Detectors for Future Light Sources

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Overview

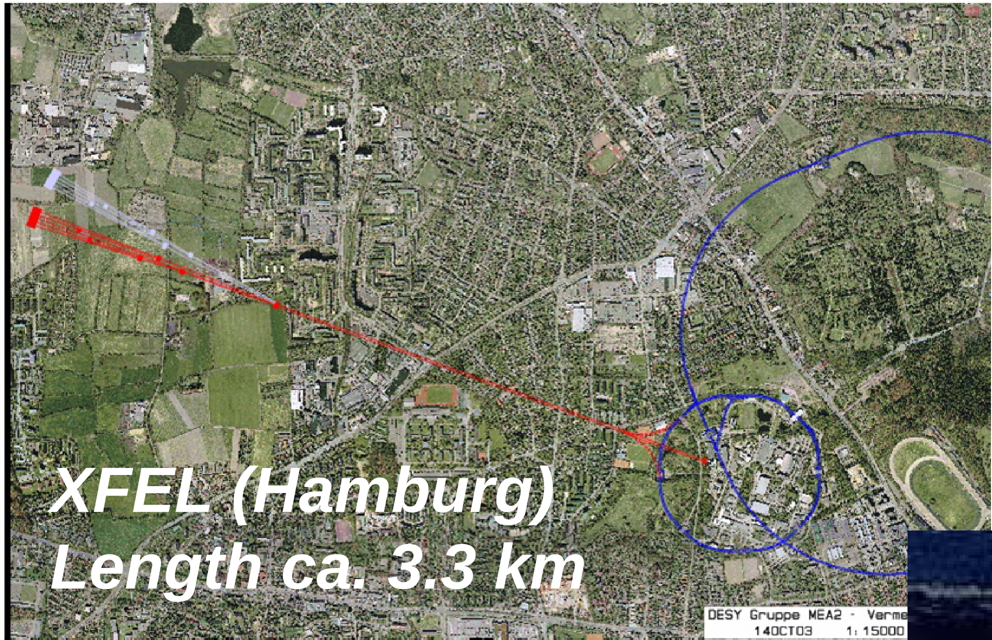
- **Radiation from X-Ray Free Electron lasers (XFEL, LCLS)**
- **Ultrafast detectors**
- **Integrating detectors**
- **Requirements by different types of experiments**

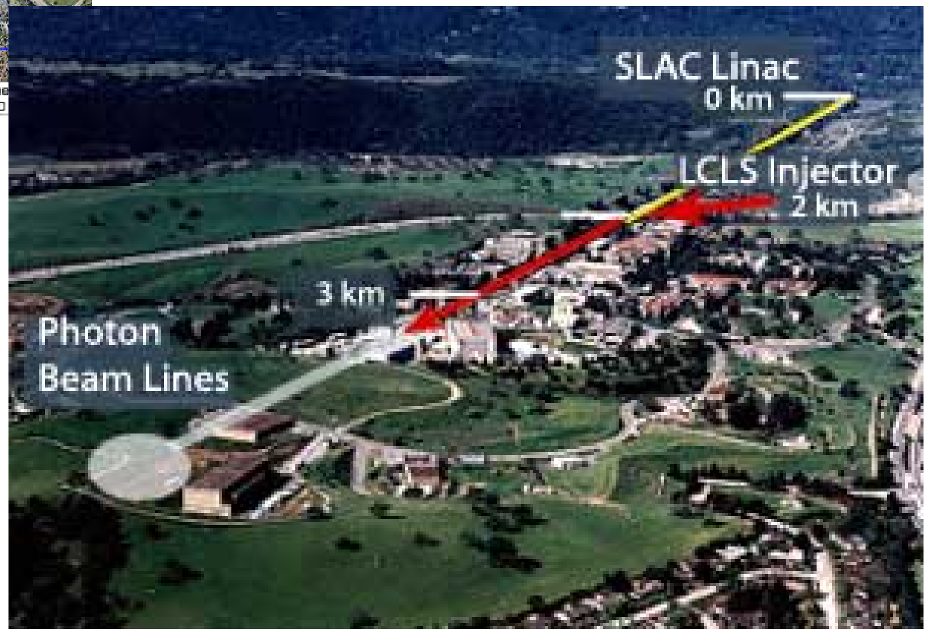
    Time-resolved pump-probe experiments

    Small particle imaging

    X-ray photon correlation spectroscopy

- **Conclusions**


XFEL (Hamburg)
Length ca. 3.3 km


SLAC Linac
0 km
LCLS Injector
2 km
3 km
Photon
Beam Lines

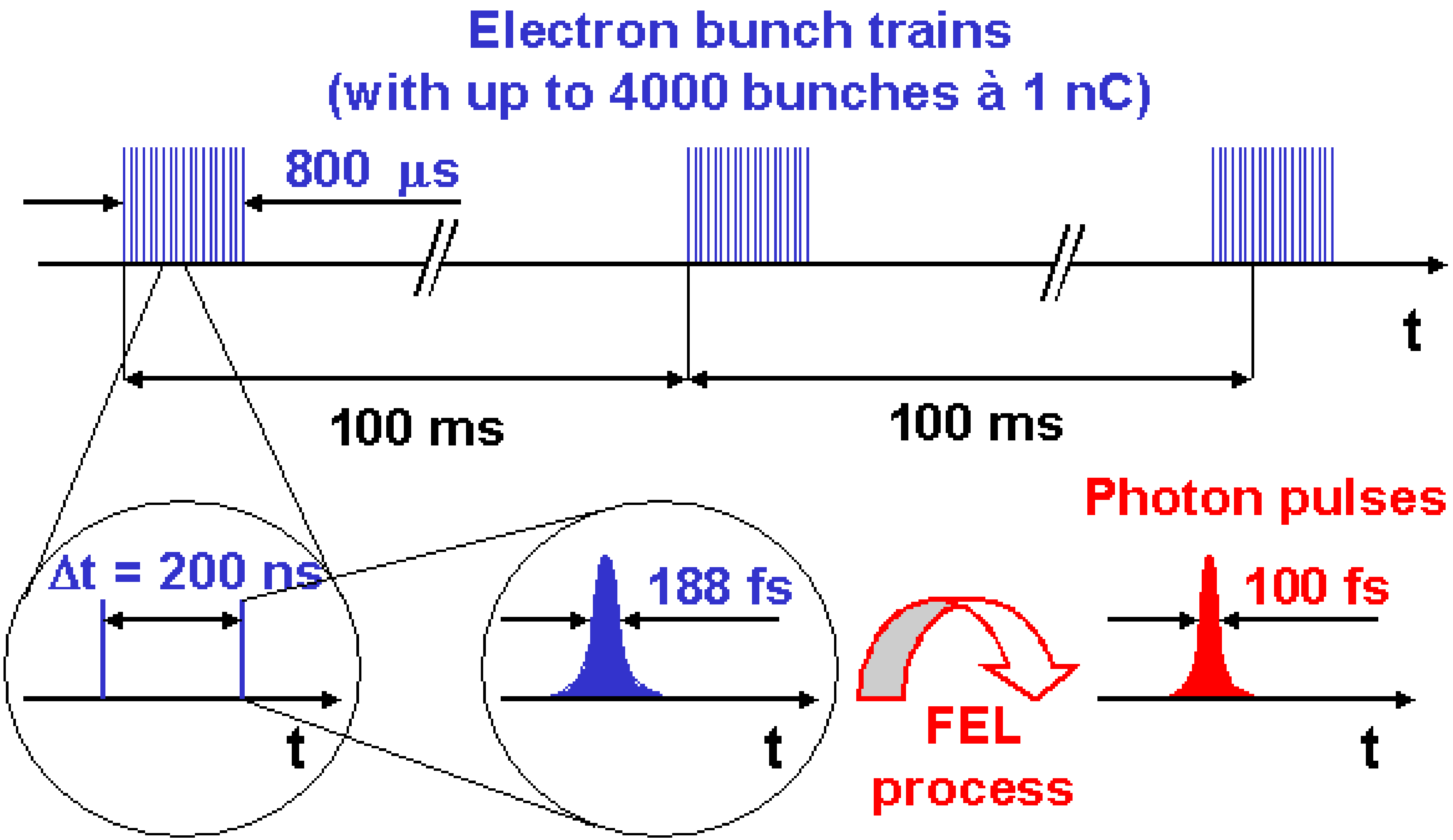
Characteristics of XFEL radiation

Photon energy	**X-rays: 3 up to 15 keV (λ= 1Å)**
	(soft X.: 200 up to 2000 eV)
Photon per pulse	**10^{12} *(up to 10^{14})***
Divergence	**< 1 up to few 10 µrad**
Source appearance	**~ 100 µm (diffraction limited)**
Bandwidth	**~ 0.1 %**
Pulse duration	**100 – 300 fs (probably decreasing)**
Repetition rate	**Macro-Bunch (MB): 10 – 100 Hz**
	single bunches within MB: < 10MHz

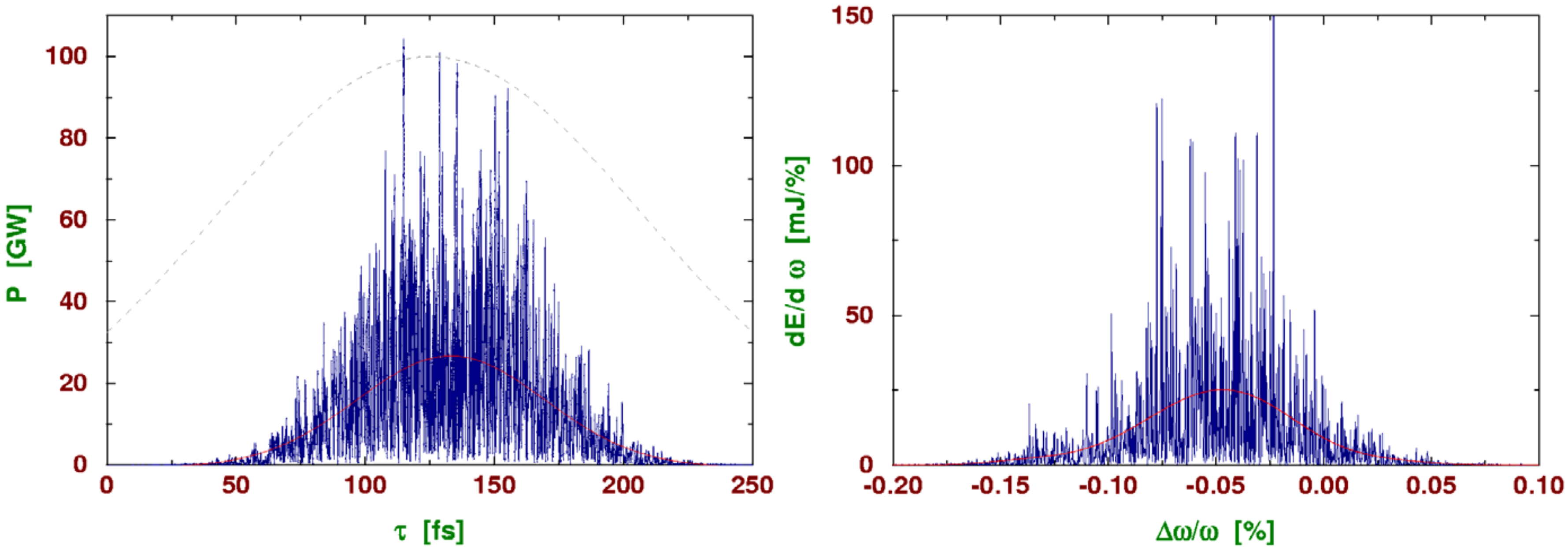
Short pulse high energy radiation from spontaneous emission

Photon energy	***100 – 400 keV***
Photons per pulse	***~10^8 / 0.1%bw***

Accelerator time pattern



XFEL: 1 Å (Δt = 100 fs FWHM; ≈ 0.1% bw)



≈ 10^{12} ph/bunch

≈ 300 modes

(⇔ 300 single (spatially and temporally) coherent wave packets of $\Delta\lambda/\lambda \approx 10^{-6}$ carrying each about 10^9 photons)

“Ultrafast” Detection Schemes

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 !

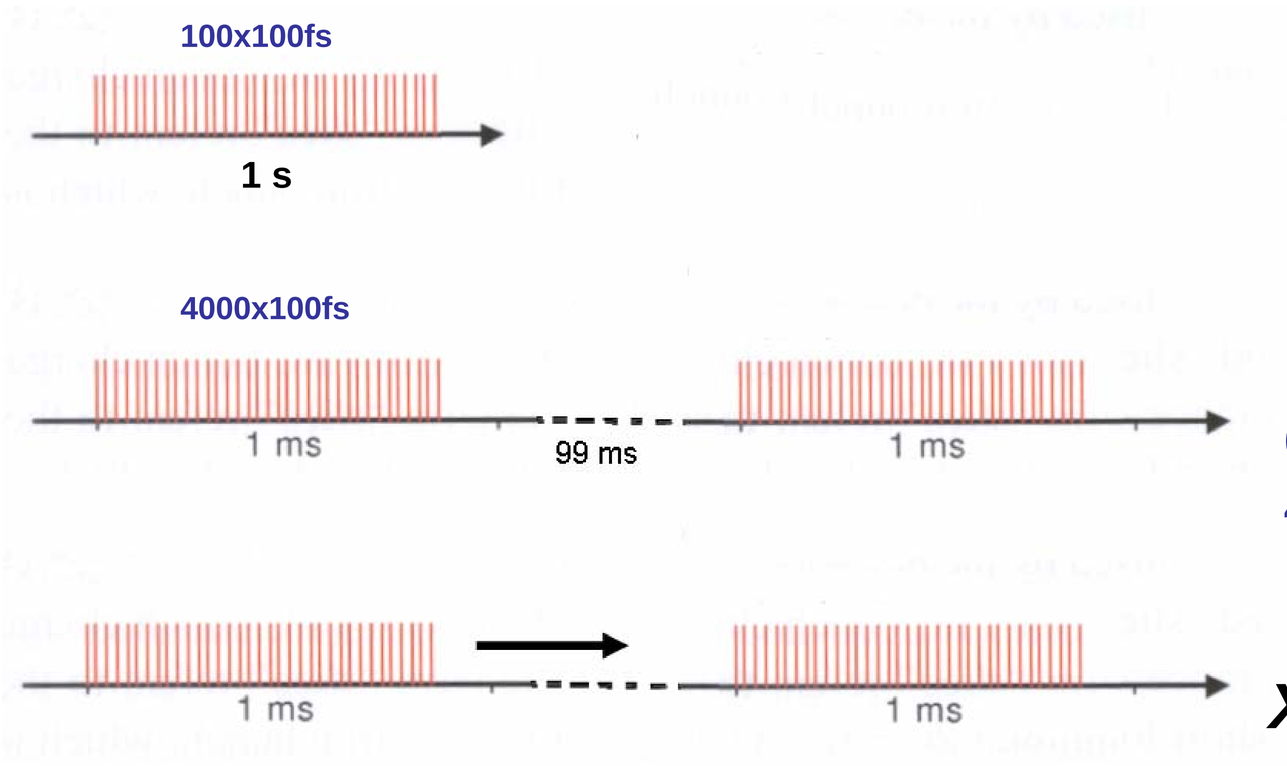
Applications:

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



100 Hz (LCLS)

10 Hz (XFEL)

(each macrobunch contains ≈ 4000 microbunches: ≈5 MHz)

XFEL (future ?)

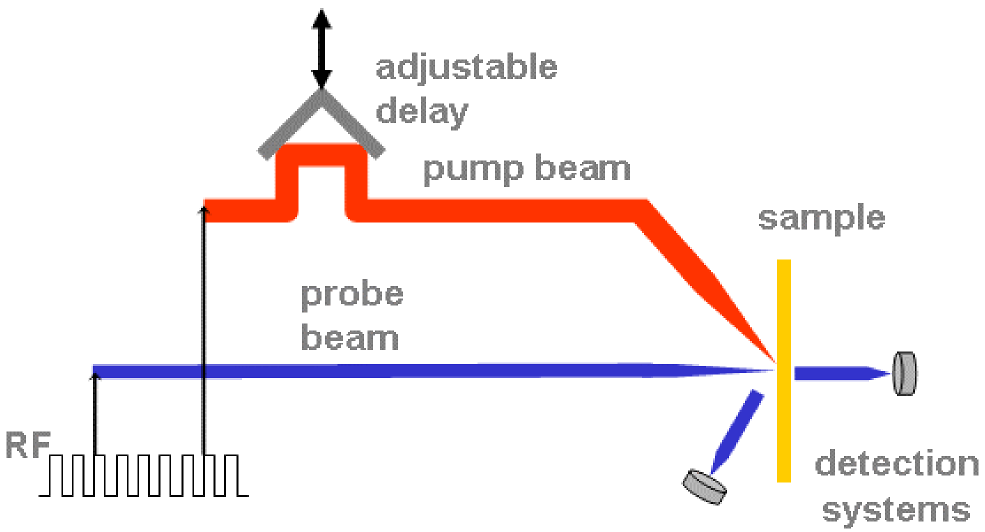
(distribute 4000 microbunches over 1s: 4 kHz)

Time-resolved pump-probe experiments

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.

Laser-to-RF jitter
X-ray-to-Rf jitter
Path length instabilities

⇒ Time delay of Pump and Probe varies (~ ps)



Time-resolved pump-probe experiments

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:

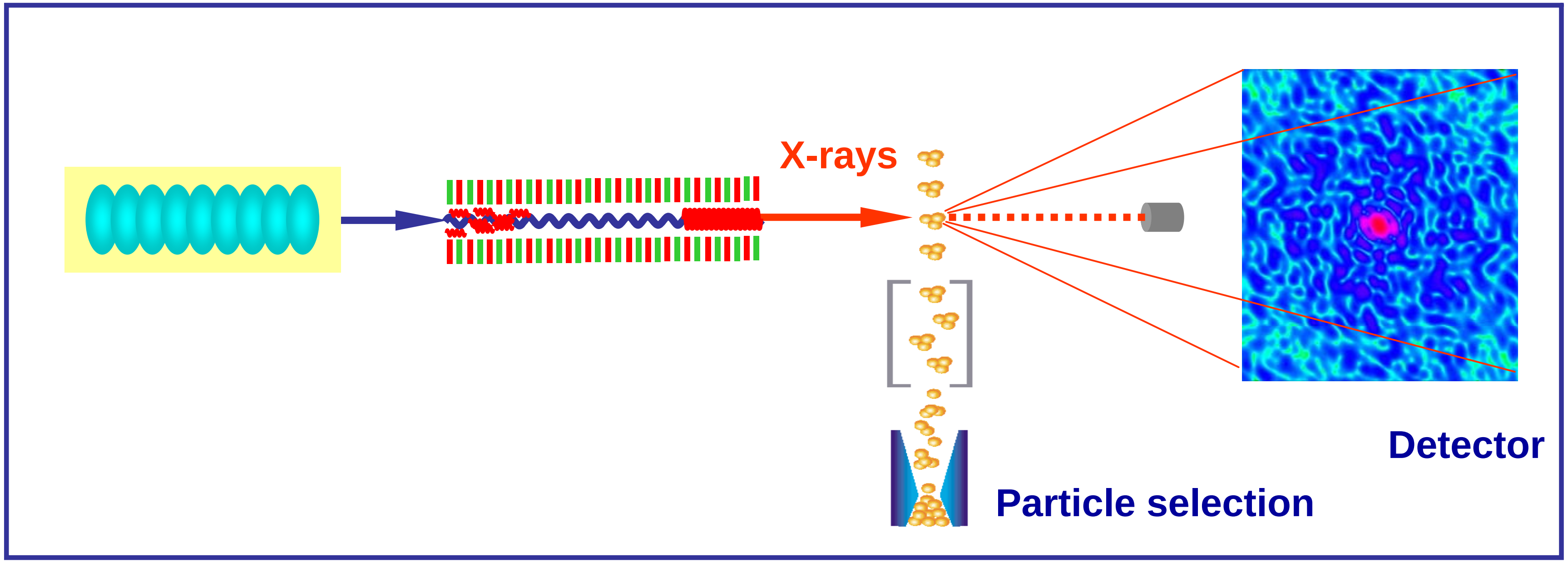
Duration, jitter, intensity, ...

2-D

Reasonable dynamic range (at least a few 1000)

High quantum efficiency

$\geq$ 1000x1000 pixels; $\leq$ (100µmx100µm) size



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

Small particle diffraction

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; 10^6 overall)
Single photon resolution
Pixel size $\leq$100 µm $(0.5K\text{-}2K)^2$
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 λ_{res}= 1Å $\Rightarrow$*	*2000 pixels*
Non-translationsym. object:	*D= 10000Å and λ_{res}= 2Å $\Rightarrow$*	*10000 pixels*

For both directions !
Tiling

Other requirements

Extremely low background

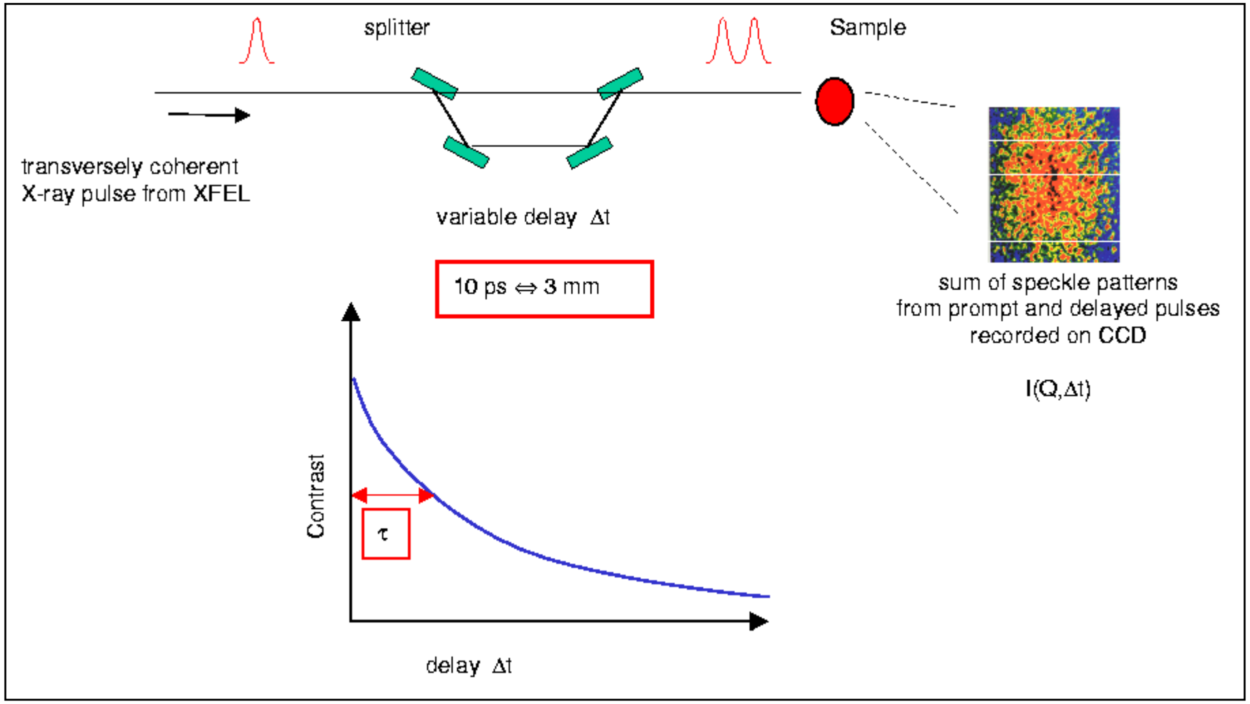
X-Ray Photon Correlation Spectroscopy

Delay Line Mode:

access: 1ps < Δt < 1ns

1 ps ⇔ 0.3 mm

1ns ⇔ 300 mm



Readout:	**LCLS**	**100 Hz**
	XFEL	**10 Hz for bunch trains**
		5 MHz (5000/0.1s) for single pulses

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,	RAL (Chair)
Prof. Y. Amemiya,	Univ. of Tokyo
Prof. Dr. A. Walenta,	U. of Siegen
Prof. Dr. L. Strüder,	MPG
Dr. E. Eikenberry,	PSI