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Photon Beam Diagnostics for X-ray, VUV, XFEL
- Applications to SASE XFEL -

Kensuke Tono
XFEL Division, JASRI/SPring-8, Japan

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SACLA Beamline Development Team, XFEL Research and Development Division, RIKEN SPring-8 Center

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XFEL Research and Development Division, RIKEN SPring-8 Center

XFEL Division, JASRI

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Contents

1. Introduction
   - What are important for photon diagnostics of a SASE FEL?
2. Photon-beam monitors at SACLA, an X-ray FEL at SPring-8
3. Monitors under development
4. Summary

Photon beam diagnostics for FEL

- Fine tuning of an FEL machine needs fine diagnostics of a photon beam.

  Since short wavelength FELs are promising tools for photon science today, FEL facilities should take care of quality of a photon beam.

  - Intensity, wavelength, pointing, coherence, etc…, and their stability.

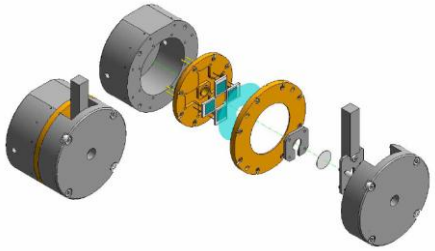
- *Shot-by-shot* and *nondestructive* measurement is mandatory for a SASE FEL.

  FEL photon monitors should measure each individual pulse because of the stochastic nature of SASE.

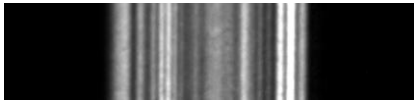
Photon diagnostics of a SASE FEL

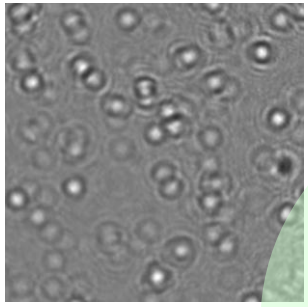
Pulse nature & high peak power

Synchronization between FEL pulses and detectors



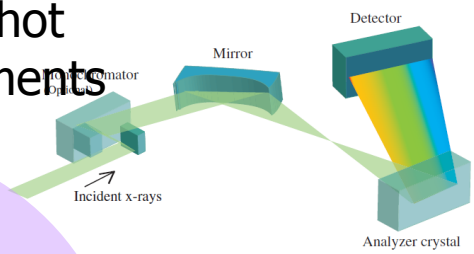
Damage/speckle-free optics





SASE FEL

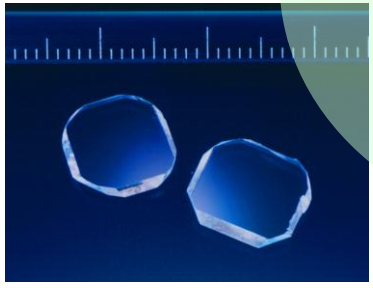
Shot-by-shot measurements

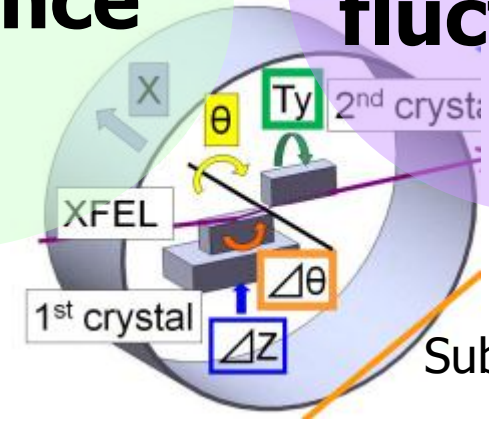


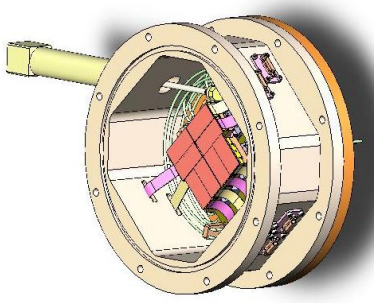
Coherence

Shot-to-shot fluctuation

Fast Detectors & DAQ systems







Sub-μrad stability

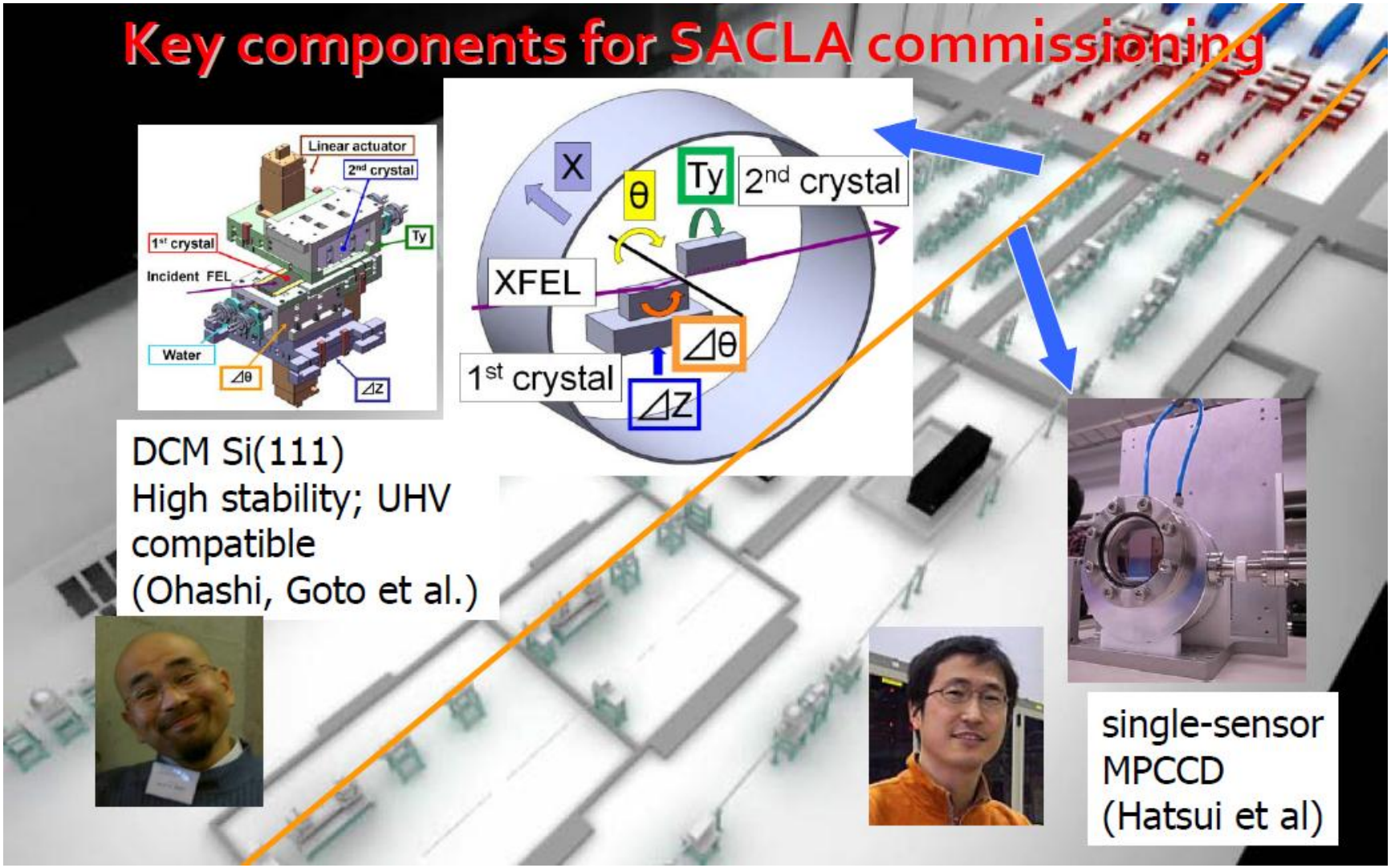
Typical photon monitors for UV, soft X-ray, and hard X-ray FELs

Monitors	Properties to be monitored	What to be detected	Materials that interact with a SASE beam	Non-destructive?
Phosphor screens	Spatial profile	Luminescence	Rare-earth-doped phosphors (Ce:YAG, etc.)	No
Solid-state detectors	Intensity	Charged particles	Si, Ge, etc.	No
	Spatial profile			
Gas monitors	Intensity	Charged particles/ Scattered light	Rare gases, N_2, Air, etc.	Yes
	position			
Spectrometers	Spectrum	Diffracted light	Gratings, Crystals (Si, etc.)	No
Streak cameras	Temporal profile	Electrons	Photocathodes (Au, etc.)	No
			Gases	Yes
Cross-correlators	Arrival time	Optical laser light	Semiconductors (Si_3N_4 etc.)	No
Auto-correlators	Temporal profile	Light / charged particles	Nonlinear media	No

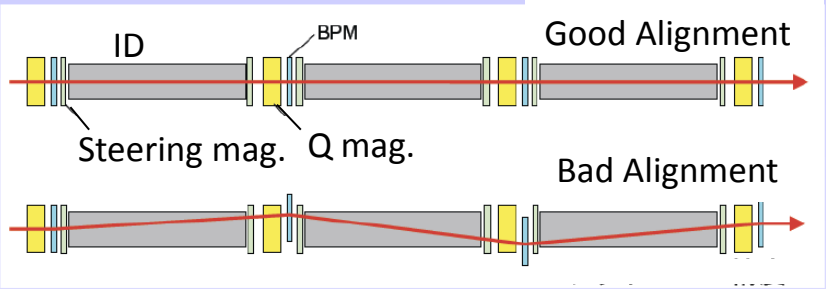
Nondestructive monitors for hard X-ray FELs

Monitors	Properties to be monitored	What to be detected	Materials that interact with a SASE beam	Non-destructive?
Phosphor screens	Spatial profile	Luminescence	Diamond	Yes
Thin-foil monitors	Intensity	Scattered / Diffracted X-rays	Diamond, Be, etc	Yes
	Position			
	Spectrum			

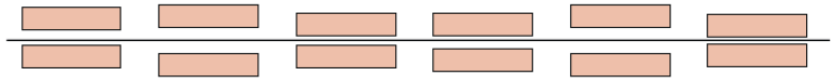
FEL machine commissioning with a photon diagnostic system



Precise ID tuning using beamline optics & monitors

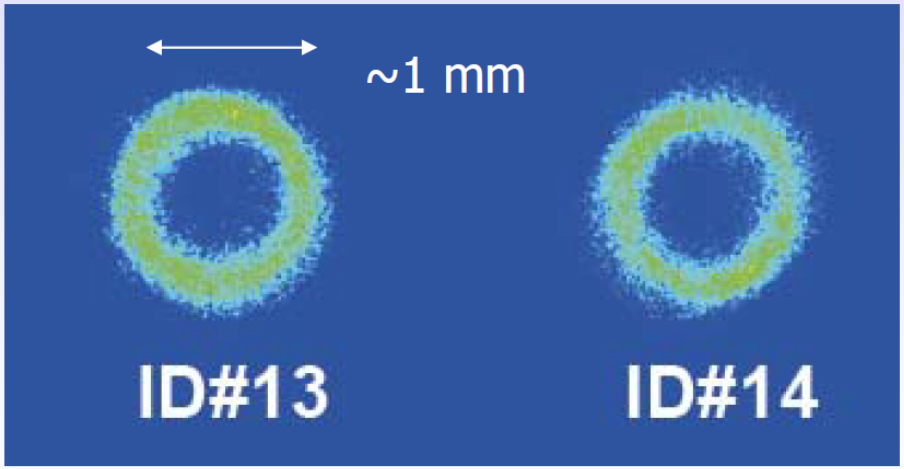


T. Tanaka et al



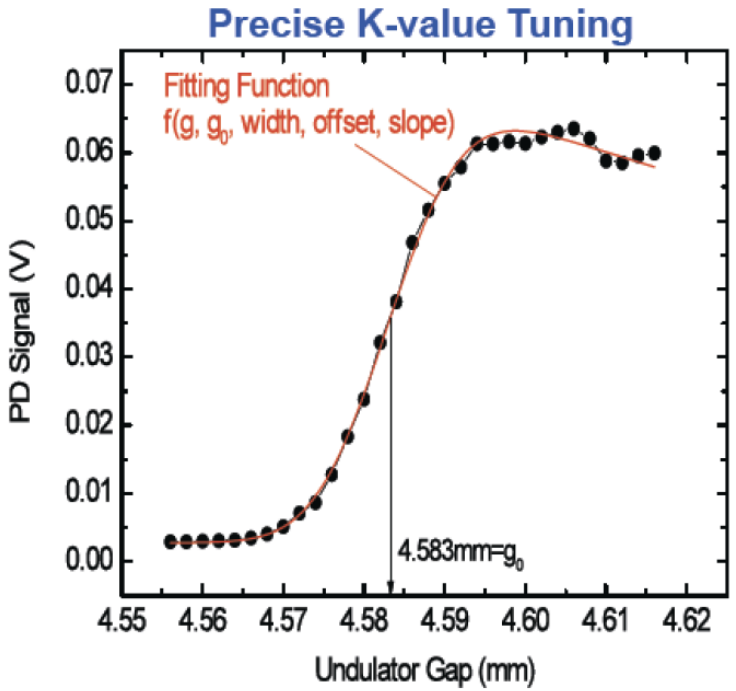
K-value mismatch → Lower gain

Profile of spontaneous radiation with monochromator



Straightness of electron beam over multiple segments of undulators
Angular accuracy:
100 um/100 m = 1 urad

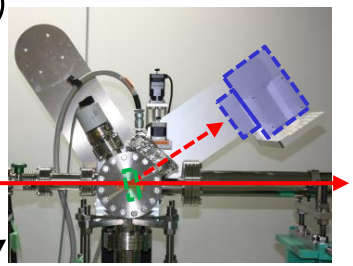
Spectrum of "edge"

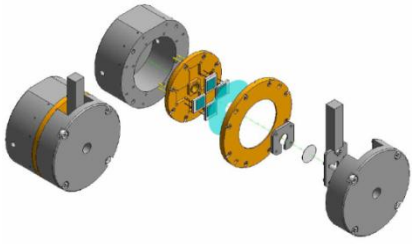


Gap adjustment < 4 um

Photon monitors in SACLA's hard X-ray beamline

Thin-foil spectrometer x1
（photon energy）





Thin-foil monitor x2
（intensity/position）

XFEL

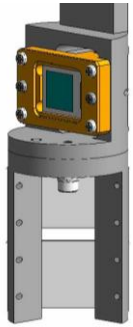
Mirror 1

Monochromator

Mirror 2a

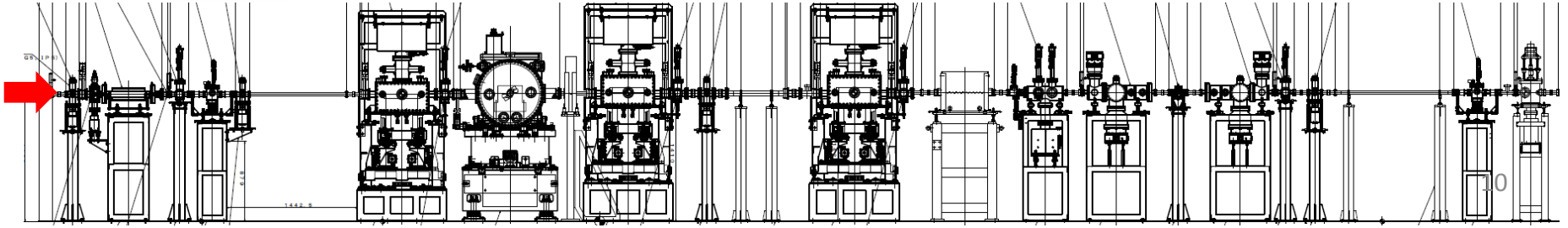
Mirror 2b

Slit

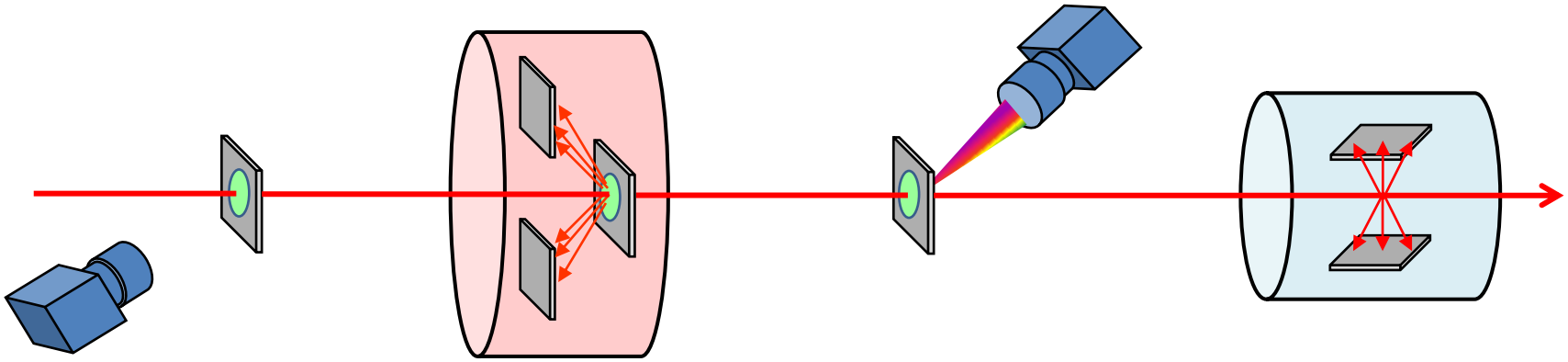


Diamond phosphor x7
（Spatial profile）

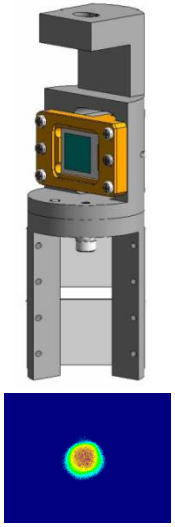
Gas monitor x1
（intensity）



Photon diagnostics in daily tuning

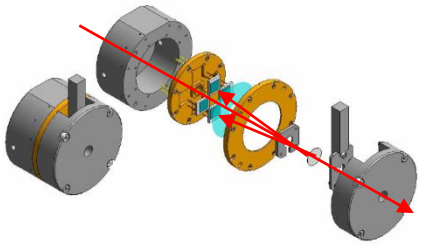


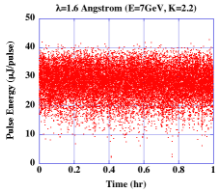
1. Screen monitor



Spatial profile

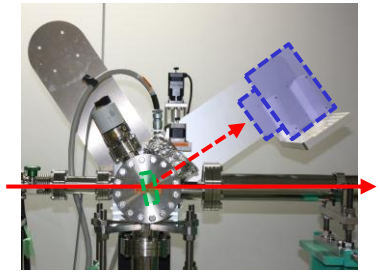
2. Thin-foil monitor

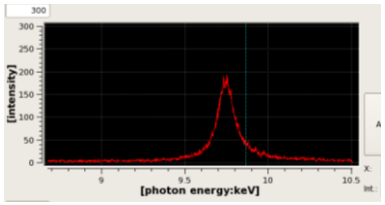




Intensity/position

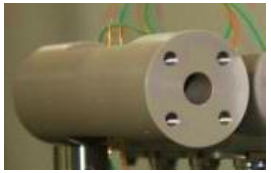
3. Thin-foil spectrometer

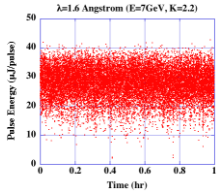




Spectrum

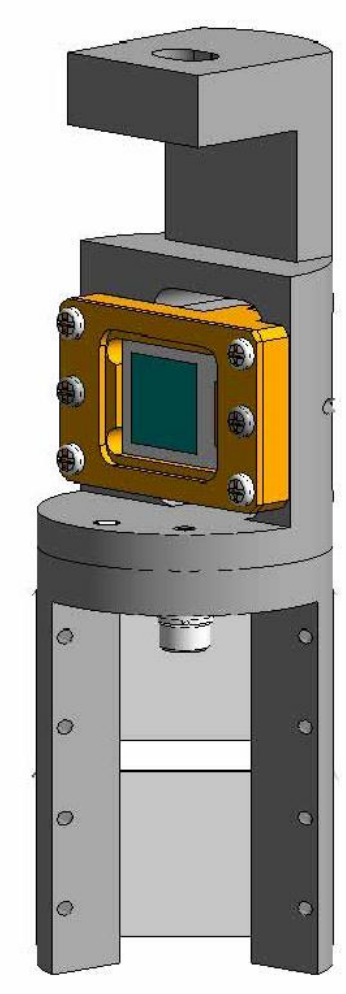
4. Gas monitor





Intensity

1. Screen monitor



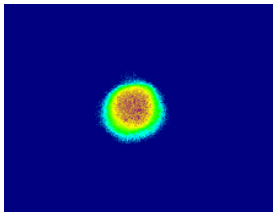
T. Kudo, K. Tono et al.

Phosphor screens

Si PIN photodiode
(intensity measurement)

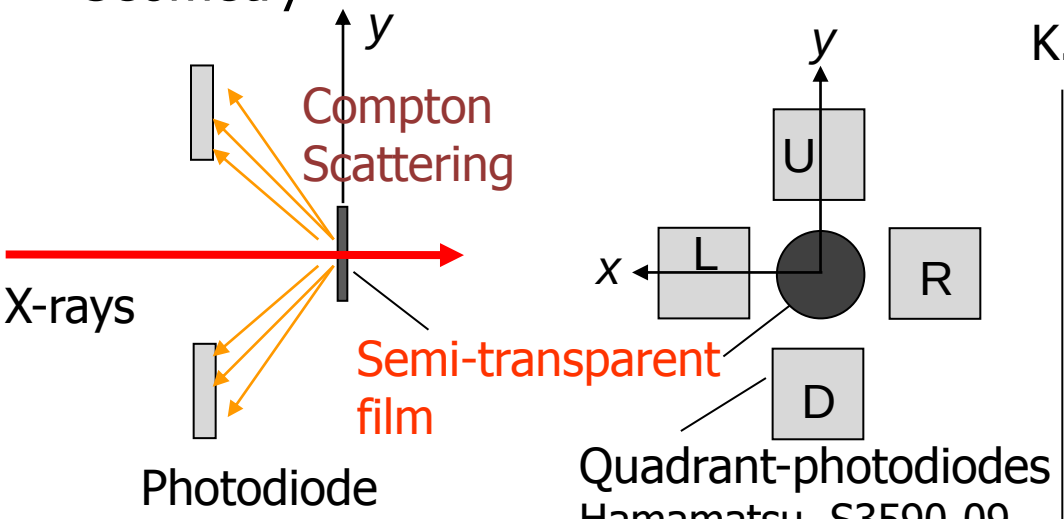
Ce:YAG plate
(high sensitivity)

B-doped diamond film
(nondestructive)



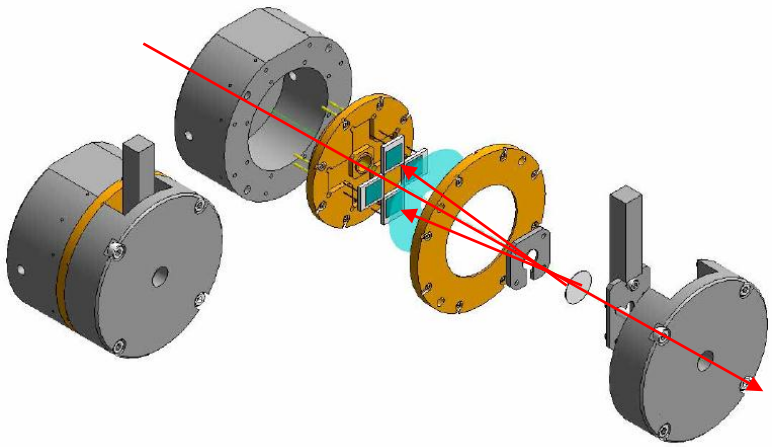
2. Thin-foil monitor (intensity/position)

Geometry



Quadrant-photodiodes
Hamamatsu, S3590-09
(10 x10 mm^2)

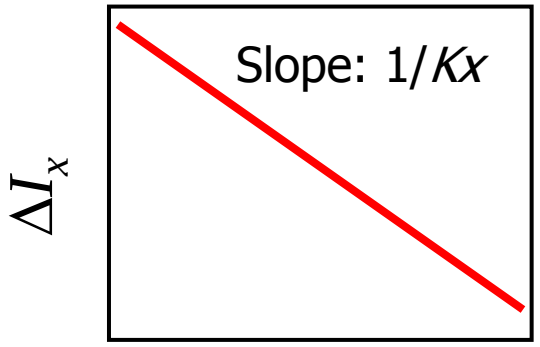
Collaboration with SLAC
K. Tono et al. *RSI* 82, 023108 (2011)



Intensity $I \propto \left(I_L + I_R + I_U + I_D\right)$

Position $x = K_x \dfrac{I_{\mathrm{L}} - I_{\mathrm{R}}}{I_{\mathrm{L}} + I_{\mathrm{R}}} = K_x \Delta I_x$

$y = K_y \dfrac{I_{\mathrm{U}} - I_{\mathrm{D}}}{I_{\mathrm{U}} + I_{\mathrm{D}}} = K_y \Delta I_y$



Alkire et al., *J. Syn. Rad.* 7, 61 (2000).

Foil dependence in position monitoring

Compton scattering + Debye-Scherrer ring (except for Si_3N_4)

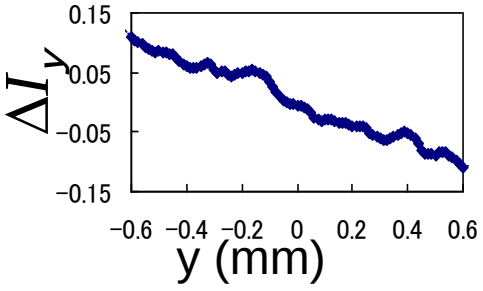
Grain-free pattern obtained from CVD nanocrystal (~30 nm) diamond

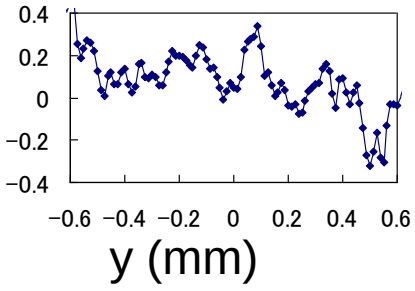
PVD-Be
t = 100 μm

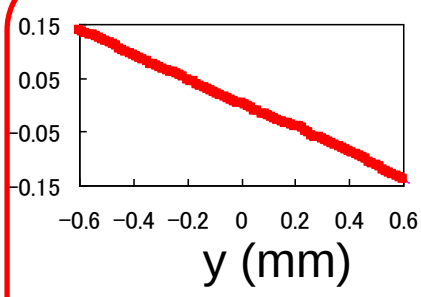
"Micro" Diamond
30 μm

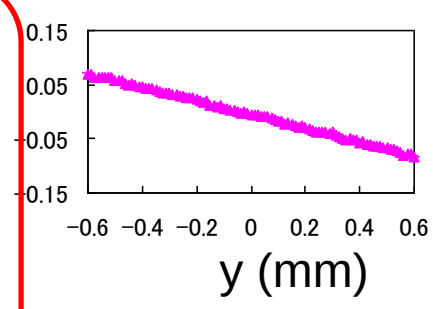
"Nano" Diamond
15 μm

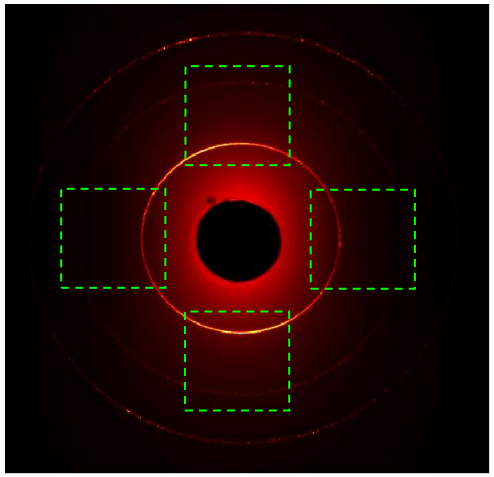
Amorphous Si_3N_4
0.5 μm

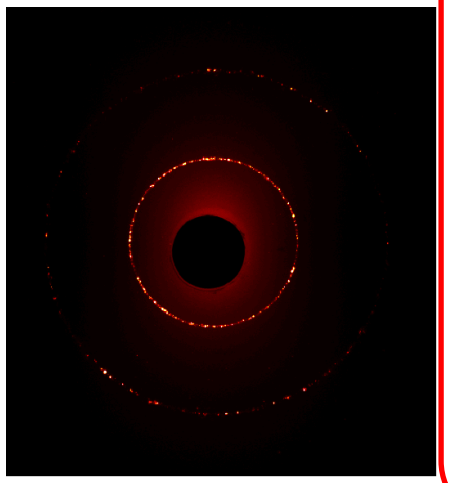


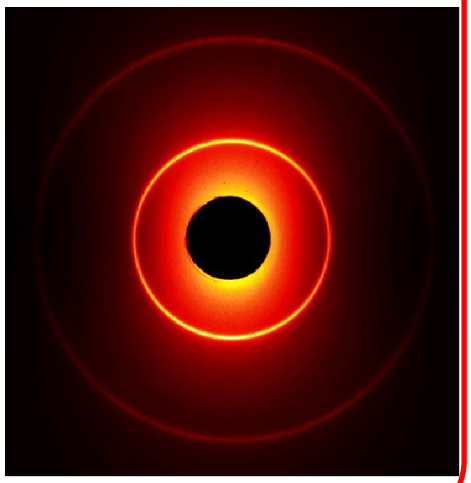


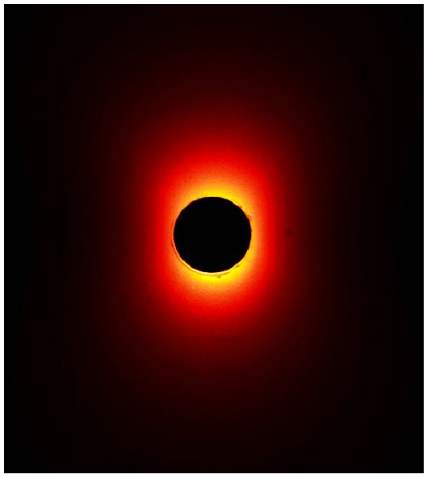






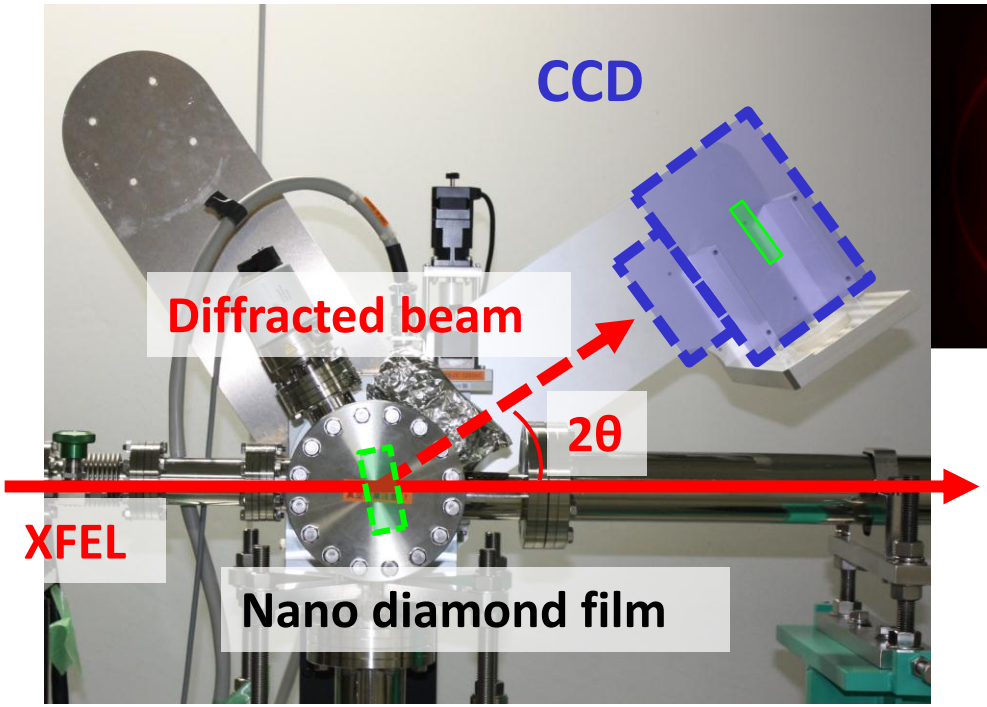


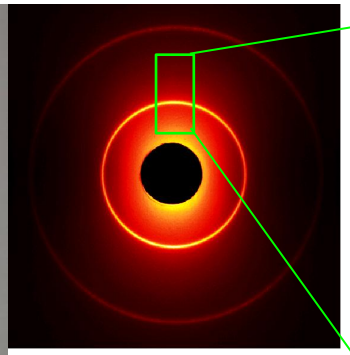


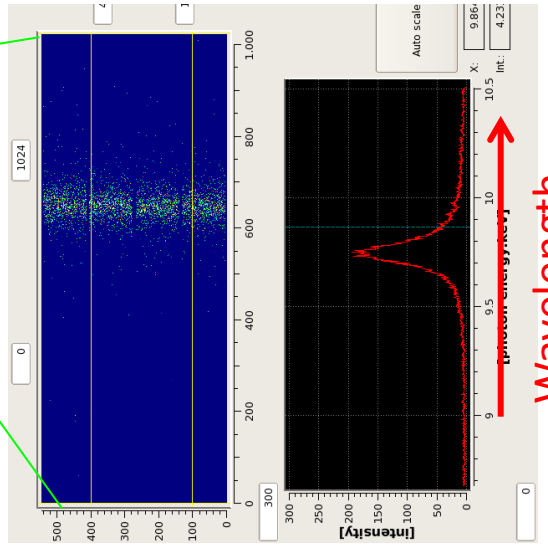


Error : ~10 μm

3. Thin-foil spectrometer (photon energy)





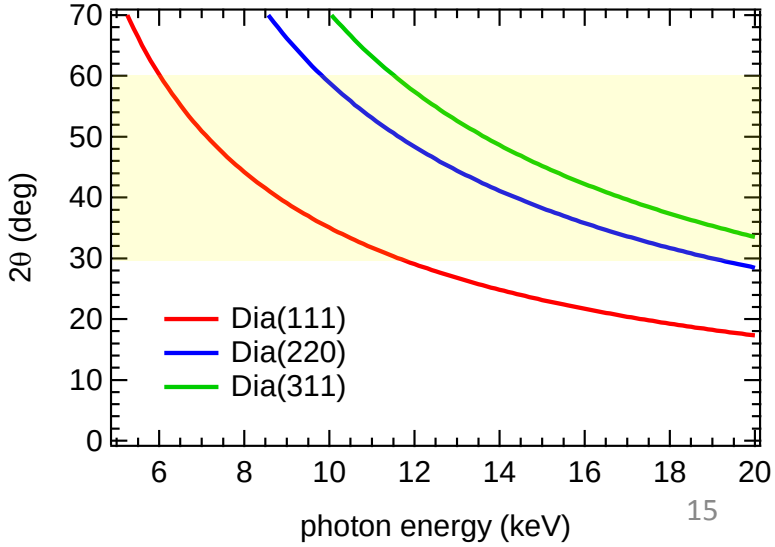


Wavelengths are calculated from positions of Debye-Scherrer rings on MPCCD.

$2d\sin\theta = n\lambda$

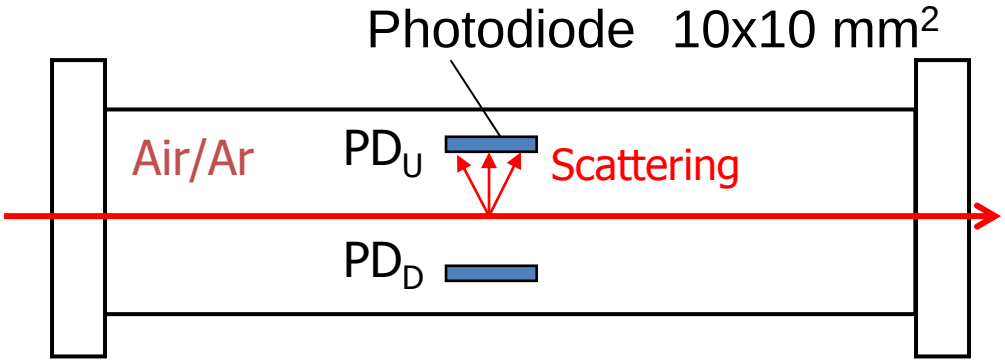
Inubushi et al.

Measurable range: 6 - 20 keV



4. Scattering-based gas monitor (intensity)

Scattering-based "gas" monitor



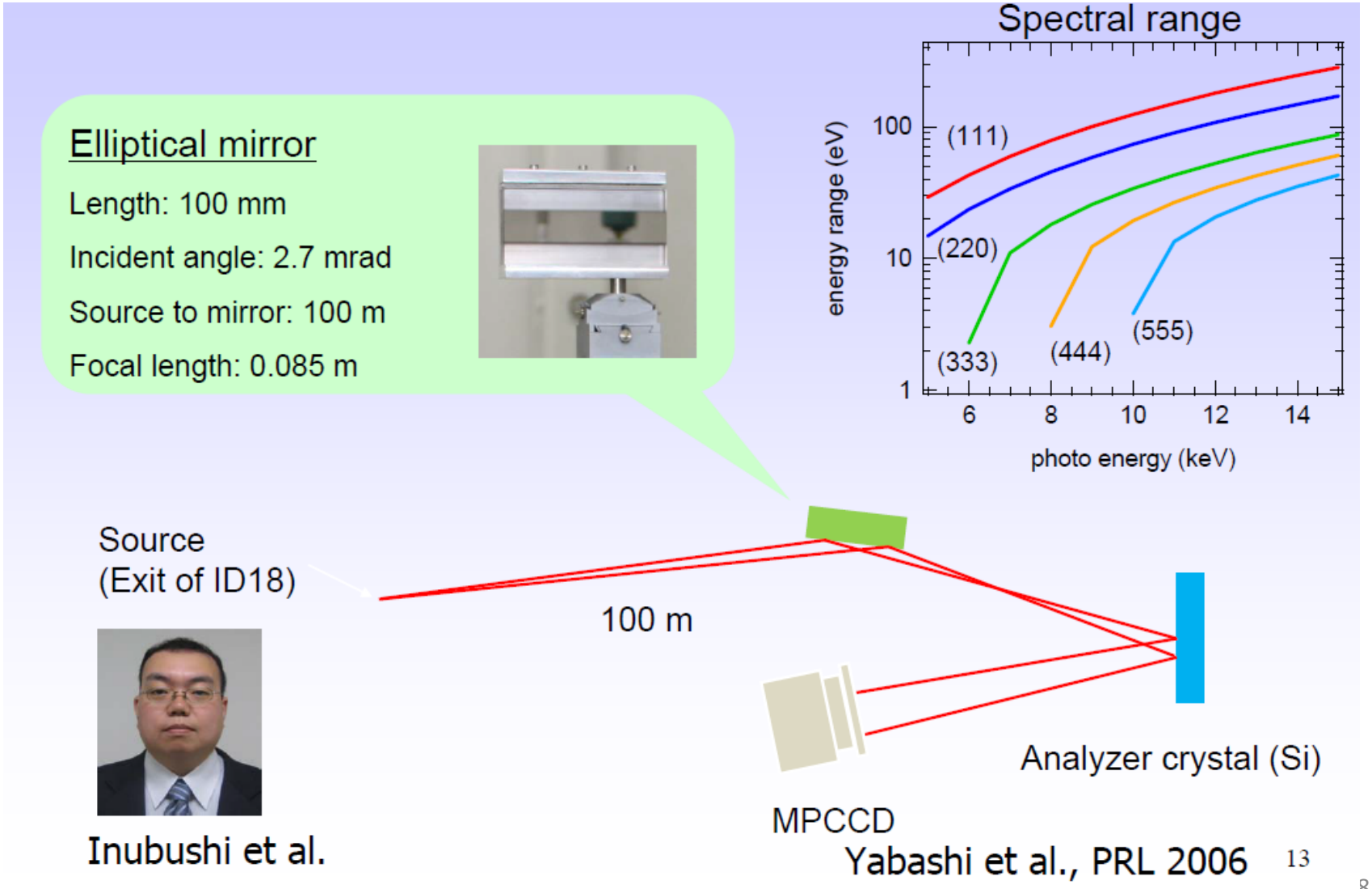
Intensity:

$I = I_U + I_D$

Photon-beam monitors under development at SACLA

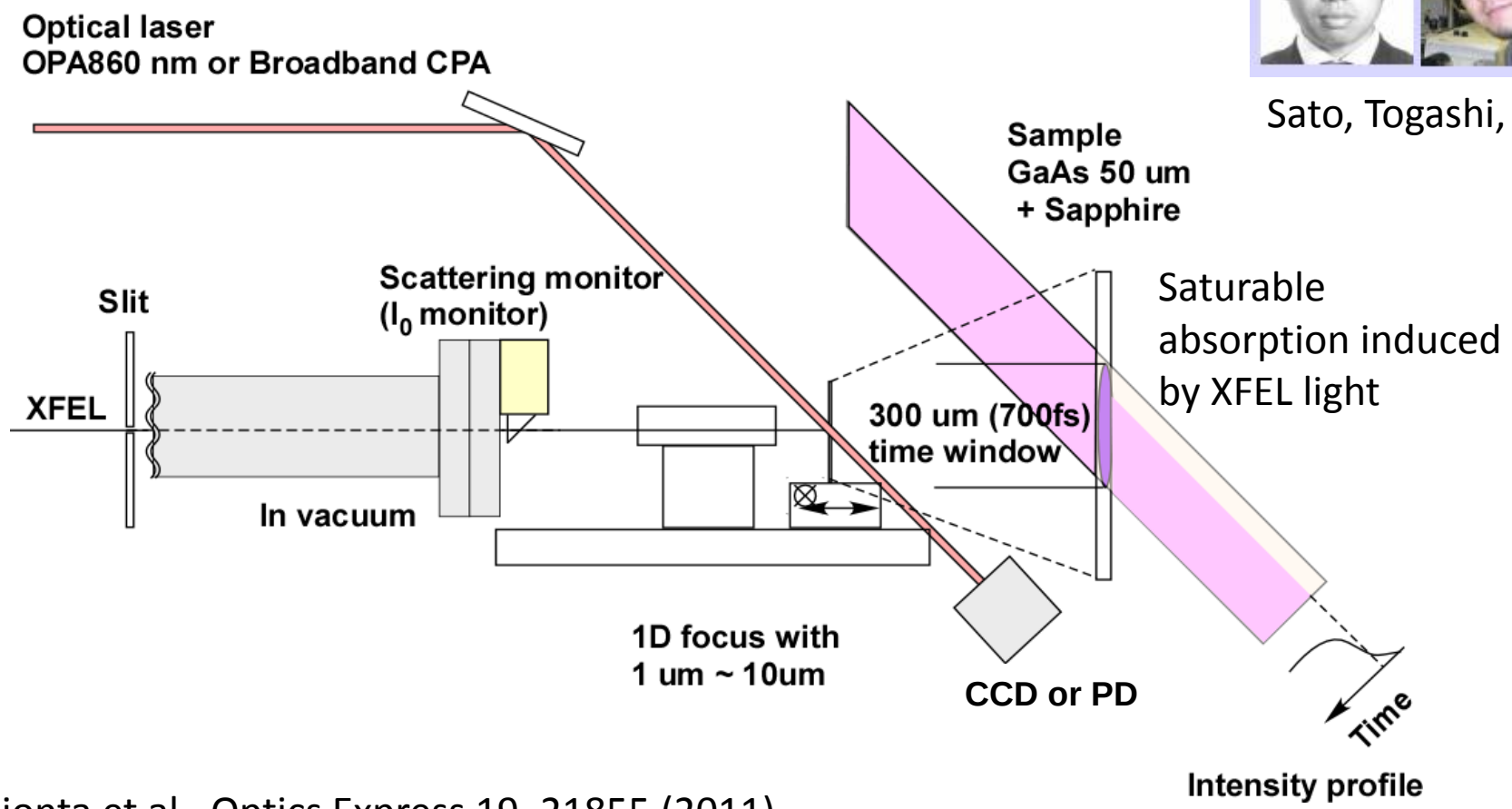
Monitors	Measurable properties	Components	Applications
High-resolution spectrometer	Spectrum	Crystal optics & 2D detector	Spectroscopy Machine tuning
Cross correlator	Timing	Reflectivity measurement	Pomp & probe experiments
Auto correlator	Temporal profile	Beam splitter & nonlinear madia	Machine tuning

High-resolution single-shot spectrometer



Timing monitor: Measurement of relative arrival time of XFEL and optical laser pulses

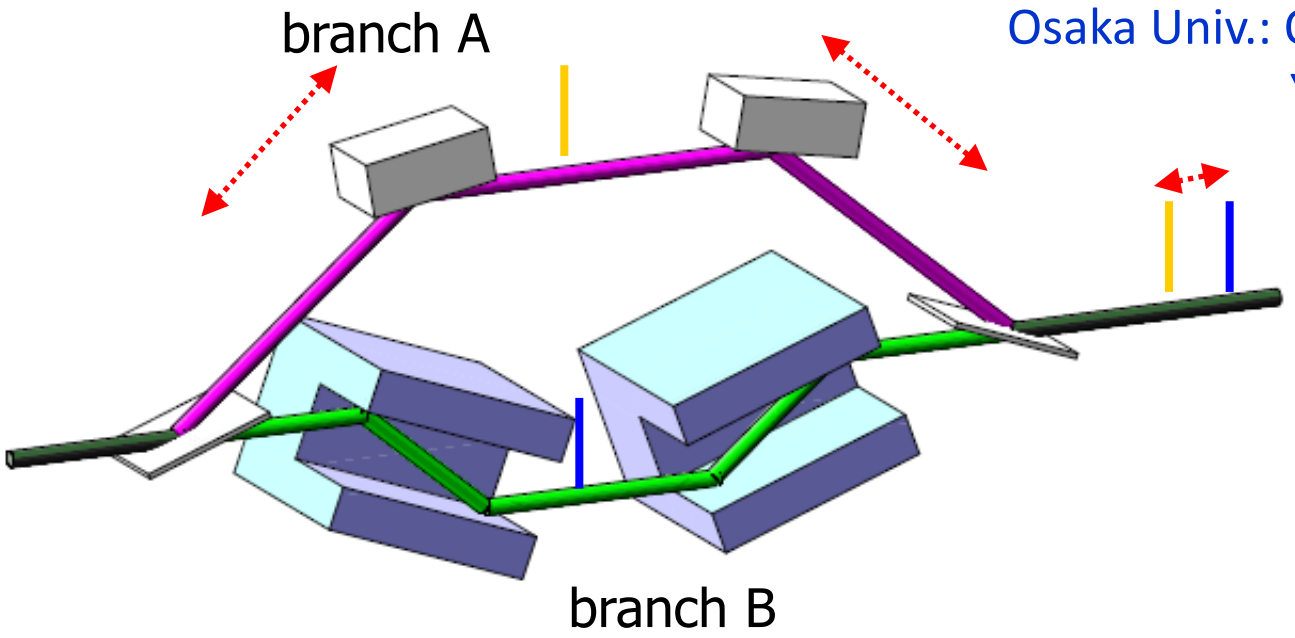
Sato, Togashi, et al.



Bionta et al., Optics Express 19, 21855 (2011).
Schorb et al., Appl. Phys. Lett. 100, 121107 (2012).
Beye et al., Appl. Phys. Lett. 100, 121108 (2012).

Temporal characterization with an X-ray autocorrelator

SACLA: Inubushi et al.
Osaka Univ.: Osaka, Sano, Yamauchi



- Components:
  - Branch A: 2 thin crystals + 2 crystals
  - Branch B: 2 channel-cut crystals
- Simple geometry & easy implementation
- Channel-cut: Large size & speckle-free quality

Prototype in 2012

Summary

- Photon-beam properties of SACLA are measured in nondestructive and shot-by-shot manners.
  - Thin foil BPM: intensity and position
  - Thin-foil spectrometer: photon energy
  - Gas monitor: intensity
  - Fluorescent diamond films: spatial profile
- Other monitors under development
  - Single-shot spectrometer
  - Cross-correlator
  - Auto-correlator
- Above XFEL monitors allow us to establish an effective tuning procedure of SACLA by working together with electron beam diagnostics.