FELBE & TELBE

The High Power Coherent THz/IR Sources at ELBE

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THz@PITZ Workshop
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HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF
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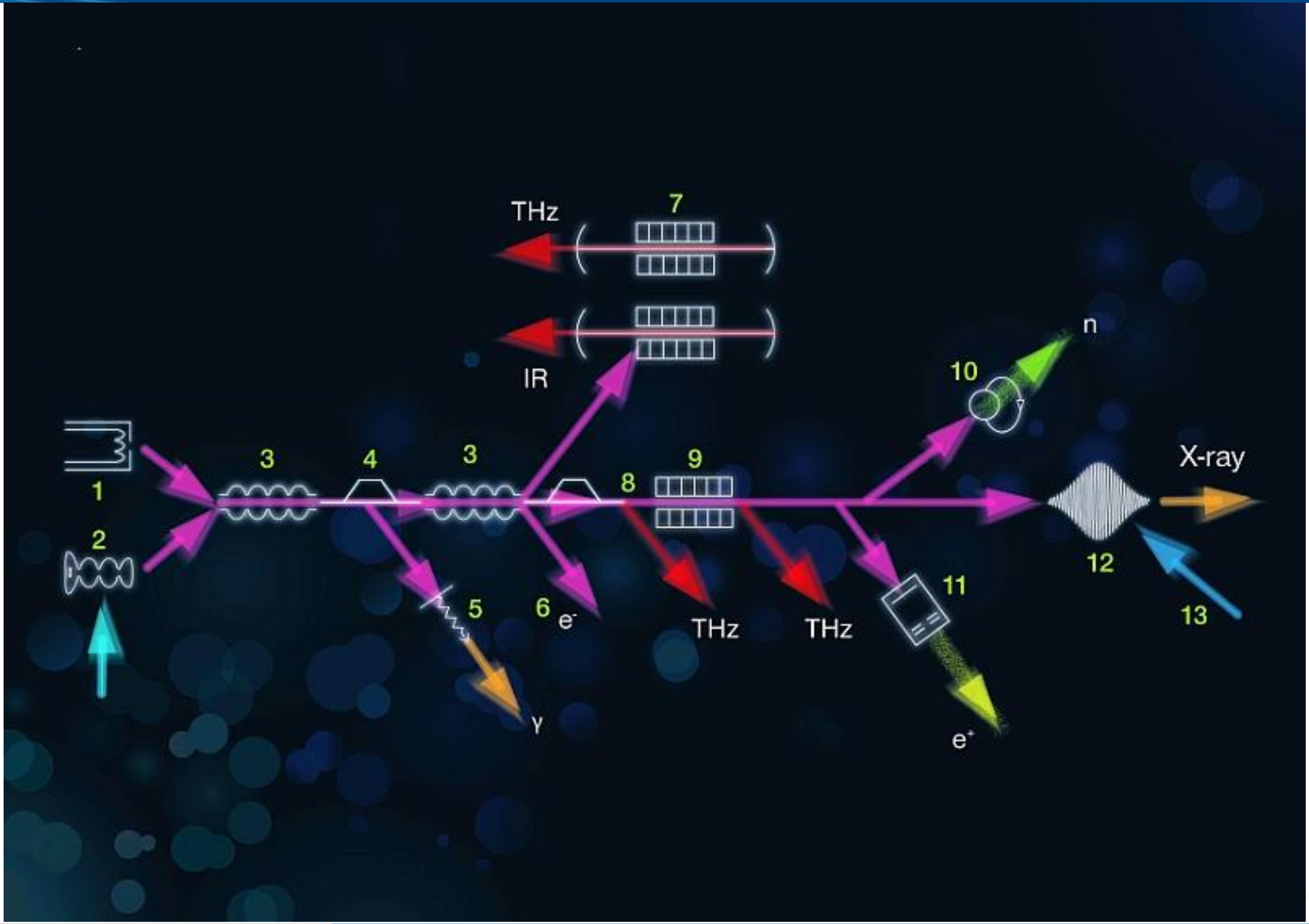
ELBE Center for High Power Radiation Sources



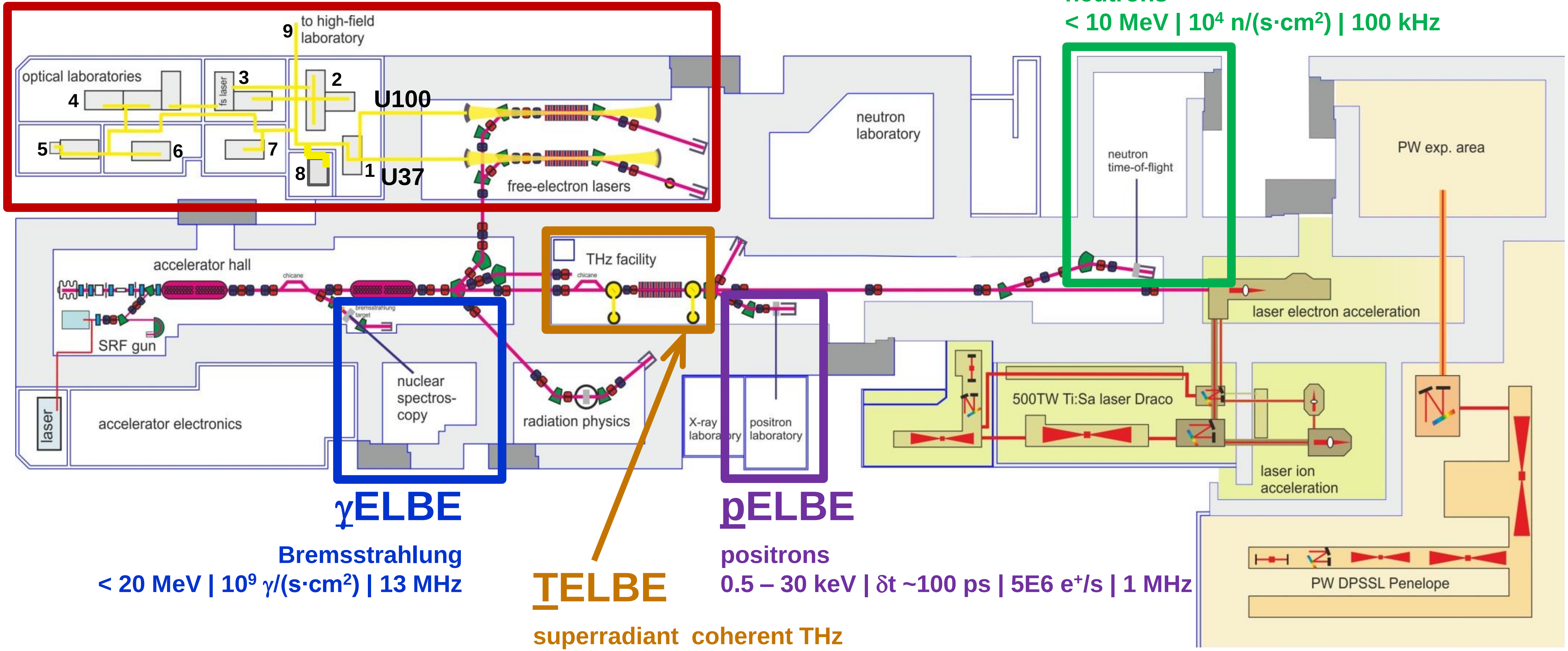
ELBE Accelerator and Secondary Sources

FELBE

coherent THz/IR FEL light
5 – 250 µm (1.2 – 60 THz) | ≤ 5 µJ/pulse | 13 MHz

nELBE

neutrons
< 10 MeV | 10^4 n/(s·cm^2) | 100 kHz



γELBE

Bremsstrahlung
< 20 MeV | 10^9 γ/(s·cm^2) | 13 MHz

pELBE

positrons
0.5 – 30 keV | δt ~100 ps | 5E6 e$^+$/s | 1 MHz

TELBE

superradiant coherent THz
0.1 – 2.5 THz (3 mm – 120 µm) | ≤ 10 µJ/pulse | 100 kHz

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ELBE Accelerator

	Thermionic Gun	SRF Gun
Gun Energy	250 keV	4 MeV
Electron Beam Energy (linac)	5 – 36 MeV	5 – 40 MeV
Bunch Charge	< 100 pC (77 pC typ.)	< 250 pC (200 pC typ.)
Max. Avg. Beam Current	1.0 mA	200 µA
Norm. Transverse Emittance	< 10 mm mrad (rms)	< 5 mm mrad
Norm. Longitudinal Emittance	< 100 keV ps (rms)	10 keV ps (rms) 1)
Micropulse Bunchlength	1 – 5 ps (rms)	2 – 3 ps (rms) 2)
Micropulse Rep. Rate	26 MHz/N (13 MHz - FEL)	10 / 25 / 50 / 100 / 250 kHz 13 MHz
Macropulse Duration	0.1 – 40 ms / CW	0.1 – 40 ms / CW
Macropulse Rep. Rate	1 – 25 Hz	1 – 25 Hz

1) Not measured because no diagnostic, instead ASTRA simulation for 200pC and typ. THz Gun parameters
2) Measured values, fit well with ASTRA simulation for 200pC and typ. THz Gun parameters

FELBE / TELBE Undulator Parameters

	FEL 1 (U37)	FEL 2 (U100)	TELBE (U300)
Undulator Period	37 mm	100 mm	300 mm
Number of Periods	54	38	8
Undulator Parameter	0.4 – 1.35	0.5 – 2.8	0.5 – 7.7
Undulator Type	hybrid NdFeB (planar)	hybrid SmCo (planar)	Electromagnetic (planar)
Resonator Length	11.53 m	11.53 m	N/A
Outcoupling Hole	1.5 / 2.0 / 3.0 / 4.0 mm	2.0 / 4.5 / 7.0 mm	N/A
Waveguide	no	partial	no
gap (undulator chamber)	13 mm	10 mm	100 mm dia.

FELBE / TELBE Source Parameters

	FEL 1 (U37)	FEL 2 (U100)	TELBE (U300)
Spectrum	5 – 40 µm 7.5 - 60 THz	18 – 250 µm 1.2 – 16.7 THz	120 – 3000 µm 0.1 – 2.5 THz
Avg. Power	≤ 44 W (13 µm)	≤ 65 W (42, 83 µm)	≤ 1 W (1 THz)
Pulsewidth (min.)	0.7 – 4 ps	1 – 25 ps	~ 1 – 22 ps
Peak Power **(P_{avg} / λ / τ_p)**	≤ 1.5 MW 34W / 14.3µm / 0.7ps	≤ 1.2 MW (*estimated*) 60W / 42µm / 4.0ps	1 MW (*estimated*) 1W / 1 THz / 10ps
Pulse Energy (max.)	≤ 3.4 µJ	≤ 5 µJ	≤ 10 µJ
Peak Field **(E_p / λ / d / τ_p)**	≤ 3 MV/cm (*estimated*) (2.3µJ / 15µm / 150µm / 1.0ps)	≤ 600 kV/cm (1.2µJ / 30µm / 300µm / 3.5ps)	300 kV/cm (*estimated*)
Bandwidth Δλ/λ	0.4 – 2 %	0.4 – 3.4 %	~ 20 %
Linear Polarization	> 98%	> 98%	~ 98%

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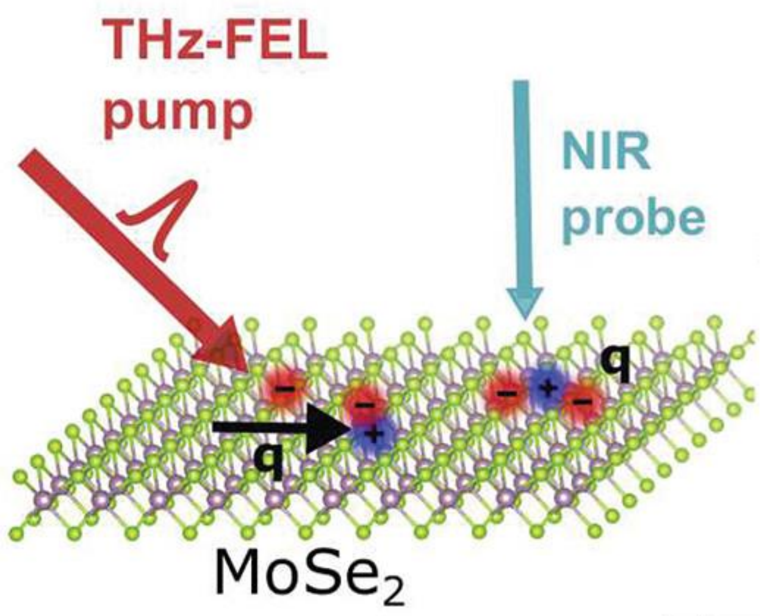
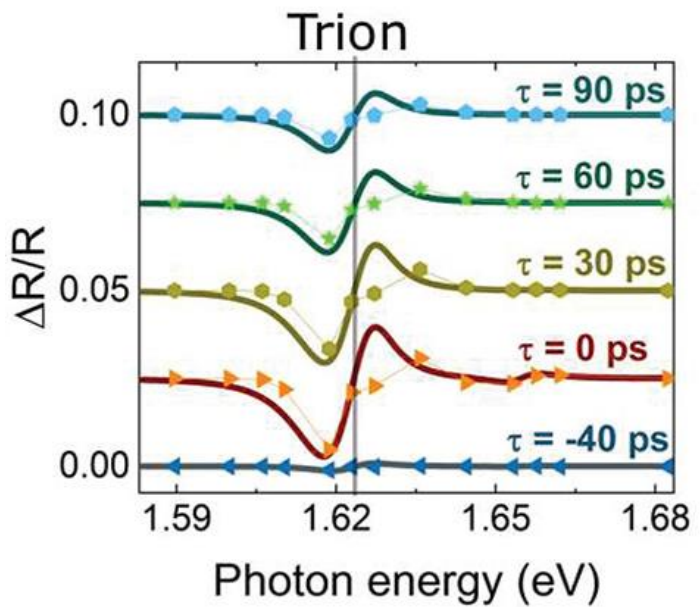
Applications for Tunable High-Field Coherent THz

- Ultrafast Dynamics
  - low-dimensional materials
  - correlated systems
  - quantum structures
  - quasi particles (excitons, magnons, etc.)
- High Fields / Phase Transitions
  - nonlinear response / harmonic generation
  - phonon/lattice driven transient phases
  - low temperature environment
  - high magnetic field
- Nanoscale Imaging (s-SNOM)
  - high spectral brightness ⇨ high S/N for resonant features
  - time-resolved dynamics with nanoscale spatial resolution





T. Venanzi, et al., ACS Photonics **8**, 2931-2939 (2021).

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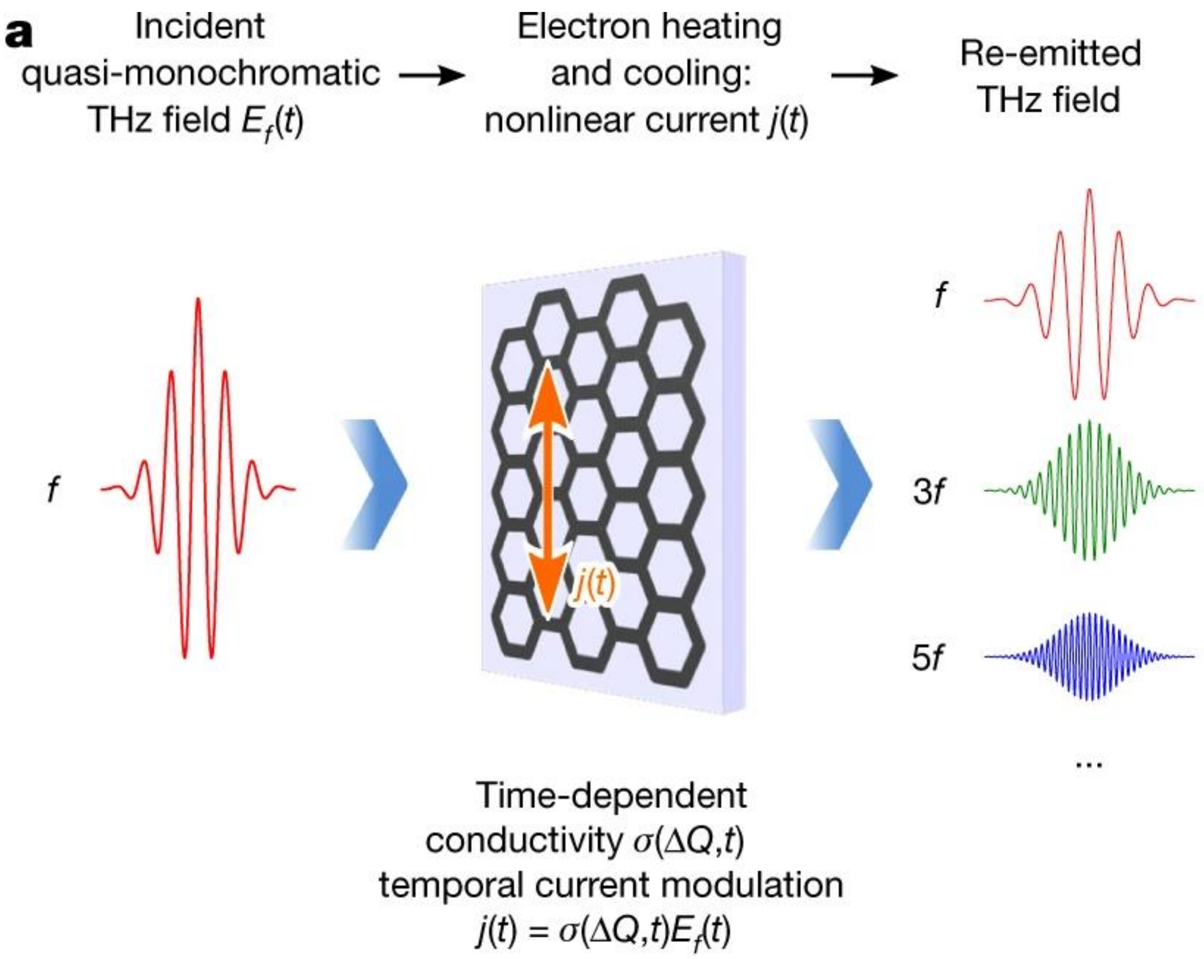

H. A. Hafez, et al., Nature **561**, 507-511 (2018).

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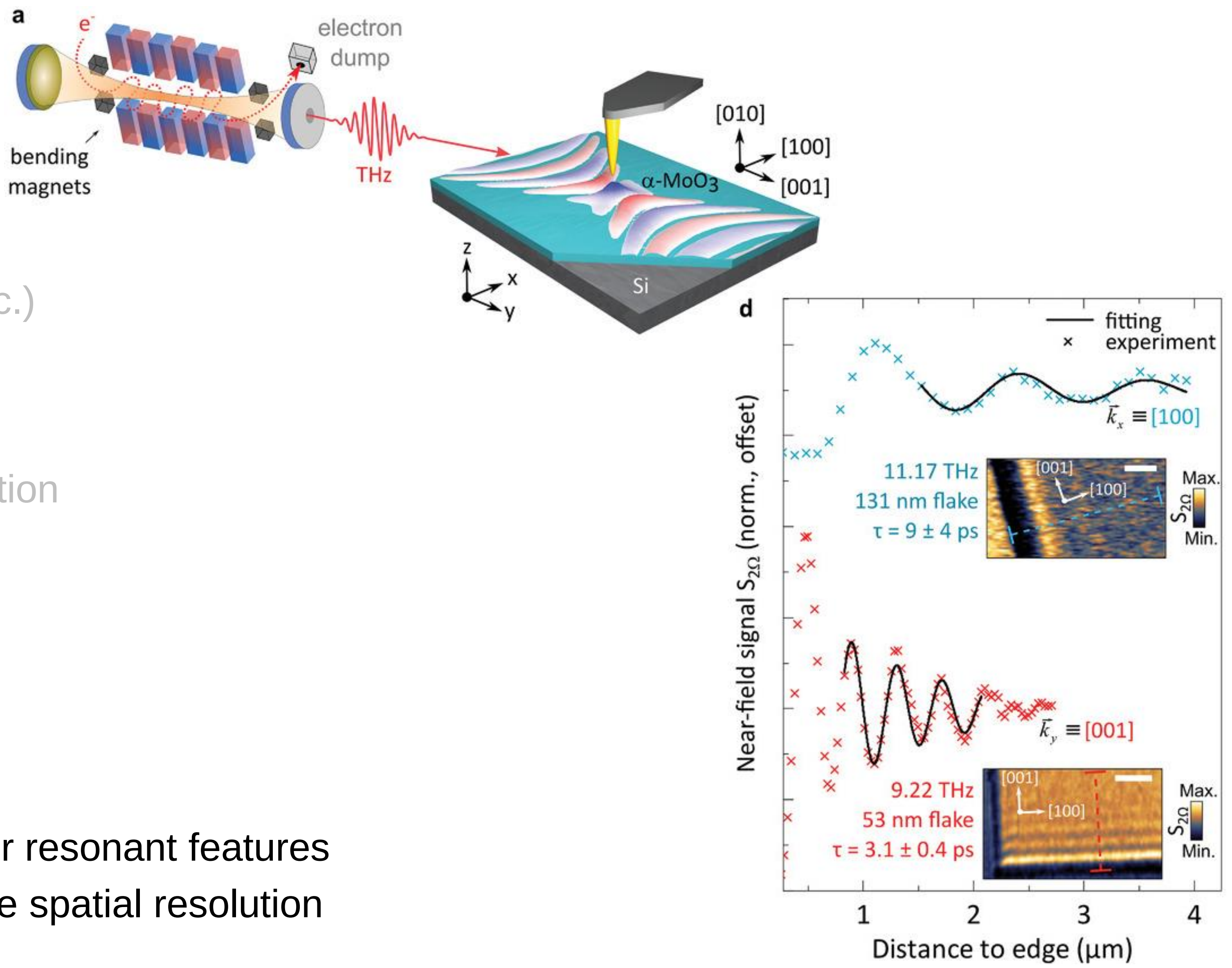

T. V. A. G. de Oliveira, et al., Adv. Mater. **33**, 2005777 (2021).

FEL (oscillator) vs. Superradiant Undulator

FEL (oscillator)	Superradiant Undulator
high stability oscillator averages upstream noise sources	accelerator noise imprinted on beam e.g. timing jitter, energy, bunch charge, etc.
not CEP stable * possibility for modulated CEP stability or seeding * phase-resolved detection recently demonstrated	**CEP stable** * relatively straightforward phase-resolved detection
high pulse energy * outcouple only small % of intracavity pulse energy	**extremely high pulse energy** pulse energy depends mainly on $(\text{bunch charge})^2$
fixed rep. rate average power can be too high as pulse energy increases * cavity dumping / pulse picking provide possible fix	**variable rep. rate** average power decoupled from pulse energy
adjustable pulsewidth / bandwidth * over limited range (e.g. 0.5 – 3% BW)	fixed pulsewidth / bandwidth * unless # undulator periods can be varied
very large spectral range possible **continuously tunable by the user**	spectral range limited by bunch compression * modulated bunches needed for higher frequencies
outcoupled mode and divergence well defined for optical transport	longitudinally extended source and complex spectral/spatial mode distribution presents challenges for optical transport

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