



Detectors for Future Light Sources

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- Radiation from X-Ray Free Electron lasers (XFEL, LCLS)
- Ultrafast detectors
- Integrating detectors
- Requirements by different types of experiments

Time-resolved pump-probe experiments

Small particle imaging

X-ray photon correlation spectroscopy

Conclusions



X-Ray FELs (XFEL, LCLS)



2 km







Photon energy

Photon per pulse Divergence Source appearance Bandwidth

Pulse duration Repetition rate X-rays: 3 up to 15 keV (λ = 1Å) (soft X.: 200 up to 2000 eV) 10¹² (up to 10¹⁴) < 1 up to few 10 µrad ~ 100 µm (diffraction limited) ~ 0.1 %

100 – 300 fs (probably decreasing) Macro-Bunch (MB): 10 – 100 Hz single bunches within MB: < 10MHz

Short pulse high energy radiation from spontaneous emission

Photon energy Photons per pulse 100 – 400 keV ~10⁸ / 0.1%bw





Electron bunch trains (with up to 4000 bunches à 1 nC)





The XFEL Pulse



XFEL: 1 Å ($\Delta t = 100$ fs FWHM; $\approx 0.1\%$ bw)



- ≈ 10¹² ph/bunch
- \approx 300 modes

(\Leftrightarrow 300 single (spatially and temporally) coherent wave packets of $\Delta\lambda/\lambda \approx 10^{-6}$ carrying each about 10⁹ photons)





Ultrafast: Time-scales at and below picosecond time resolution

What are they needed for:

Time-resolved measurements at ultrafast time-scale **Pulse duration measurements Time delay measurement for pump-probe applications**

What exists up to now:

Fast photodiodes (X-ray and laser sensitive) : ~250 ps X-Ray streak cameras : ~500 fs, very low sensitivity, no 2D

The sub-picosecond regime is very difficult to reach !





Applications:

o Integrate over many exposures (e.g. for constant time delay in pump-probe experiments)
o Illuminate each pixel with several photons (no single photon counting, but single photon sensitivity)

What types exist:

o CCDs couple to various X-ray sensitive media Image intensifiers Phophor screens (via fiber or optical means) Direct illumination

o Image plate detectors

o Pixel Detectors: 2-D > 1000x1000 pixels, <100µm size low noise, high quantum efficiency fast



Readout Timing









Use X-rays and optical laser to pump/probe the investigated system. Both systems will be referenced timewise to the RF signal of the accelerator.







Requirements: Readout must enable to sample at pump/probe rate LCLS 100 Hz XFEL 10 Hz for bunch trains 5 MHz (4000/0.0008s) for single pulses

This data must be correlated with other information about the X-ray-, (laser) pulse:

Duration, jitter, intensity,

2-D Reasonable dynamic range (at least a few 1000) High quantum efficiency ≥ 1000x1000 pixels; ≤ (100µmx100µm) size



Small particle diffraction





- # structure solution without phases by collecting slices in q-space, accumulation of identical orientations, followed by crystallographic procedures
- # 3D structure solution by oversampling and reconstruction methods





Aims

Atomic resolution of ~1 Å for viruses, small particles Molecular resolution of ~2 Å for particles of µm-size

Crystallographic procedure

Very high dynamic range (> 1000/pixel; 10⁶ overall) Single photon resolution Pixel size \leq 100 µm (0.5K-2K)² Single shot capability

Oversampling

Requires to sample q-space with (at least) 2 times
higher resolution than ratio $n = D/\lambda_{res}$.Virus particle:D = 1000Å and $\lambda_{res} = 1$ Å $\Rightarrow 2000$ pixels
Non-translationsym. object: D = 10000Å and $\lambda_{res} = 2$ Å $\Rightarrow 10000$ pixels
For both directions !
TilingOther requirements

Extremely low background



X-Ray Photon Correlation Spectroscopy



sum of speckle patterns

from prompt and delayed pulses

recorded on CCD

 $I(Q,\Delta t)$

Sample

ЛΛ

Delay Line Mode: access: 1ps < Δt < 1ns 1 ps \Leftrightarrow 0.3 mm 1ns \Leftrightarrow 300 mm



2-D; 1000x1000 pixels; <(100µmx100µm) pixel Moderate dynamic range (few x 1000)



Conclusions (I)



General

Single-photon counting detectors seem impossible Energy resolution (10%) for background suppression ? High quantum efficiency Very low noise due to dark current Homogenity and distortions must be minimized

Data acquisition

Enable readout/storage at least at repetition rate (of macro pulses) Correlate with photon beam parameters and diagnostics Software integrated into data acquisition system (autocorrelator?)



Conclusions (II)



LCLS: DETECTOR ADVISORY COMMITTEE

Advise both LCLS and the MIE on detector development. Meets on a regular basis to evaluate progress on R&D and construction. Membership:

> Dr. Gareth Derbyshire, Prof. Y. Amemiya, Prof. Dr. A. Walenta, Prof. Dr. L. Strüder, Dr. E. Eikenberry,

RAL (Chair) Univ. of Tokyo U. of Siegen MPG PSI Deutsches Elektronen-Synchrotron XFEL Research



DESY is world-wide one of the leading accelerator centres exploring the structure of matter. The main research areas range from elementary particle physics over various applications of synchrotron radiation to the construction and use of X-ray lasers.

Particle accelerators produce high intensive radiation for most diverse, innovative applications. By the planned upgrade of the PETRA storage ring into a 3rd generation synchrotron light sour-

PETRA storage ring into a srd generation synchrotron right source and the construction of the free-electron-lasers (VUV-FEL and XFEL) DESY will take up an international top position in future research with photons. These novel sources impose high demands on photon detection (multi-element systems with submicrosecond time resolution, high spatial resolution and high quantum efficiency). We are looking for a

Physicist (PhD)

with marked experience record in detector R&D for a corresponding development program in the frame work of a new detector group. The job profile covers definition and elaboration of detector requirements, detector development and tests as well as their actual implementation and application in photon experiments. Strong and broad-spread knowledge in detector development is thus indispensable, Ideally, the successful candidate proves experience in the application of x-ray detectors in experiments with synchrotron radiation. He or she will show capability of working in a team and readiness for coordination of the collaboration with external research groups. If you are interested in this position, please send your complete application papers by indicating the code to our personnel department. For further information, please contact Dr. G. Grübel on +49 40/898-2484.

Salary and benefits are commensurate with public service organisations. DESY operates flexible work schemes, such as flexitime or part-time work. DESY is an equal opportunity, affirmative action employer and encourages applications from women. DESY has a Betriebskindergarten.

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