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Characterization of Electron Bunches in Ultrafast Electron Diffraction Beamlines at KAERI

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Contents

Application of Time-resolved Electron and X-ray Diffraction

Gas, surface, thin film (Disordered media)

Electron	→	Coulomb scattering	→	High scattering power	→	Short penetration depth

Mutually complementary tools

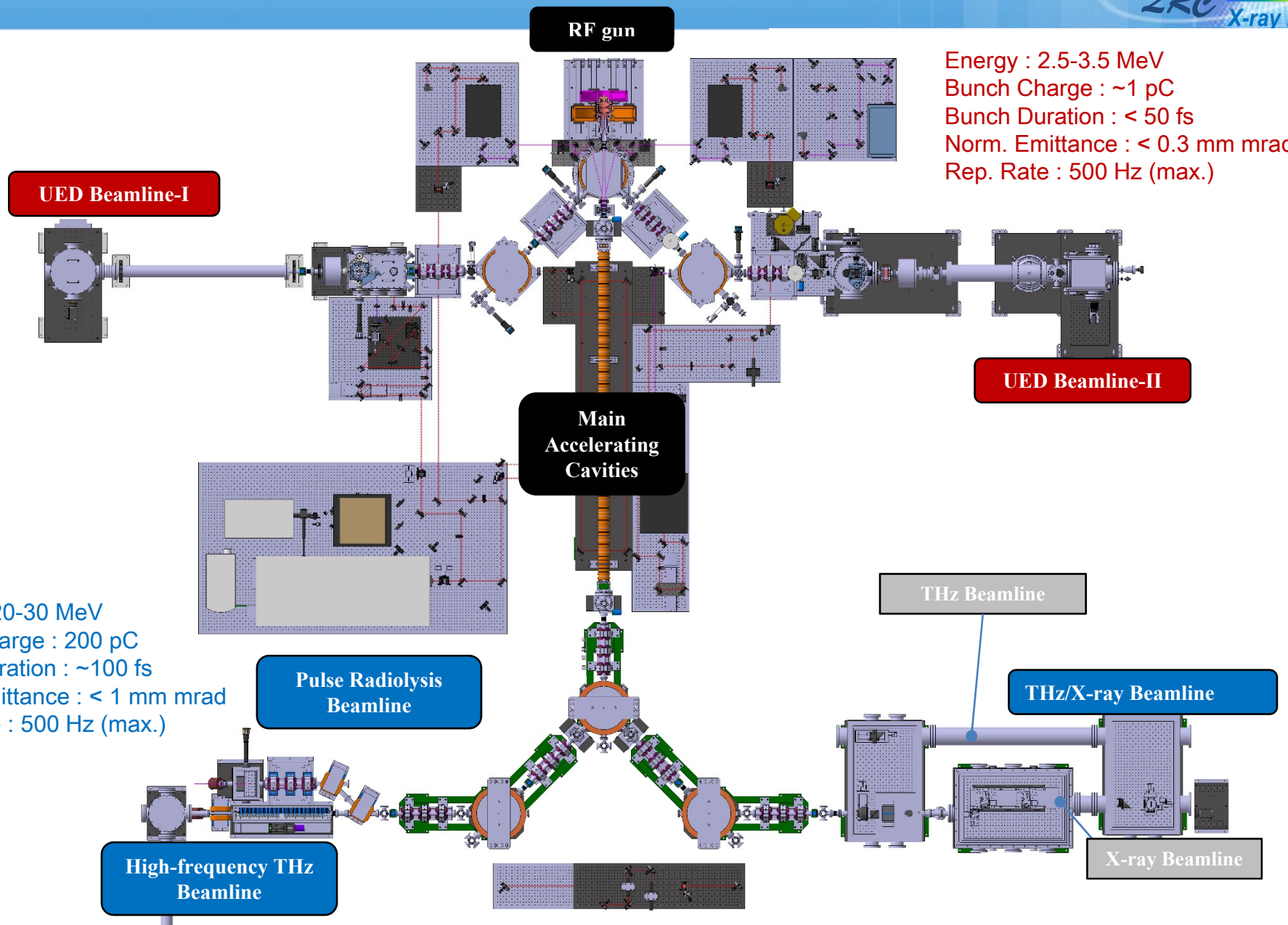
X-ray	→	Thomson scattering	→	Low scattering power	→	Long penetration depth

Solution, crystal (Ordered media)

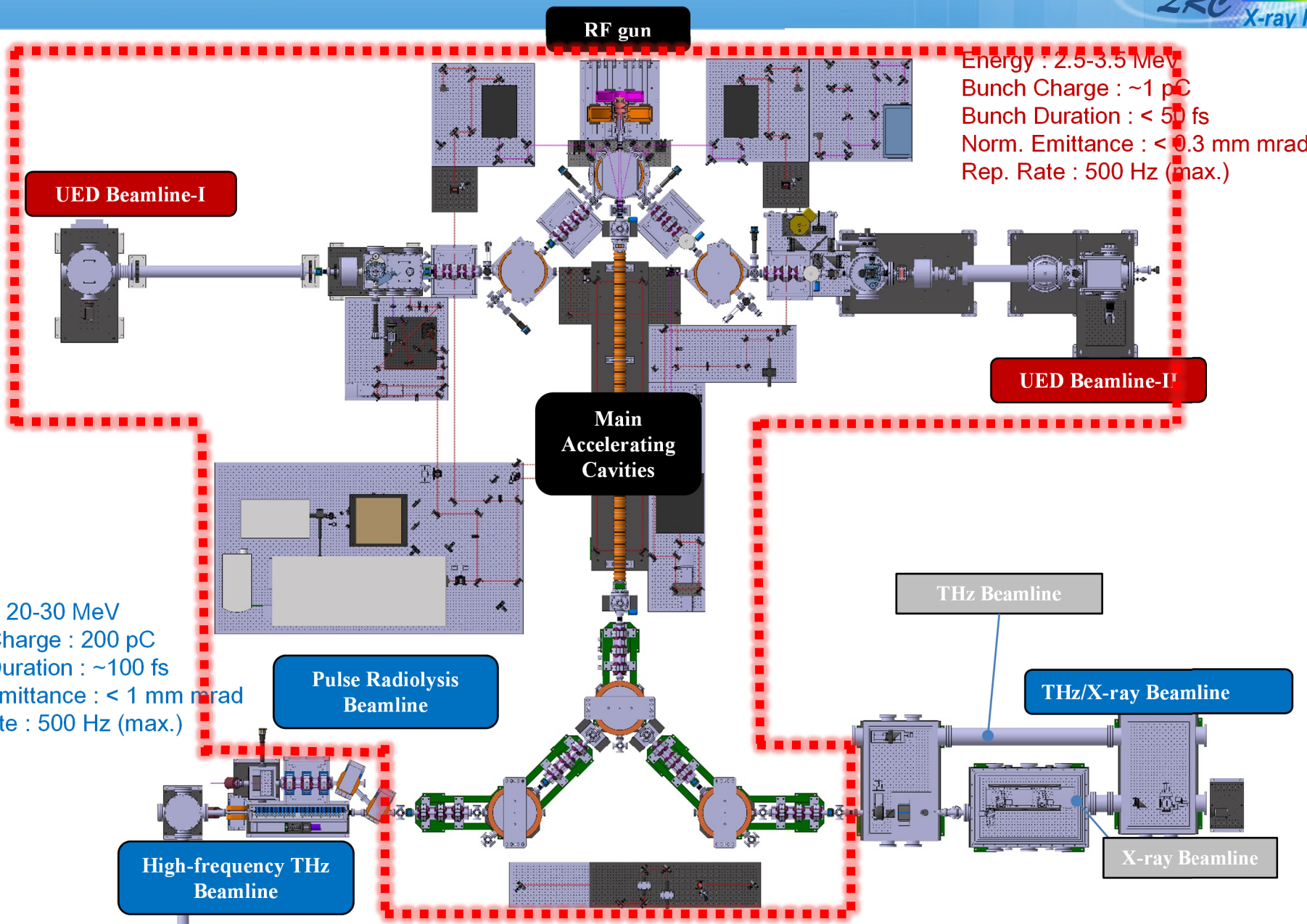
X-FEL vs. UED

	X-FEL	UED
Source	X-ray	Electron
Wavelength	10-0.1 nm	0.1-0.001 nm
Interaction with	Electrons	Nuclei & Electrons
Scattering Power	Low	High
Penetration Depth	High	Low
Minimum Photon/Particle Numbers for Single-shot Measurement	10^{12} photons	10^{6} electrons
Facility Size	Huge (~ km)	Compact (~ m)
Coherence Length	A few mm	A few nm

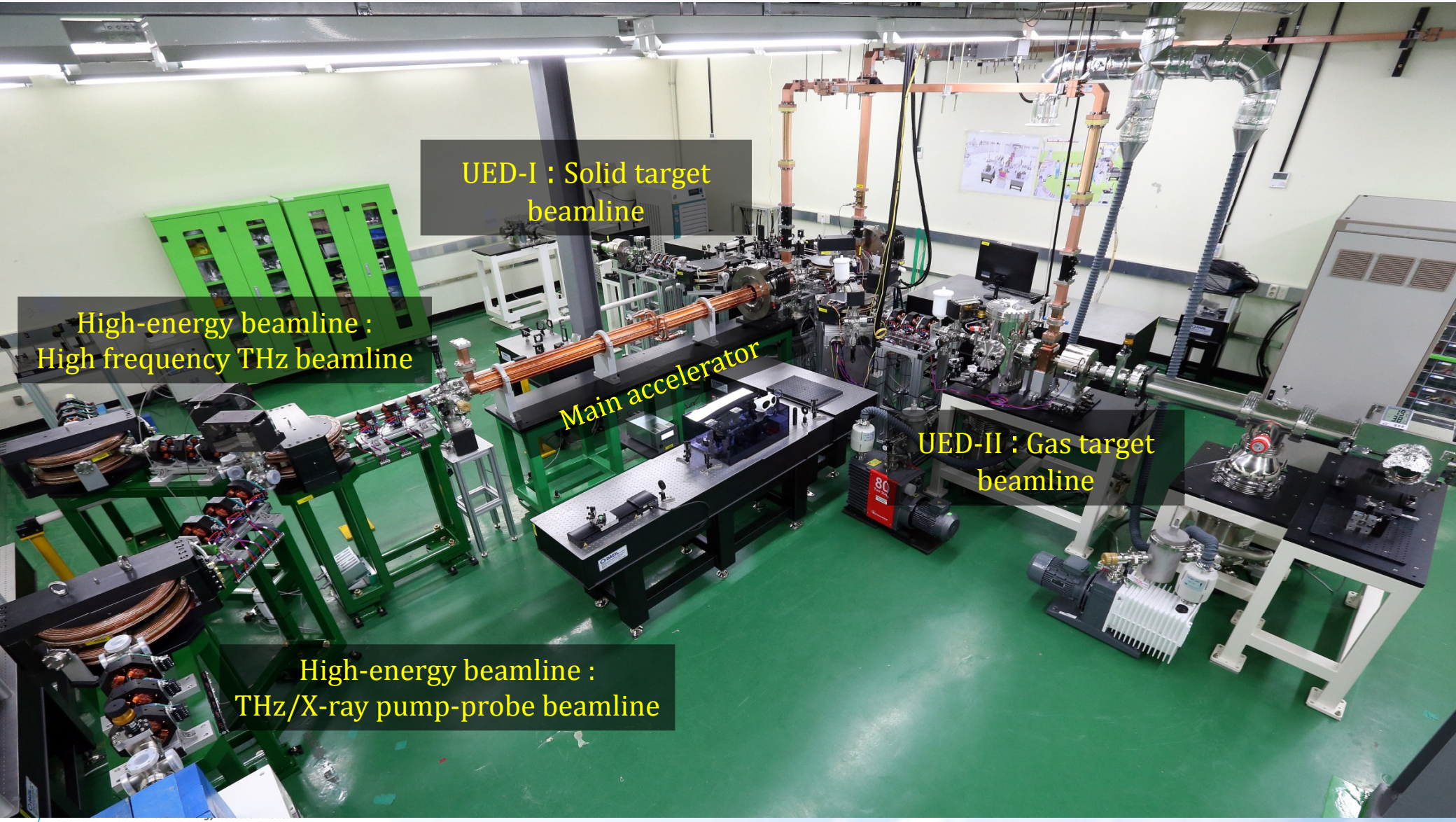
Accelerator Facility Overview



Accelerator Facility Overview



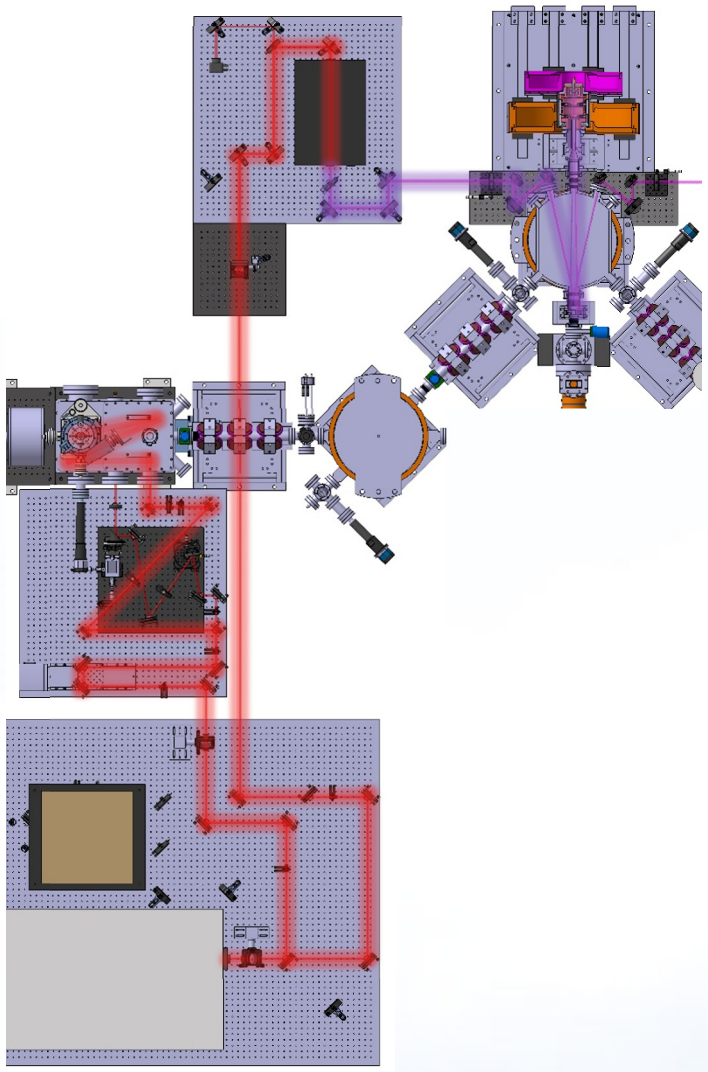
Current Beamline



Target Beam Parameters of UED Beamlines

Beam parameters	Target	Simulation	Units
Laser spot size@cathode (FWHM)	< 1	0.5	mm
Laser pulse length@cathode (FWHM)	< 200	130	fs
Bunch charge	> 0.16	1	pC
Beam kinetic energy	~3	3	MeV
Energy spread (rms)	< 0.3	0.17	%
Normalized emittance	< 0.3	0.29	mm mrad
Bunch length (rms)	< 50	32	fs
Timing jitter	< 50	13	fs

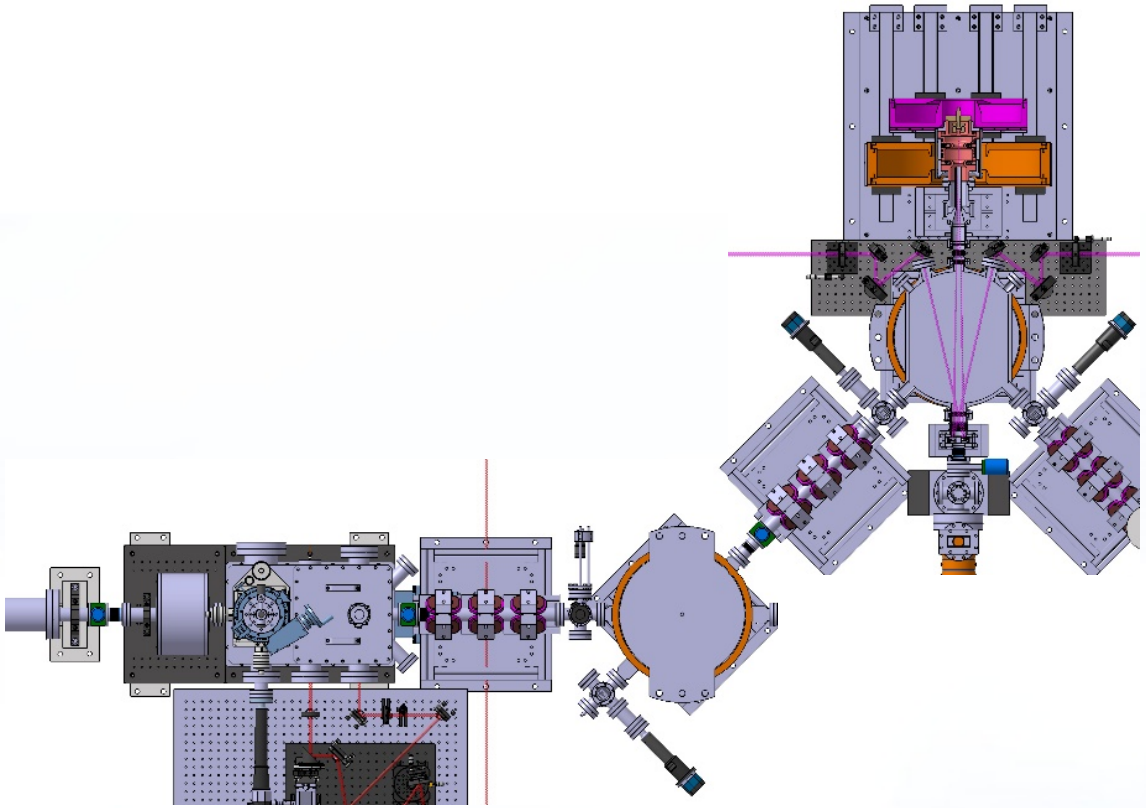
90-degree Bending Structure



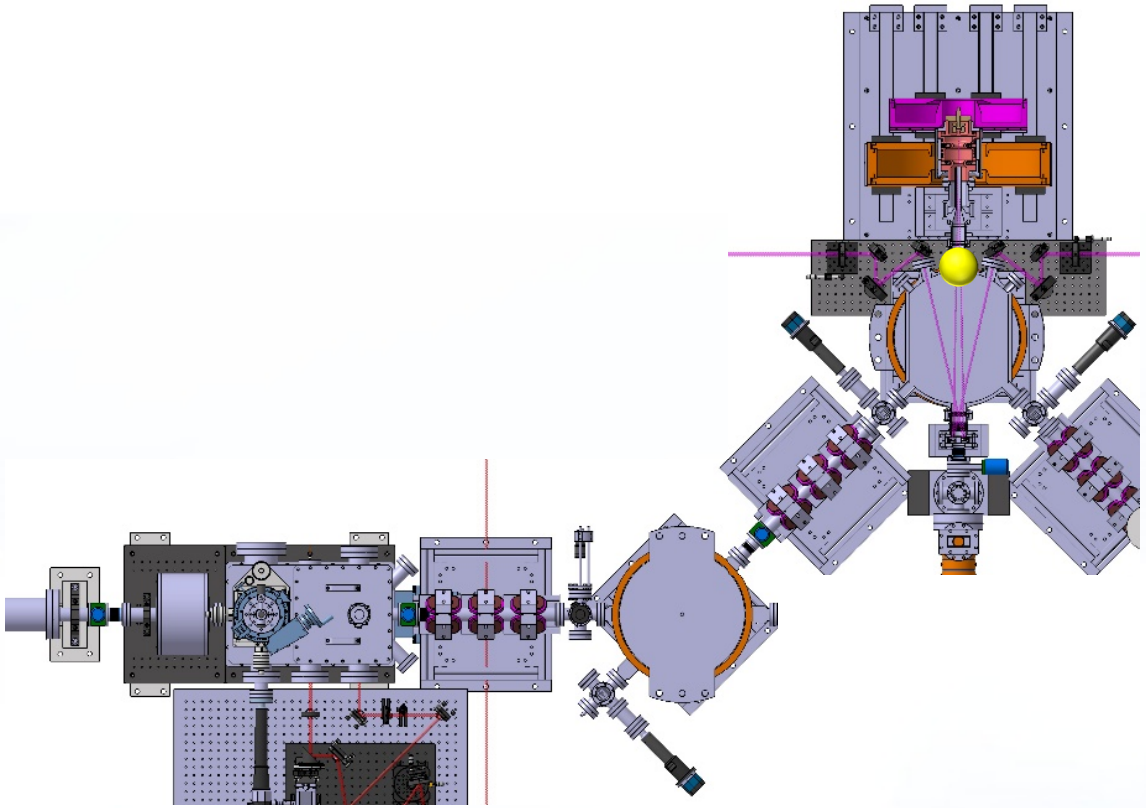
Beam parameters	Target	Units
Number of electrons	> 1.0×10^6	electrons
Normalized emittance	< 0.3	mm mrad
Bunch length (rms)	< 50	fs
Timing jitter (rms)	< 50	fs

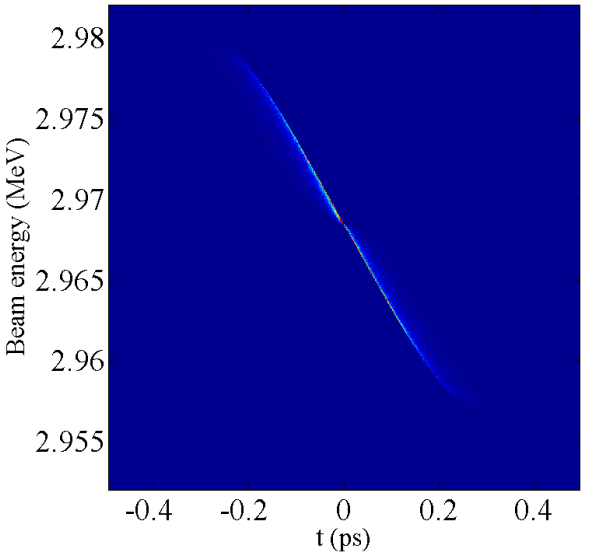
- Single shot measurement
- High temporal-spatial resolution

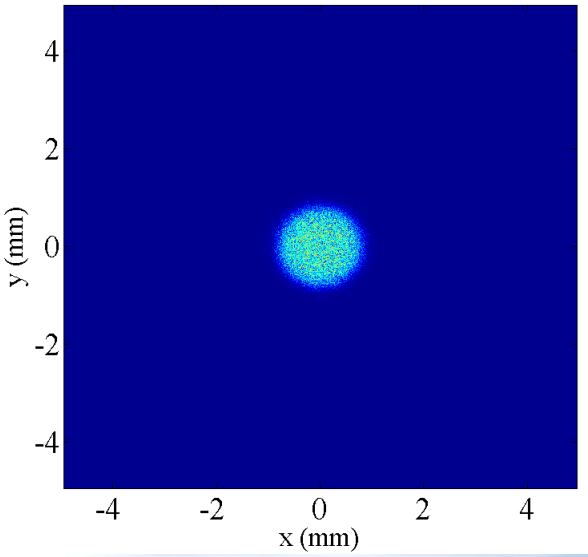
90-degree Bending Structure



90-degree Bending Structure







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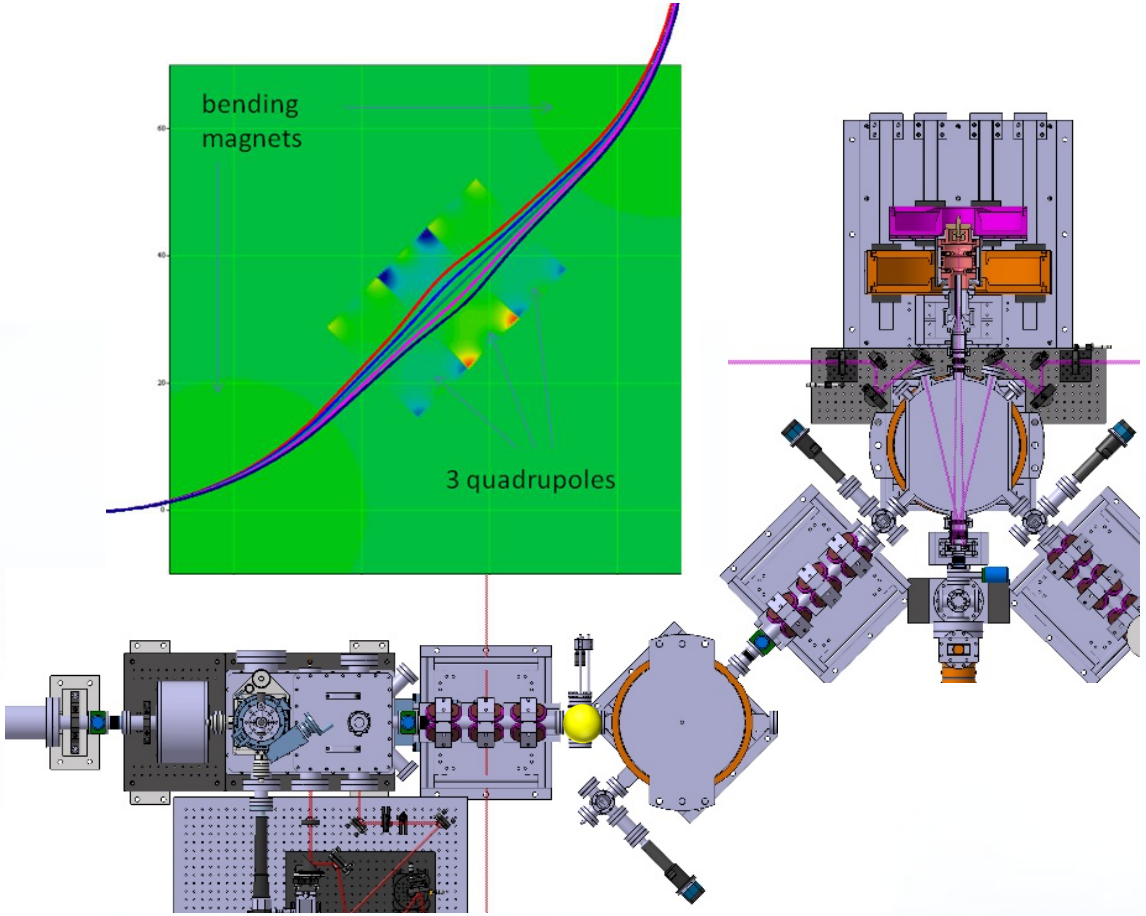
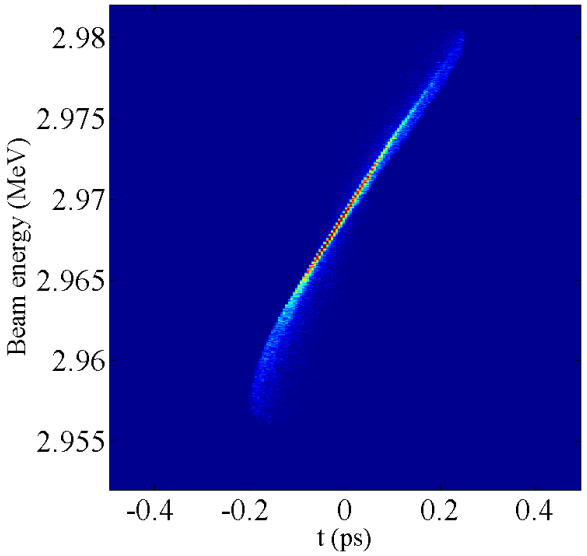
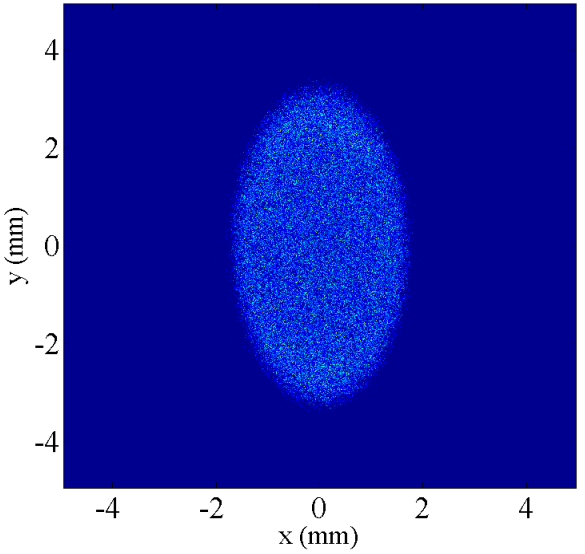
90-degree Bending Structure







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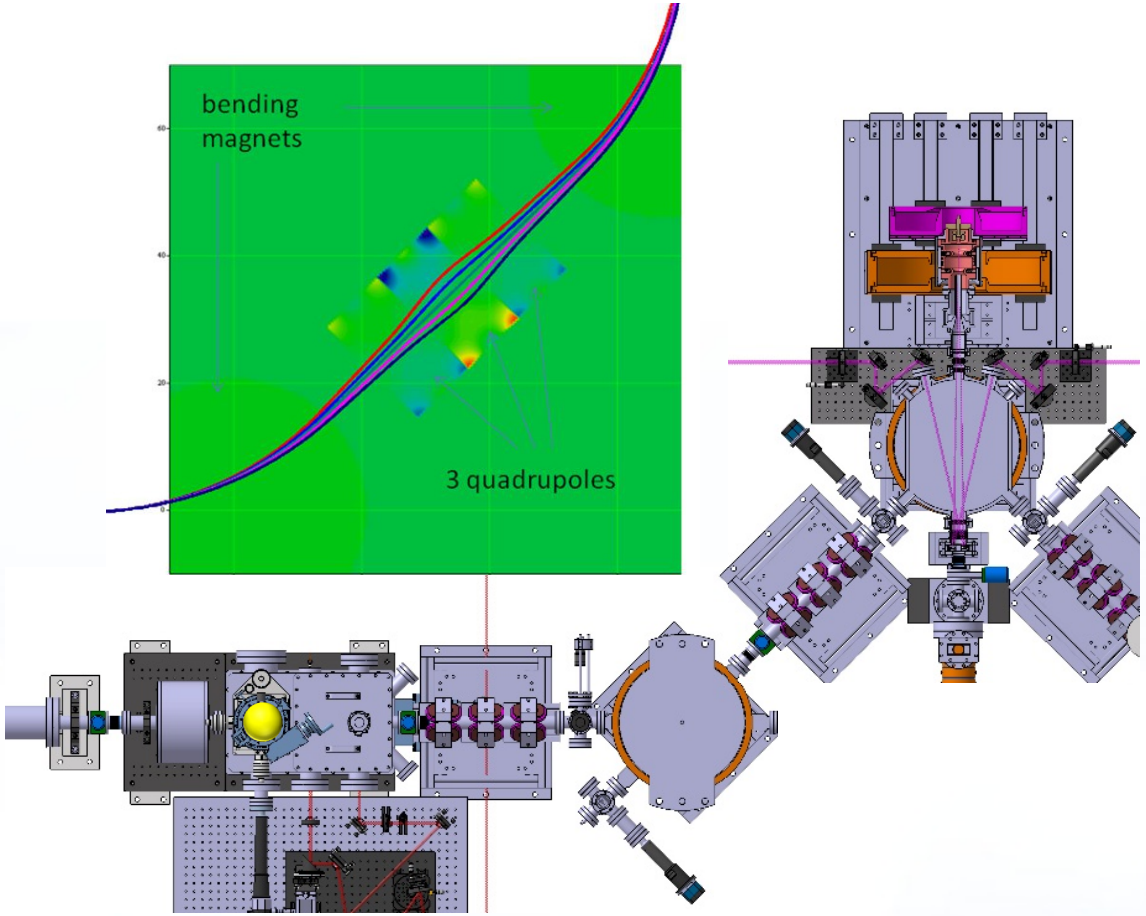
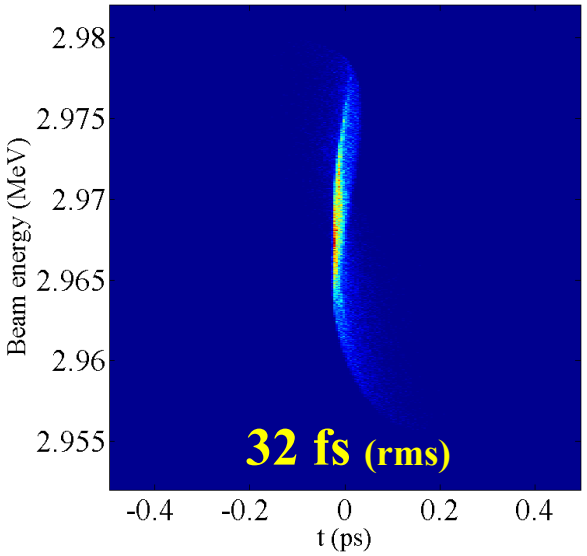
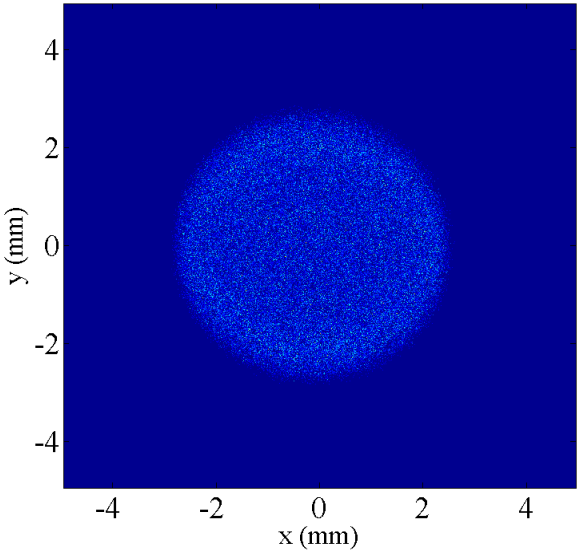
90-degree Bending Structure







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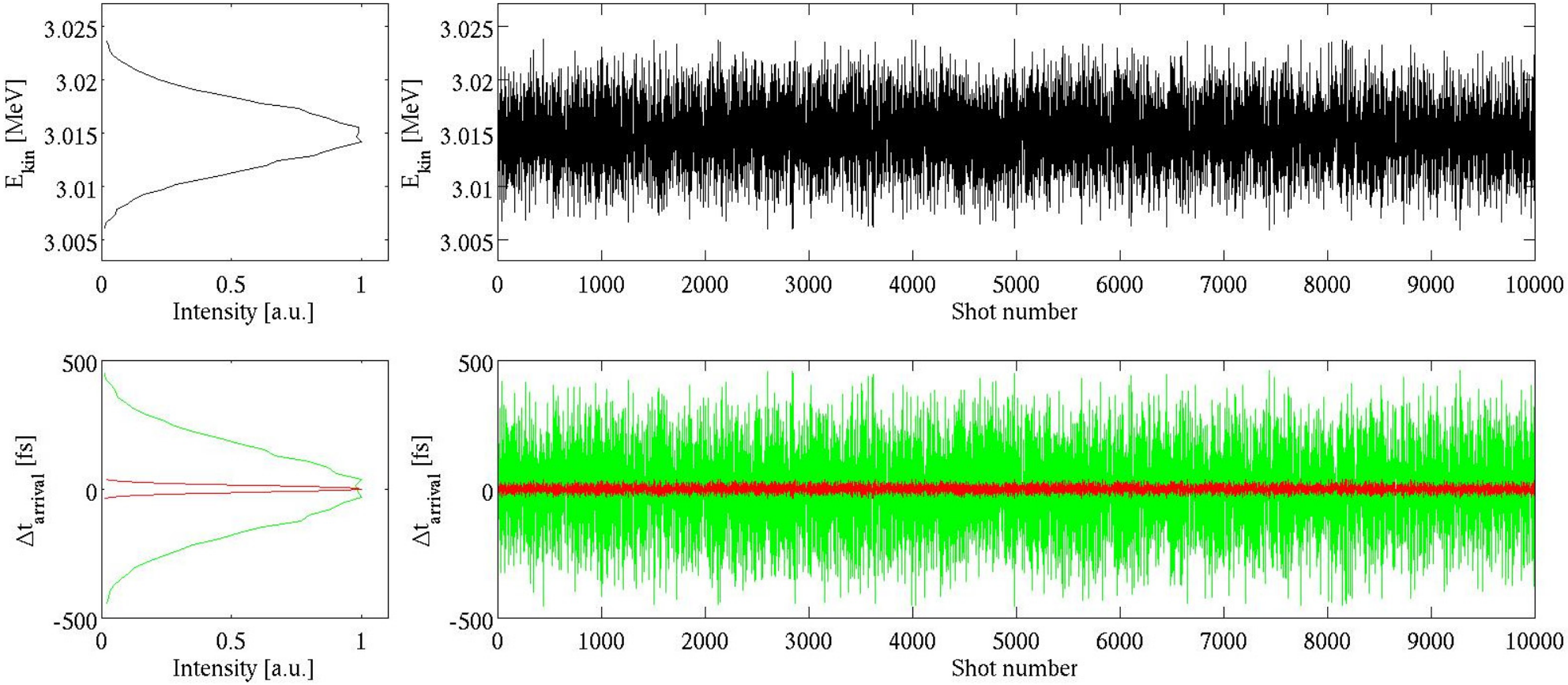
Main Factor of Timing Fluctuation

1. Timing Fluctuation by RF gun Temperature
   - Injection Phase Fluctuation
   - Electron Energy Fluctuation

2. RF Amplitude Fluctuation : $< 10^{-4}$

3. Timing Fluctuation between Laser Pulses and RF Phase
   - RF Master Oscillator v.s Laser Oscillator : 10 fs
   - RF Master Oscillator v.s Klystron : 20 fs
   - RF Travelling from Klystron to Photogun
   - Laser Travelling from Regen. Amplifier to Photogun

Timing Stability of Electron Beam



Δt_{jitter} (rms)

3 m with 90-degree bend = 13 fs **3 m straight line = 152 fs**

RF Phase and Amplitude Change by Temperature

Phase fluctuation due to cavity temperature change.

$\Delta\varphi \cong 2\alpha Q_L \Delta T$

α : linear thermal expansion coefficient, $16.668\text{x}10^{-6}$

Q_L : Loaded quality factor, 7398

ΔT : Temperature change

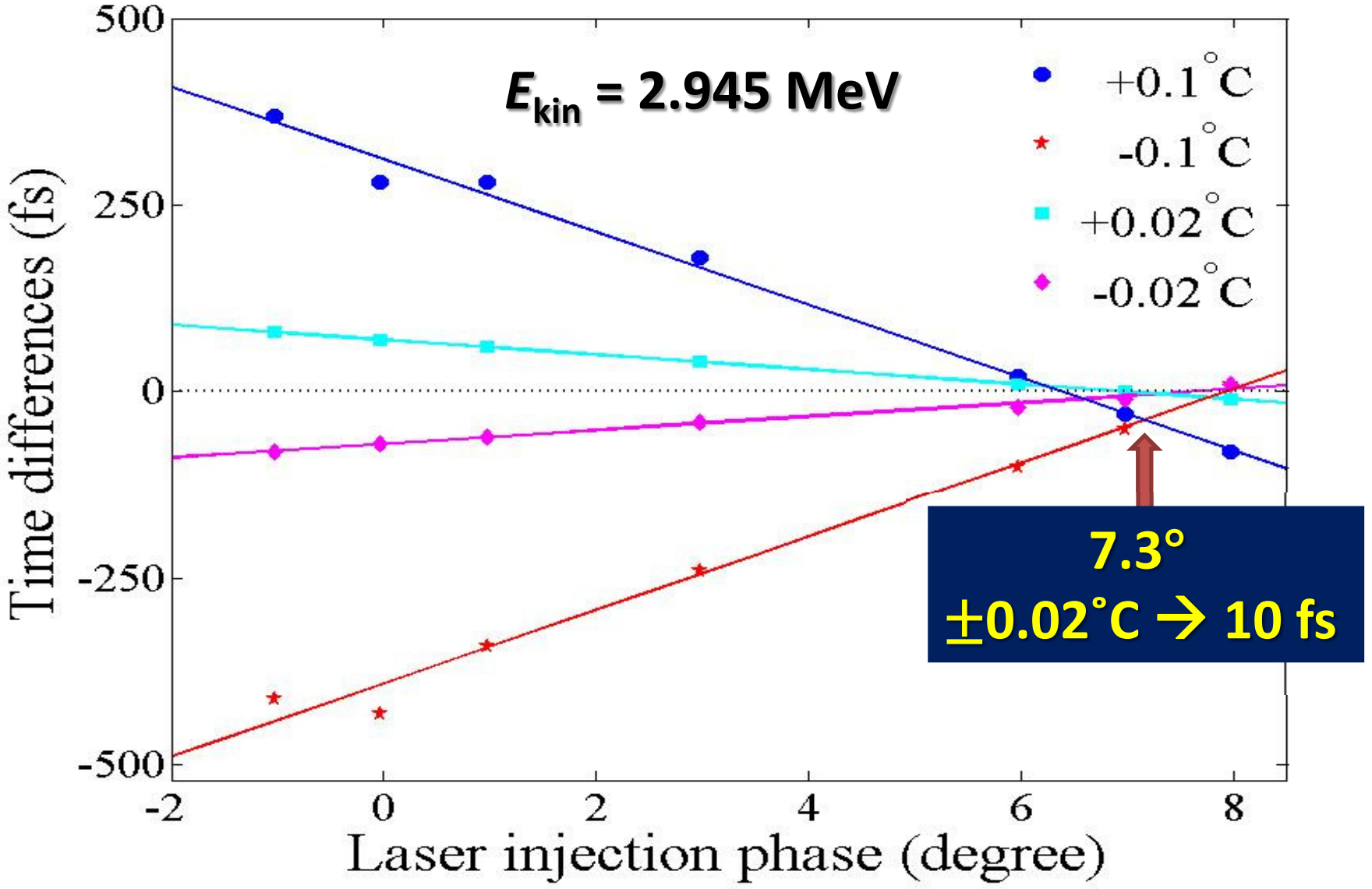
If $\Delta T = \pm 0.02°\text{C}, \Delta\varphi \sim \pm 0.28^{\circ}$

Voltage fluctuation due to cavity temperature change.

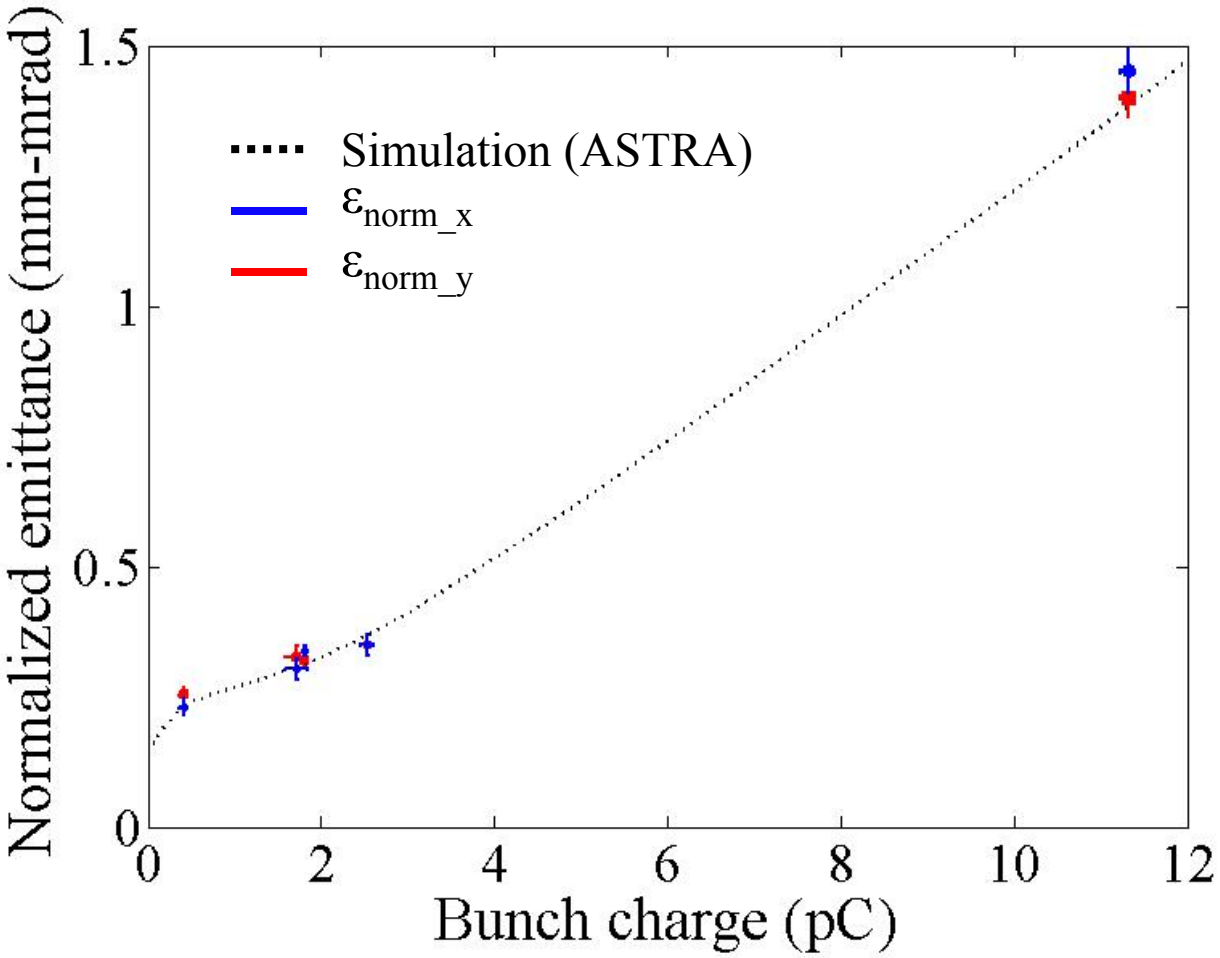
$$\frac{\Delta V}{V} \cong \frac{(\Delta\varphi)^2}{2}$$

If $\Delta T = \pm 0.02°\text{C}, \frac{\Delta \text{V}}{\text{V}} \sim \pm 1.2 \times 10^{-5}$

Timing Fluctuation by RF gun Temperature



Emittance Measurement



Parameters	
Laser spot size @cathode	200 μm FWHM
Bunch charge	0.4 – 11.3 pC
Beam energy	3 MeV
ε_{norm_x}	0.23 – 1.45 mm-mrad
ε_{norm_y}	0.25 - 1.40 mm-mrad

Main Factor of Timing Fluctuation

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   - Injection Phase Fluctuation
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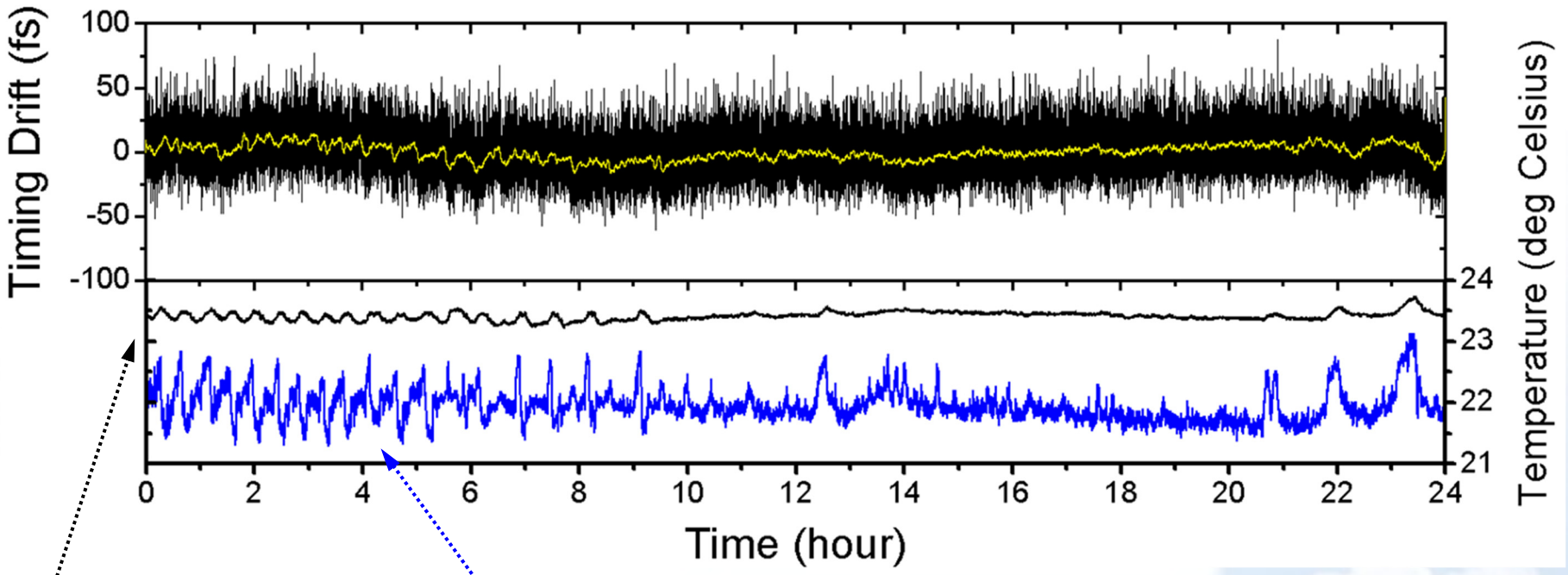
   - RF Master Oscillator v.s Laser Oscillator : 10 fs
   - RF Master Oscillator v.s Klystron : 20 fs
   - RF Travelling from Klystron to Photogun
   - Laser Travelling from Regen. Amplifier to Photogun

RF-laser Timing Synchronization

12.5 fs rms stability maintained over 24 hours



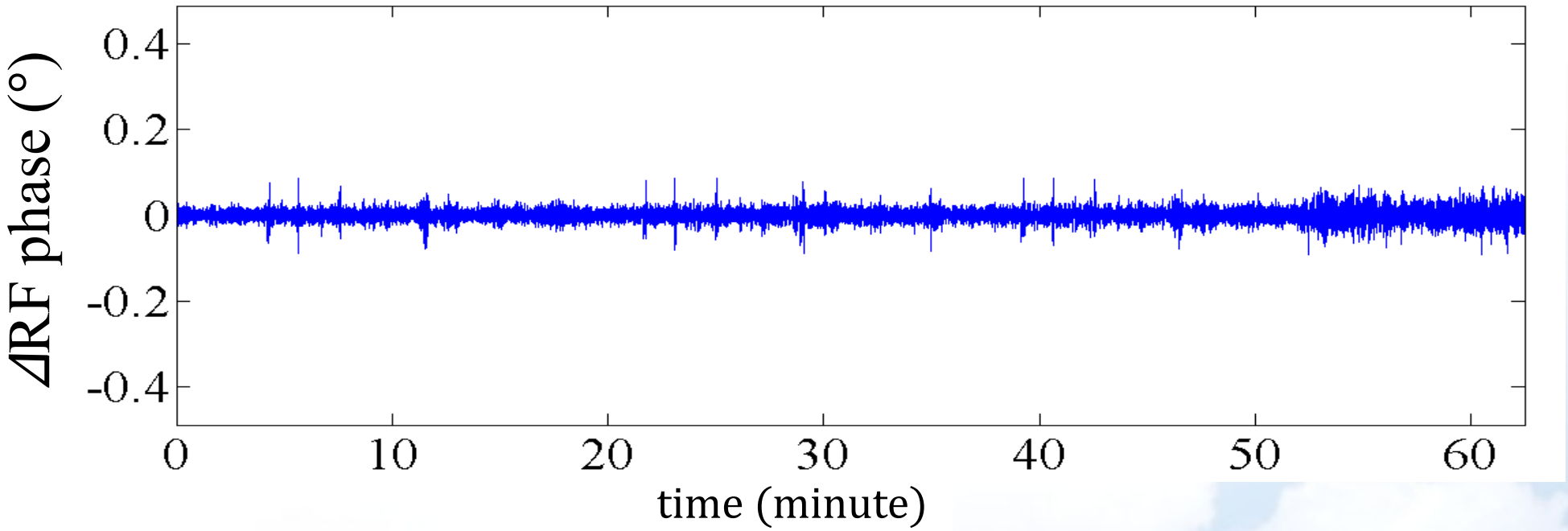
FLOM-PD box temperature (water-cooling)

Laboratory temperature

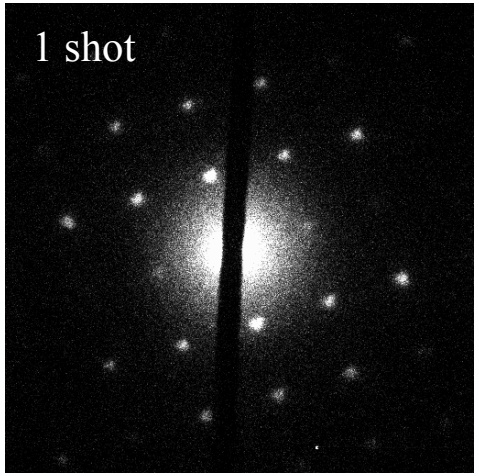
H. Yang et al, "10-fs-level synchronization of photocathode laser with RF-oscillator for ultrafast electron and X-ray sources," Sci. Rep. 7, 39966 (2017)

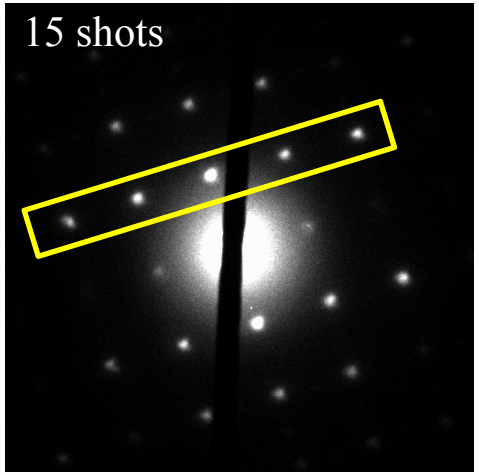
Phase Fluctuation of the RF gun

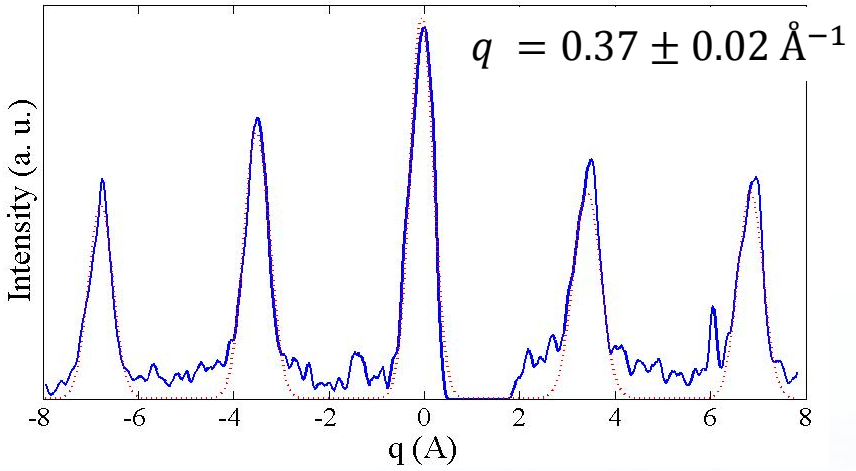
RF phase fluctuation 0.017 deg (16.8 fs) rms

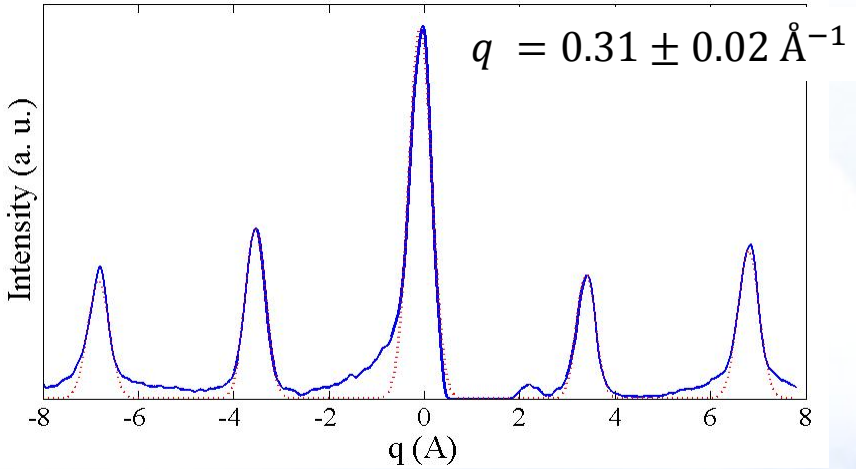


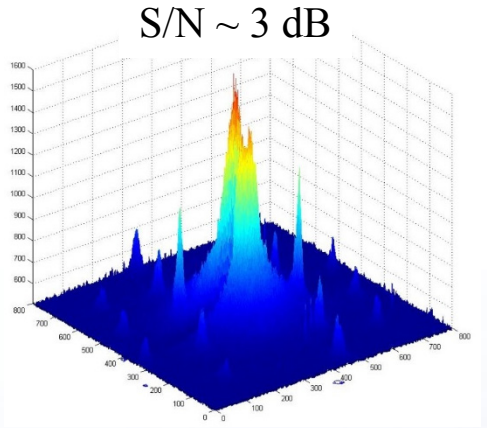
Electron Diffraction Image of Single-crystal Si

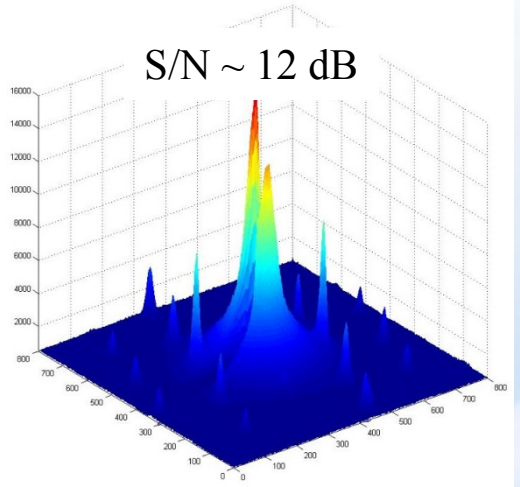












Silicon thin film

- Single-crystalline
- Film thickness of 200 nm

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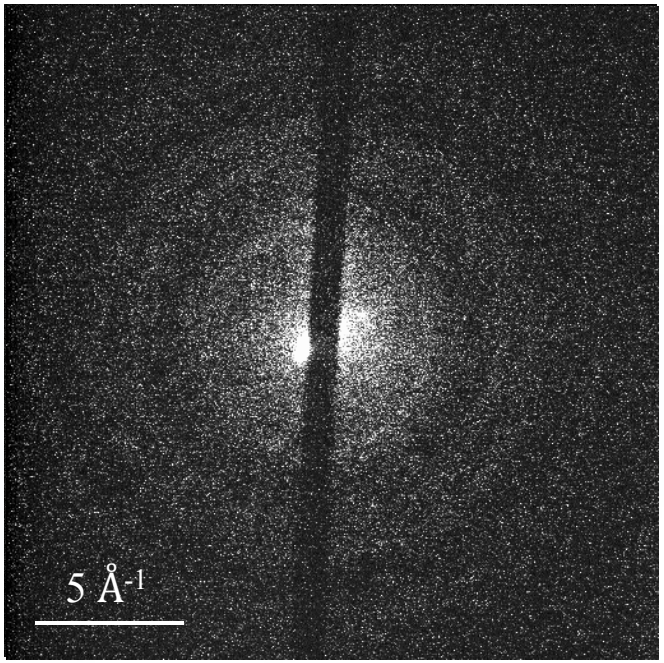
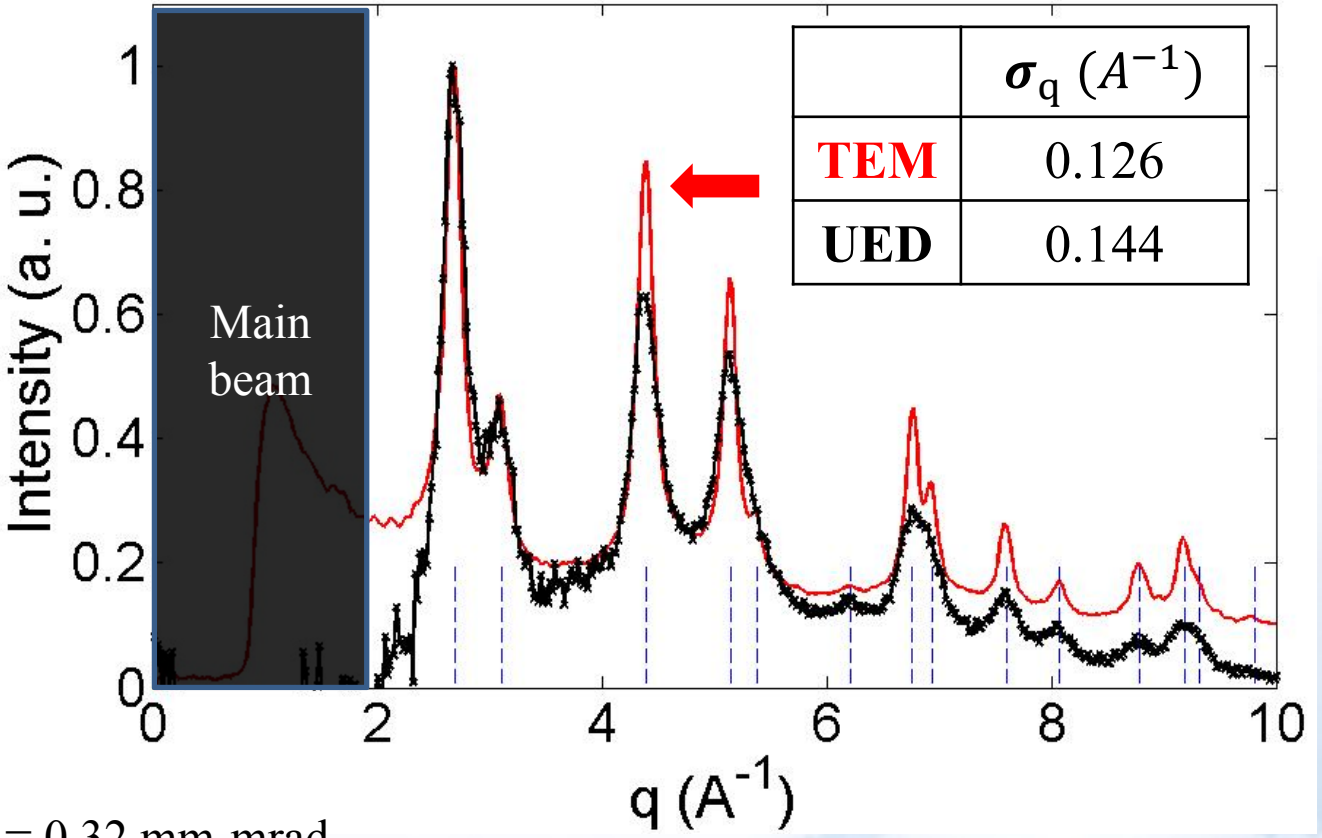
Electron Diffraction Image of Poly-crystal Au





	σ_q (A^{-1})
TEM	0.126
UED	0.144

- Beam parameters

  Q = 1.8 pC, E_k = 2.75 MeV, ε_n = 0.32 mm-mrad

Gold thin film

- Poly-crystalline
- Film thickness of 50 nm

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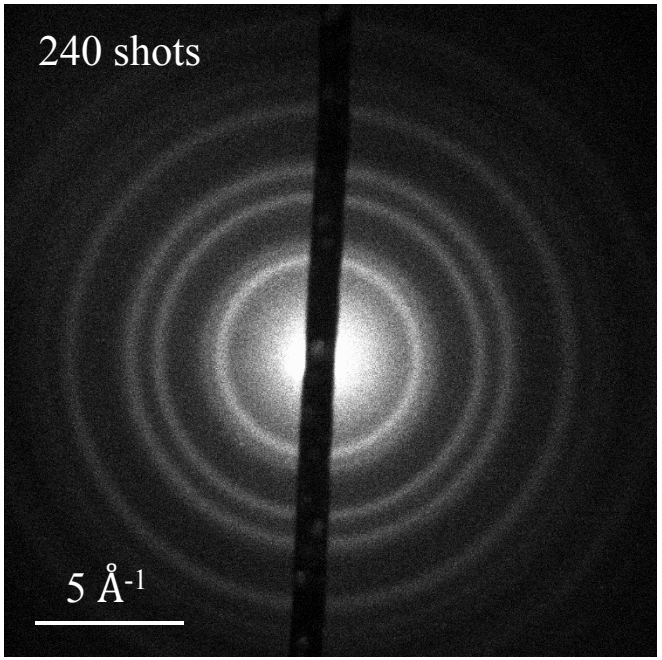
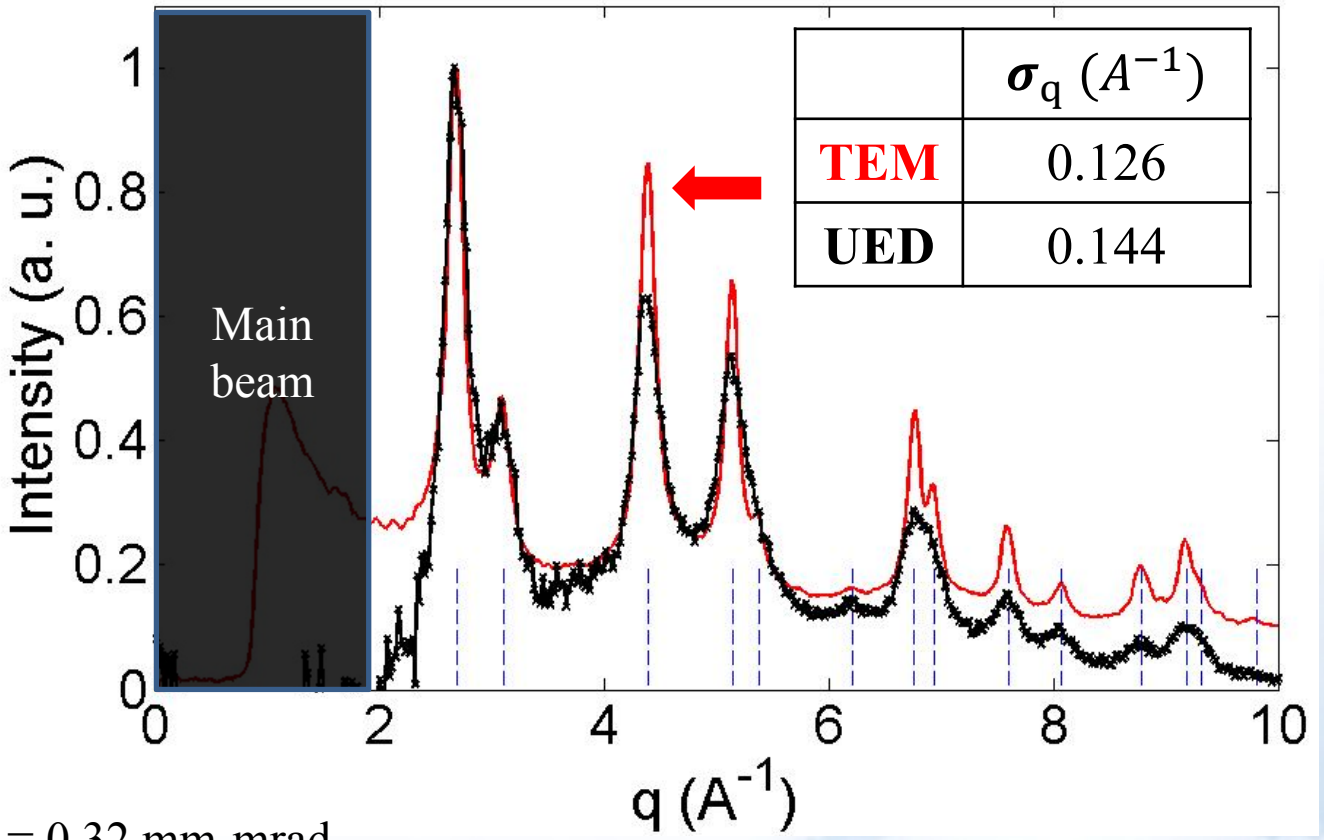
Electron Diffraction Image of Poly-crystal Au





	σ_q (A^{-1})
TEM	0.126
UED	0.144

- Beam parameters

  Q = 1.8 pC, E_k = 2.75 MeV, ε_n = 0.32 mm-mrad

Gold thin film

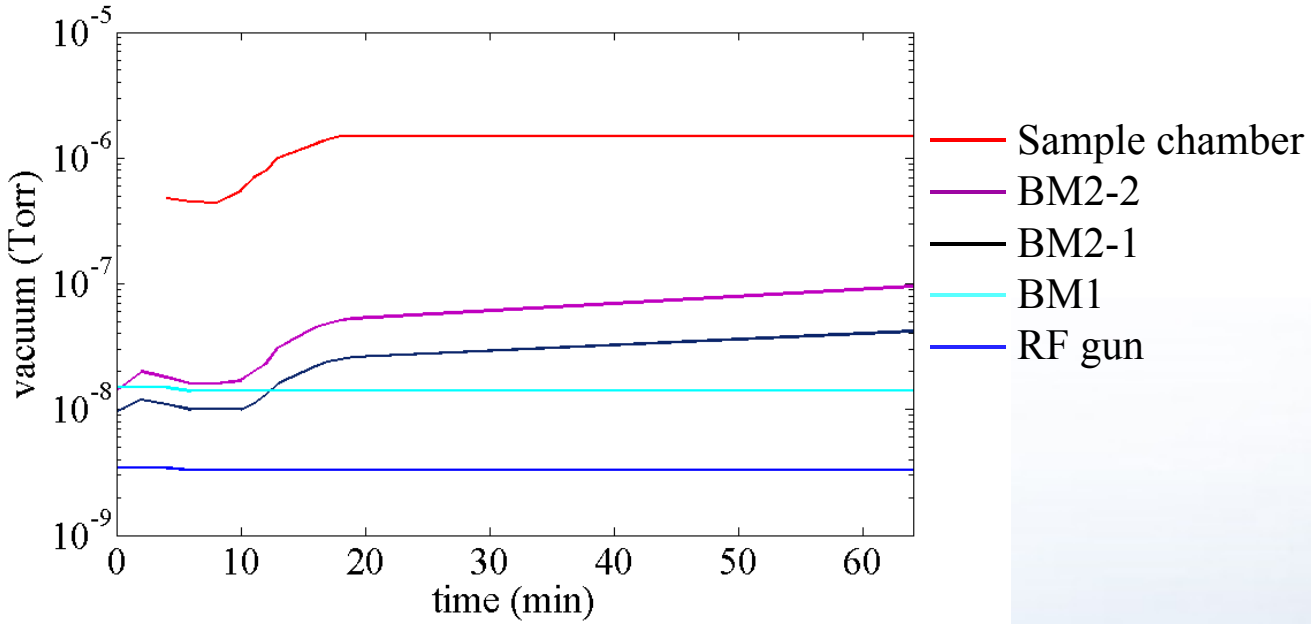
- ❖ Poly-crystalline
- ❖ Film thickness of 50 nm

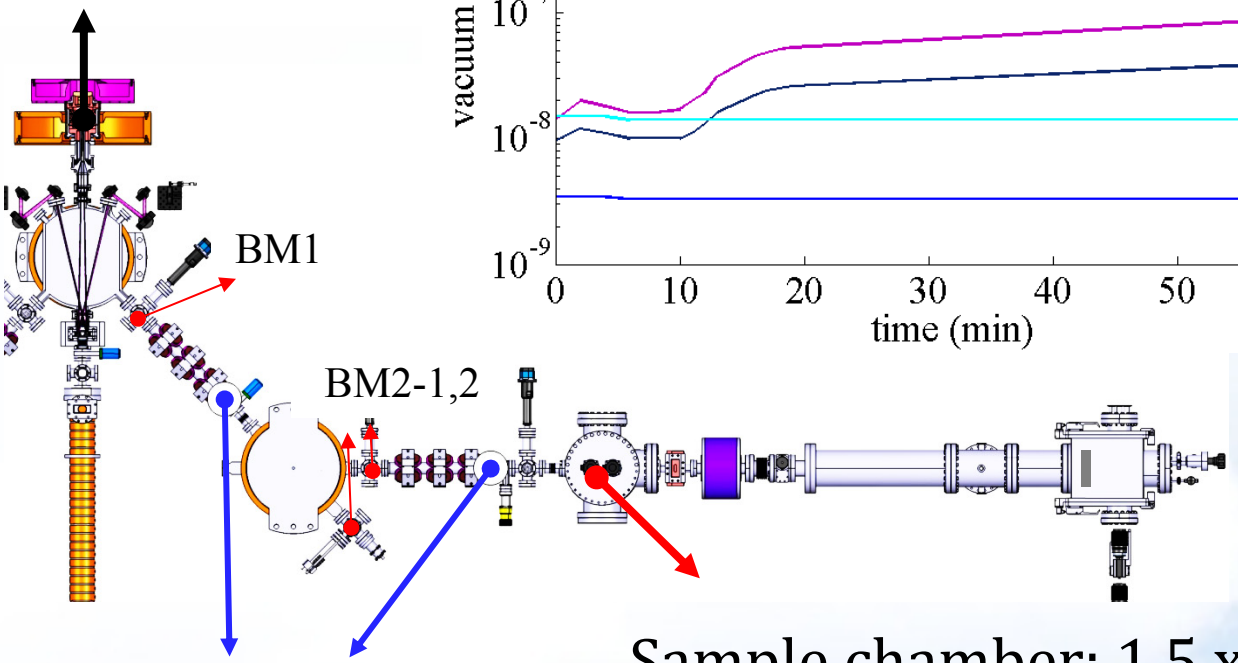
Beam Parameters

Beam parameters	Simulation	Measurement	Units
Laser spot size@cathode (FWHM)	0.5	0.2-0.5	mm
Laser pulse length@cathode (FWHM)	130	130	fs
Bunch charge	1	0.4-2.5	pC
Beam kinetic energy	3	2.8-3	MeV
Energy spread (rms)	0.17	~ 0.23	%
Normalized emittance	0.29	0.23-0.34	mm mrad
Bunch length (rms)	32	-	fs
Timing jitter	13	-	fs

Differential Pumping for Gas Sample

RF gun : 3.3 x 10^{-9} Torr





Sample chamber: 1.5 x 10^{-6} Torr

Pipe for differential pumping

- R = 5 mm
- L = 50 cm
- Liquid nitrogen cold trap

Summary

- 90-degree bending structure is expected to reduce bunch length and timing jitter.
- Measured beam parameters are in good agreement with simulation.

- Bunch length measurement : transverse deflecting cavity or Michelson interferometer using CTR generated by electron beam.
- Timing jitter measurement : transverse deflecting cavity spectral decoding or laser-induced ponderomotive deflecting .
- Bismuth samples are being prepared to measure temporal resolution.

TUP046 - Ultrafast Electron Diffraction Facility Based on an RF Photogun and Achromatic 90-degree Bends for Sub-100-Femtosecond Timing Jitter
TUP047 - A Linac-Based All-in-One THz-Pump and X-Ray-Probe Sources
WEP013 - Photocathode RF Gun Development at KAERI for Time-Resolving Pump / Probe System
WEP035 - Measurements of Electron Bunch Timing Jitter Using Spectral Decoding Technique for Ultrafast Electron Diffraction Experiments
WEP059 – Development of T-Ray-Pumped Ultrafast Electron Diffraction Beamline

Thank you for your kind attention.