KAERI MeV-UED: Setup and Applications to Ultrafast Chemical Dynamics

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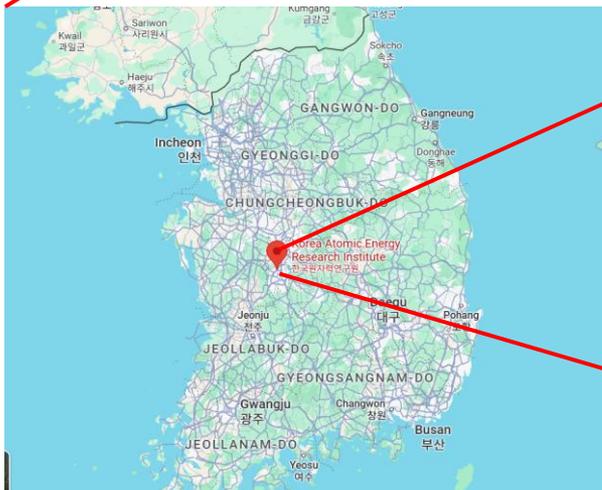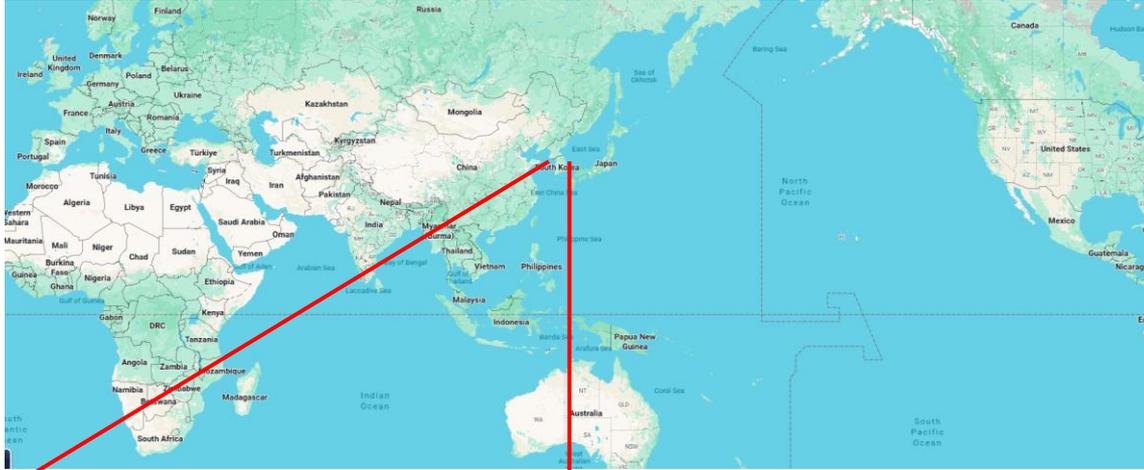**Korea Atomic Energy Research Institute**

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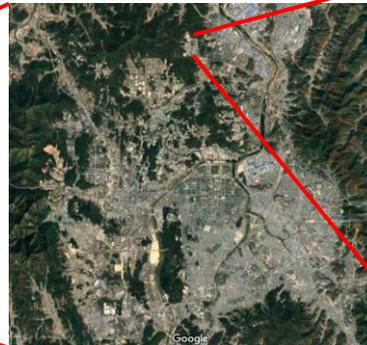
❖ Korea Atomic Energy Research Institute (KAERI)

2. KAERI MeV-UED

❖ MeV-UED

- Towards jitter-free UED

- Electron–THz interaction

❖ Current research projects

- Solid phase

- Gas-phase UED

Korea Atomic Energy Research Institute

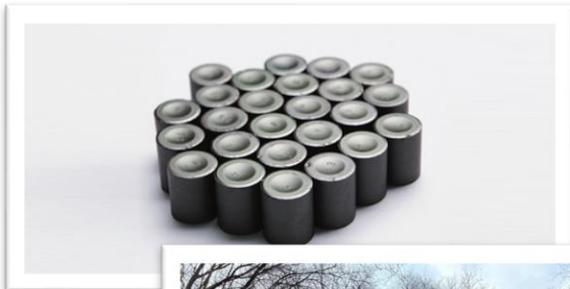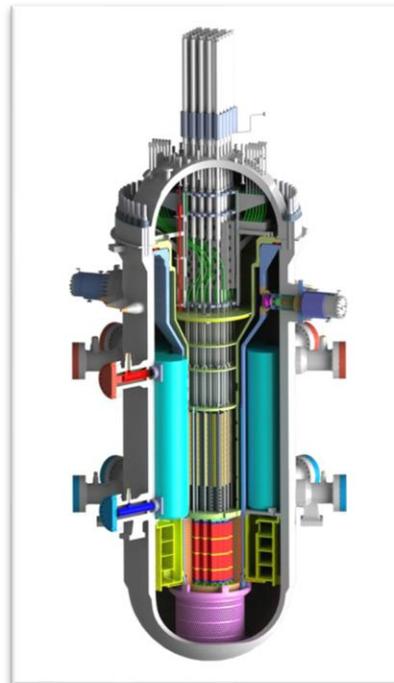# Korea Atomic Energy Research Institute (KAERI)

South Korea

Daejeon

KAERI

Korea **Atomic Energy** Research Institute (KAERI)

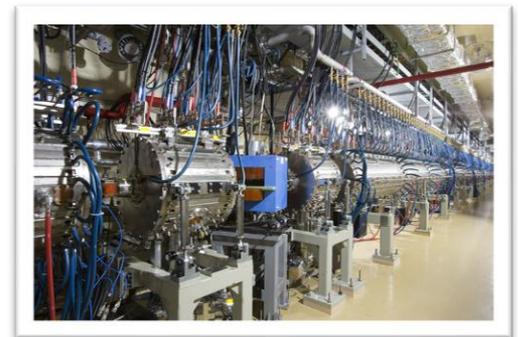Research reactor

Proton accelerator

Nuclear fuel design & disposal

Designing nuclear reactor

Mev-UED

2. KAERI MeV-UED

❖ **MeV-UED**

- ▪ **Towards jitter-free UED**

- ▪ Electron–THz interaction

KAERI Korea Atomic Energy
Research Institute
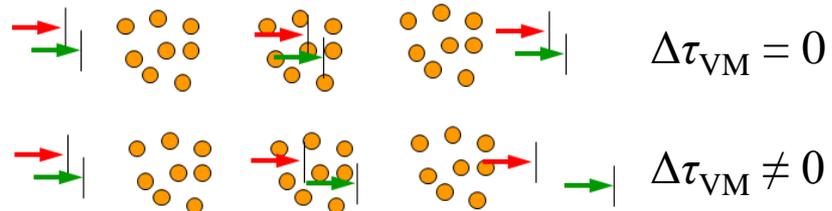
Overview of KAERI MeV-UED
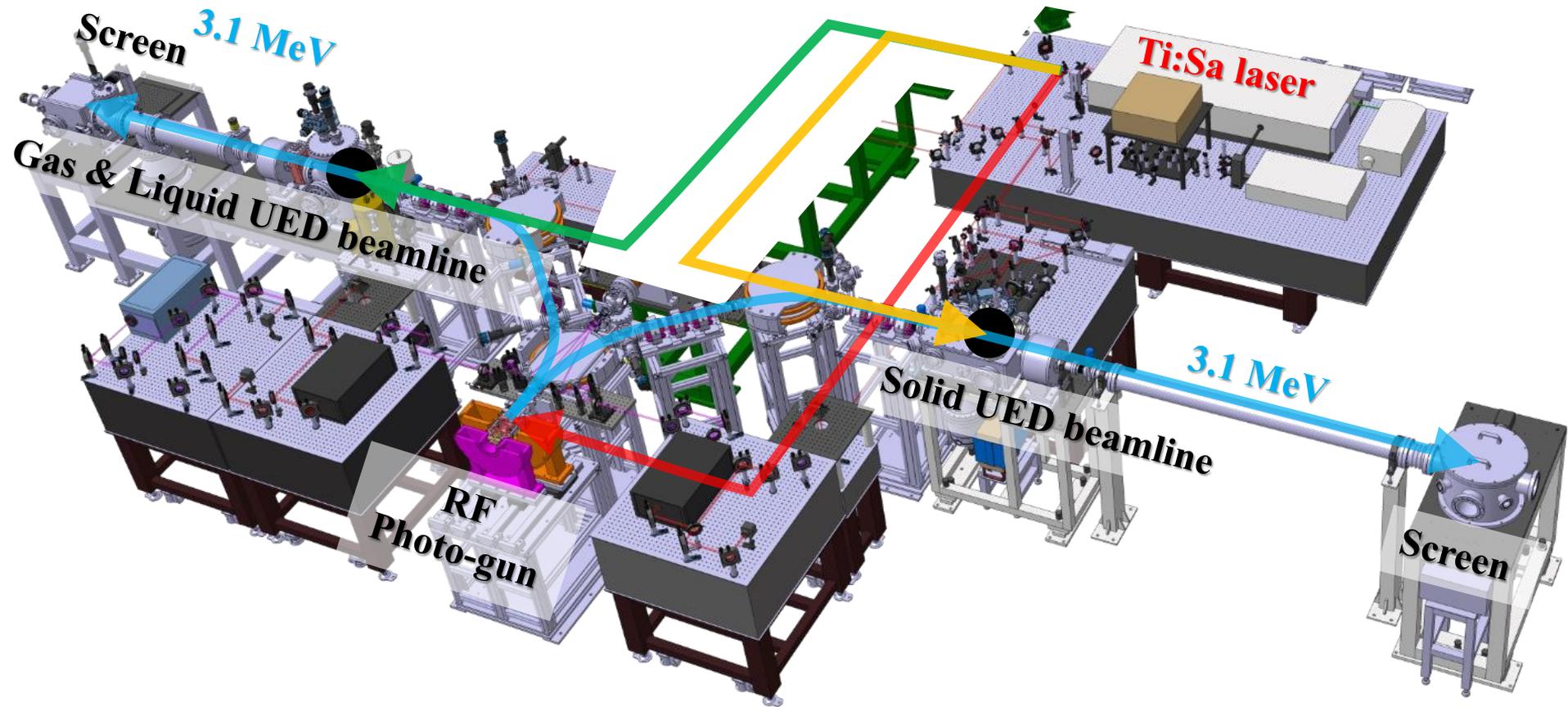
Towards jitter-free UED

$$\Delta\tau_{\text{overall}} = \sqrt{\Delta\tau^2_{\text{laser pump}} + \Delta\tau^2_{\text{electron probe}} + \Delta\tau^2_{\text{jitter}} + \Delta\tau^2_{\text{VM}}}$$
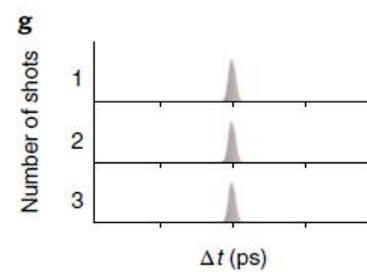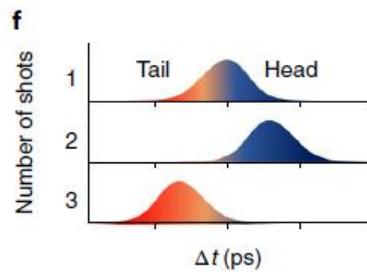

Achromatic 90° bending structure

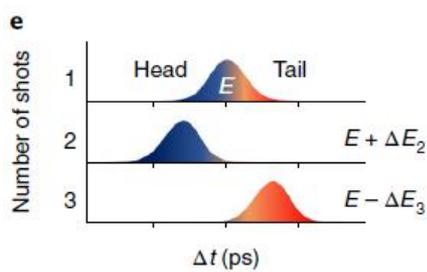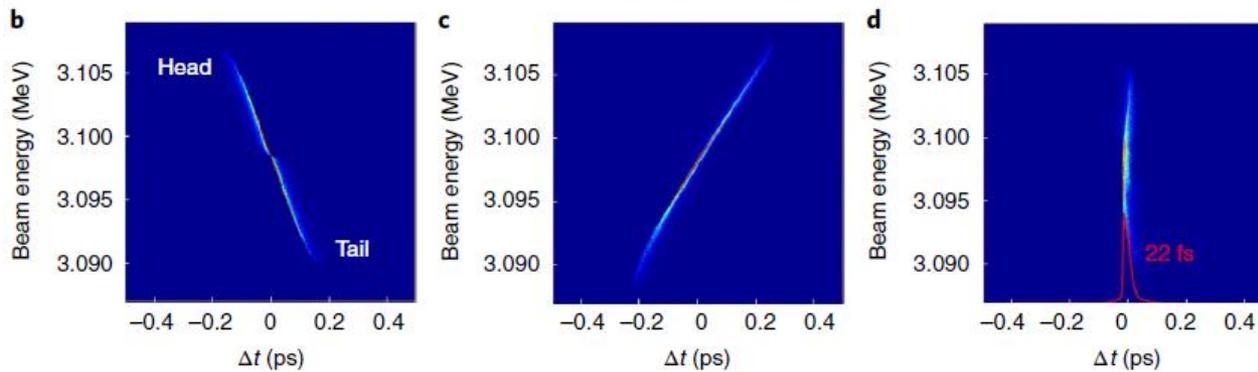- Electron bunch length ($\Delta\tau_{\text{electron}}$) of 25 ± 8 fs (RMS) @ **0.6 pC**

- Relative arrival-time jitter ($\Delta\tau_{\text{jitter}}$) reduction up to 7.8 fs (RMS)

- Velocity-mismatching-free scheme ($\Delta\tau_{\text{VM}} = {\sim}0$ fs)

$$\Delta\tau_{\text{VM}} = 0$$

$$\Delta\tau_{\text{VM}} \neq 0$$

H. W. Kim *et al.*, *Nat. Photon.* (2020)

Towards jitter-free UED

2. KAERI MeV-UED

❖ **MeV-UED**

- ▪ Towards jitter-free UED

- ▪ **Electron–THz interaction**

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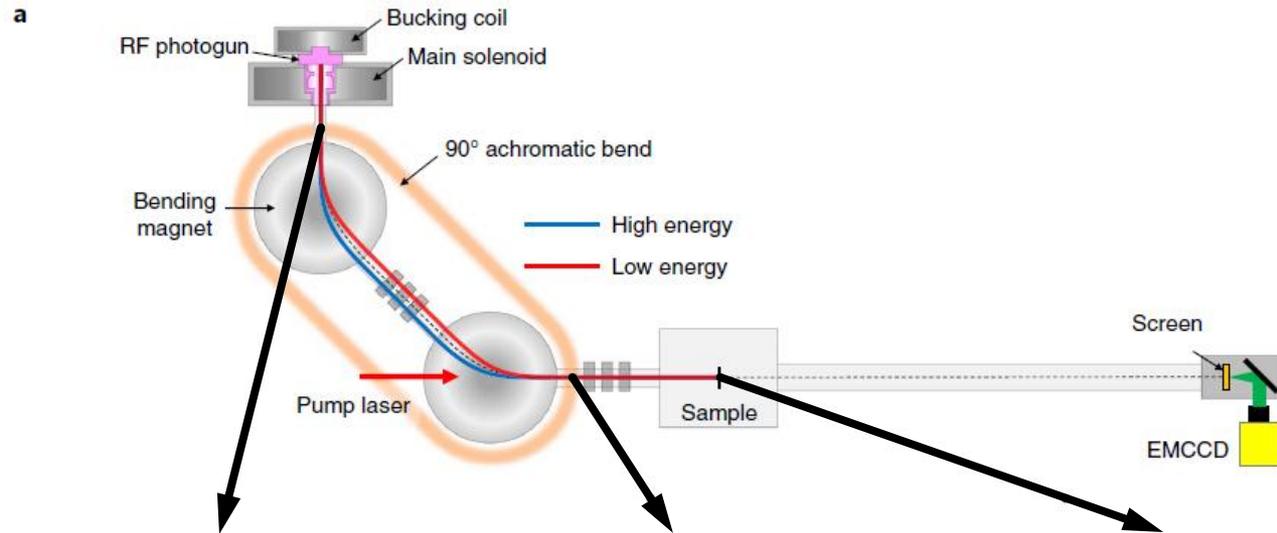
THz streak camera using split-ring resonator (SRR)
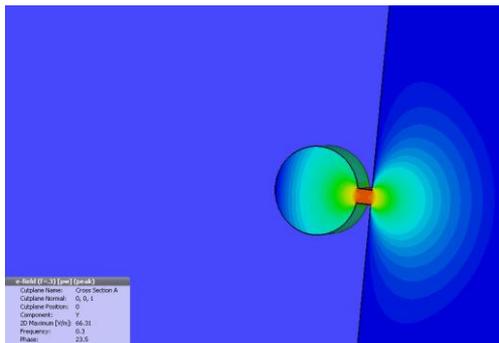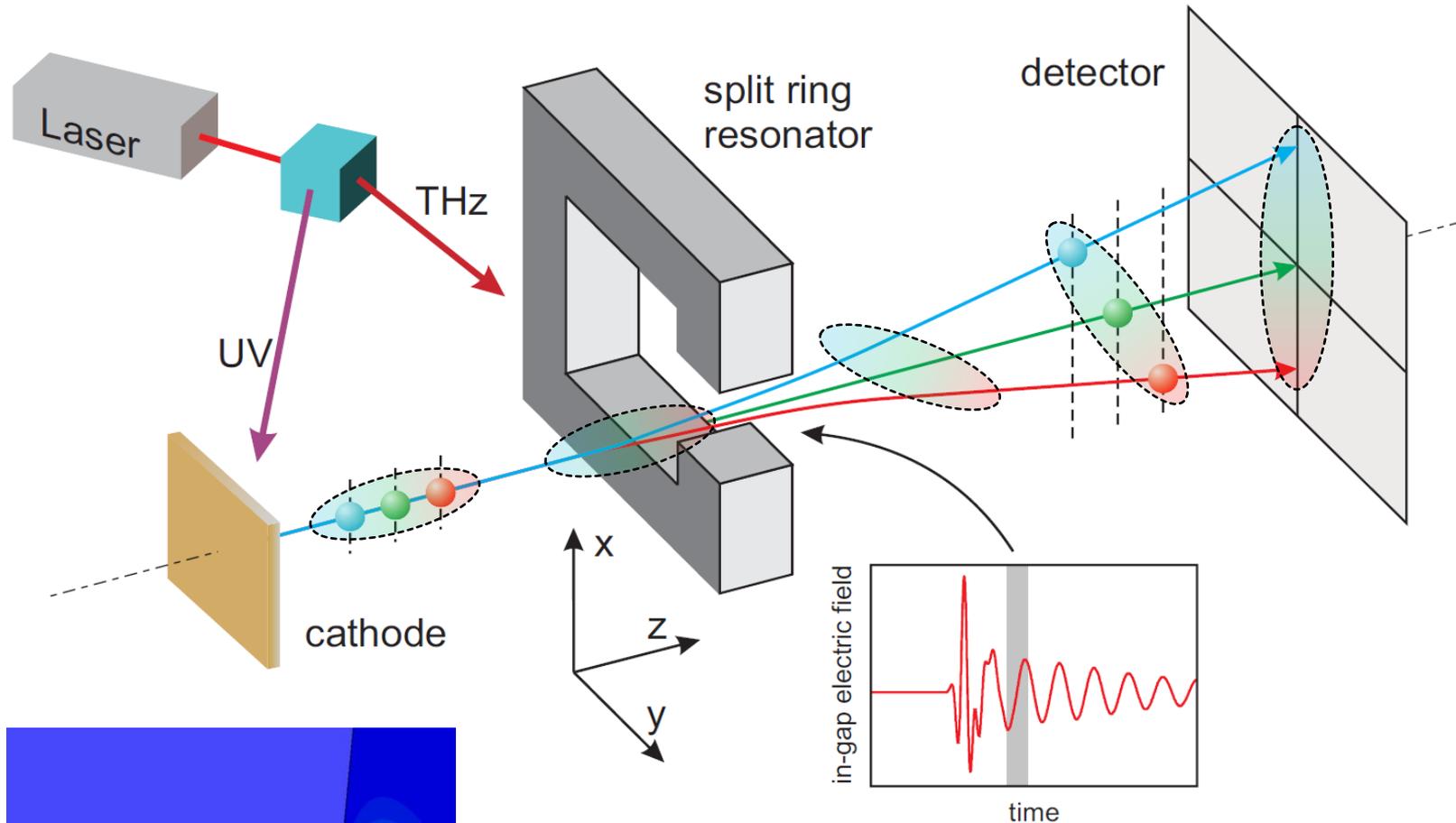
- Streaking velocity (V_{ST}) of 10 μrad/fs @ 0.3 THz (Sim.)
- Sub-10 fs accuracy is possible.

Fabianska *et al.*, *Sci. Rep.* (2014)

THz streaking experiments with SRR
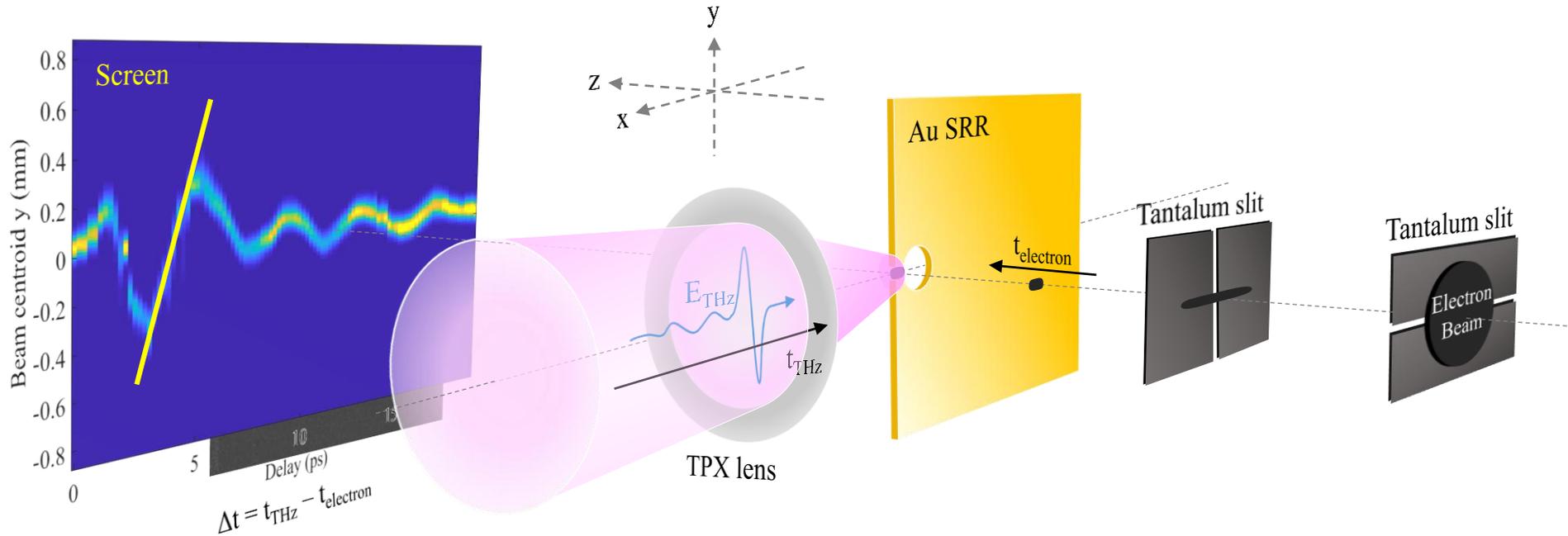
Streaking velocity (V_{ST})

10 µrad/fs @ 0.3 THz (Sim.)

6.74 µrad/fs @ 0.3 THz (Exp.)

H. W. Kim *et al.*, *Nat. Photon.* (2020)

Electron bunch length ($\Delta\tau_{\text{electron}}$) and relative arrival-time jitter ($\Delta\tau_{\text{jitter}}$)
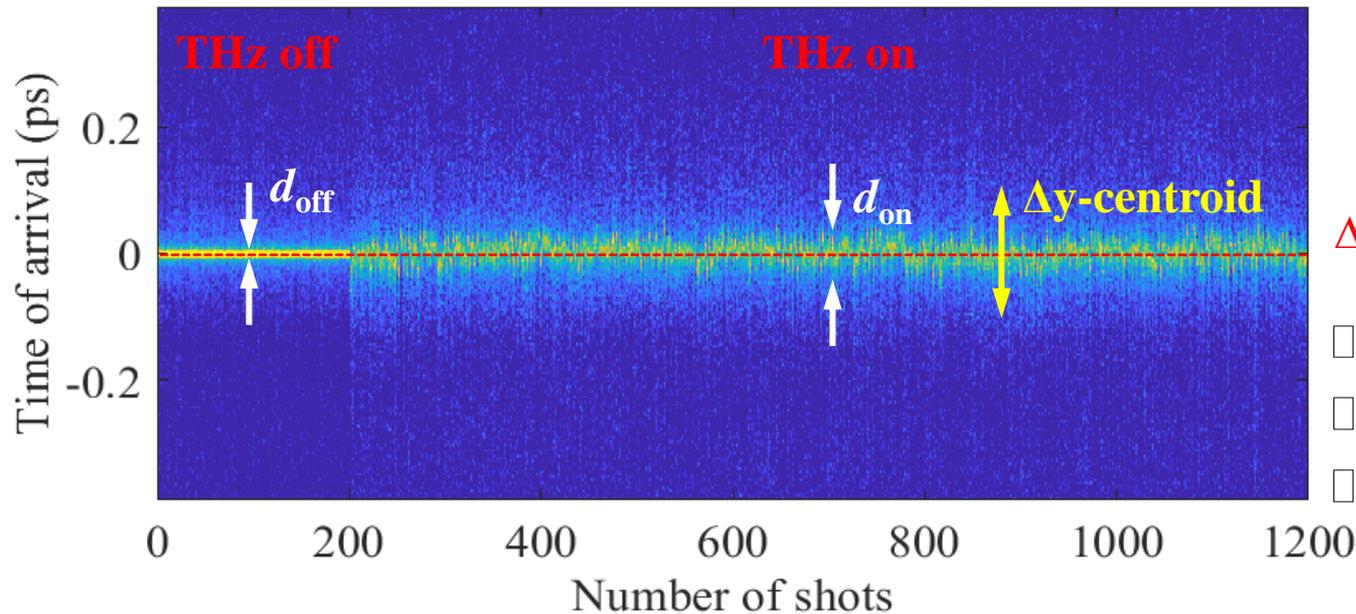
Electron bunch length
($\Delta\tau_{\text{electron}}$)

$$\Delta\tau_{electron} = \frac{v_e \times \sqrt{d_{on}^2 - d_{off}^2}}{V_{ST} \times D}$$

☐ v_e : electron velocity

☐ V_{ST} : streaking velocity

☐ D : distance to the screen

- Electron bunch length ($\Delta\tau_{\text{electron}}$) of **25 ± 8 fs (RMS)** @ **0.6 pC, 3.1 MeV**

- Relative arrival-time jitter ($\Delta\tau_{\text{jitter}}$) between THz & electron pulses of **8 fs (RMS)**

H. W. Kim *et al.*, *Nat. Photon.* (2020)

Electron bunch length ($\Delta\tau_{\text{electron}}$) and relative arrival-time jitter ($\Delta\tau_{\text{jitter}}$)

● ● ● Experimental data with error
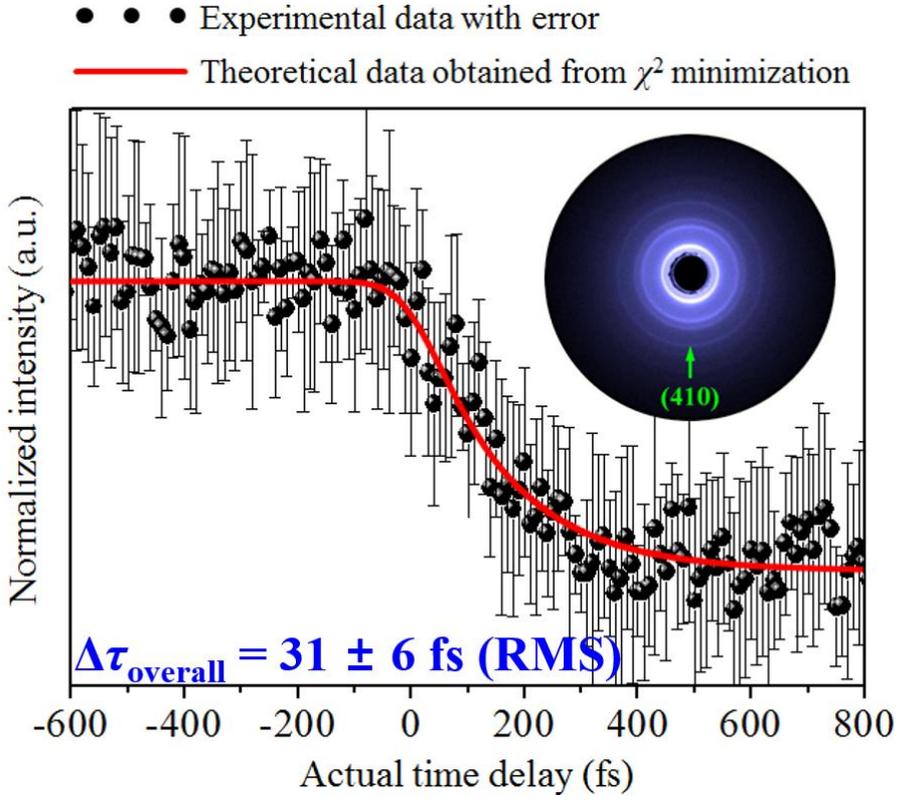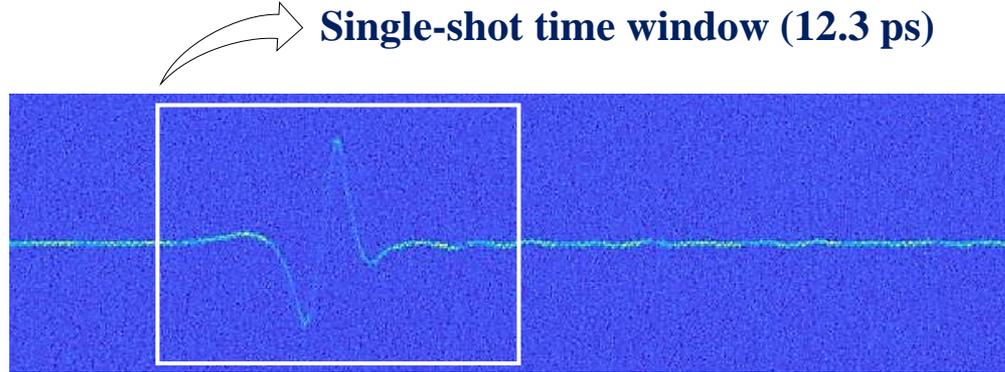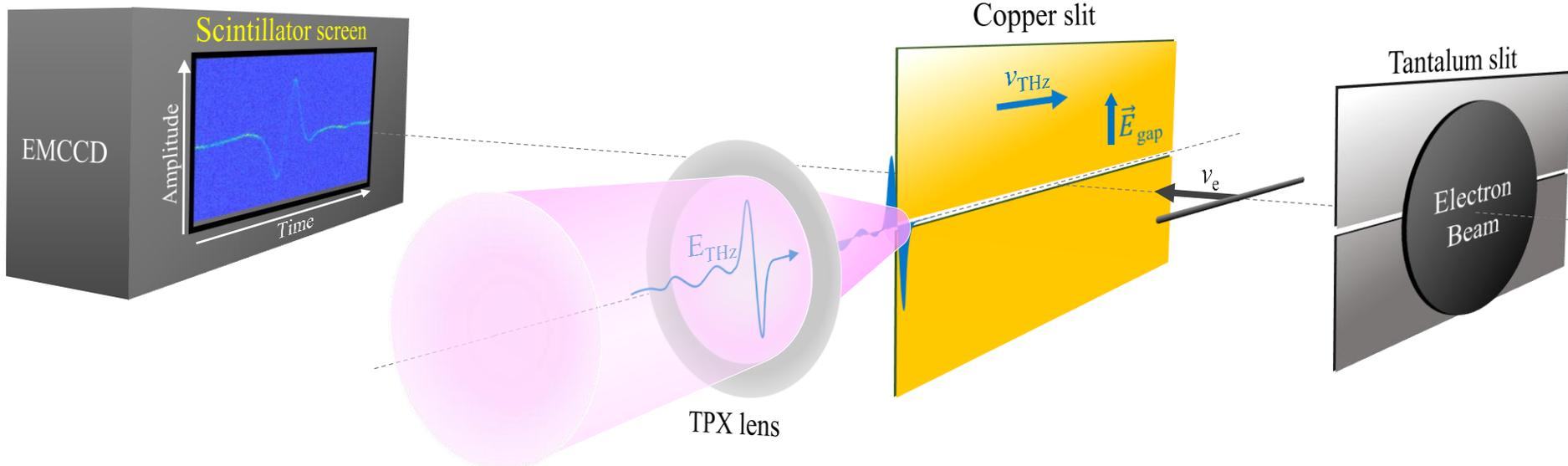
—— Theoretical data obtained from χ^2 minimization

$\Delta\tau_{\text{overall}} = 31 \pm 6$ fs (RMS)

$$\Delta\tau_{\text{overall}} = \sqrt{\Delta\tau_{\text{laser pump}}^2 + \Delta\tau_{\text{electron probe}}^2 + \Delta\tau_{\text{jitter}}^2 + \Delta\tau_{\text{VM}}^2}$$

32 fs   19 fs   **25 fs**   **8 fs**   0 fs

Real-time optical waveform visualization by using electron oscilloscope

Single-shot time window (12.3 ps)

- Fine temporal resolution (**< 100 fs**)
- Enough single-shot time window (**> 10 ps**)
- **Full-field** (amplitude & phase) measurements
- **Real-time & single-shot** operation
- Signal integrity (= **No distortion**)

Baek *et al.*, *Nat. Commun.* (2021)

2. KAERI MeV-UED

❖ **Current research projects**

- ▪ Solid phase

- ▪ Gas phase

Solid phase: Perovskite thin films (ABX$_3$)

Perovskite thin films (ABX$_3$)

❖ **Next-generation** high-efficiency solar cells

❖ **Super star** in the solar cell community since 2010

Most of the photophysical studies until now

❖ Optical measurements probing the electronic

   transitions with high time resolution but **only indirectly probe the nuclear response**

❖ **Motion of organic cations** in screening and protecting carriers from recombination

Dr. Nam Joong Jeon

Dr. Bong Joo Kang

"**Although perovskite solar cell efficiencies have climbed above 20% mark, the fundamental working mechanism responsible for these efficiencies and the associated long carrier lifetimes is not understood.**"
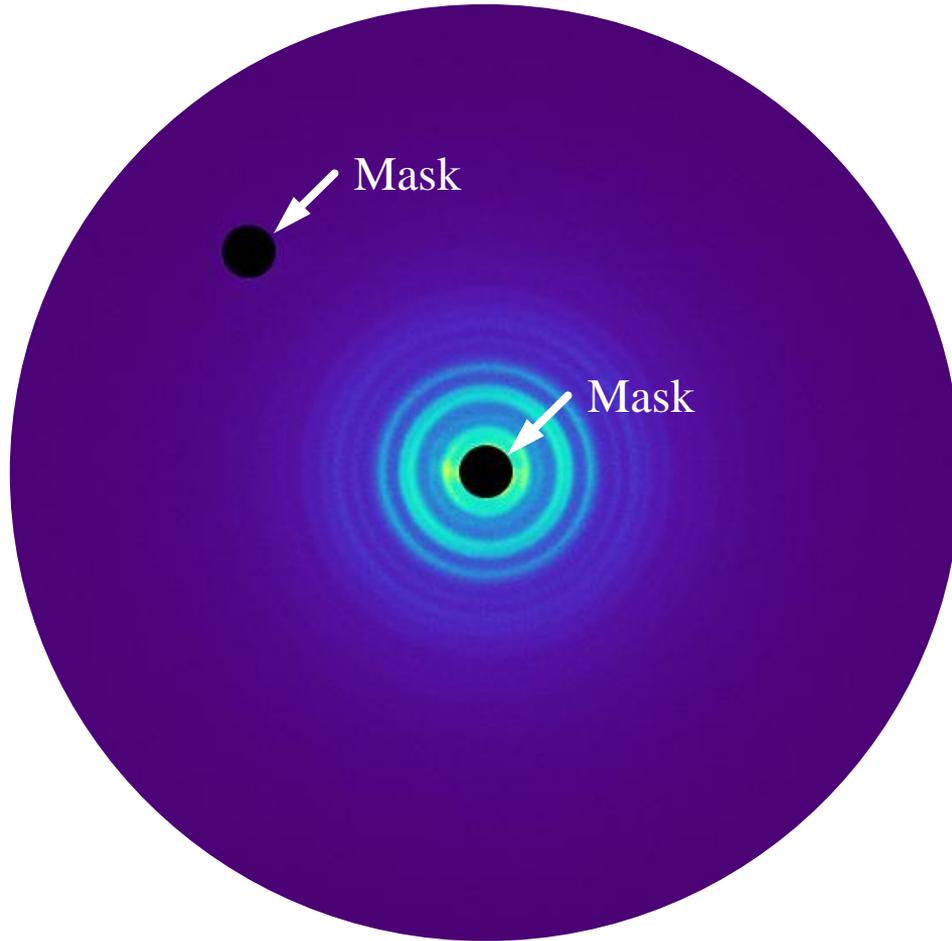
Yoo *et al.*, *Nature* (2021)
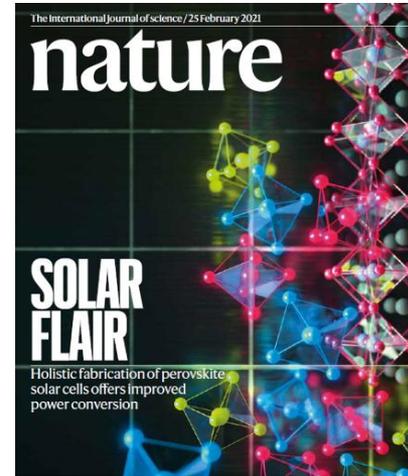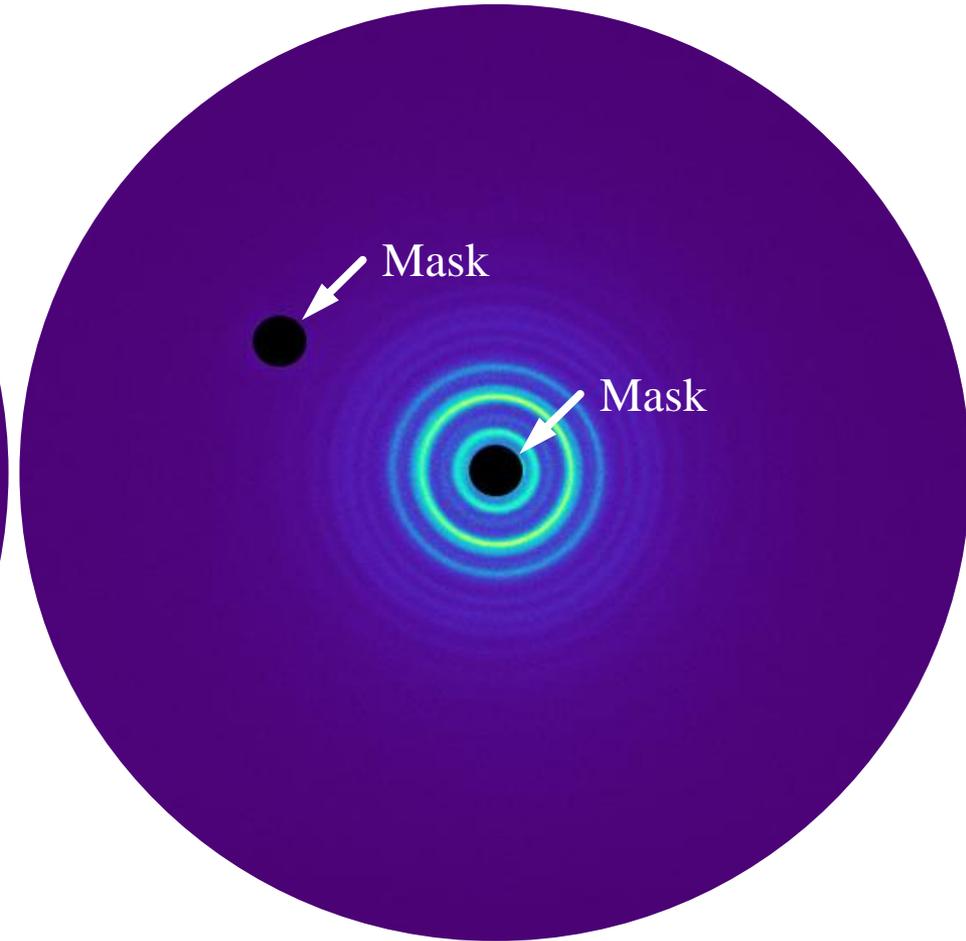
Exemplary 2D raw data of $(FAPbI_3)_{1-x}(MAPbBr_3)_x$
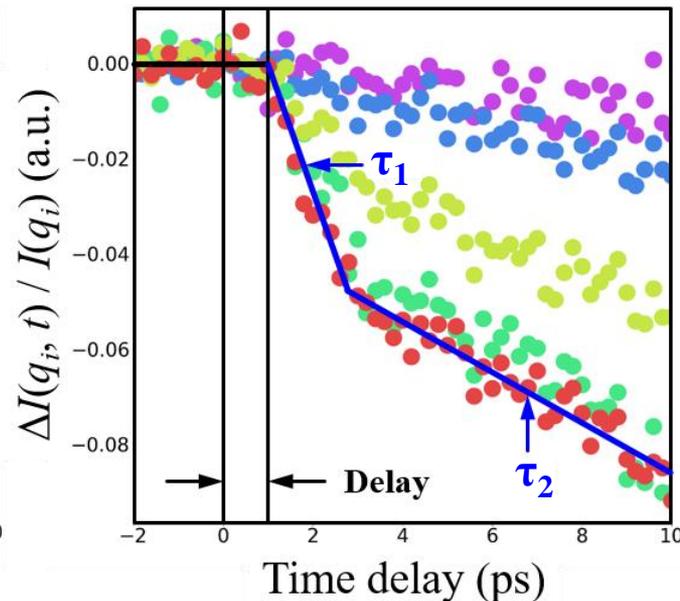
Br 0 mol% ($x = 0$)

Br 0.8 mol% ($x = 0.008$)
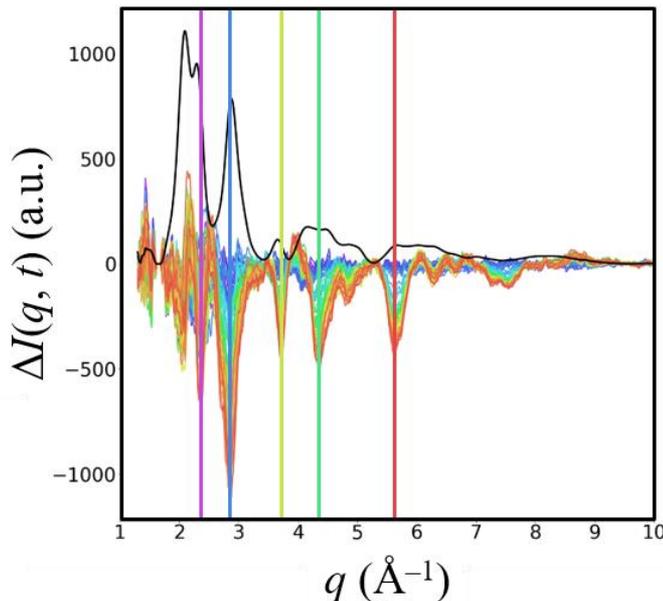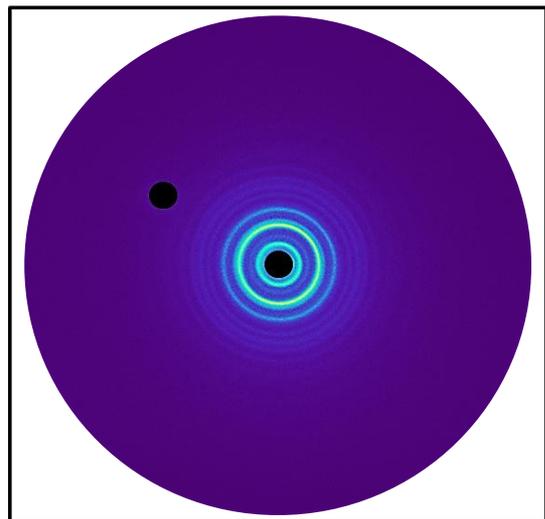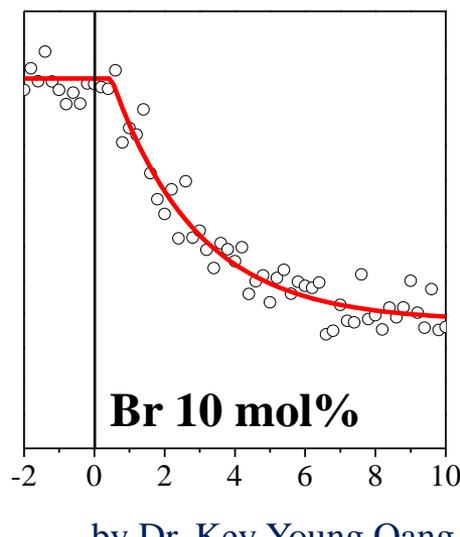

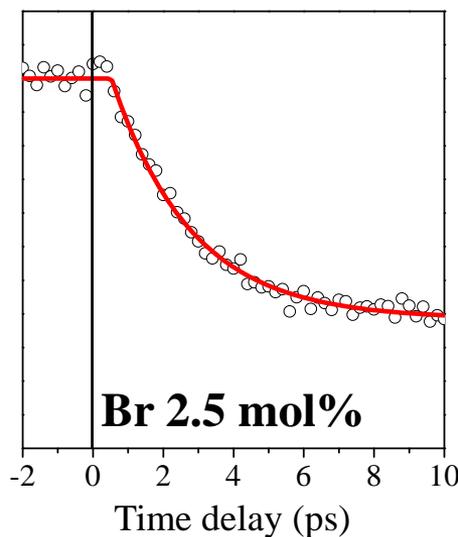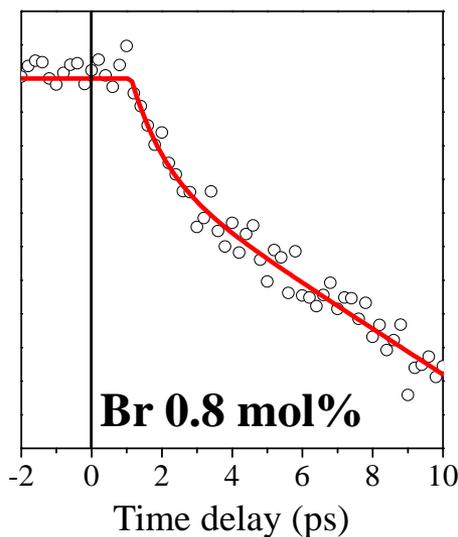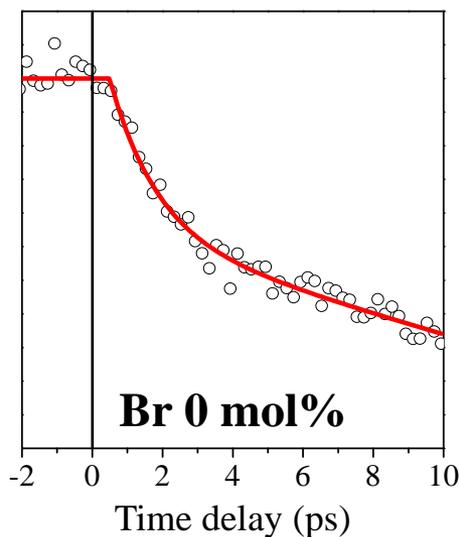❖ **$(FAPbI_3)_{1-x}(MAPbBr_3)_x$**; Best power conversion efficiency of **25.4% at $x = 0.8$ mol%**

by Dr. Key Young Oang

Solid phase: Perovskite thin films (ABX$_3$)

Br 0.8 mol%; 90 μJ/cm^2 @ 400 nm; –2 ps ~ +10 ps (200-fs step)

Results of the fit with the sum of two exponentials

Br 0 mol%

Br 0.8 mol%

Br 2.5 mol%

Br 10 mol%

by Dr. Key Young Oang

Gas phase: Sample feeding system

e-beam

Pump beam

Gas flow-cell (ϕ 0.5 mm)

Cavity (cell)
ID = 2 mm

Gas flow (continuous)
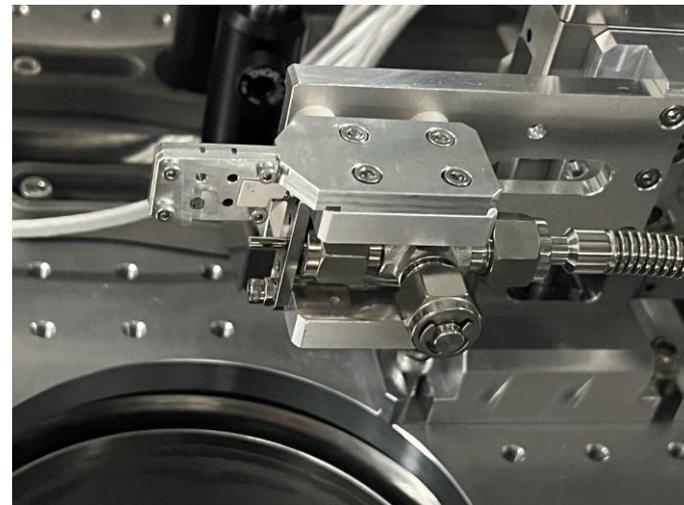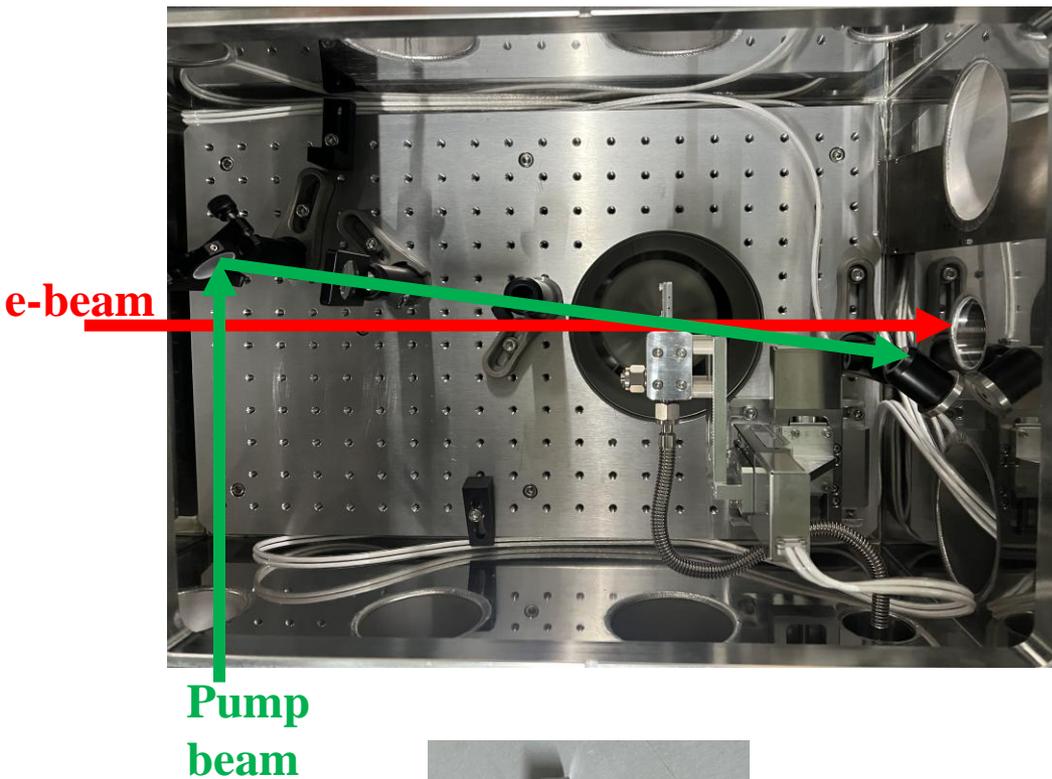
Inlet & outlet
ID = 0.5 mm
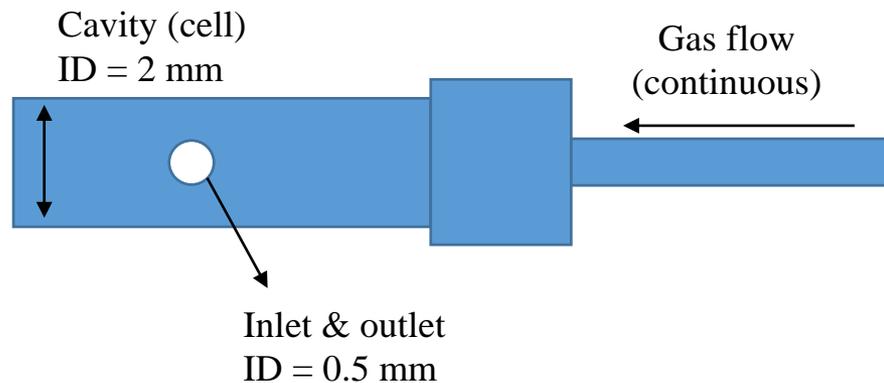
Gas flow cell design kindly provided by **Dr. Ming-Fu Lin.**

Gas phase: reference sample measurement

Reference sample: CHBr$_3$

J. Am. Chem. Soc. 2024, 146, 41, 28070–28079
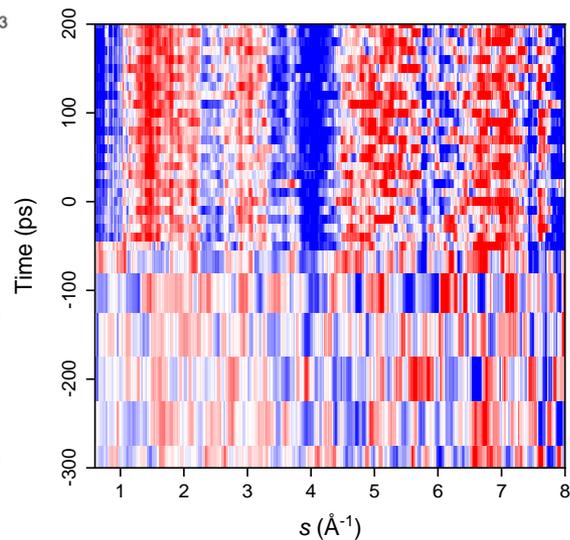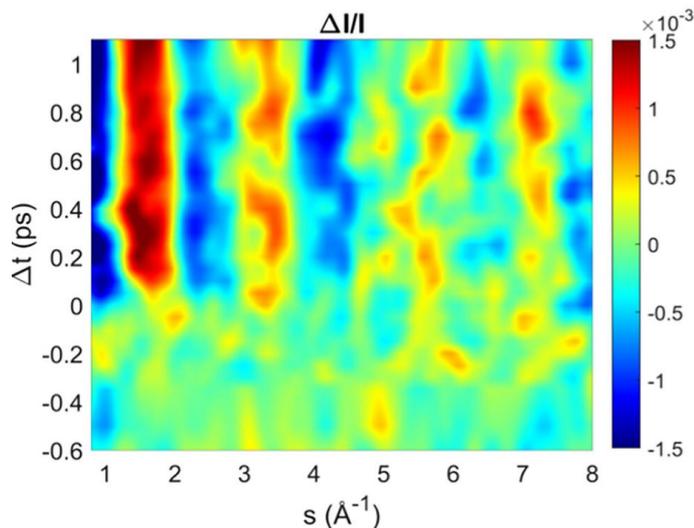
MeV-UED Specifications

Source Parameters

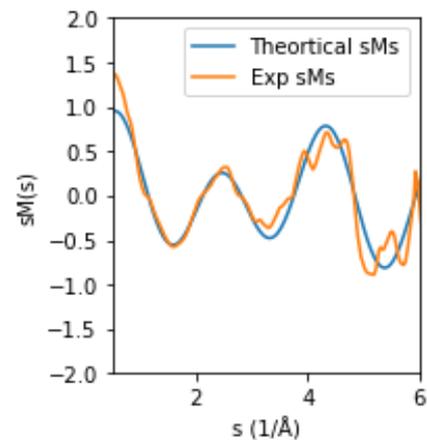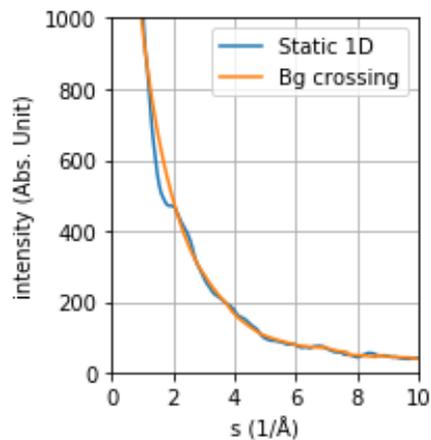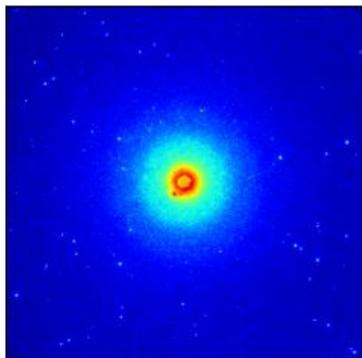| Parameter	Value
Electron beam energy	3.1 MeV
Repetition rate	100 Hz 200 Hz 250 Hz
Charge per pulse	100 fC (10^6 electrons)
Beam emittance	0.25 mm-mrad
Bunch length	< 80 fs FWHM
s range	> 0.5 Å^{-1}
Beam spot size (sample position)	200-300 um

Laser Properties

Parameter	Value
Wavelength range (pulse energy)	267 nm (< 300 uJ), 400 nm (< 1.2 mJ), 800nm (< 3 mJ), 0.1 ~ 3 THz (~ 100 kV/cm) 200 nm (under development)
Repetition rate	100 Hz 200 Hz 250 Hz
Nominal pulse duration	50 fs (FWHM, optical)
Optical delay	0~1.33 ns (physical delay stage)
Beam spot size (sample position)	>130 um

Welcoming new research proposals!

Acknowledgements

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ibS CARD — Center for Advanced Reaction Dynamics

Collaborators
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UNIST

Collaborators
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Prof. Hyeong-Ryeol Park

KRICT

Collaborators
Dr. Nam Joong Jeon   Dr. Bong Joo Kang

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Collaborators
Prof. Loh Zhi Heng

SLAC NATIONAL ACCELERATOR LABORATORY

Special thanks
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Thank you for your attention.