Improvements of Transverse and Longitudinal Beam Diagnostics in SACLA

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Outline

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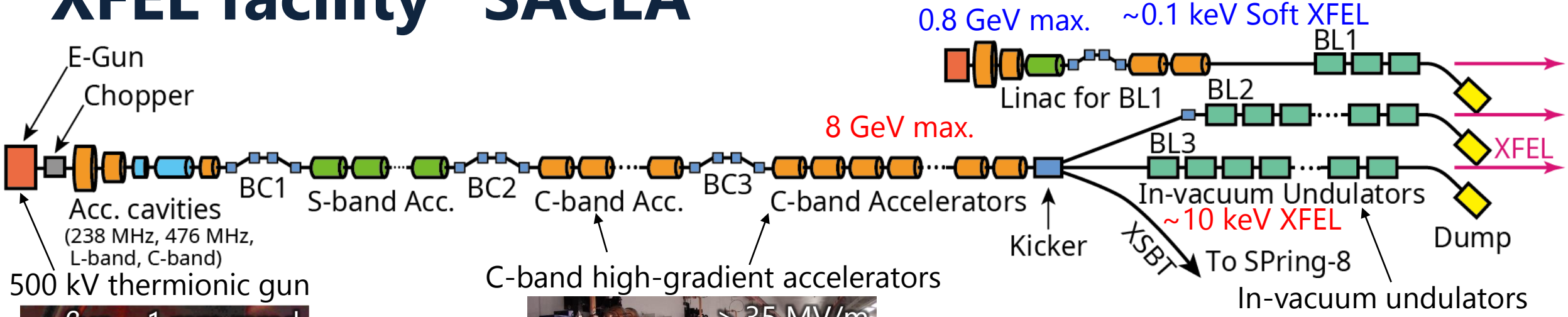
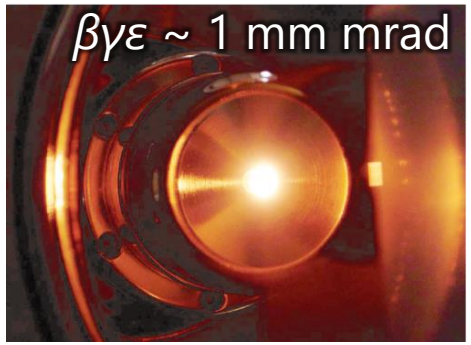
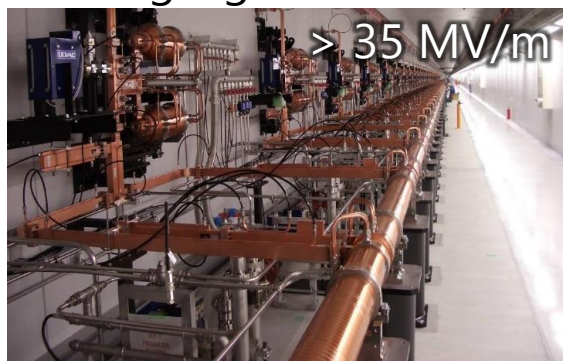
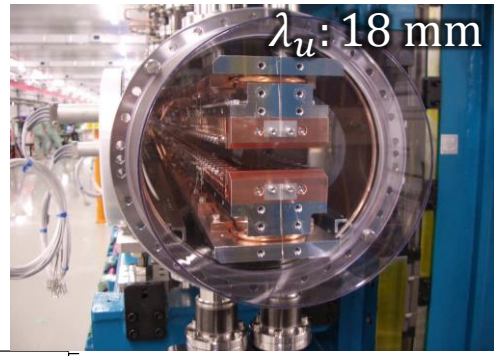
  - Current problems
- L-band transverse RF deflector cavity in the injector section
  - Brief introduction and typical results
- Improvements of transverse profile monitor
  - Mitigation of coherent OTR
  - Beam test results
- Summary

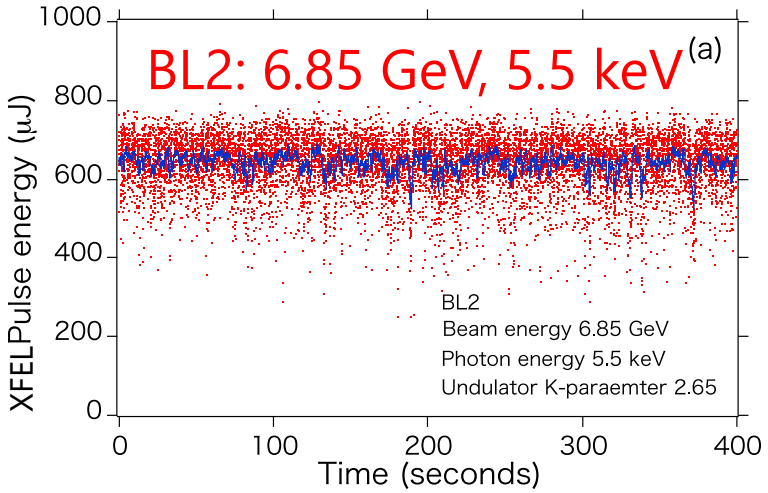
XFEL facility "SACLA"

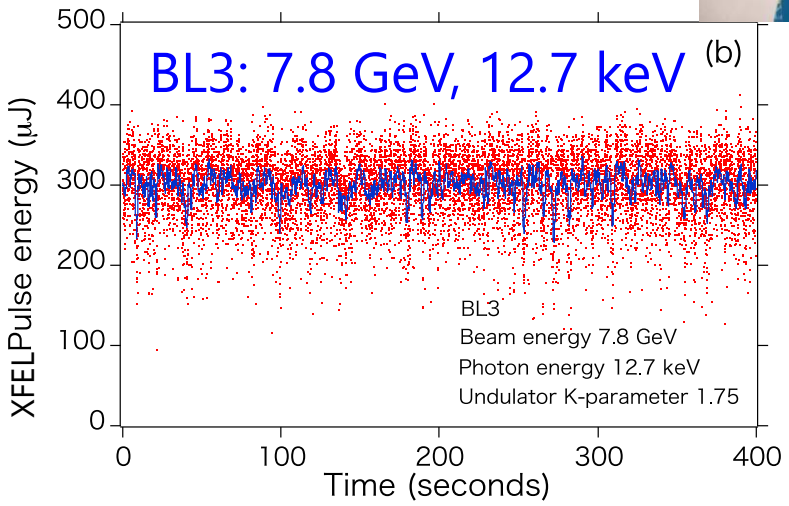










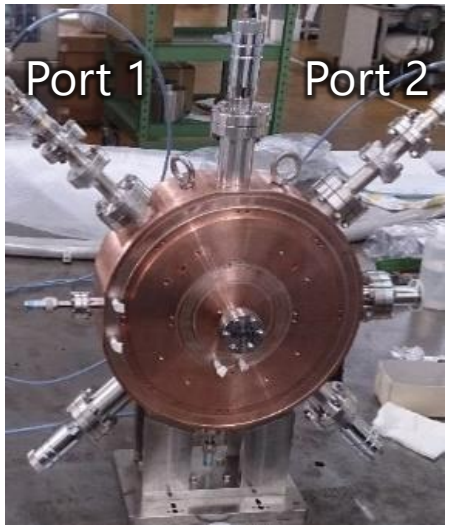


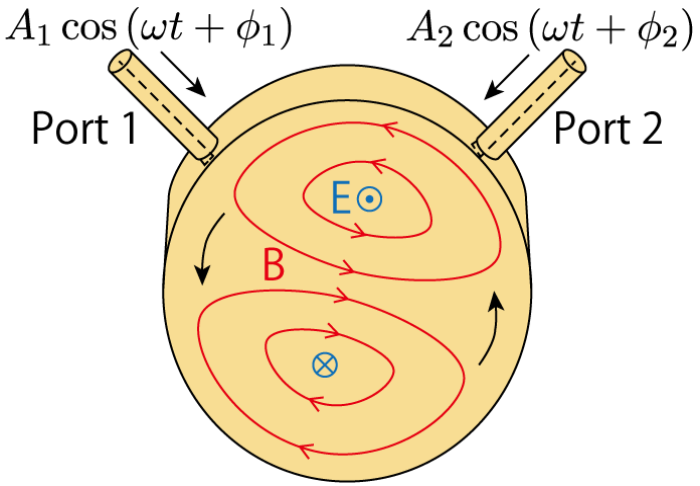
Current problems

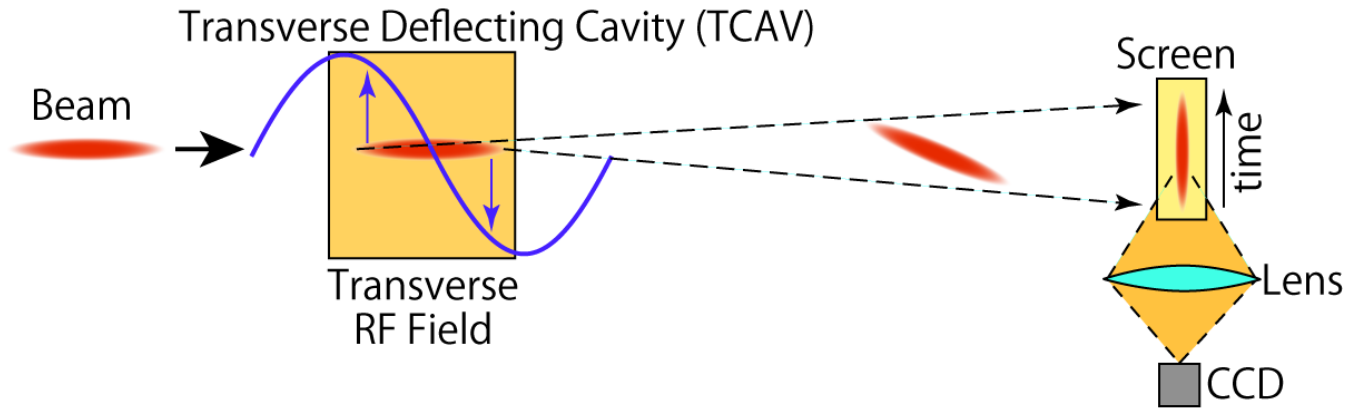
- Bunch compression condition is hard to be reproduced after the replacement of the gun cathode.
  - We had only one transverse deflector cavity (TCAV) to monitor a longitudinal bunch profile after BC3.
    - C-band TCAV after BC3 is essential to the tuning of BC2 and BC3.
    - A new TCAV was needed for tuning of velocity bunching and BC1.
  - We installed a L-band TCAV (1428 MHz) to the velocity bunching section.
- Transverse profile monitors did not work properly due to coherent OTR (optical transition radiation).
  - Transvers profile monitors are necessary for the emittance measurement and the envelop matching in the undulator section.
  - A short-bunch beam (< ~ 100 fs) generates intense coherent OTR.
  - We tried several mitigation schemes of COTR.

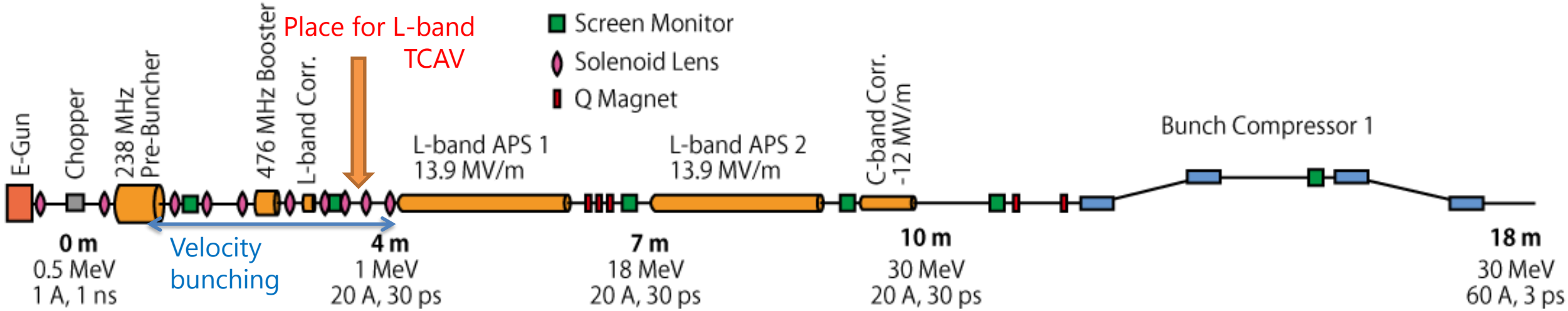
L-band transverse deflector

- Polarization control is need.
  - Longitudinal magnetic field in a solenoid lens rotates the stretched image.
- Two input ports intersecting with a right angle can generate arbitrary polarization.

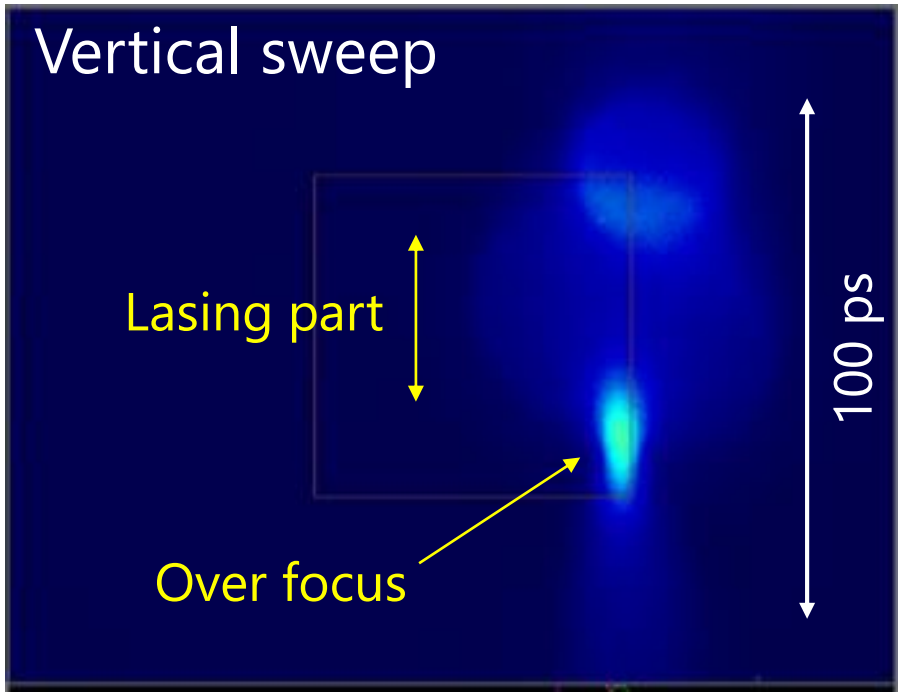


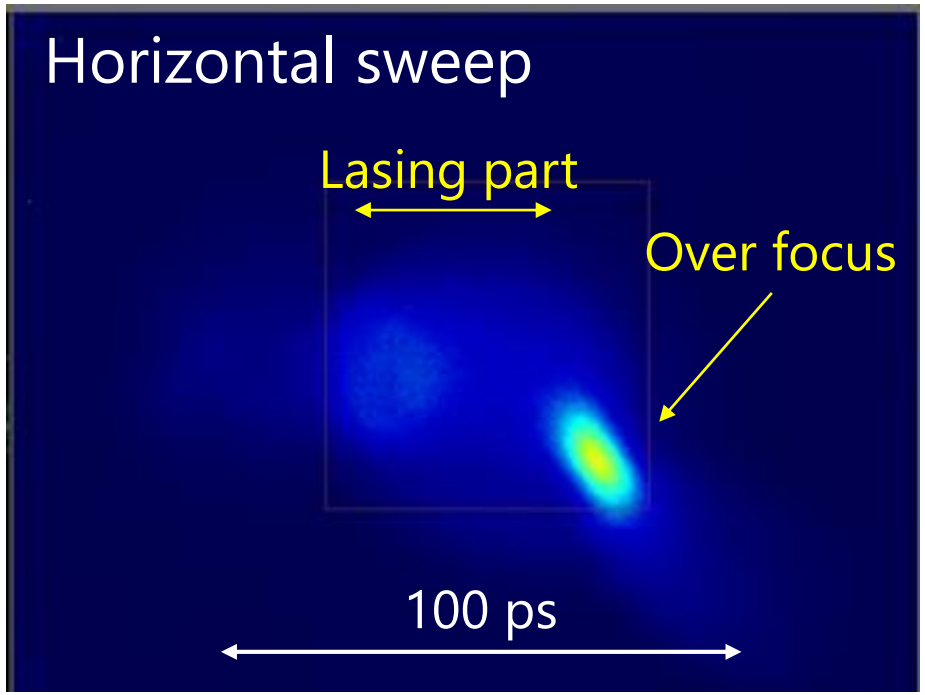


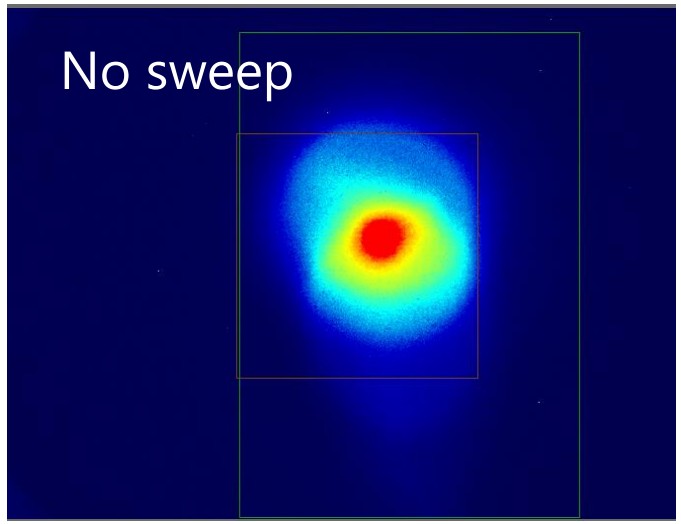




Temporal Profiles (linear polarization)

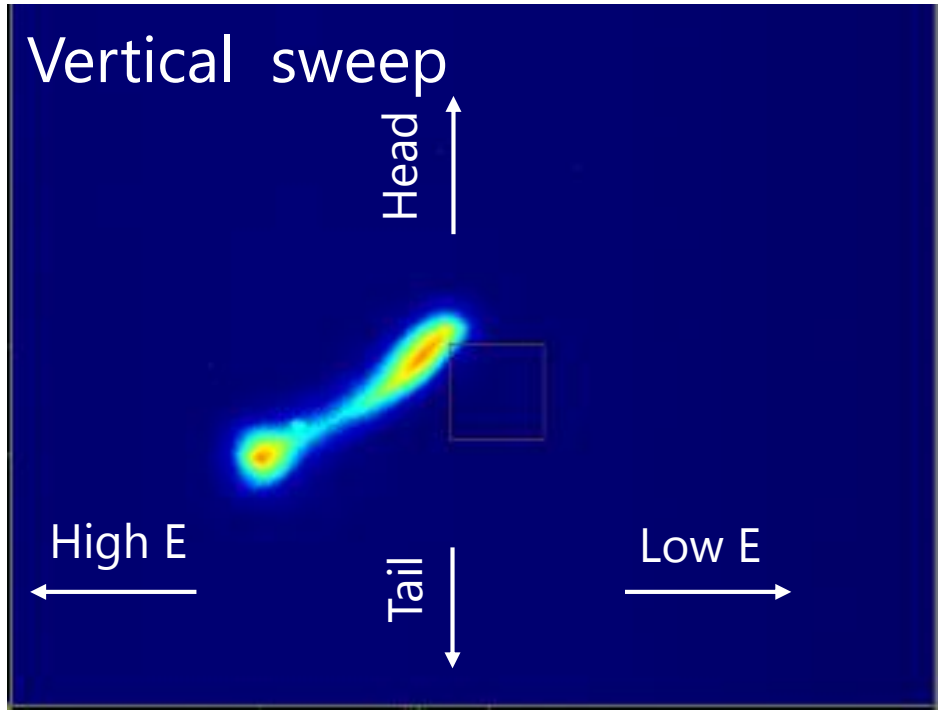


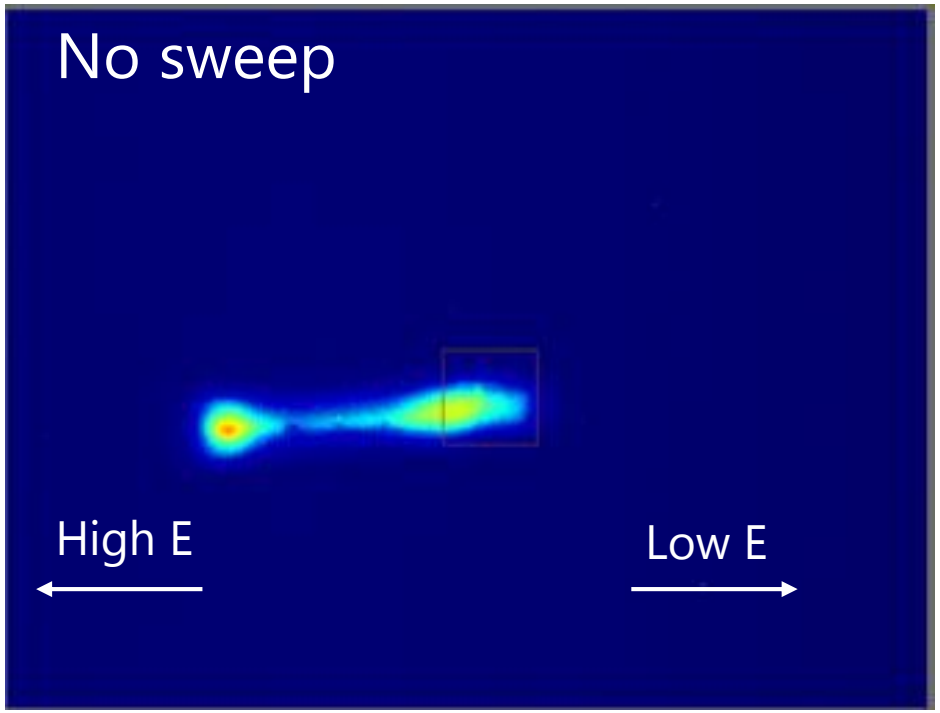




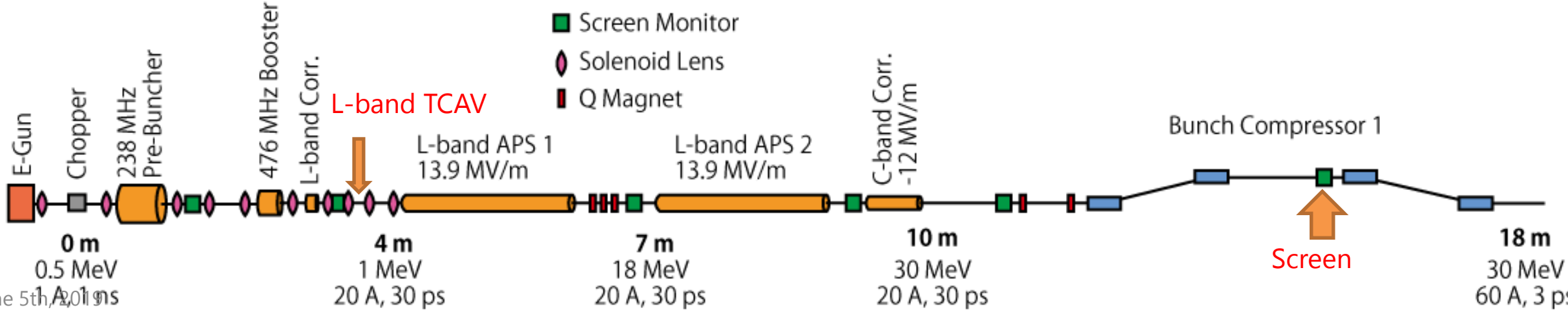
- Polarization was adjusted to obtain vertical or horizontal sweep on the screen.
- Position-to-time coefficient: 0.07 mm/ps
- Temporal resolution: ~ 10 ps
- Large chromatic aberration exists due to a large energy chirp.
- These images are still useful to reproduce the longitudinal profile in the velocity bunching section.

Energy v.s. time phase-space (BC1)





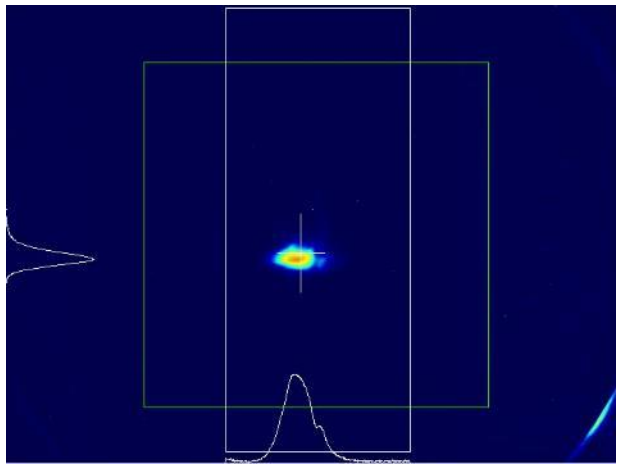
- E-T phase-space profile was appropriately obtained at the dispersive section of BC1.



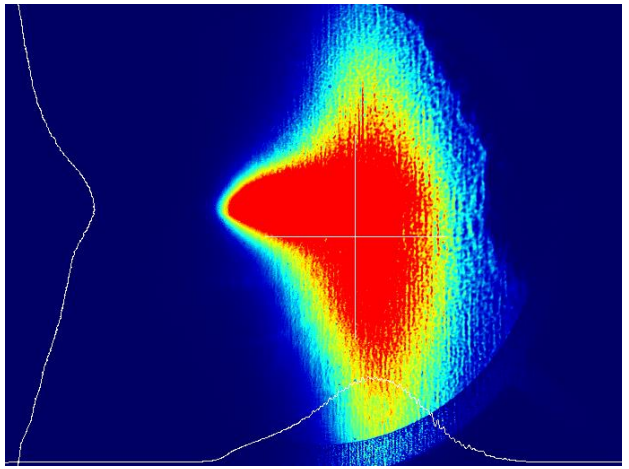
Coherent OTR problem

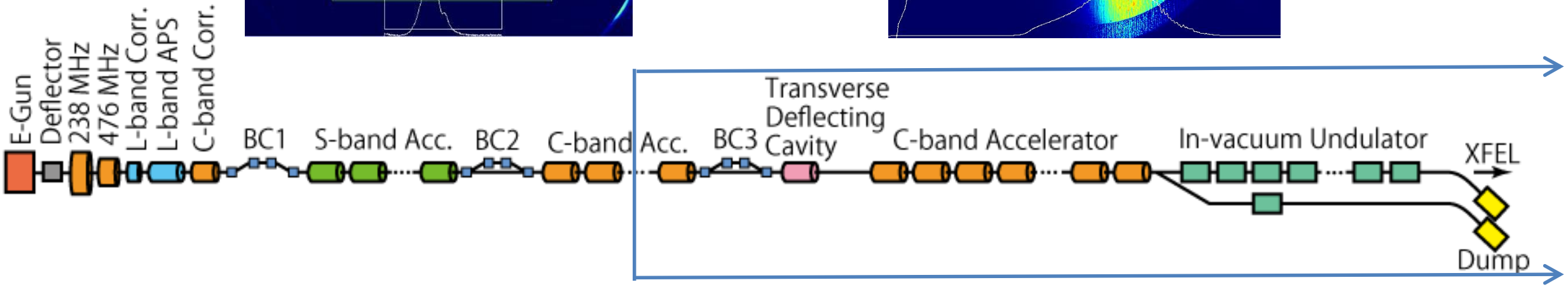
- OTR (optical transition radiation) profile monitors after BC3 did not work due to coherent OTR (COTR) problem.
- Short-bunch (<100fs) beam produced intense COTR.

OTR Target: stainless-steel mirror



Intense COTR



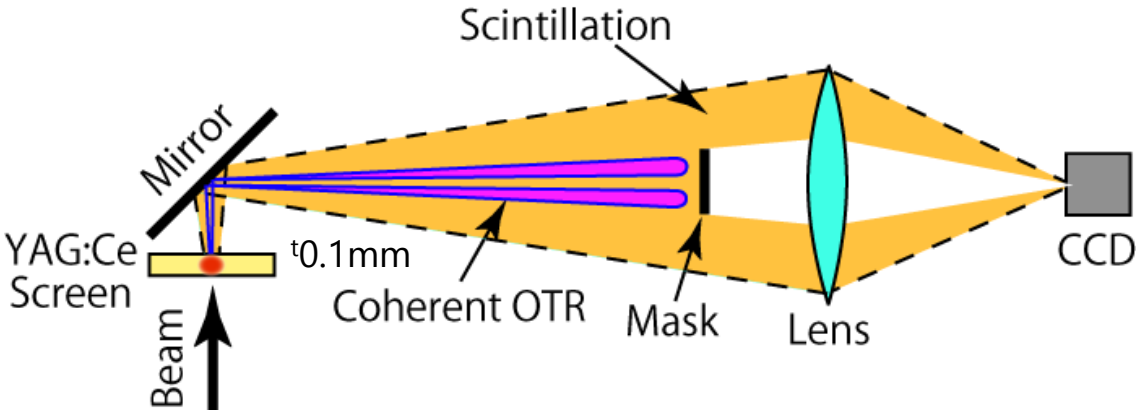


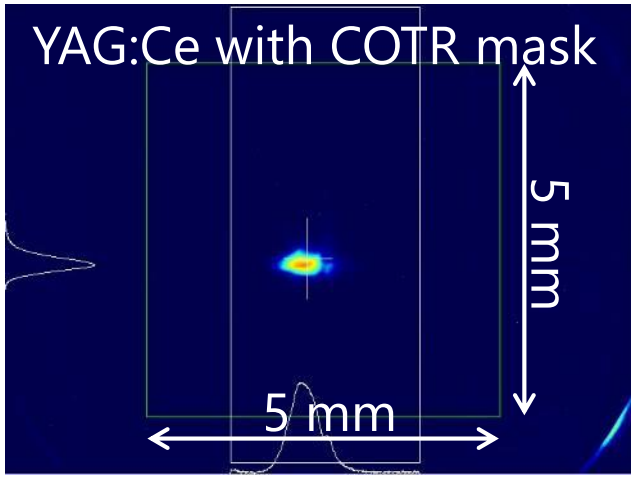
COTR mitigation schemes

- OTR targets were replaced with YAG:Ce.
  - COTR is still generated by YAG:Ce.
- Some COTR mitigation schemes have been tested.
  - Use the $1/\gamma$ directionality of OTR

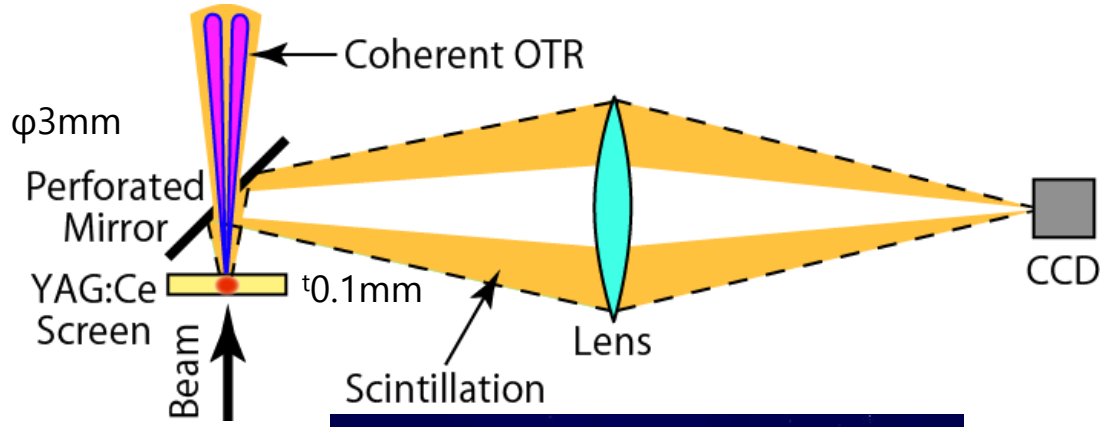
H. Maesaka *et al.*, IBIC'12, MOIC02.
S. Matsubara *et al.*, IBIC'12, MOCC04.
Y. Otake *et al.*, PRAB **16**, 042802 (2013).

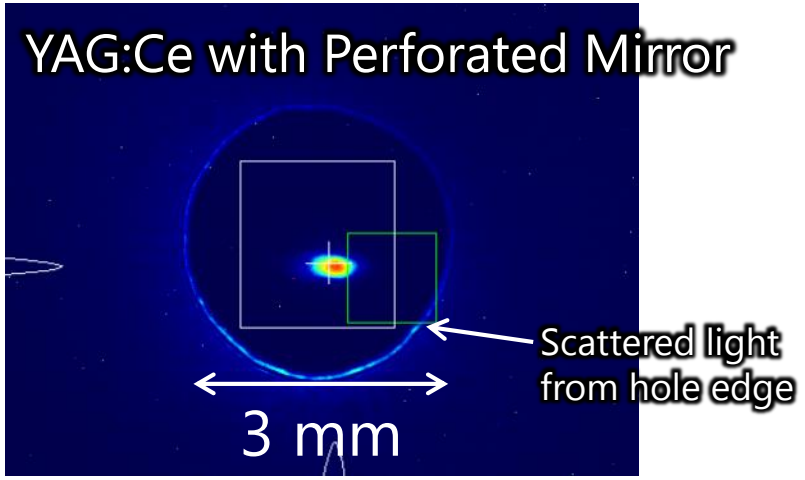
Mask scheme





Perforated mirror scheme

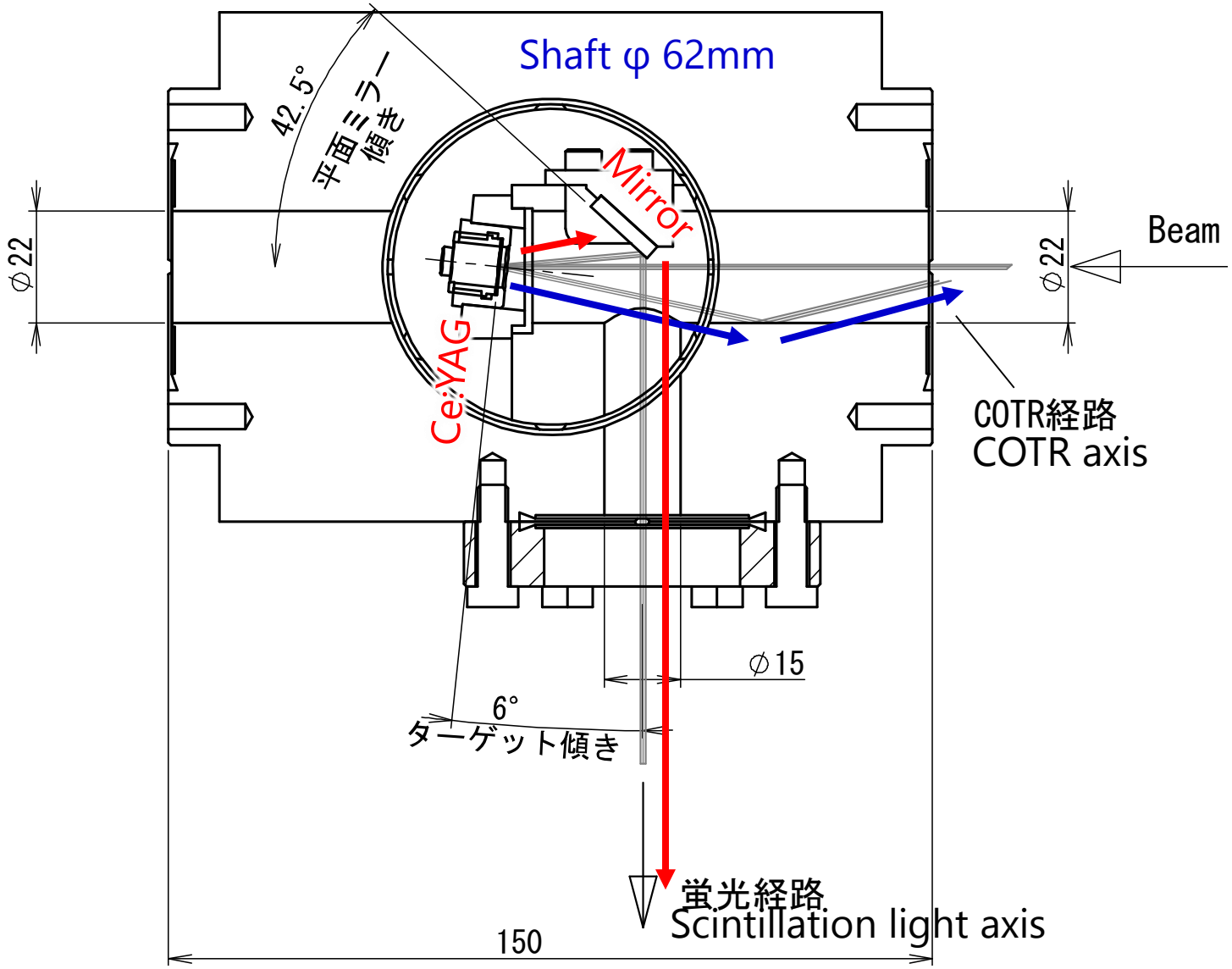




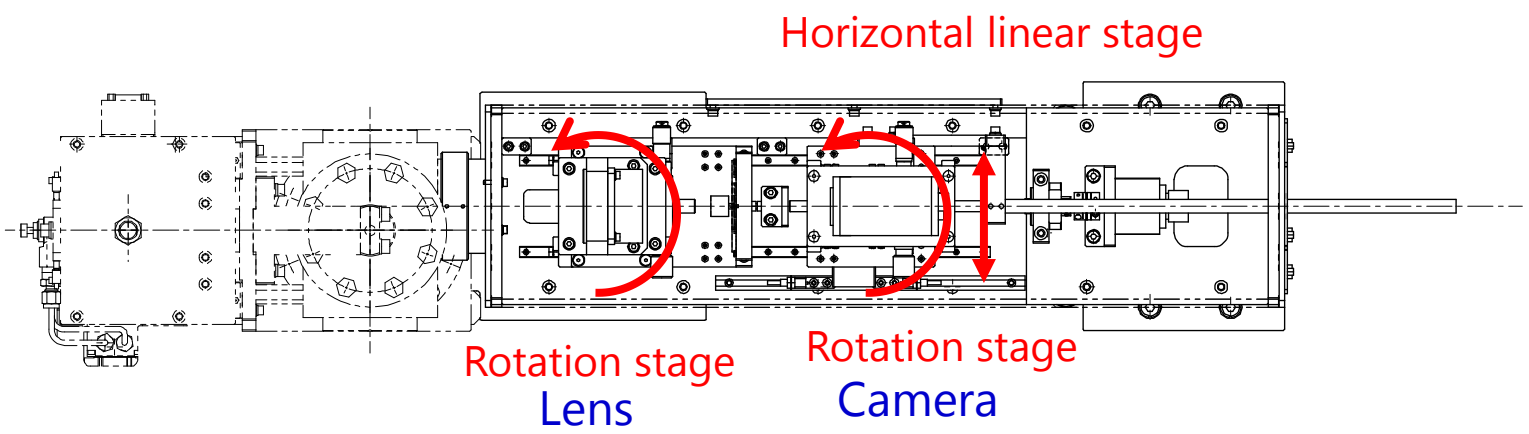
PSI scheme

R. Ischebeck et al., PRAB 18, 082802 (2015).

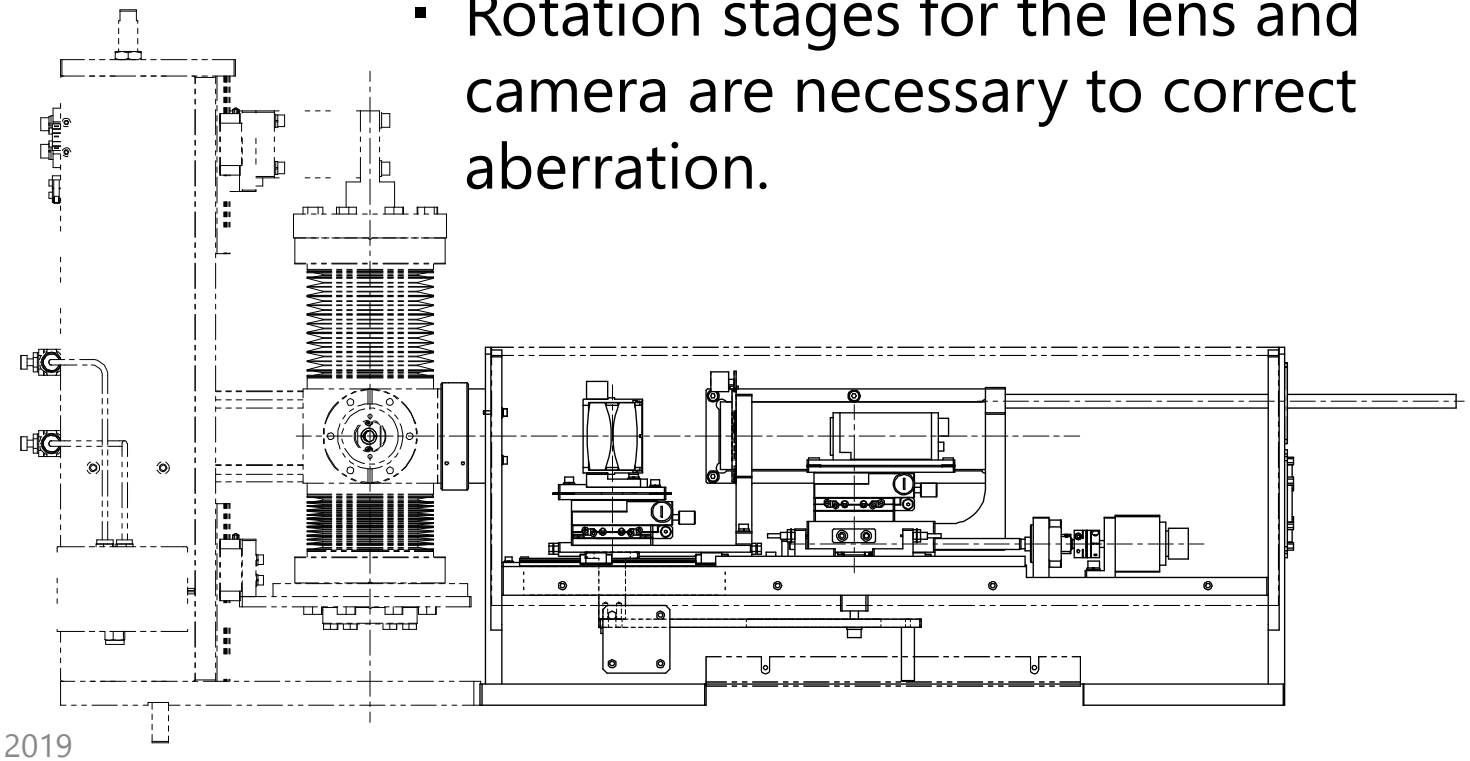
- Some profile monitors based on PSI scheme were installed in 2017.

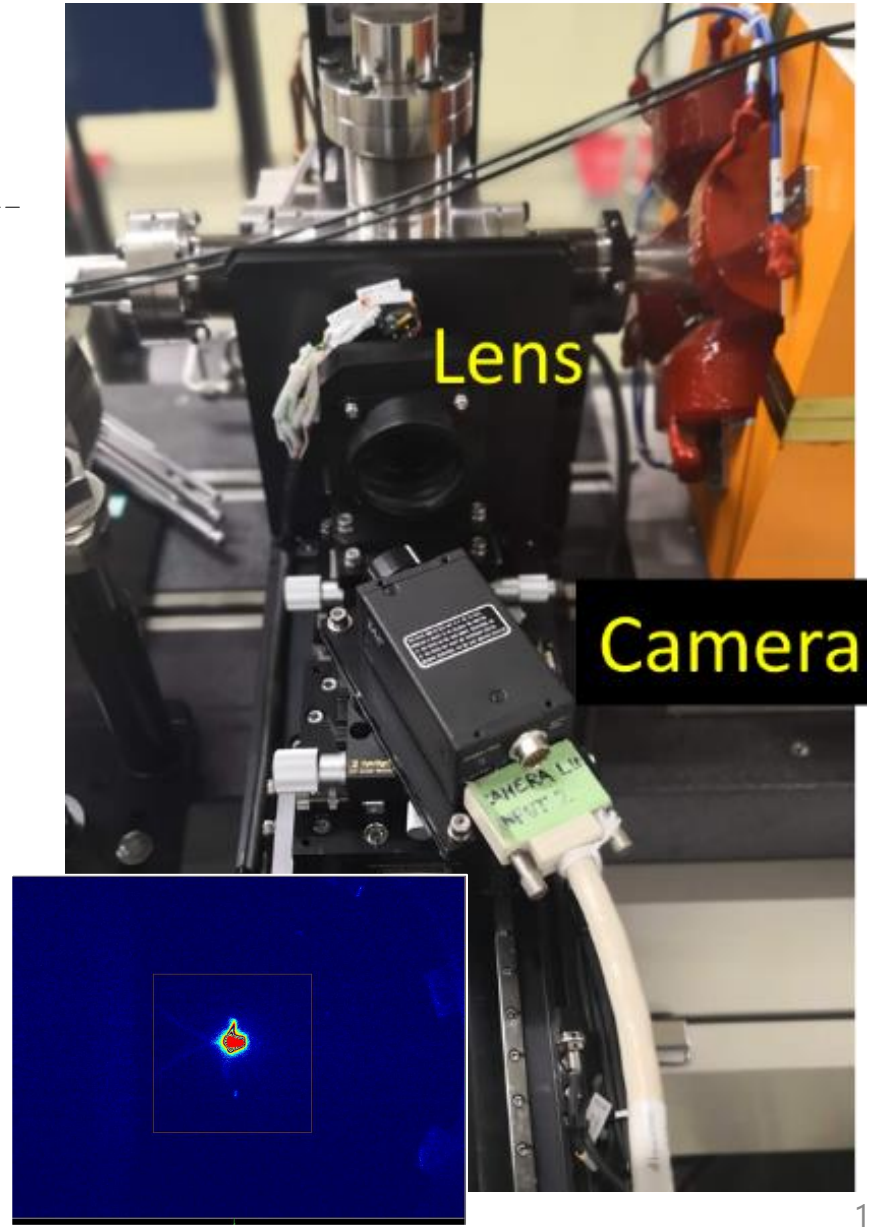


Imaging system for PSI scheme



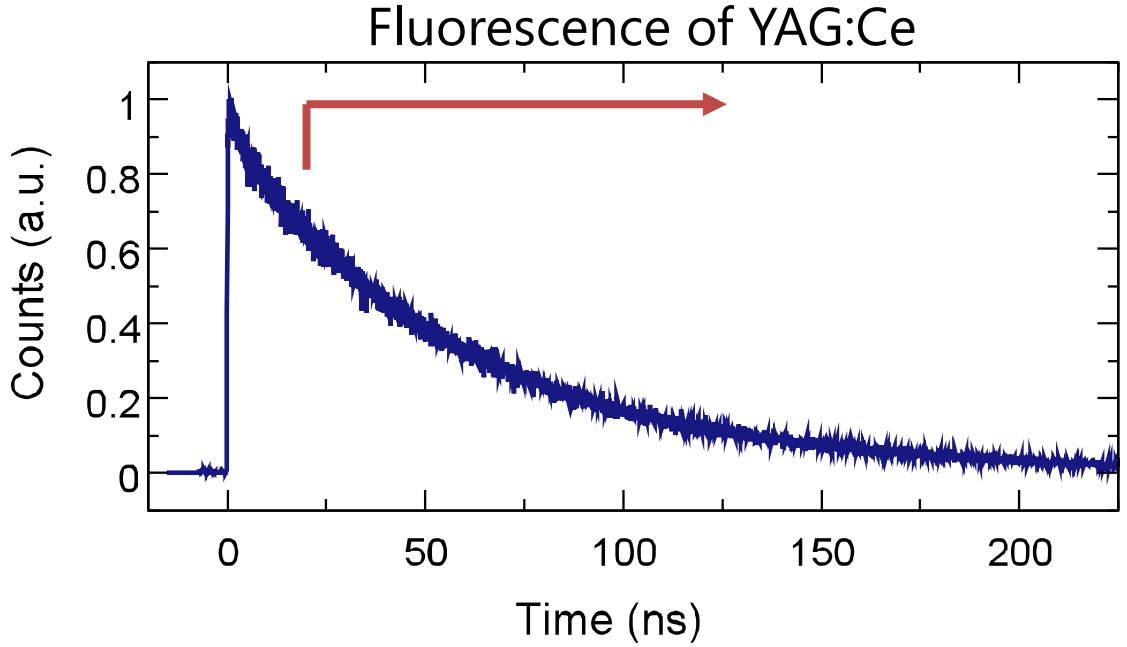
- Rotation stages for the lens and camera are necessary to correct aberration.

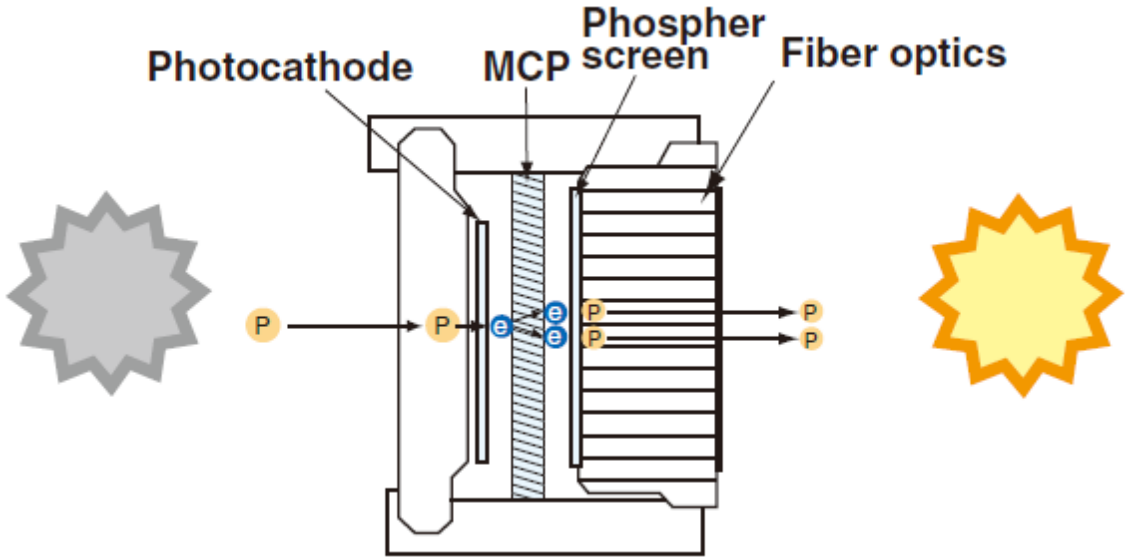


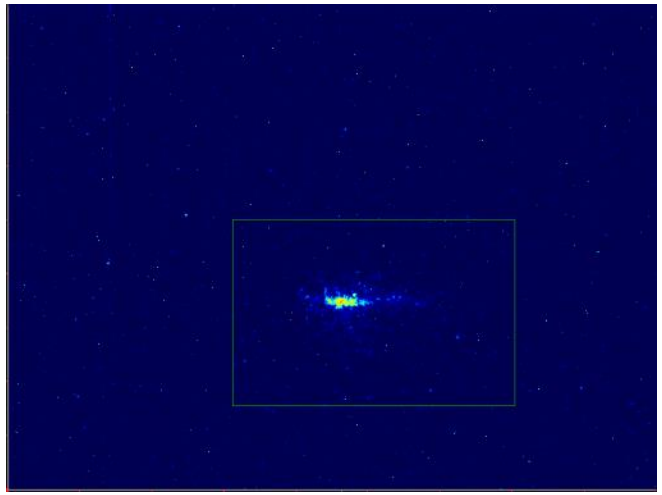


Fast gate scheme

- Fluorescence lifetime of YAG:Ce is about 50 ns.
- COTR is prompt radiation.
- COTR can be temporally discriminated from YAG scintillation.
- We installed a fast gate camera to one of the profile monitors.

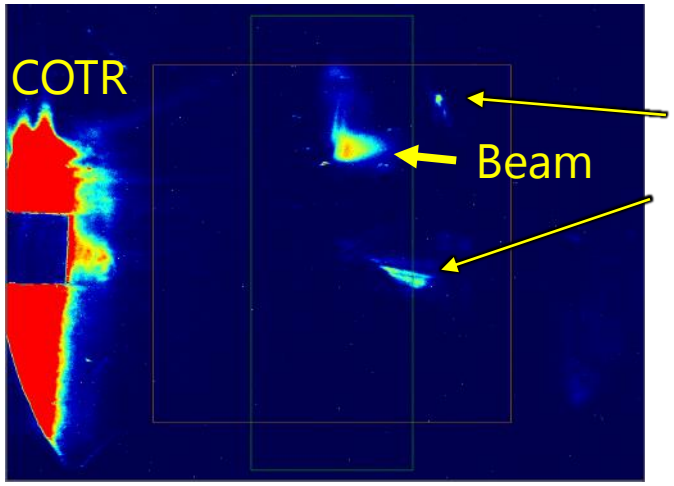






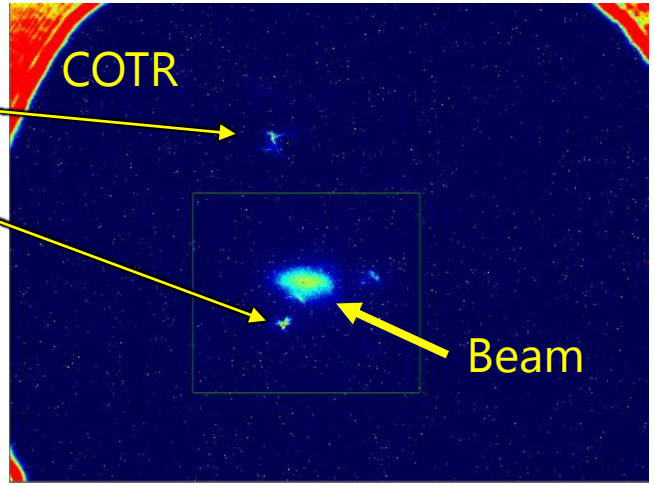
Profile monitor images

Mask scheme

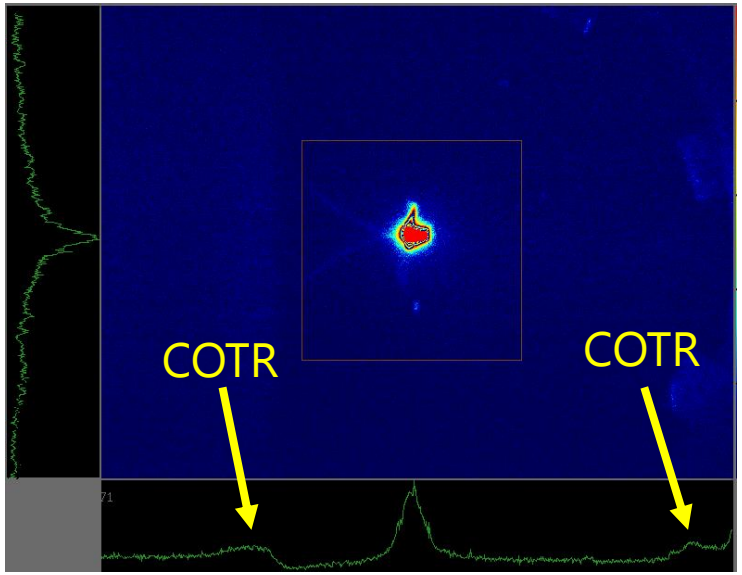


Hot spots due to imperfections

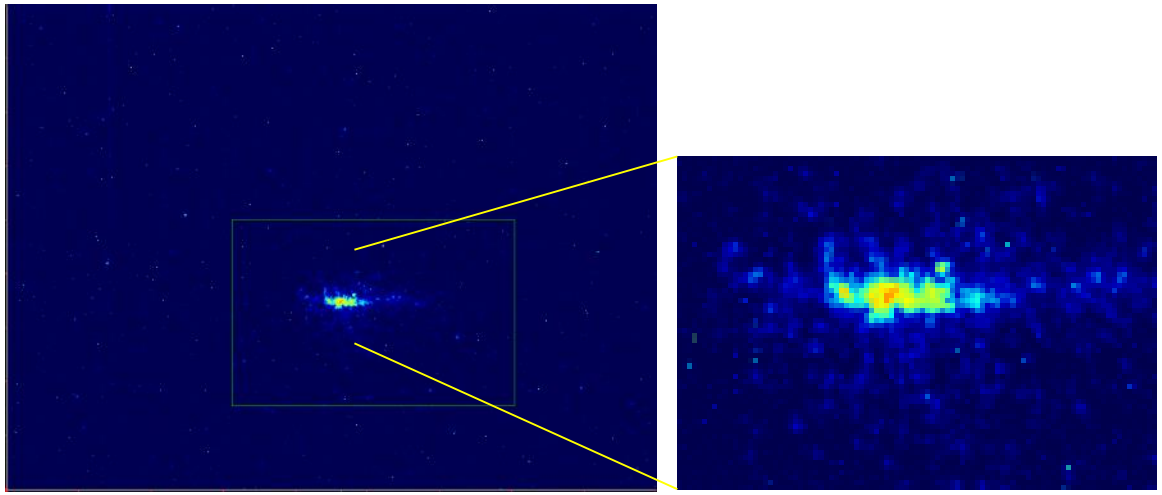
Perforated mirror scheme



PSI scheme

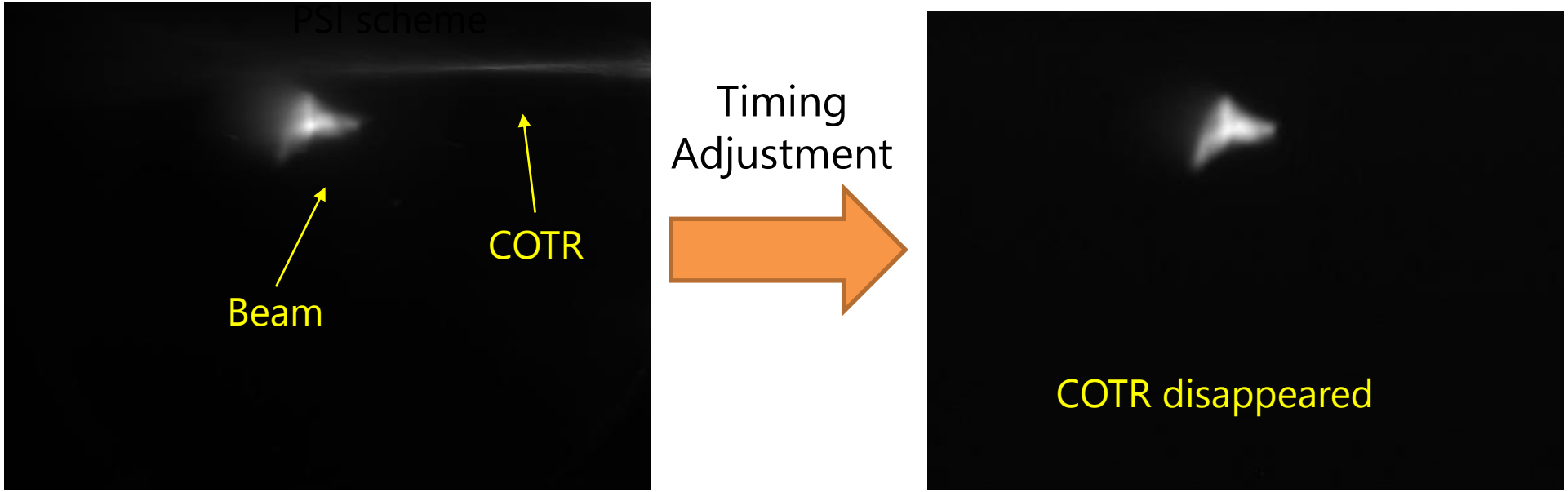


Fast gate scheme



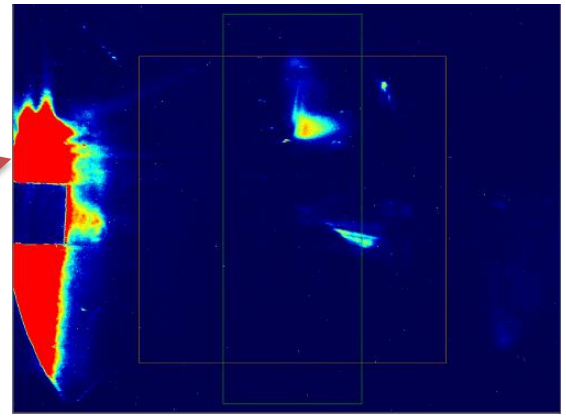
Timing shift of normal cameras

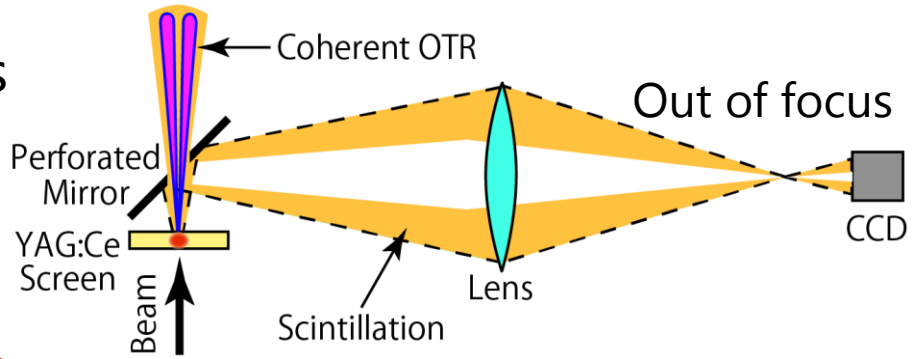
- Timing jitter of the camera system is about 100 ns.
- We can get beam profiles without COTR by adjusting the camera trigger timing just after COTR.
- Geometrical COTR mitigation scheme is still needed.
  - General imaging device may be damaged by intense COTR.
- Since the image intensity changes shot-to-shot due to the timing jitter, software normalization is necessary.

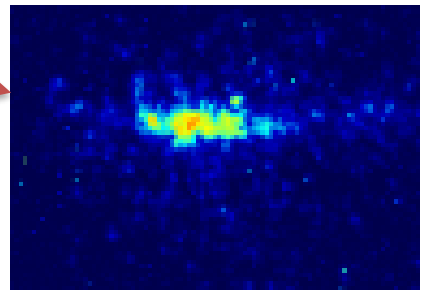


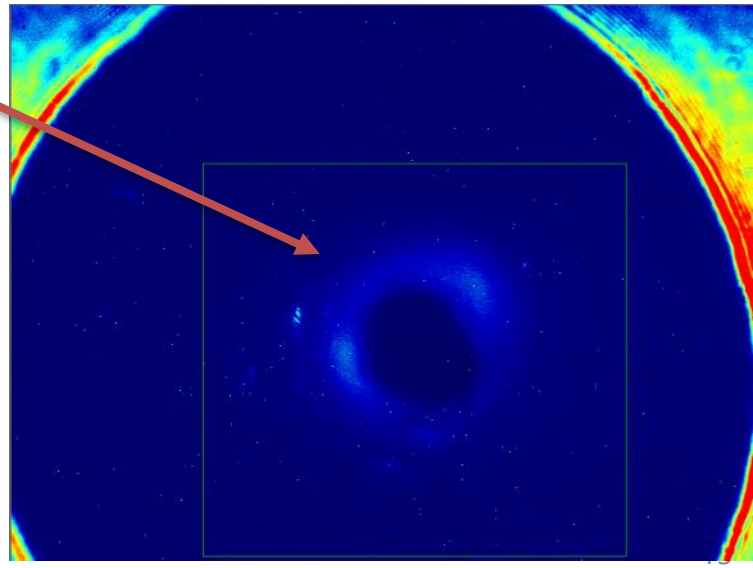
Known problems

- Mask scheme
  - Intense stray COTR light is observed around the beam image.
  - Bothersome mask adjustments are needed.
- Perforated mirror scheme
  - Shadow of the mirror hole can appear if the image is out of focus.
  - Stray COTR light still exists.
- PSI scheme
  - Stray COTR light still exists.
- Fast gate scheme
  - Expensive.
  - Image intensifier has poor resolution.
    - a few 10 μm
- Timing shift of the normal camera
  - Software normalization is needed.









Comparison of COTR mitigation schemes

Geometrical COTR mitigation schemes

	COTR separation	Tuning	Cost
COTR mask	Acceptable	Difficult	Reasonable
Perforated mirror	Good	Easy	Reasonable
PSI scheme	Very good	Moderate	Expensive a little

Temporal COTR mitigation schemes

	COTR separation	Resolution	Tuning	Jitter	Cost
Fast gate camera	Very good	Bad	Easy	Good	Expensive
Timing shift of a normal camera*	Good	Good	Easy	Moderate	Free

*: Geometrical COTR mitigation scheme must be used together to protect the camera from the intense COTR.

We employed the timing shift of normal camera combined with geometrical schemes (perforated mirror and PSI scheme) for most of our profile monitors.

Summary

- Transverse and longitudinal profile monitors are important for the XFEL facility SACLA.
- L-band TCAV
  - We designed a L-band TCAV and installed it to the velocity bunching section.
  - Temporal profile and energy v.s. time phase-space distribution were successfully obtained.
- Transverse profile monitors suffered COTR problems.
  - We tried several geometrical COTR reduction methods.
  - Mask, perforated mirrors and PSI scheme
  - Timing shift of the camera trigger worked well.
- Now, the COTR problem was almost solved by the combination of the geometrical COTR reduction and the timing shift of the camera trigger.