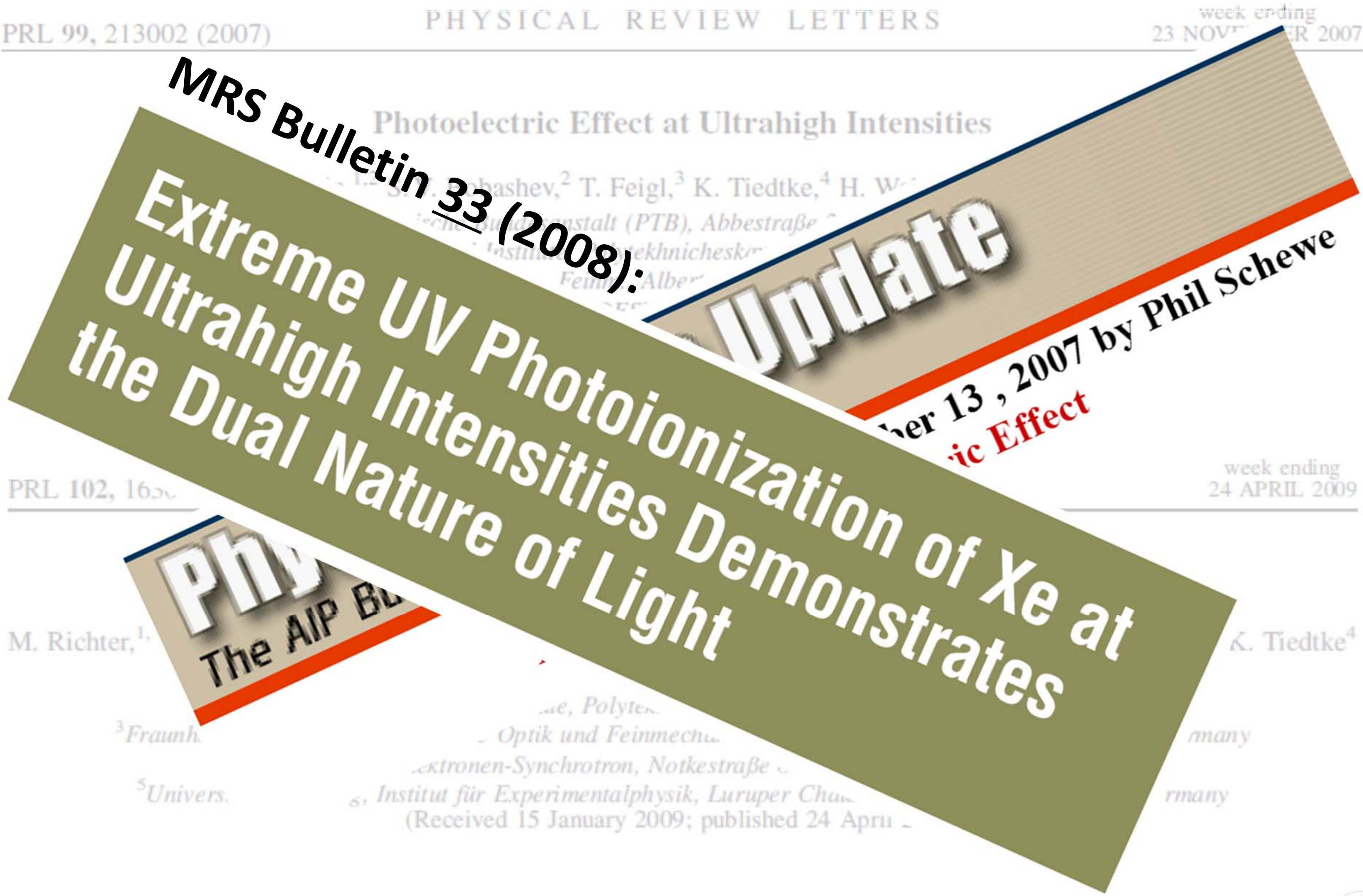

Multiple Ionization of Xenon in the EUV.

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KURZGEFASST **(Physik Journal 7 (2008) Nr. 1, S. 21)**

Photoelektrischer Effekt extrem

Physiker am Freie-Elektronen Laser in Hamburg (FLASH) haben den photoelektrischen Effekt bei einer Wellenlänge von 13,3 nm im extrem ultravioletten Spektralbereich und bei sehr hohen Photonenintensitäten untersucht. Dabei beobachteten sie, dass die bestrahlten Xenon-Atome bis zu 21 Elektronen verloren. Die Forscher weisen darauf hin, dass bisherige theoretische Ansätze nicht ausreichen, um die Wechselwirkung von Licht und Materie unter diesen extremen Bedingungen beschreiben zu können.

A. A. Sorokin et al., Phys. Rev. Lett. **99**, 213002 (2007)

Synchrotron kompakt

Erstmals ist es gelungen, eine Synchrotron-Strahlungsquelle im Labormaßstab zu realisieren. Das deutsch-britische Forscherteam kombinierte dafür erfolgreich einen in Jena entwickelten Hochintensitätslaser mit einem Undulator. Der Laser beschleunigte die Elektronen aus einem Helium-Plasma auf Energien zwischen 55 und 75 MeV. Im Undulator emittierten die hochenergetischen Elektronen Synchrotronstrahlung im optischen Bereich von sehr enger spektraler Bandbreite.

H.-P. Schlenvoigt et al., Nature Physics, doi:10-1038/nphys811 (2007)

Multiple Ionization of Xenon in the EUV.

Multiple Ionization of Xenon in the EUV.

PHYSICAL REVIEW LETTERS

BRENNPUNKT **(Physik Journal 8 (2009) Nr. 6, S. 18)**

Unerwartet aufgeladen

Experimente mit hochintensiver Strahlung am Freie-Elektronen-Laser in Hamburg zeigen eine überraschend hohe Ionisation von Xenon-Atomen.

Freie-Elektronen-Laser (FEL) wie FLASH in Hamburg und bald auch LCLS in Stanford (USA) erschließen einen bisher unerforschten Parameterbereich in der Wechselwirkung von Licht mit Materie [1]. Großforschungsanlagen dieser Art erzeugen kurzwelliges Licht mit einer Intensität, die diejenige aller existierenden Strahlungsquellen um viele Größenordnungen übersteigt. Das derzeit ambitionierteste Projekt ist der Europäische Röntgen-FEL (XFEL), der in Hamburg gebaut wird [1]. Er wird in seiner Endausbaustufe kohärente Strahlung mit bis zu 12 keV Photonenenergie liefern.

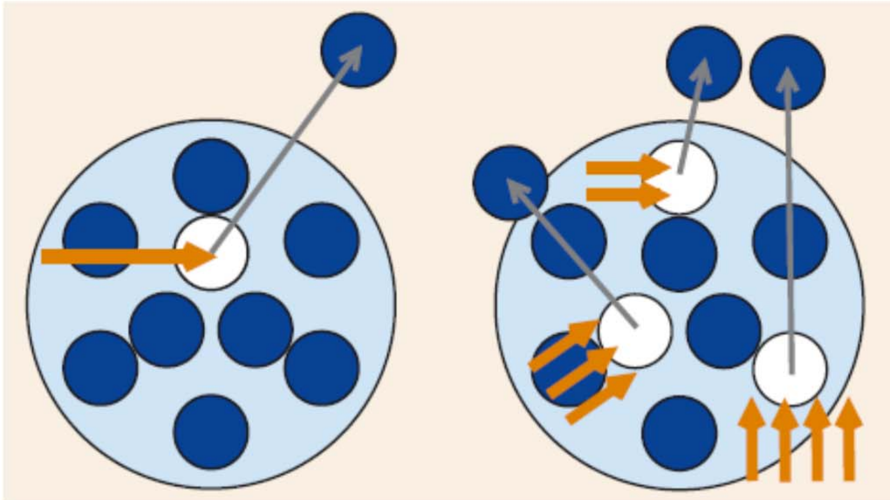


Abb. 1 Bei geringen Lichtintensitäten werden Atome (hellblau) durch den Photoeffekt einfach ionisiert, wobei ein Elektron (dunkelblau) das Atom verlässt (links). Beim hochintensiven FEL-Licht kommt es durch Multiphotonen-Prozesse zur Vielfach-Ionisation der Atome (rechts).

What do we need to find a new theoretical model?

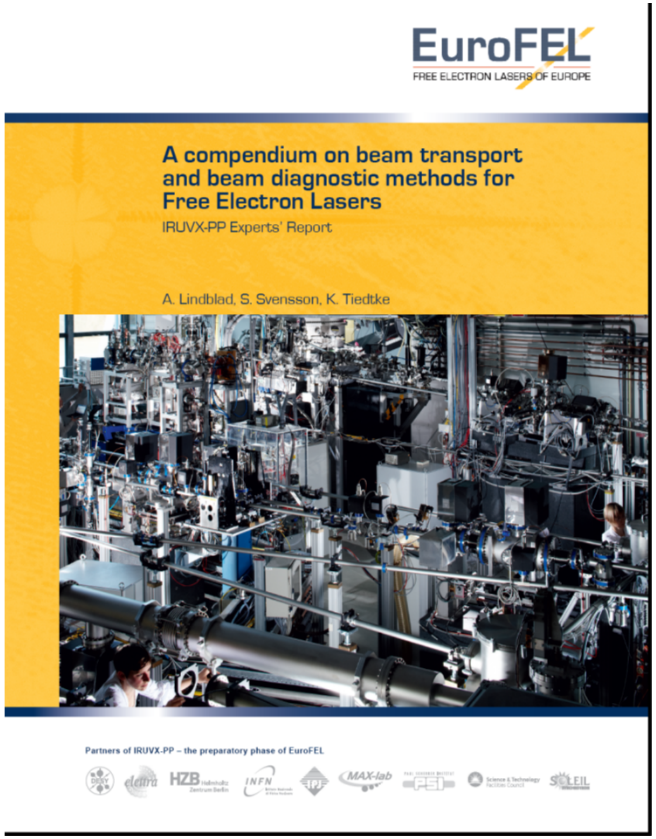
For a theoretical model one obviously needs the quantities of all relevant photon beam parameters like:

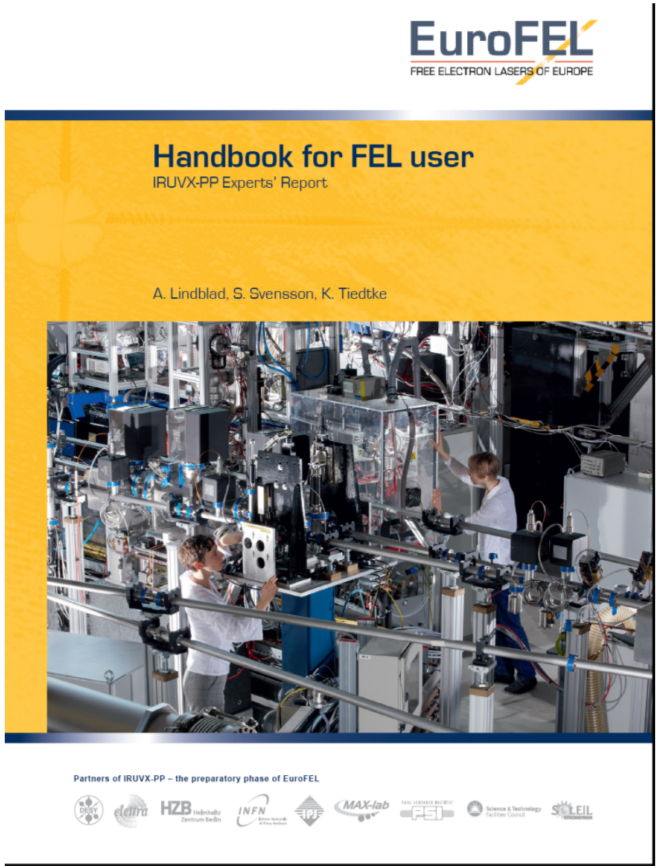
- Pulse energy
- Pulse length
- Focus size
- Wavelength
- etc

And in contrast to synchrotron experiments one needs most of these information for every single pulse => online, non destructive.

WP7 initiated systematic surveys on possible diagnostics techniques and these surveys have been summarized by Andreas Lindblad in …

Andreas Lindblad





EuroFEL Workshop on Photon Beamlines and Diagnostics

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH

Section A: accelerators, spectrometers, detectors and associated equipment

Volume 635 (2011), Supplement 1

PhotonDiag 2010

Edited by M. Zangrando, U. Flechsig, F. Siewert, M. Roper, K. Tiedtke and C. Gerth

Abstracted/Indexed in: Current Contents: Engineering, Computing and Technology; Current Contents: Physical, Chemical and Earth Sciences; EI Compendex Plus; Engineering Index; INSPEC. Also covered in the abstract and citation database SCOPUS®. Full text available on ScienceDirect®.

0168–9002(20110411)635:1S;1–8

635 1S

NUCLEAR INSTRUMENTS AND METHODS IN PHYSICS RESEARCH (SECTION A)–VOL. 635/1S (2011) S1–S122

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Volume 635, Supplement 1 April 11, 2011 ISSN 0168-9002

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH

Section A: accelerators, spectrometers, detectors and associated equipment

Editors:

William Barletta
(*Coordinating Editor*)

Robert Klanner, Fulvio Parmigiani, Fabio Sauli, David Wehe

Founding Editor – Kai Siegbahn

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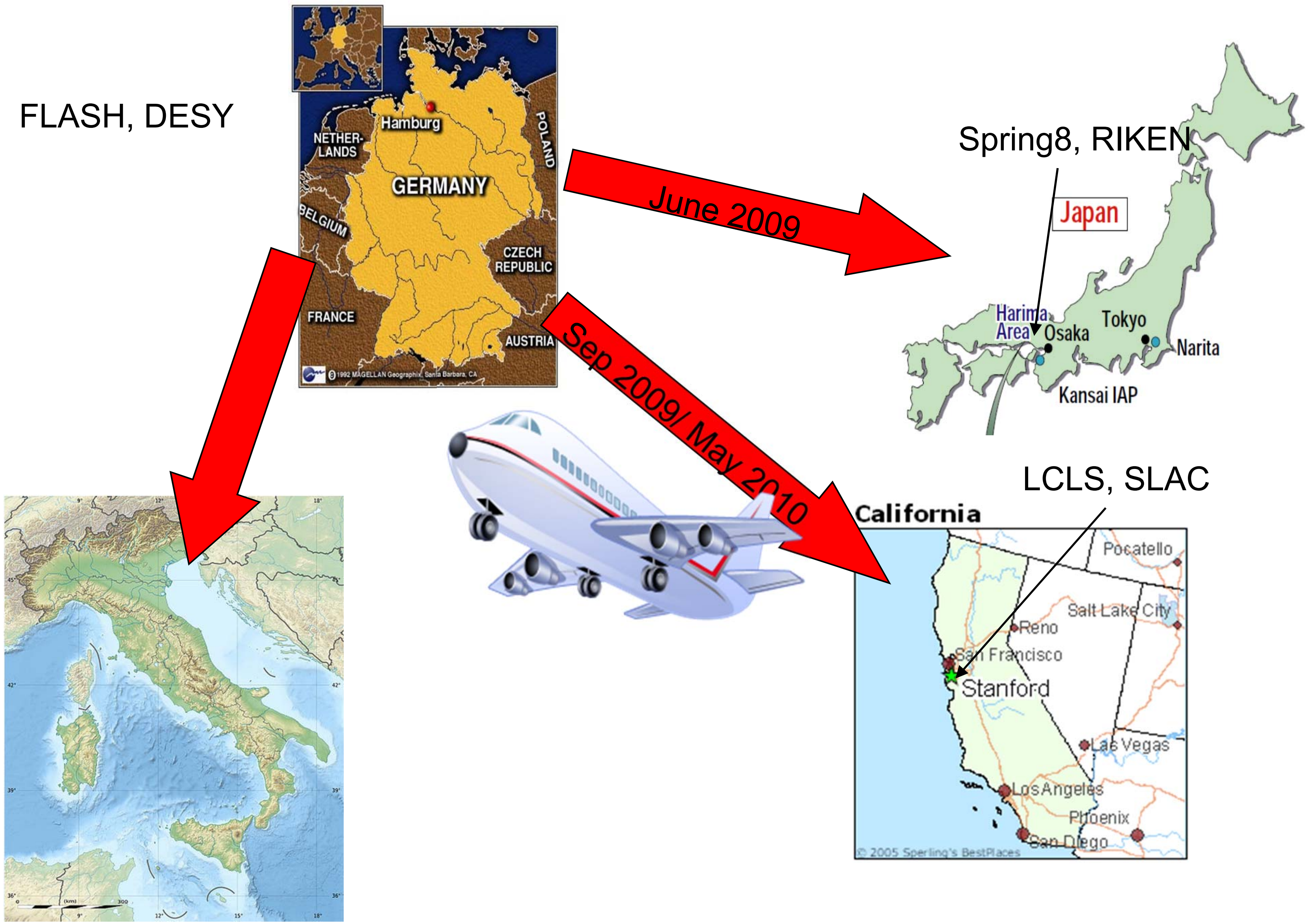
http://www.elsevier.com/locate/NIMA

Round Robin test of intensity monitors



Fourth part: FERMI@ ELETTRA

March, 2011

ELETTRA:	Cristian Svetina, Marco Zangrando, Daniele Cocce,
PSI:	Juraj Krempasky
MAXLAB:	Andreas Lindblad
DESY:	K. Tiedtke, M. Markert, H. Kühn, S. Bonfigt, B. Keitel, S. Kapitzki, A. Sorokin

Round robin results.

Spring-8

IOP Publishing — Metrologia
Metrologia 47 (2010) 21–23 — doi:10.1088/0026-1394/47/1/003

Radiometric comparison for measuring the absolute radiant power of a free-electron laser in the extreme ultraviolet

Norio Saito[1,2], Pavle N Juranić[2,3], Masahiro Kato[1,2], Mathias Richter[2,4], Andrey A Sorokin[2,3,4,5], Kai Tiedtke[2,3], Ulf Jastrow[3], Udo Kroth[4], Hendrik Schöppe[4], Mitsuru Nagasono[2], Makina Yabashi[2], Kensuke Tono[2], Tadashi Togashi[2,6], Hiroaki Kimura[6], Haruhiko Ohashi[6] and Tetsuya Ishikawa[2]

[1] National Institute of Advanced Industrial Science and Technology (AIST), NMIJ, Tsukuba 305-8568, Japan
[2] RIKEN, XFEL Project Head Office, Kouto, Sayo, Hyogo 679-5148, Japan
[3] Deutsches Elektronen-Synchrotron, DESY, Notkestrasse 85, D-22603 Hamburg, Germany
[4] Physikalisch-Technische Bundesanstalt, PTB, Abbestrasse 2-12, D-10587 Berlin, Germany
[5] Ioffe Physico-Technical Institute, Polytekhnicheskaya 26, 194021 St Petersburg, Russia
[6] Japan Synchrotron Radiation Research Institute, Sayo, Hyogo 679-5198, Japan

IOP Publishing — Metrologia
Metrologia 47 (2010) 518–521 — doi:10.1088/0026-1394/47/5/002

Measurement of the single-shot pulse energy of a free electron laser using a cryogenic radiometer

Masahiro Kato[1,2,7], Norio Saito[1,2], Kai Tiedtke[2,3], Pavle N Juranić[2,3], Andrey A Sorokin[2,3,4], Mathias Richter[2,5], Yuichiro Morishita[1], Takahiro Tanaka[1,2], Ulf Jastrow[3], Udo Kroth[5], Hendrik Schöppe[5], Mitsuru Nagasono[2], Makina Yabashi[2], Kensuke Tono[2], Tadashi Togashi[2,6], Hiroaki Kimura[6], Haruhiko Ohashi[6] and Tetsuya Ishikawa[2]

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[5] Physikalisch-Technische Bundesanstalt, PTB, Abbestraße 2-12, D-10587 Berlin, Germany
[6] Japan Synchrotron Radiation Research Institute, Sayo, Hyogo 679-5198, Japan

E-mail: masahiro-katou@aist.go.jp

LCLS

Pulse energy monitoring of X-ray FEL beam by gas-monitor detector

A.A. Sorokin, P. Juranić, U. Jastrow K. Tiedtke, DESY/XFEL
M. Richter, PTB
M. Yabashi , M. Nagasono, SPRING 8
Stefan Moeller, Jacek Krzywinski, SLAC
Stefan Hau-Riege, LLNL

Pulse energy monitoring at the SXR beamline using gas-monitor detectors

A.A. Sorokin, U. Jastrow, P. Juranić, S. Kapitzki, K. Tiedtke, DESY
M. Richter, PTB
U. Arp, NIST
S. Moeller, J. Turner, W. Schlotter, SLAC

Acknowledgement

Members of IRUVX-PP WP7 and WP3 Expert Groups Photon Beam Transport and Diagnostics and Metrology for FEL Optics:

Rafael Abela, Anna Bianco, Marion Bowler, Günter Brenner, Roberto Cimino, Daniele Cocco, Henrik Enquist, Uwe Flechsig, Christopher Gerth, Anthony Gleeson, Fini Jastrow, Ulf Johansson, Libor Juha, Pavle Juranic, Barbara Keitel, Jörgen Larsson, Andreas Lindblad, Eric Louis, Bernd Löchel, Rolf Mitzner, Paul Morin, Robert Nietubyć, Luca Poletto, Paul Radcliffe, Amparo Rommeveaux, Mark Roper, Frank Siewert, Ryszard Sobierajski, Andrey Sorokin, Giovanni Sostero, Sibylle Spielmann-Jaeggi, Svante Svensson, Cristian Svetina, Muriel Thomasset, Peter van der Slot, Hubertus Wabnitz, Christian Weniger, Marco Zangrando.

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End

DESY

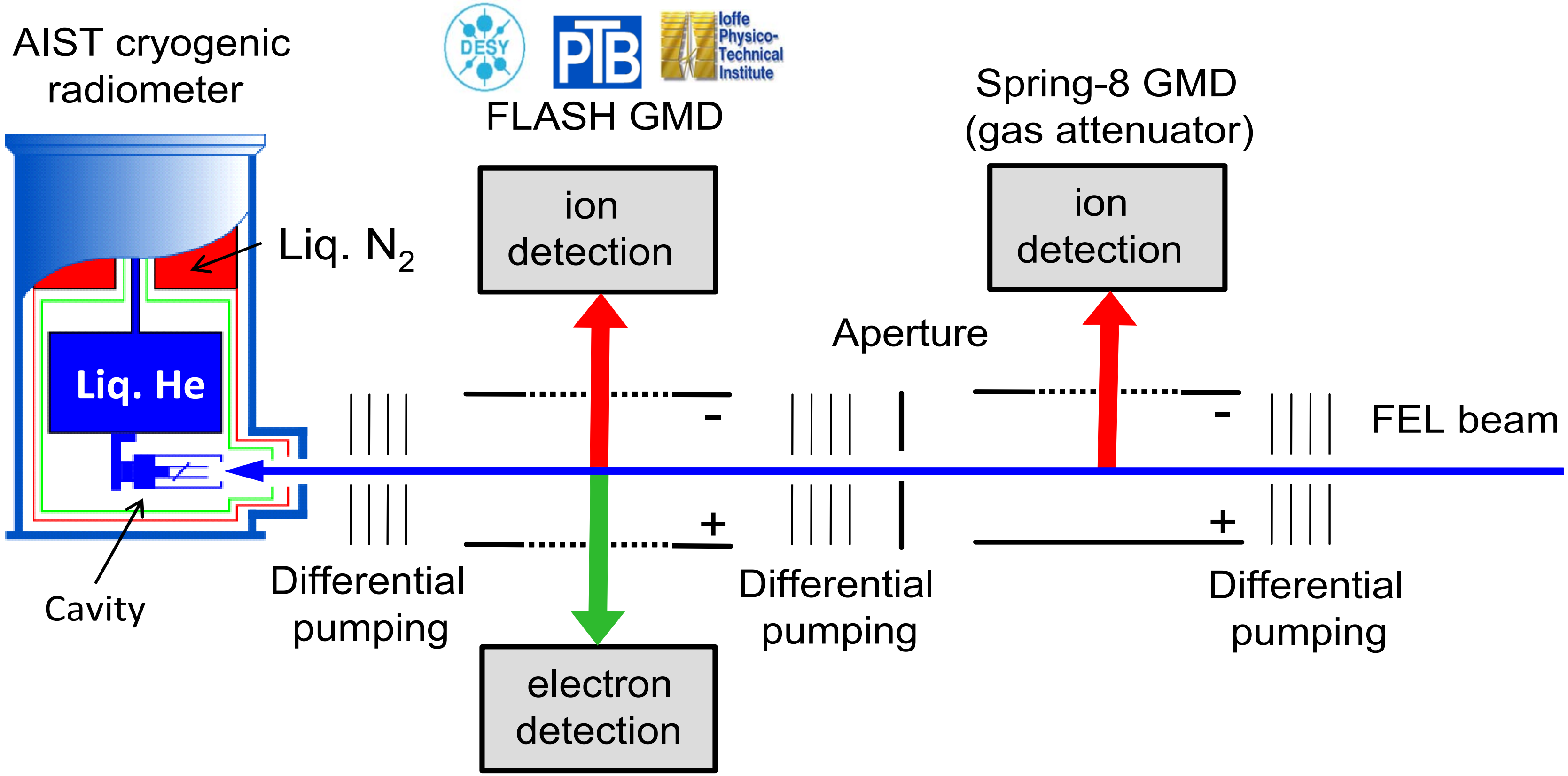
First part: EUV-FEL of Spring-8 (Japan)

Comparison between the pulse energy monitor of FLASH with a cryogenic radiometer of AIST.

by DESY/PTB and RIKEN/AIST
June 23-26, 2009

AIST: N. Saito, M. Kato,
RIKEN: M. Yabashi, M. Nagasono
PTB: M. Richter, A. Sorokin
DESY: K. Tiedtke, P. Juranic

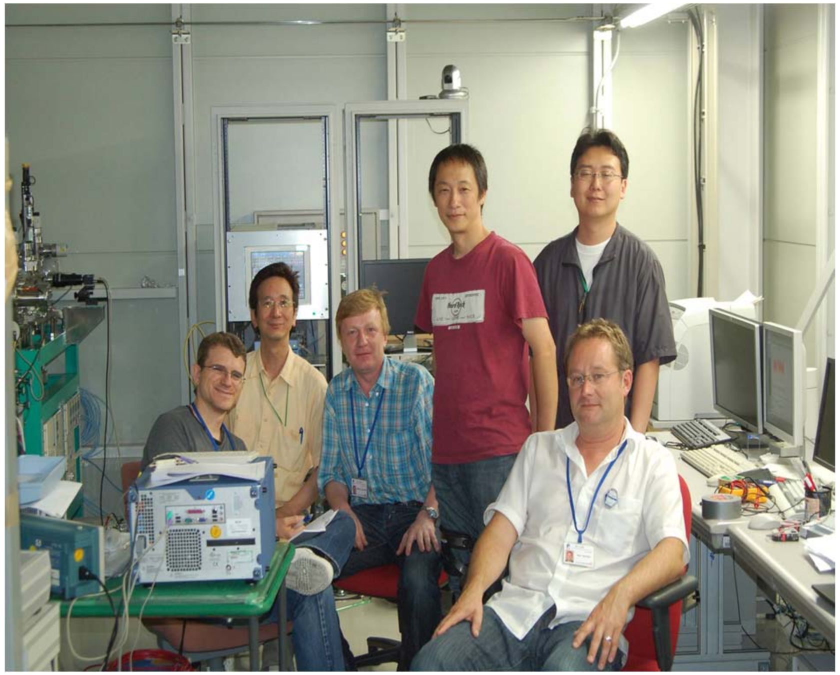
Experimental set-up at the Spring-8 EUV FEL.

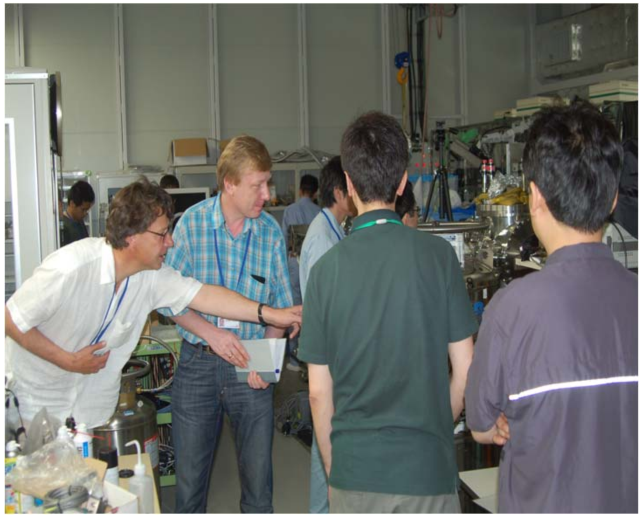


The first results…

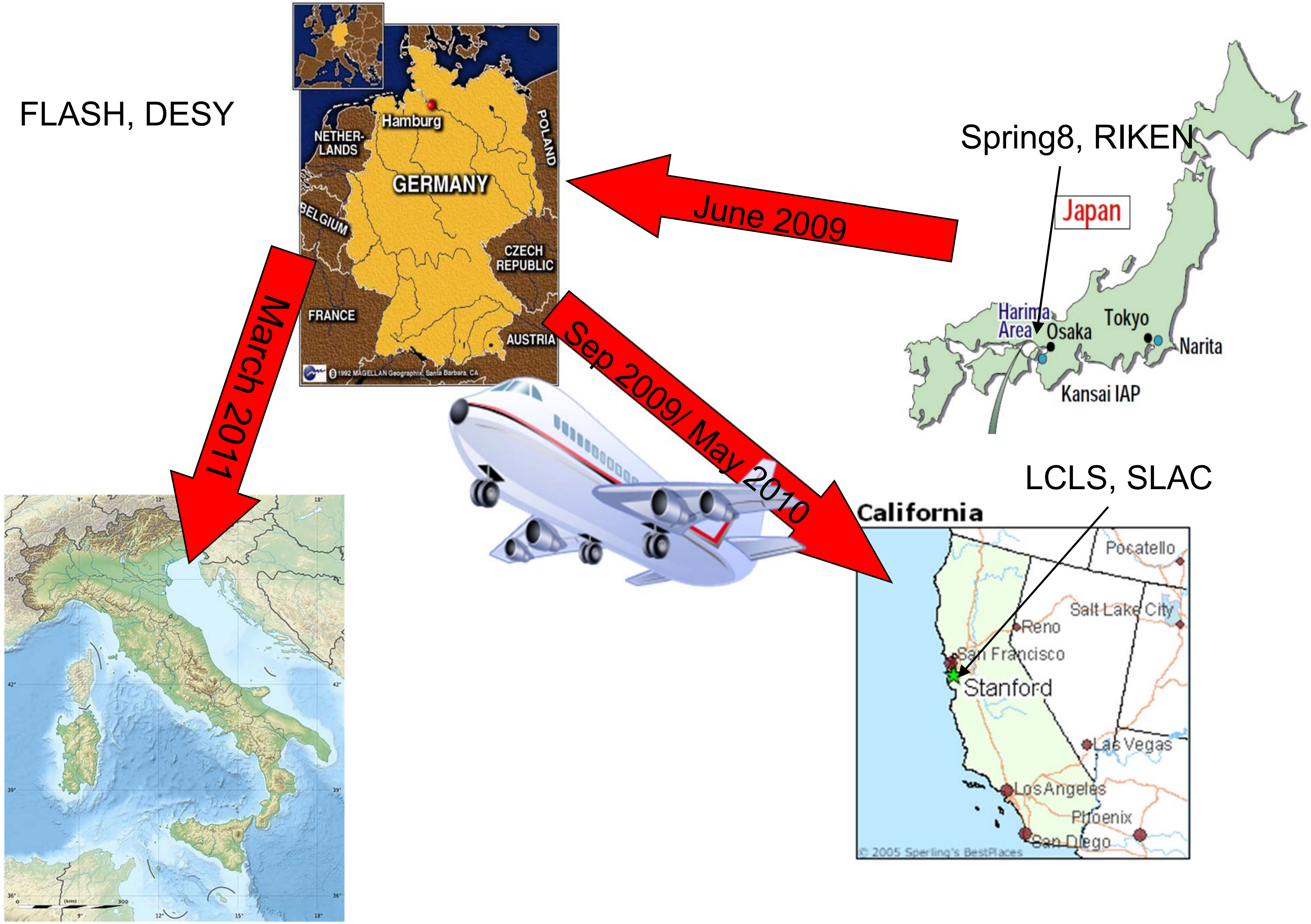
Date	Time (Japan)	AIST/GMD
23.06.2009	12:25	0,94549996
23.06.2009	12:30	0,974769845
23.06.2009	12:37	1,034721729
23.06.2009	12:41	1,019547581
23.06.2009	12:48	1,026827426
23.06.2009	12:53	0,953185532
23.06.2009	13:20	0,978404082
23.06.2009	13:30	0,975169773
23.06.2009	13:40	0,94306757
23.06.2009	14:34	1,018131403
23.06.2009	14:45	0,995017069
23.06.2009	14:55	1,023343428
23.06.2009	15:05	1,045446745
23.06.2009	15:10	0,996964191
23.06.2009	15:15	0,972385488
		0,993498788

Everybody is happy!





Round Robin test of intensity monitors



Second & third part: LCLS AMO and SXR beamlines

AMO station: September, 2009

SXR station: June, 2010

NIST: U. Arp,
LCLS: S. Moeller, W. Schlotter, J. Turner, J. Bozek, C. Bostedt , J. Kryzywinski

PTB: M. Richter
DESY: K. Tiedtke, U. Jastrow, P. Juranic, S. Kapitzki, A. Sorokin

Round Robin test of intensity monitors