テラヘルツ放射光の現状と大強度CSRの利用

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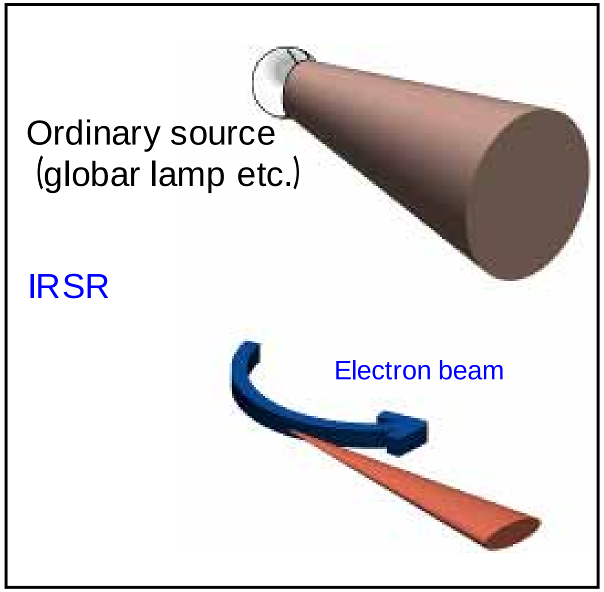
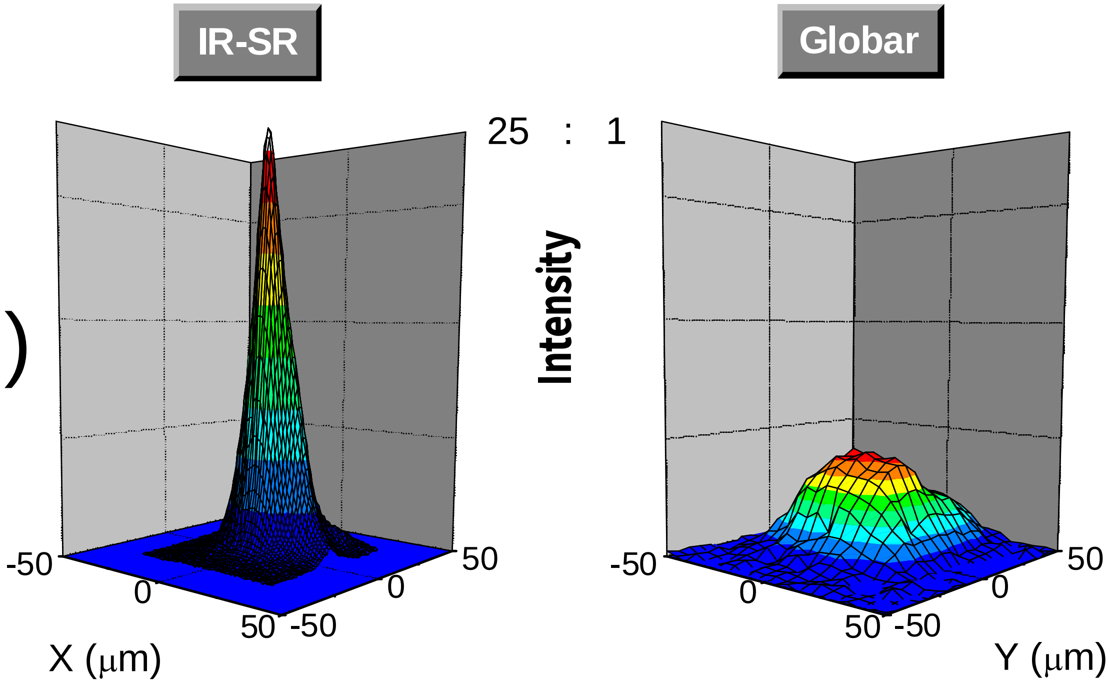
Outline

- IRSR + THzSR?
  - characteristics
  - IRSR + THzSR beamlines in the world
- Applications of THzSR
  - Conventional use
  - Microscopic use
- Future
- Does we need intense IR + THz sources?

Advantage of IRSR compared with ordinary sources

- High brilliance
  - Excellent for spectromicroscopy
- Broadband
  - Useful for spectroscopy
- Linear/circular polarization
  - Crystallic asymmetry, Molecular orbital, polar direction, MCD
- Pulse (sub-pico-second)
  - Time structure





THzSR+IRSR beamline in the world

Japan	UVSOR-II 6B	THz+IR, multipurpose, microscopy, MCD	
	SPring-8 43IR	IR, microscopy under extreme conditions	
USA	NSLS	U2A	IR, microscopy under high pressure (geology)
		U2B	IR, microscopy for biology
		U4IR	THz+IR, surface science
		U10A	IR, multipurpose (solid state physics)
		U10B	IR, multipurpose, wide energy range
		U12IR	THz+IR, pump-probe (solid state physics)
	ALS	1.4.2	IR, multipurpose, surface science
		1.4.3	IR, microscopy (biology)
	SRC	031	IR, microscopy
France	super-ACO	SIRLOIN,	IR, multipurpose
	SOLEIL		
UK	SRS	13.3	IR, microscopy, surface science
	Diamond		
Sweden	MAX I	073	IR, high resolution (gas)
Germany	ANKA		IR Edge radiation
	BESSY II		IR, microscopy, THz-CSR
Italy	DAΦNE	SINBAD	THz+IR
	Elletra		IR
Taiwan	SRRC		IR, microscopy
Switzerland	SLS		IR microscopy
	ESRF		IR, microscopy
China NSRL, Canada CLS,,			under consideration

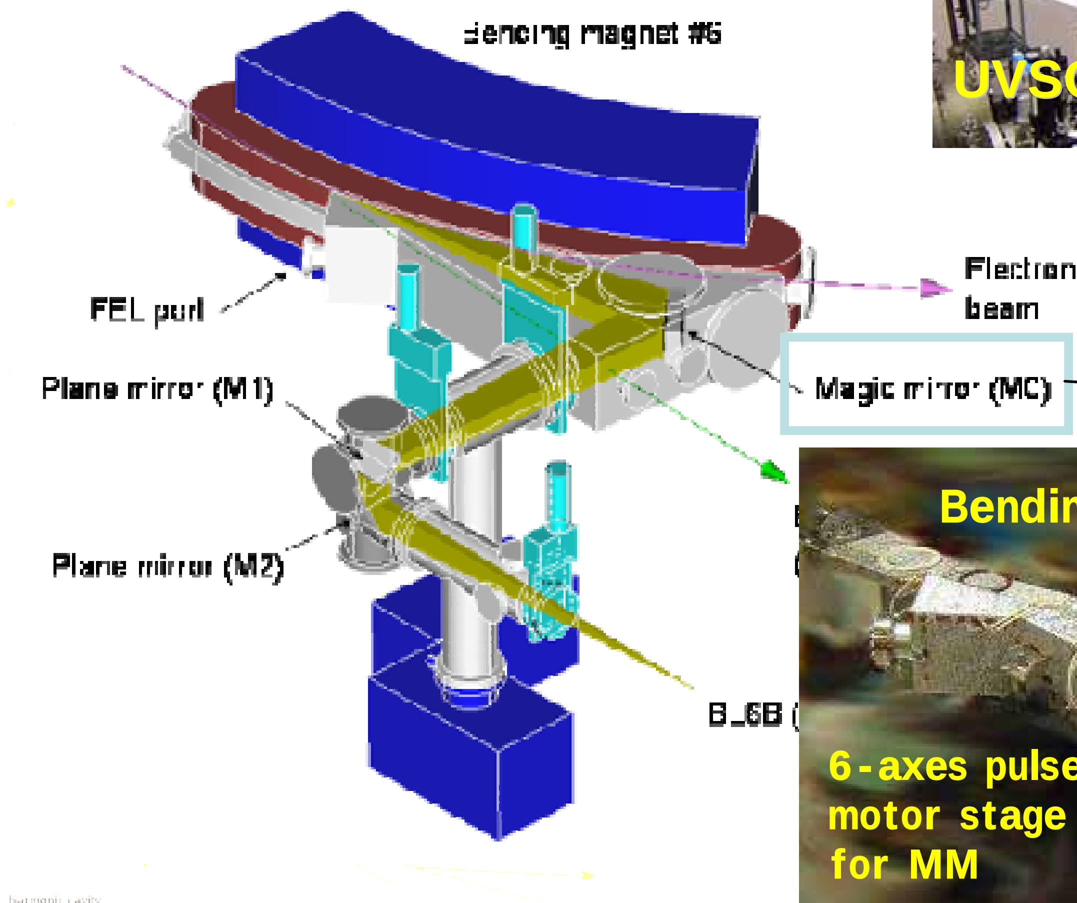
Red: THz
Blue: IR.

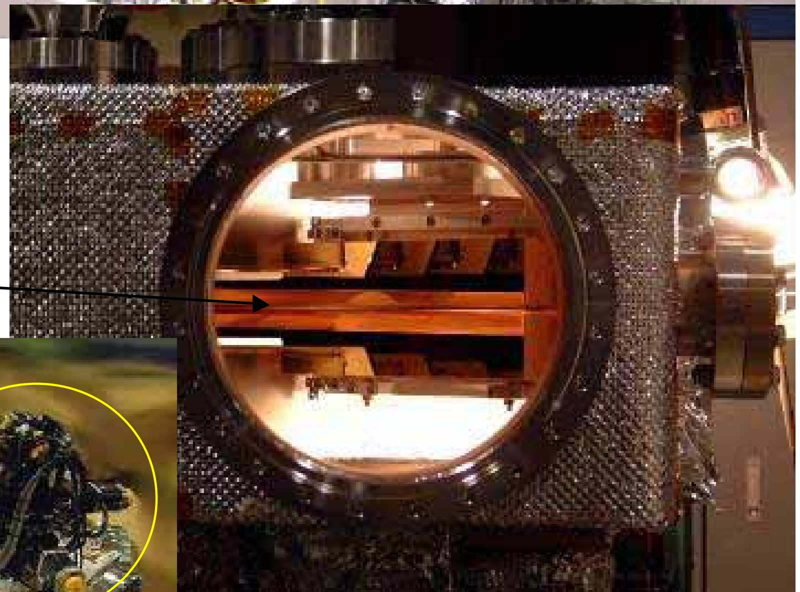
Reconstructed IR+THz beam line (BL6B) at UVSOR-II (since 2004)

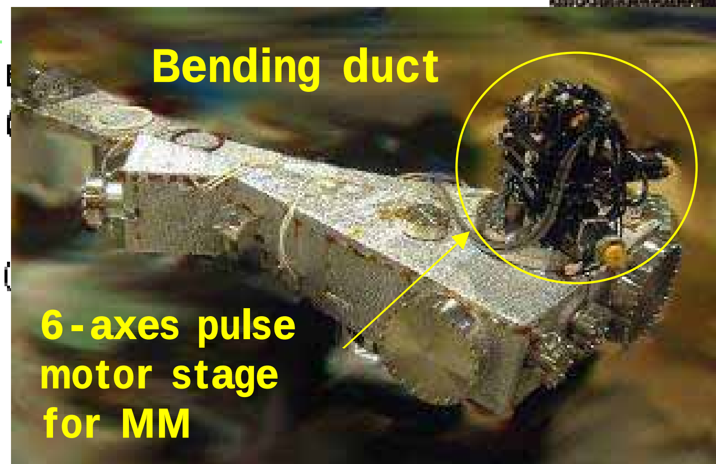
Acceptance angle of SR

From 80(H) x 60(V) $mrad^2$

To **215(H) x 80(V) $mrad^2$**

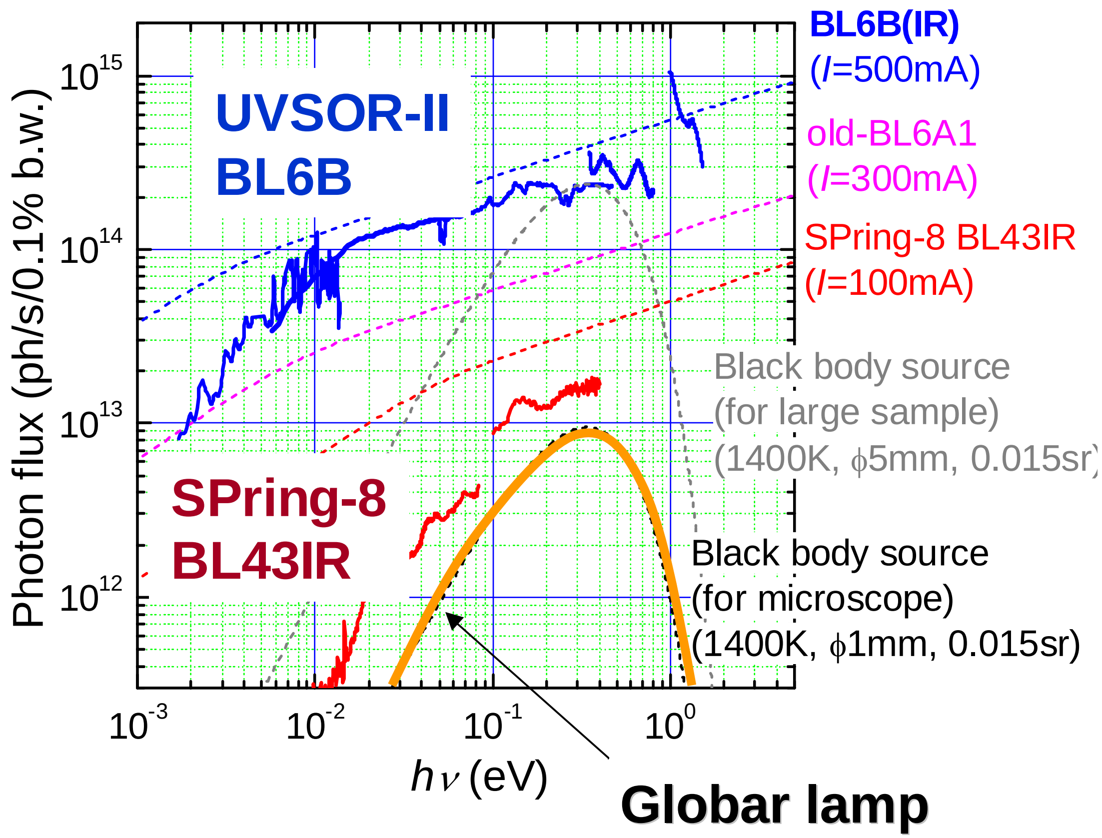




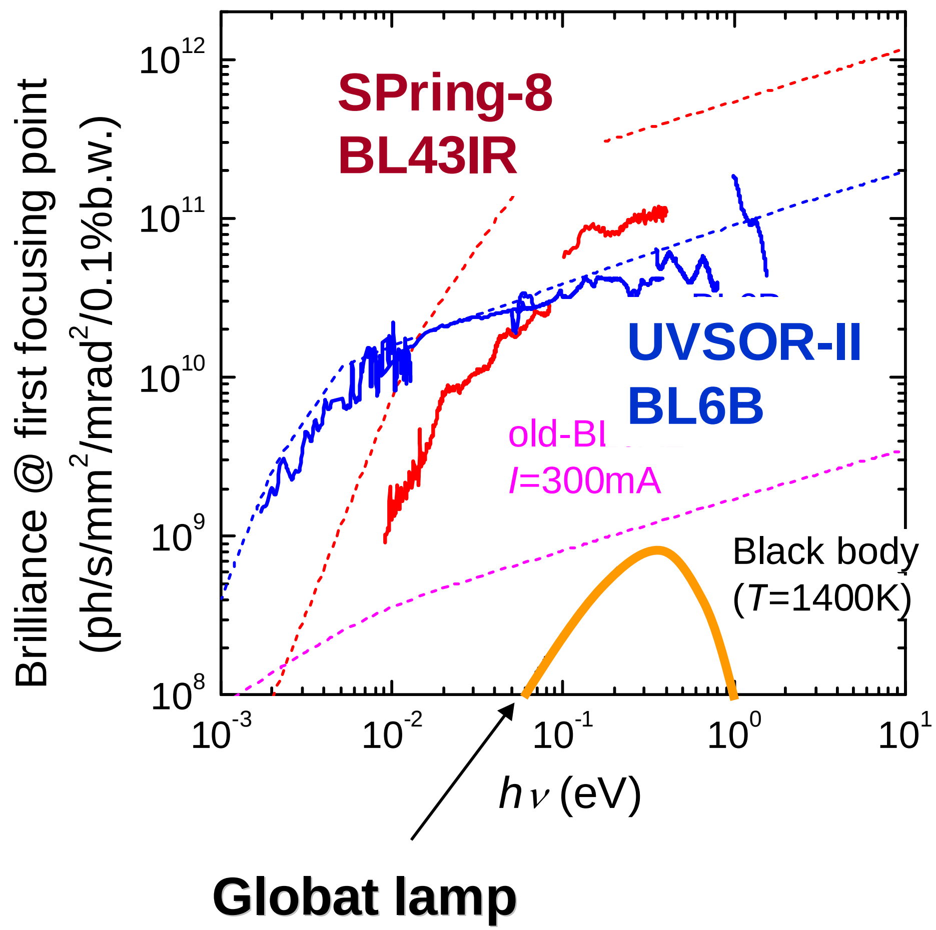


Intensity and brilliance of IRSR compared with a globar lamp

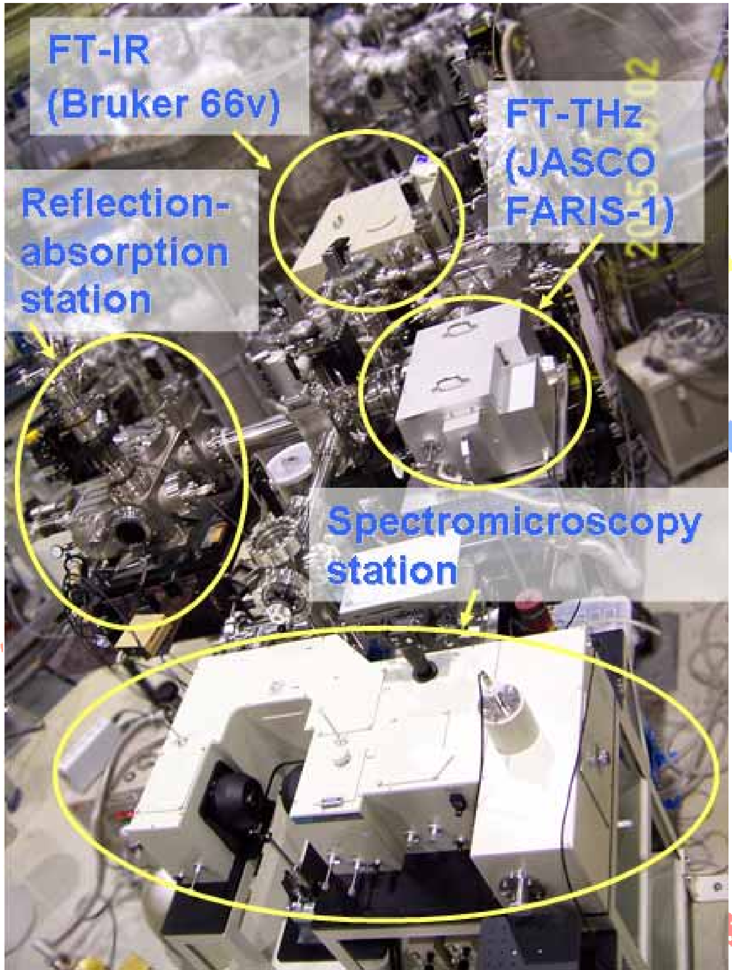
Intensity

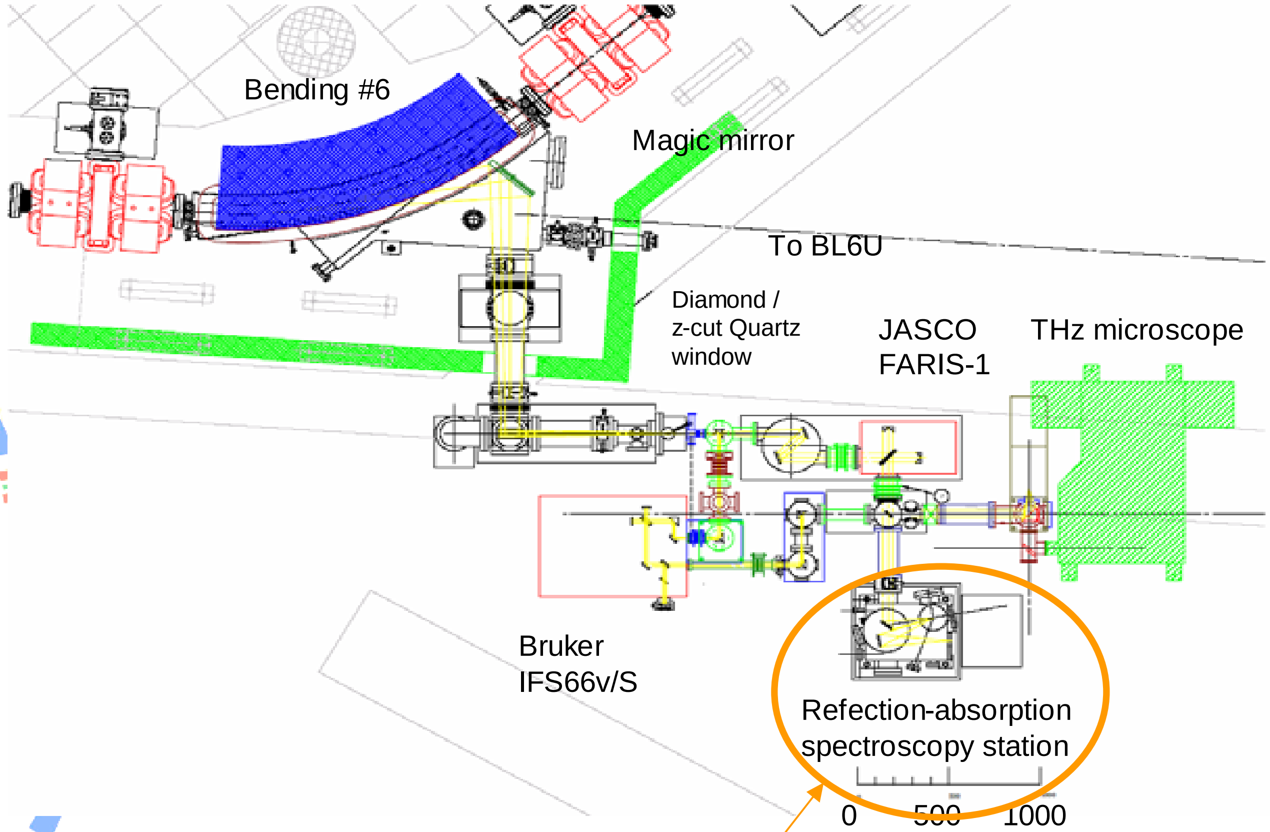


Brilliance



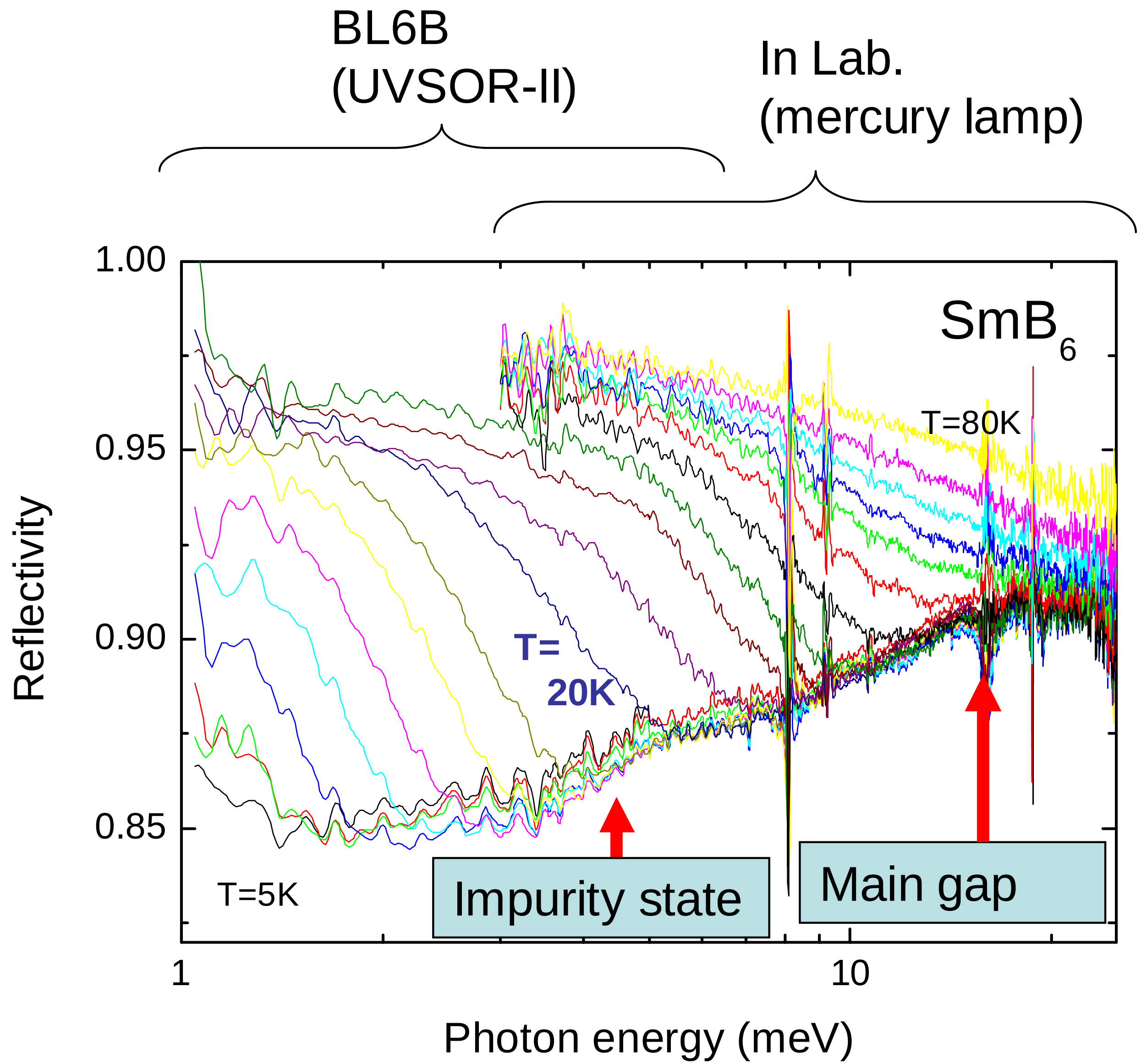
End stations of BL6B at UVSOR-II

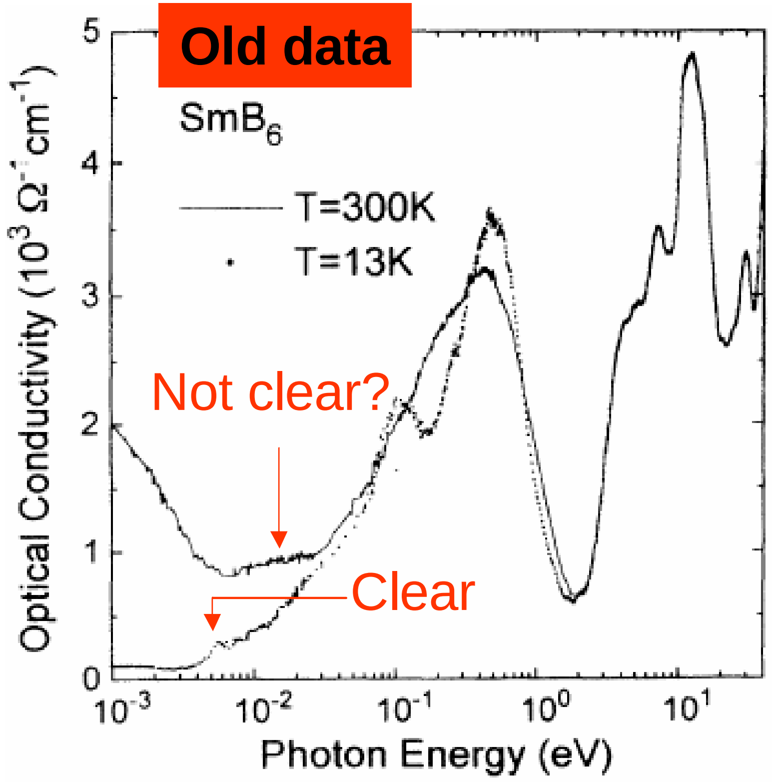




This chamber can be removed for the other experiments (IR-MCD, FIR-RAS and so on).

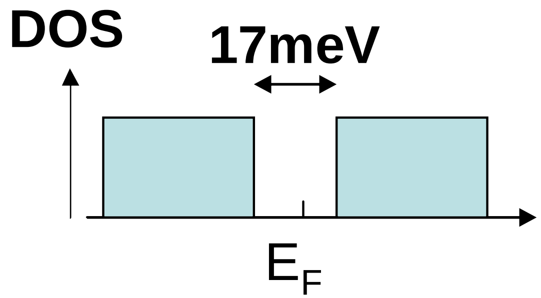
Hot carriers in SmB_6



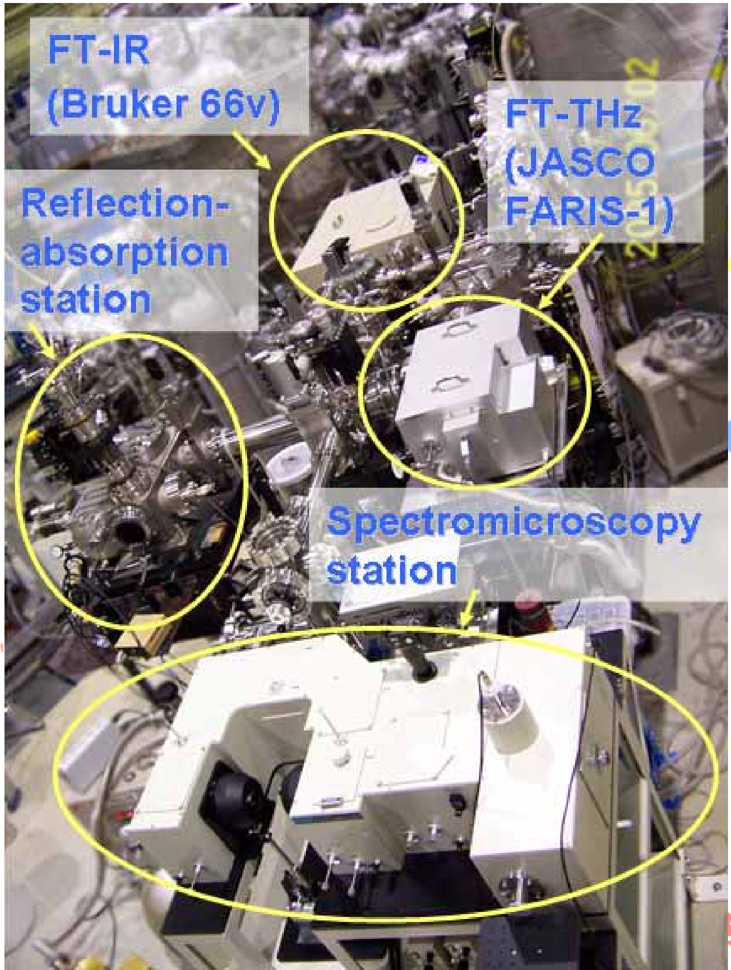


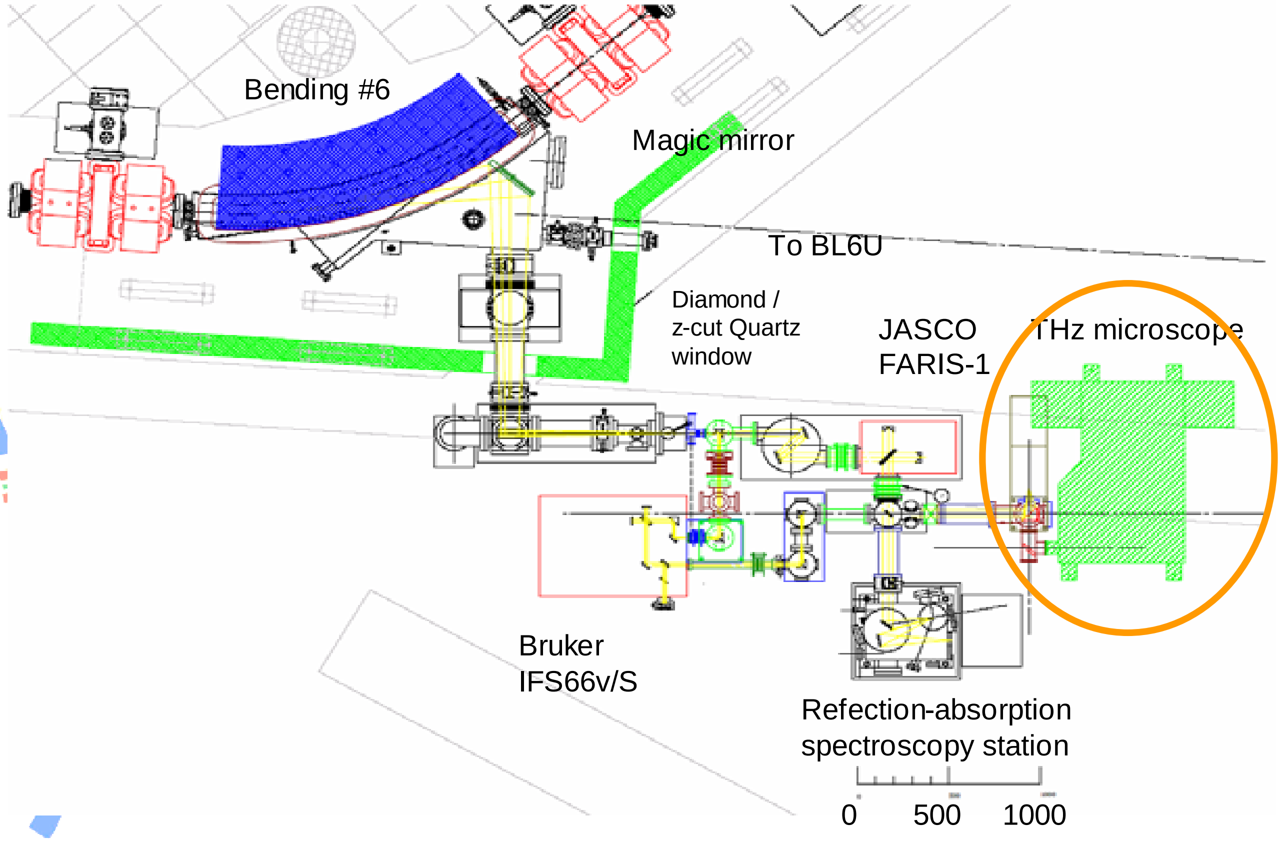
[S. K. et al., Phys. Rev. B **50**, 1406 (1994).]

Large spectral change is due to the thermally excited carriers across the small energy gap.



End stations of BL6B at UVSOR-II





THz spectroscopy under pressures

Microscope

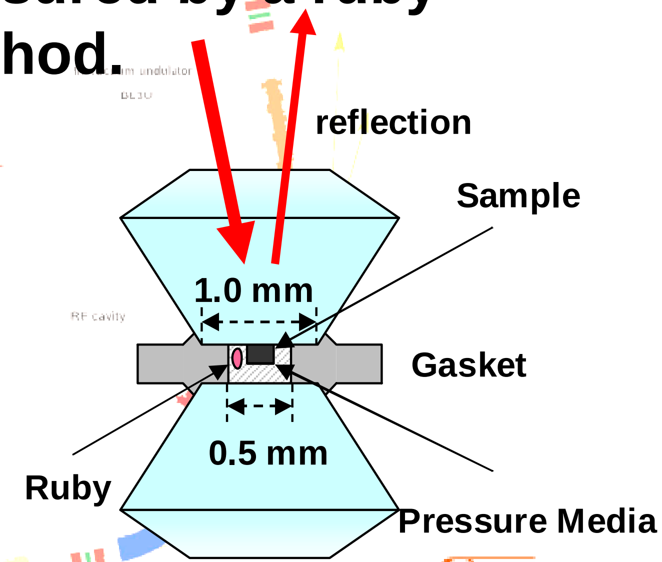
- Horizontal optical pass
- Energy range
  - Laboratory: 50 meV ～ 1.2 eV
  - UVSOR-II BL6B: 5 meV ～ 50 meV

Microsope @ BL6B

Diamond anvil pressure cell

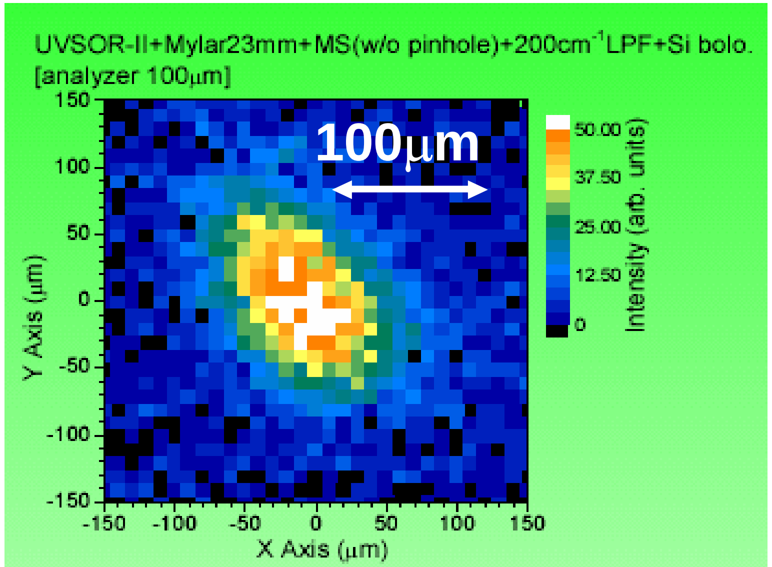
- Pressure media：Apiezon grease N
- Pressure is measured by a ruby fluorecence method.

Diamond anvil cell



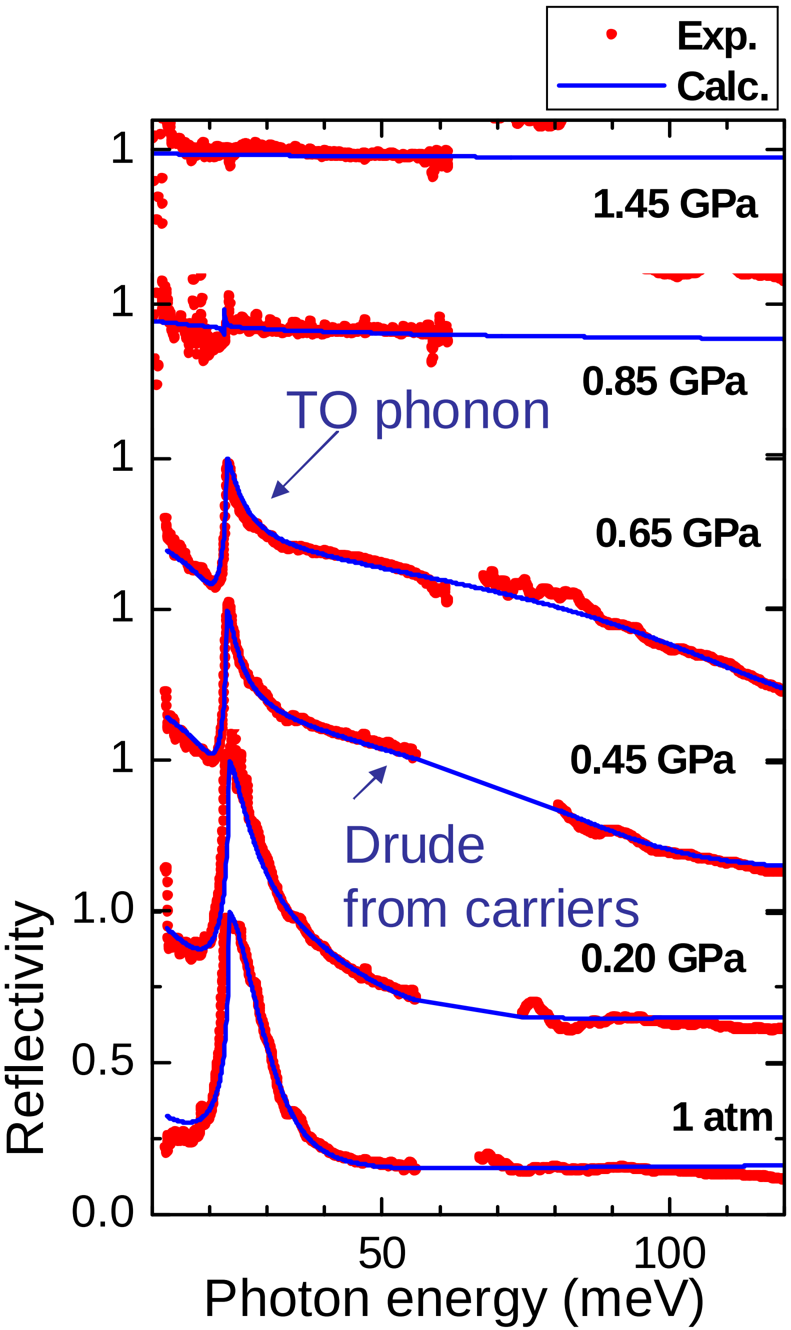
DAC

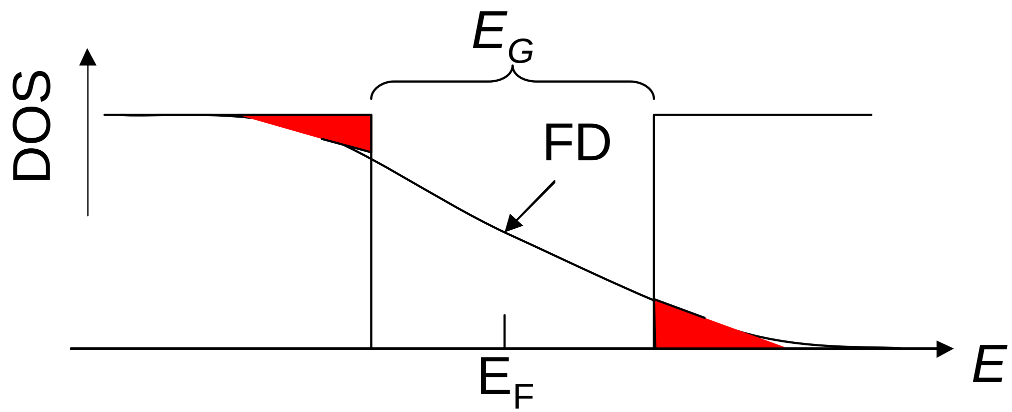
Spatial resolution of microscope in the THz region at BL6B

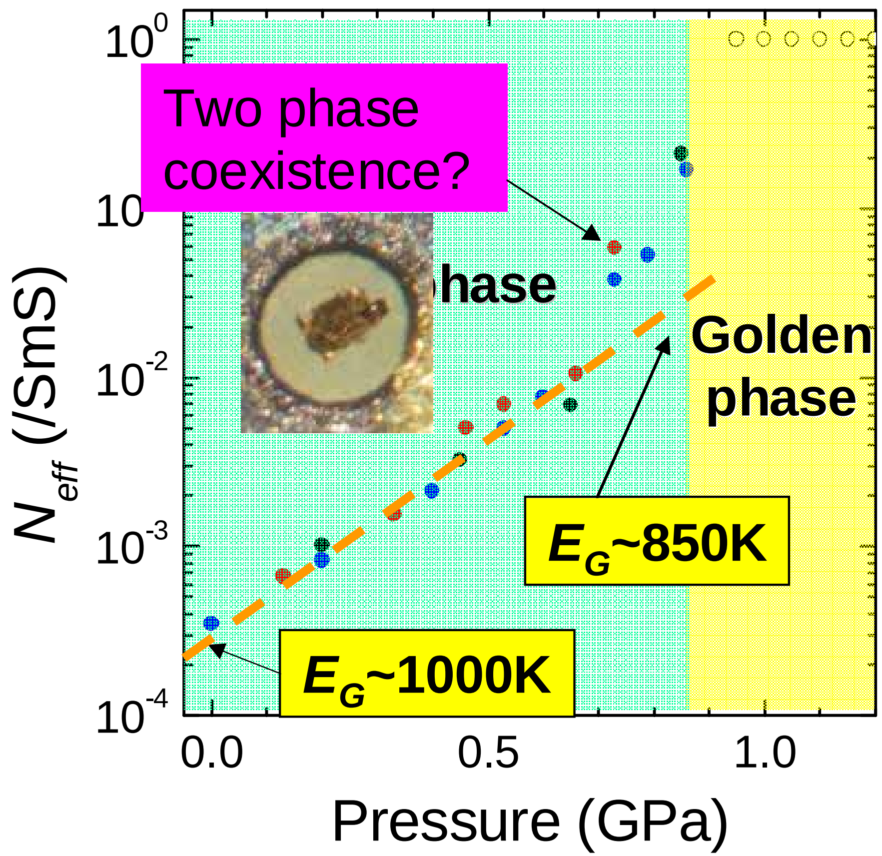


Pressure dependence of $R(\omega)$ in SmS

[T. Mizuno, SK et al.]

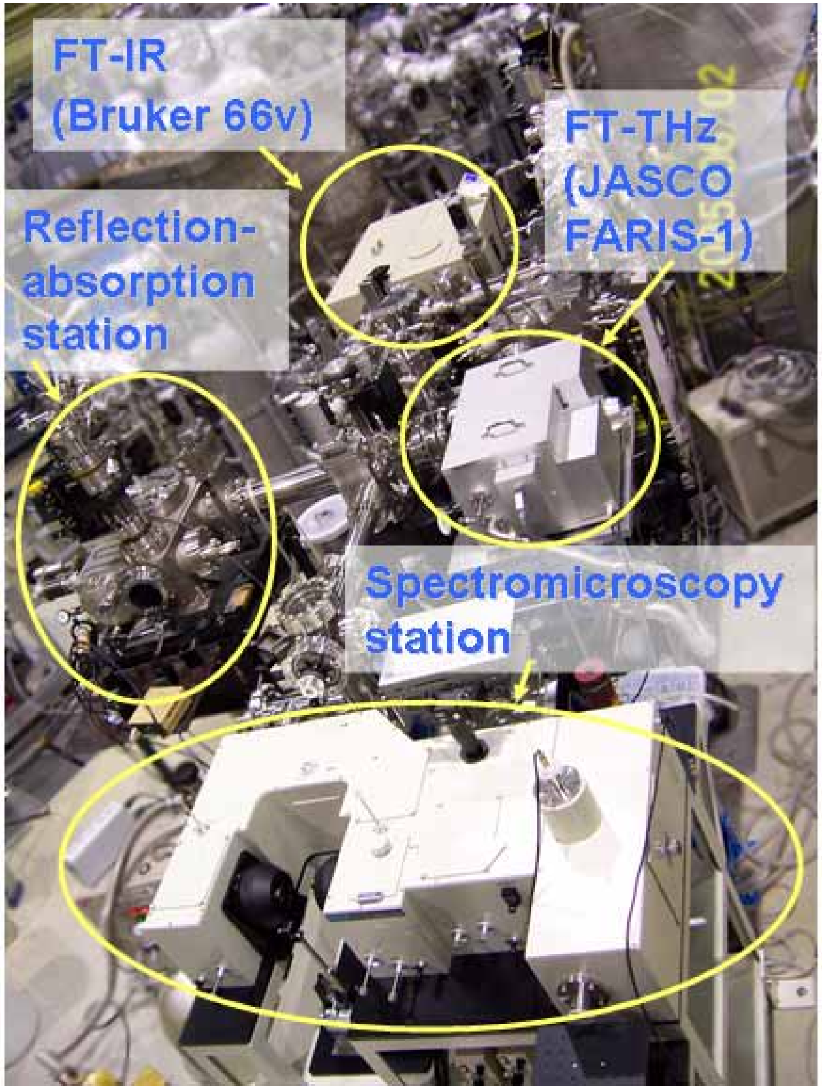






Scientific program at BL6B

- Electrodynamics of solids @ multi-extreme conditions
  - Very low temperature (~0.4K)
  - High pressures (~20GPa)
  - High fields (~6T)
- THz microspectroscopy
- FIR-RAS of adsorbed molecules
- THz spectroscopy of protains
- THz excitation with coherent SR.
  - 10^3~10^4 higher intensity than the present IRSR.



今後の動向？　(私感)

- (オリンピックではないけれど，)より速く，より高く，より遠くへ。
  - ➢時分割
  - ➢より高い空間分解能
    - – 近接場分光など
  - ➢高磁場，高圧力，高電圧，極低温，，，

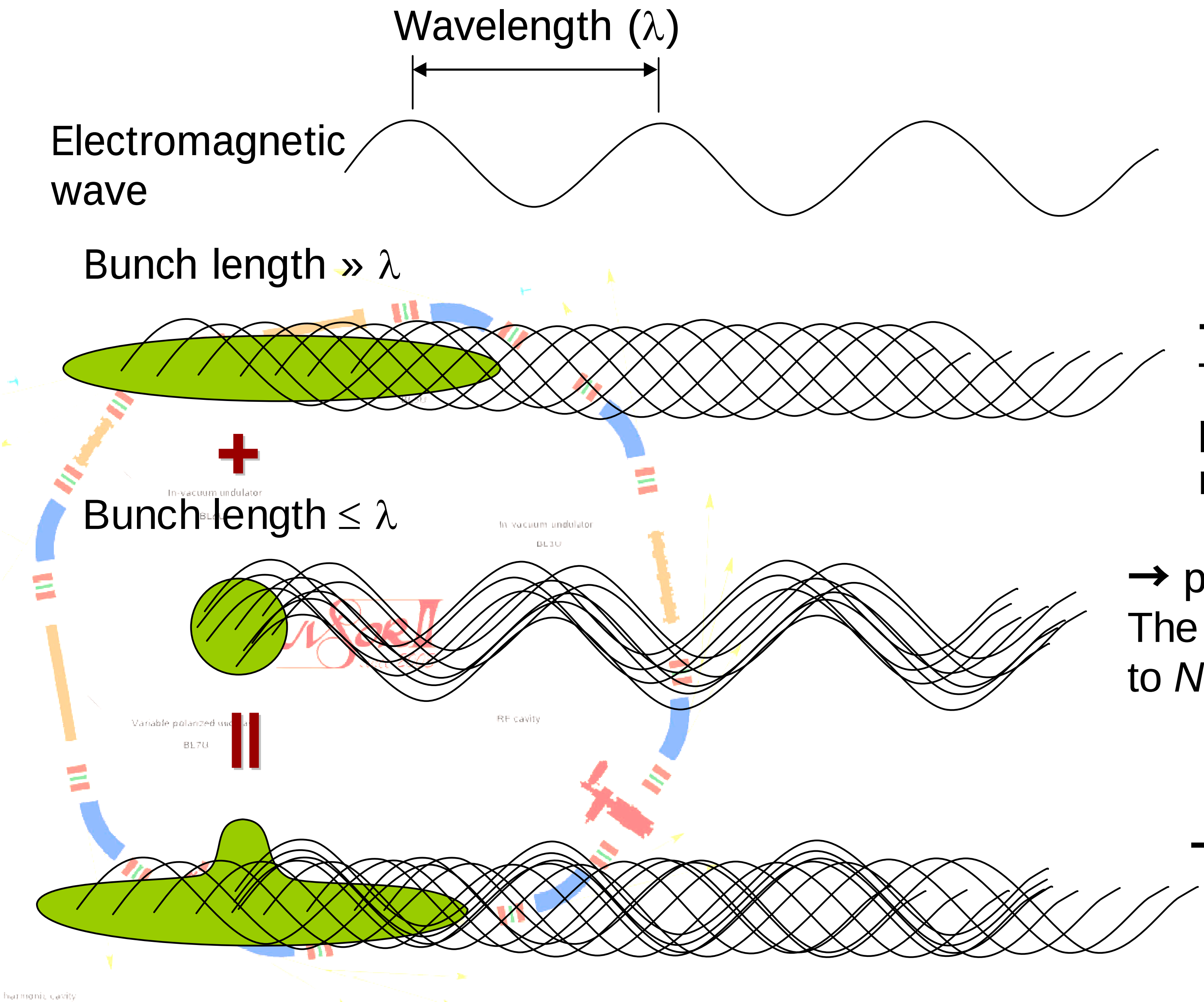
例) 化学変化や相変化のビデオ撮影

例) パルス超高磁場によるスペクトル変化

- 異次元の世界へ。
  - ➢プローブ光だけではなく励起光としての利用。
  - ➢化学反応の赤外光による制御，など。

⇒ **大強度が必要。**

Coherent Synchrotron Radiation (CSR)



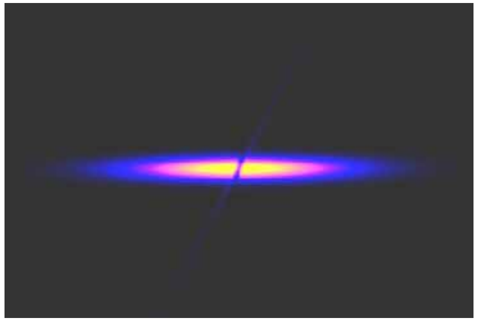
→ no interference
The intensity is proportional to the number of electron (N_e).

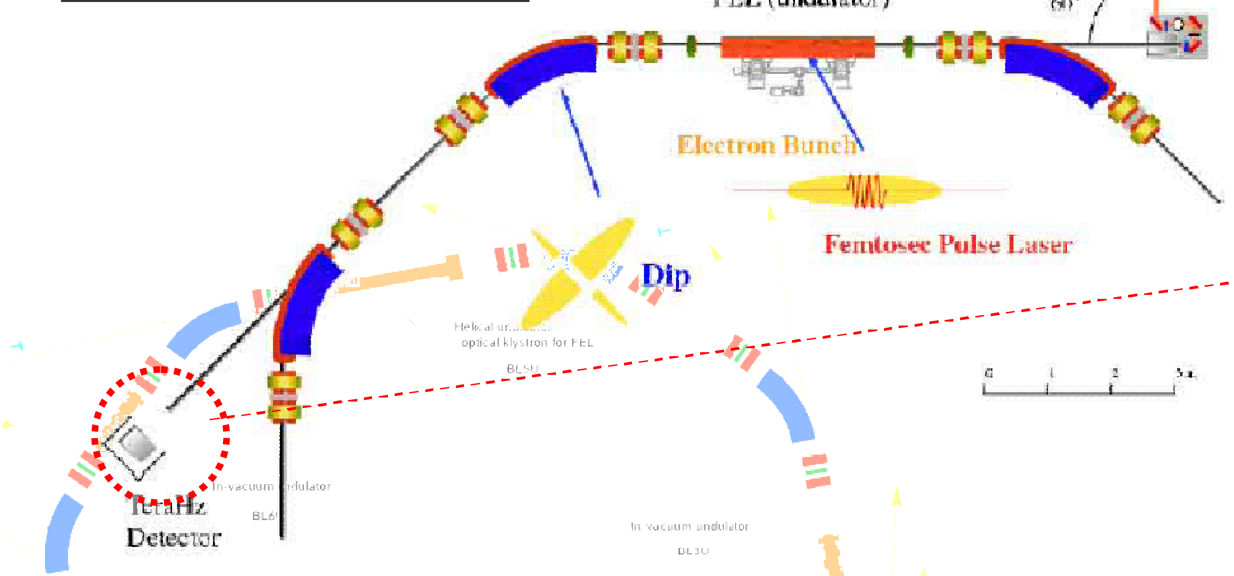
→ perfect interference
The intensity is proportional to N_e^2.

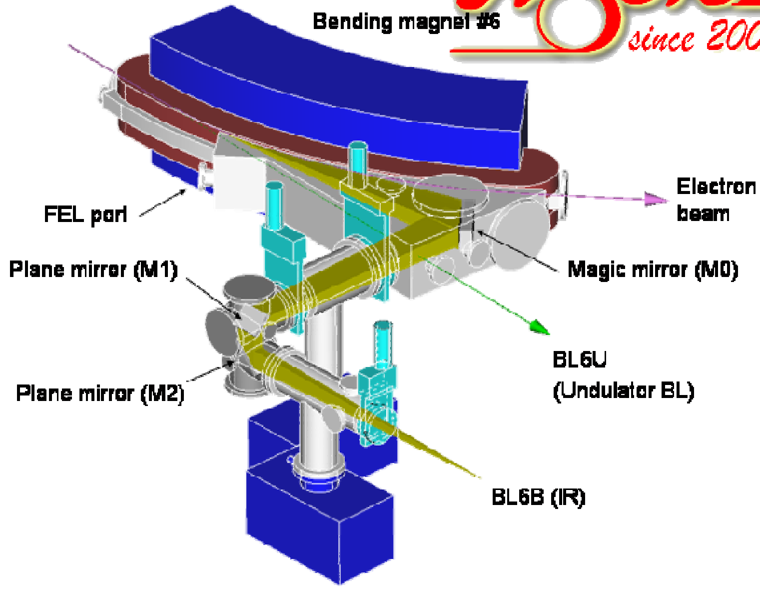
→ partial interference

Intense CSR induced by a laser bunch slicing

[M. Shimada et al., submitted.]

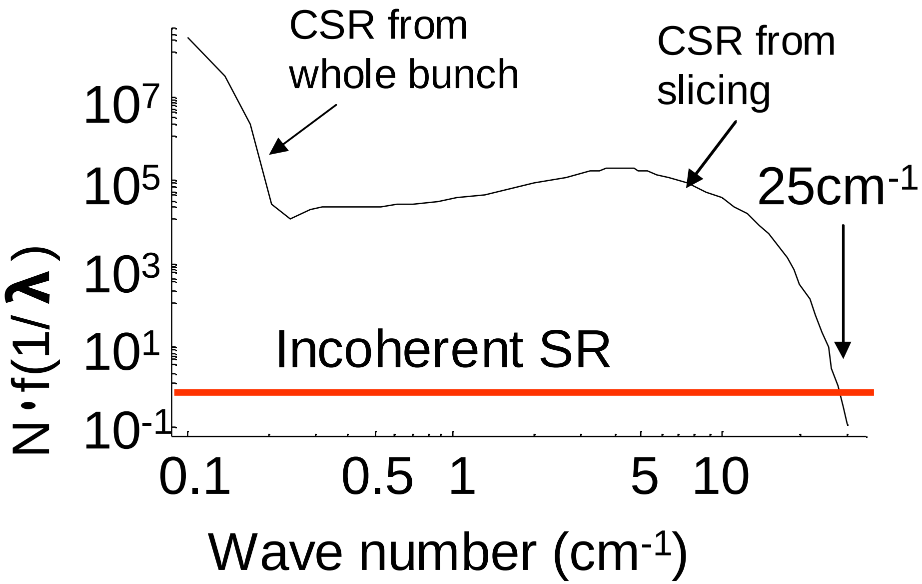






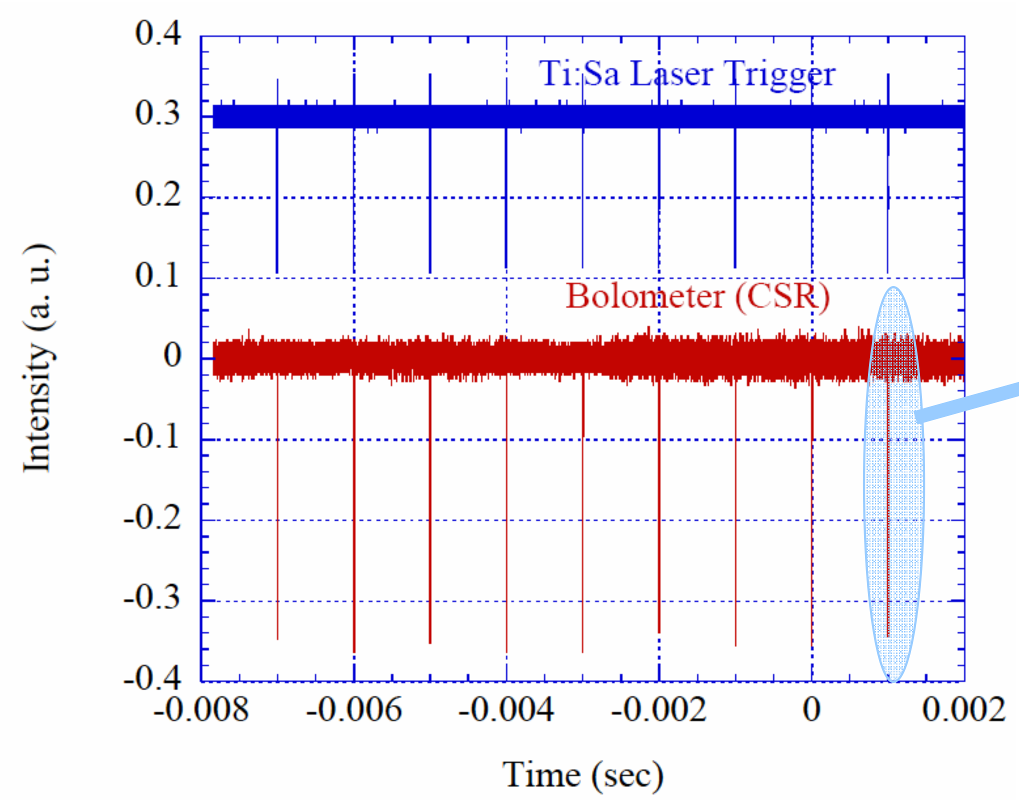
UVSOR-BL6B IR Beamline

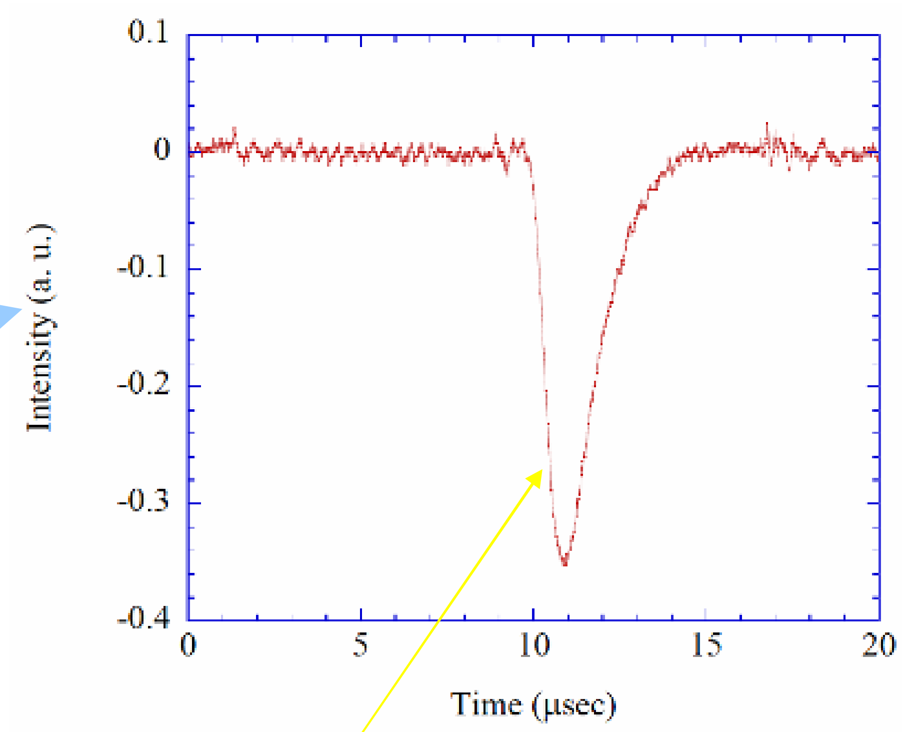
(S. Kimura et al., AIP Conf. Proc. 705 (2003),



Coherent Terahertz Pulses by Bunch Slicing

[M. Katoh et al., Proc. EPAC06, 3377 (2006).]



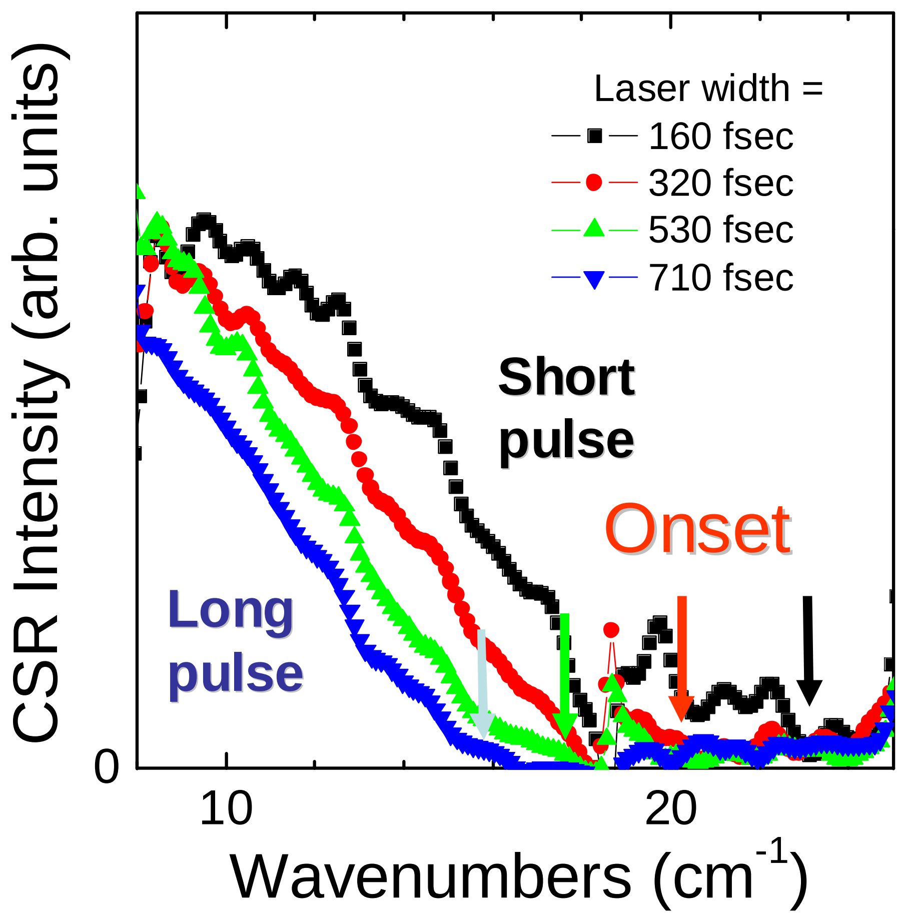


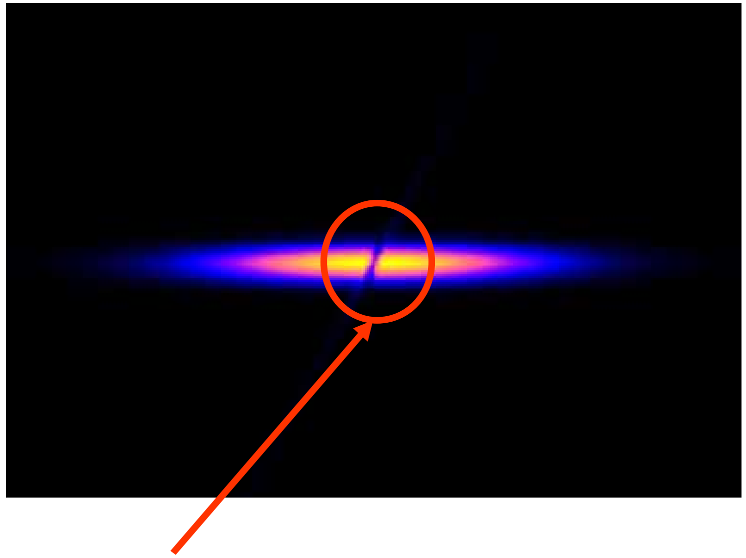
Stable and periodic.

The width originates from the InSb hot electron detector response.

Laser pulse width dependence of CSR spectrum

[M. Katoh et al., Proc. EPAC06, 3377 (2006).]





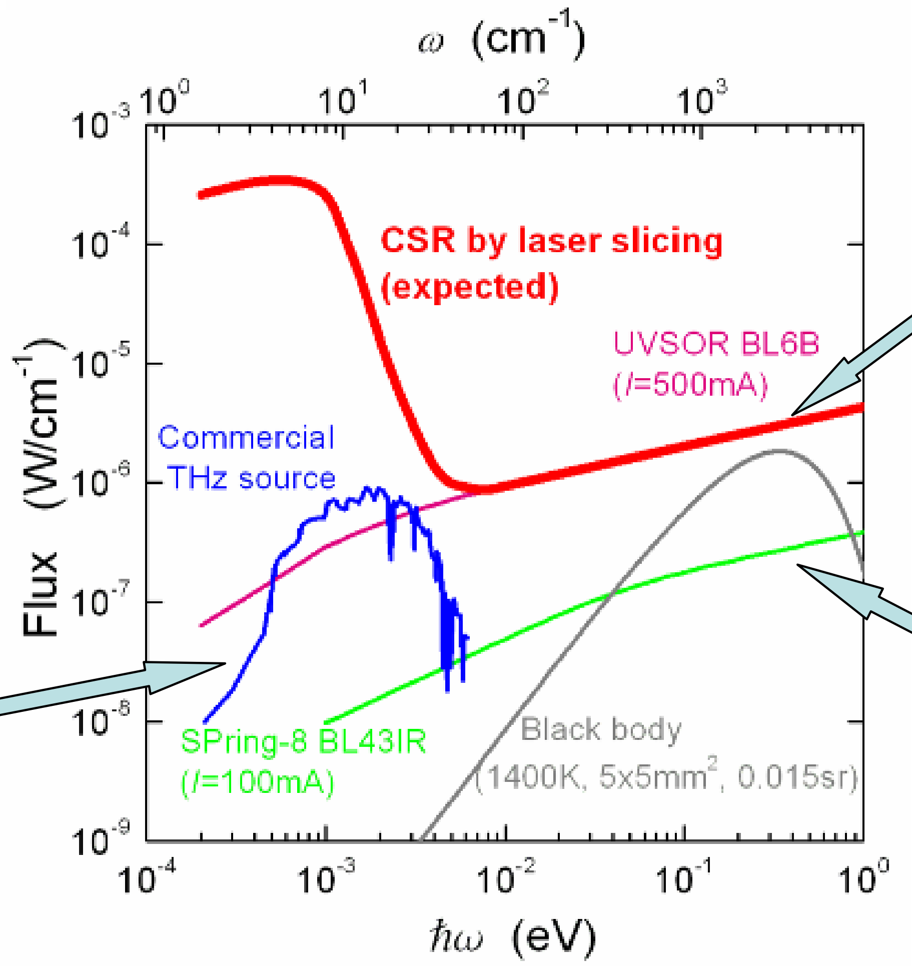
The dip is made by laser.

Onset shifts to the lower wavenumber side with increasing pulse width.

This is the evidence of the CSR originates from the dip induced by laser.

Average power of CSR

Commercial THz source



UVSOR-II BL6B

SPring-8 BL43IR

Application of CSR @ BESSY-II

(Conventional use)

Use of intense sub-THz light

[M. Ortolani et al., PRL **97**, 097002 (2006).]

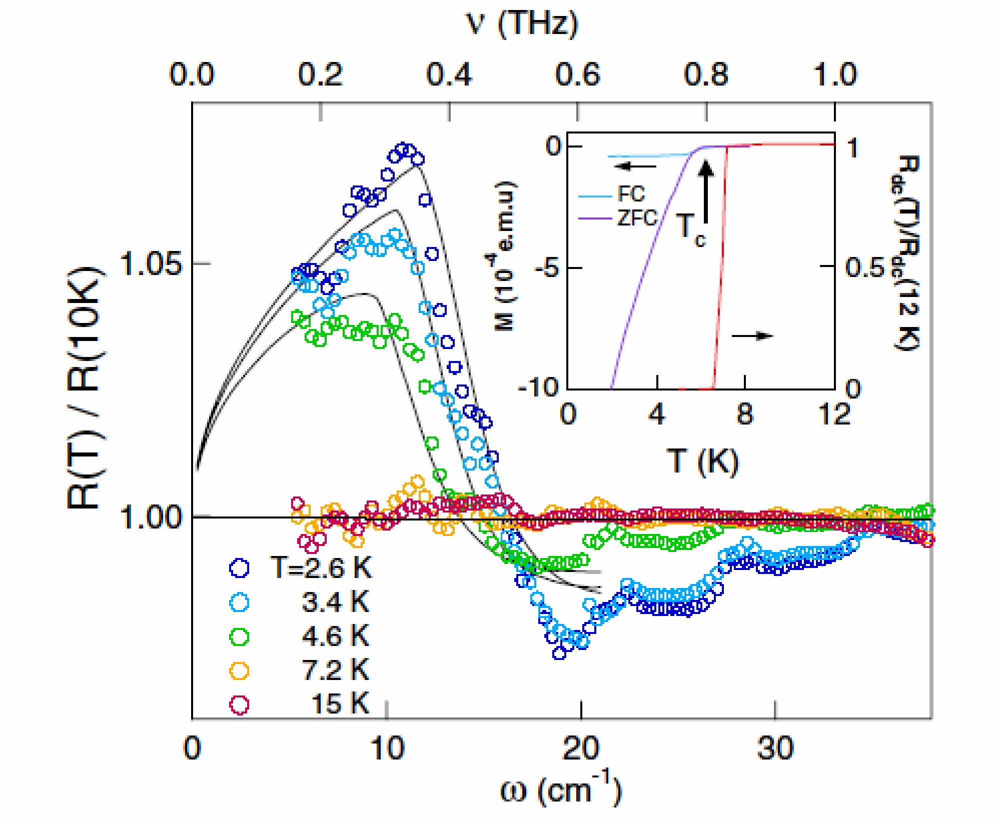


FIG. 1 (color online). Reflectivity of a strongly B-doped diamond film in the sub-THz region, normalized to its values at 10 K. The lines are fits obtained by assuming a BCS reflectivity below T_c and a Hagen-Rubens model at 10 K. The inset shows on the left scale the magnetic moment of the sample, as cooled either in a 10 Oe field (FC) or in zero field (ZFC), its resistance normalized to its value at 12 K on the right scale. The FC values are multiplied by 10.

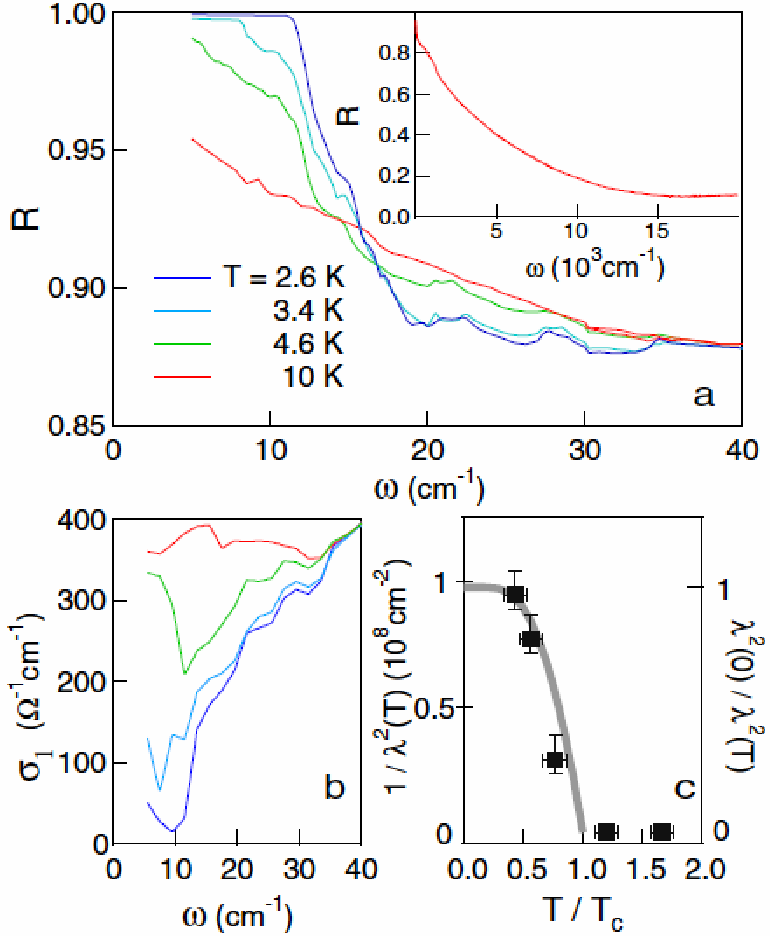


FIG. 2 (color online). Optical response of superconducting diamond: (a) absolute reflectivity obtained from the ratios of Fig. 1 and the $R(\omega)$ at 10 K shown in the inset; (b) real part of the optical conductivity; (c) inverse square of the penetration depth (■), compared with its behavior for a dirty BCS superconductor (gray line). In (a), the points at $T < T_c$ and $\omega < 2\Delta$ are replaced by those of the fits in Fig. 1. This allows one to discard unphysical values $R > 1$, due to residual noise, which would affect the Kramers-Kronig transformations.

THz SNOM @ BESSY-II

(Microscopic use)

[U. Schade et al., APL 84, 1422 (2004).]

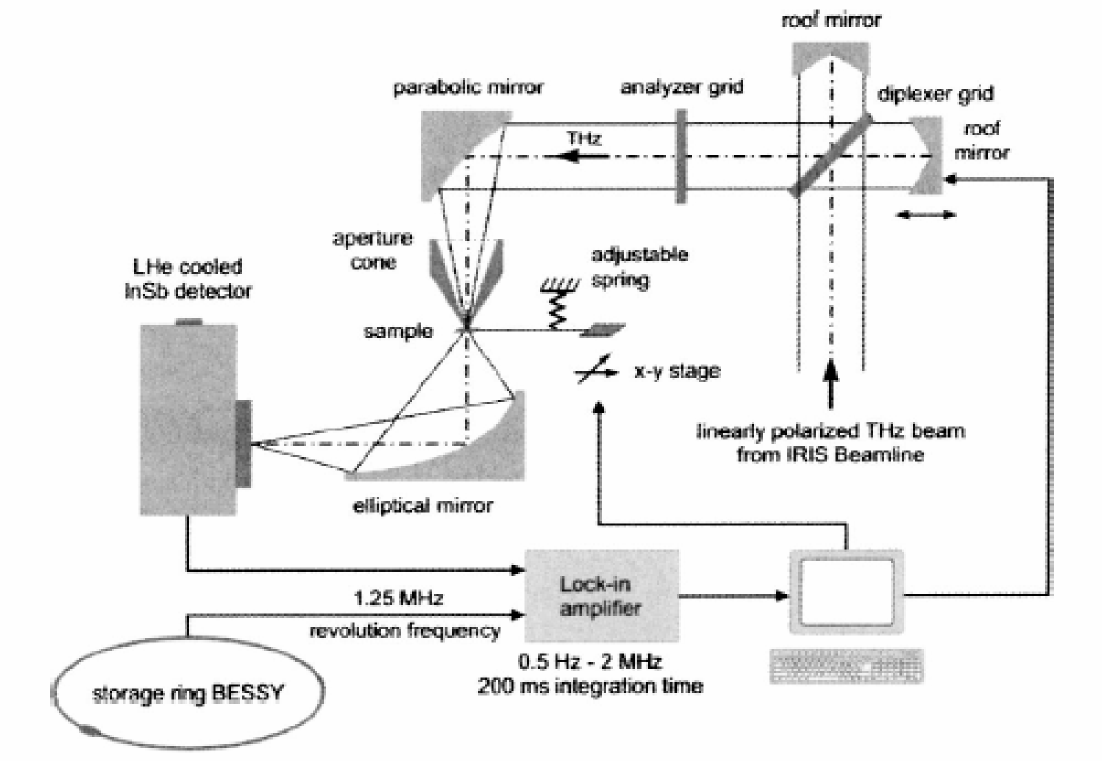
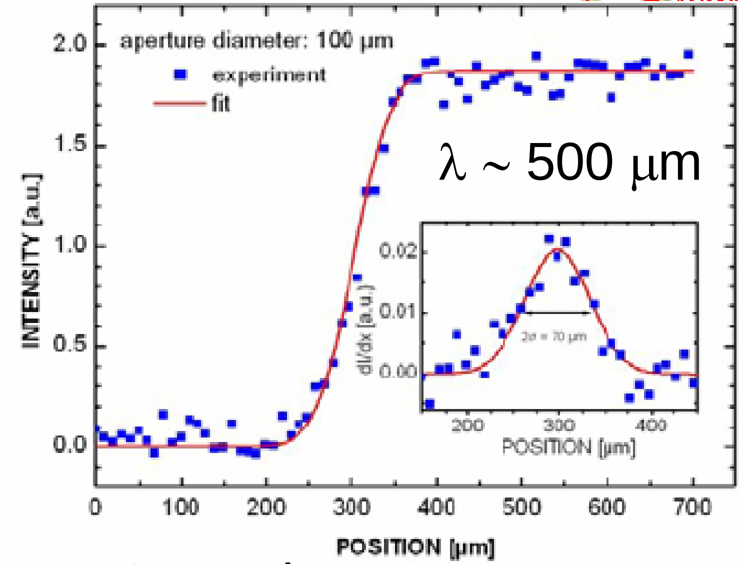
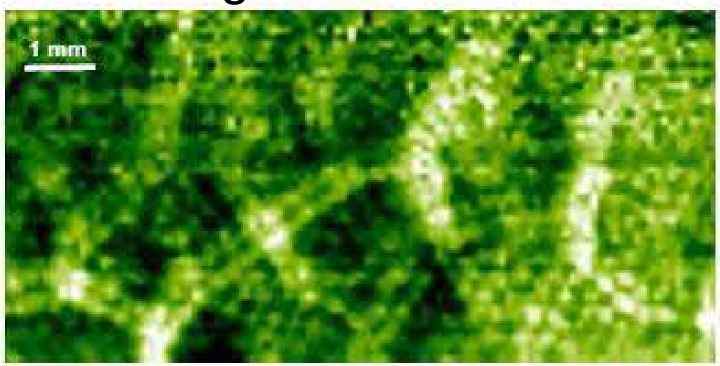


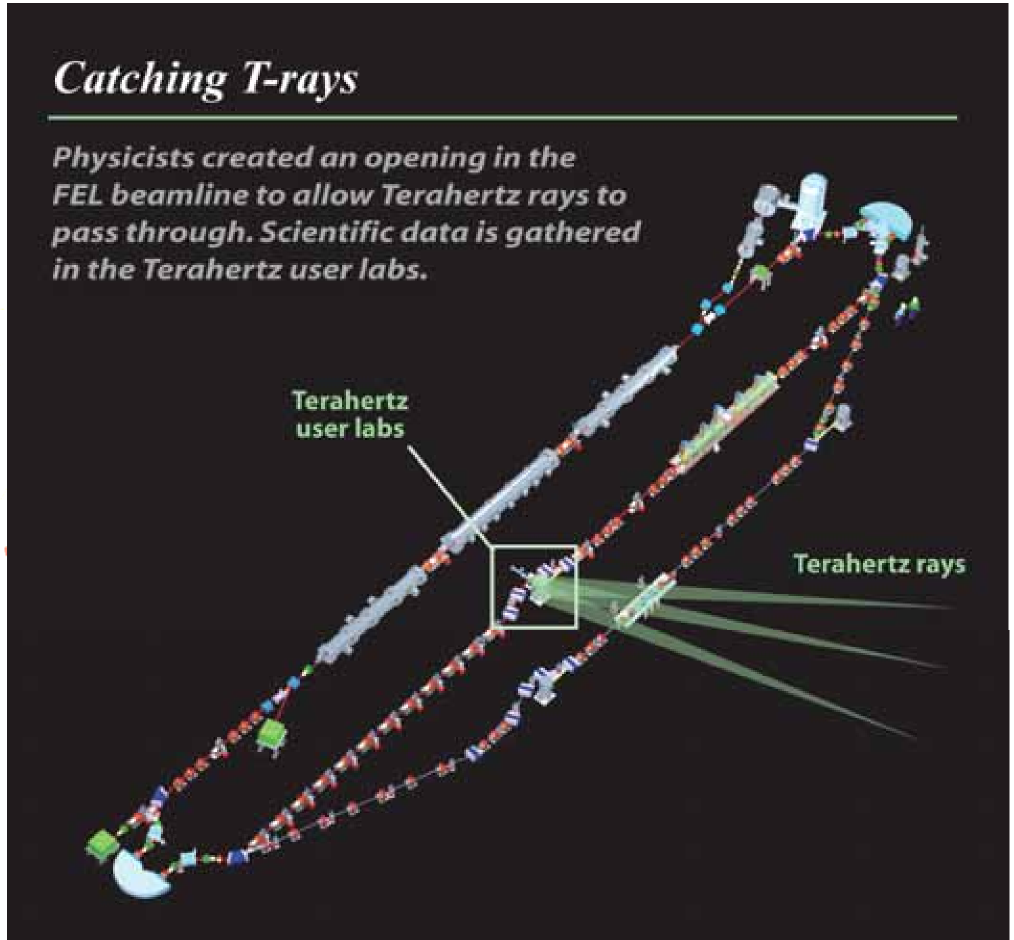
FIG. 1. Schematic diagram of the THz scanning near-field infrared microscopy setup.



VISIBLE image

THz image



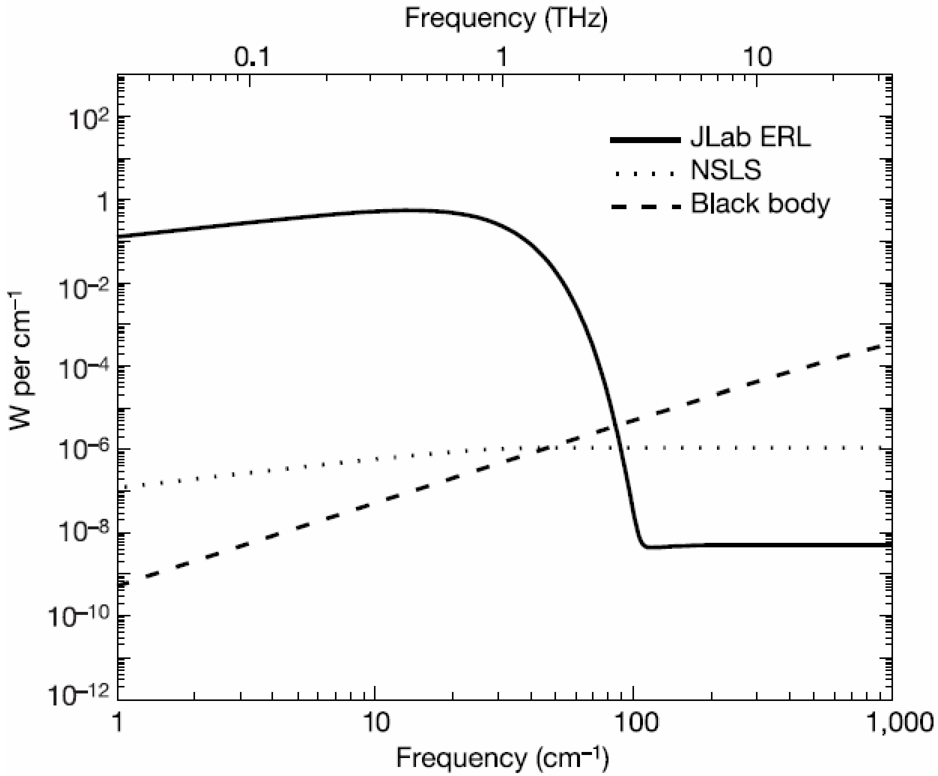


[G.L. Carr et al., Nature, **420**, 153 (2002).]

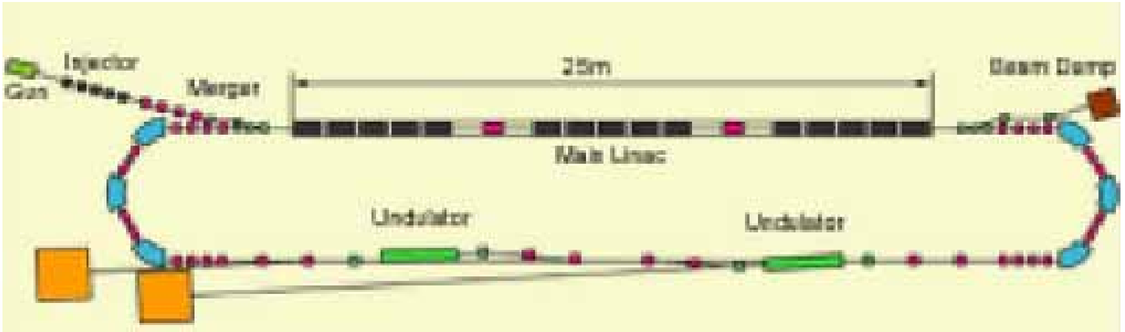
High-power terahertz radiation from relativistic electrons

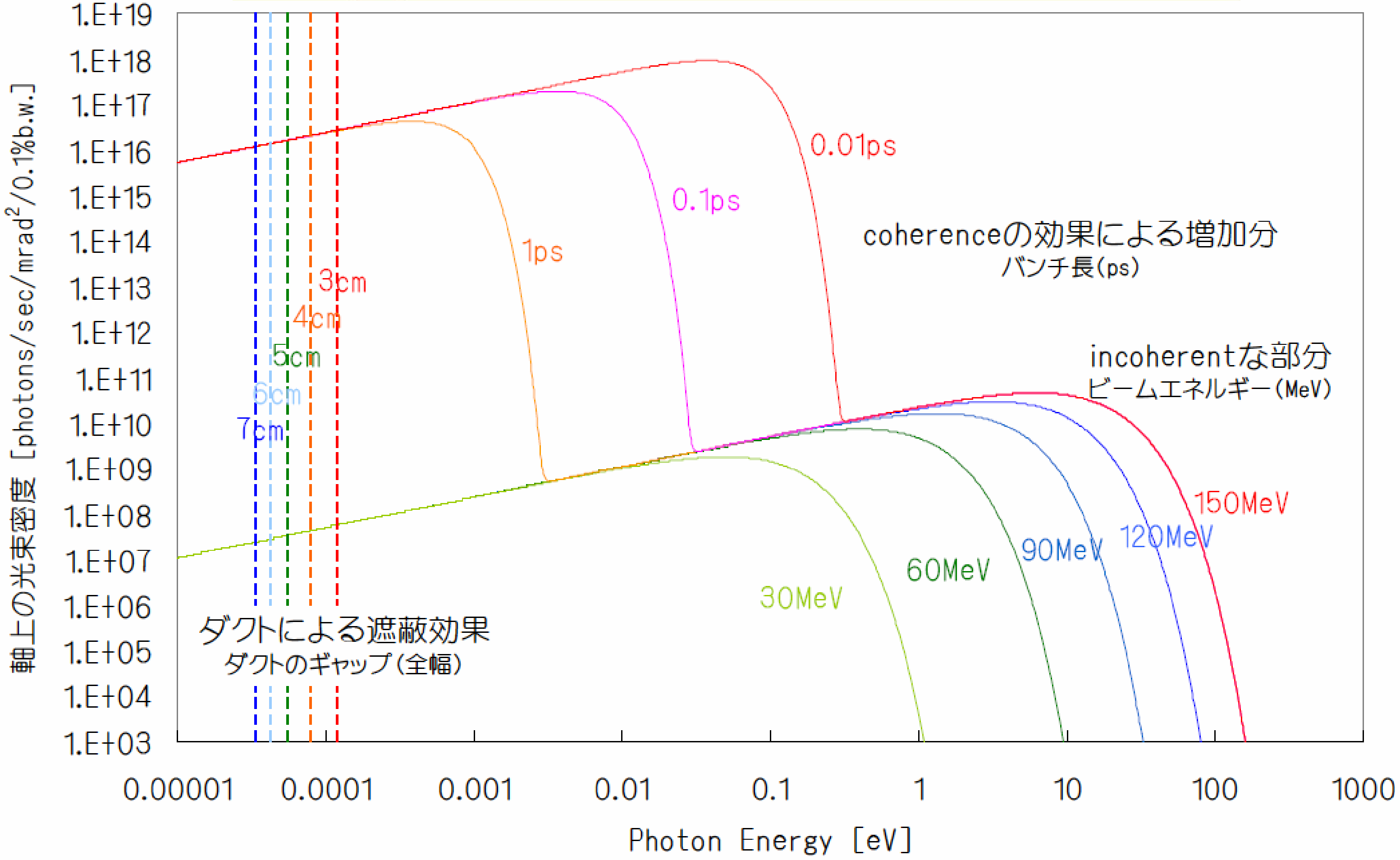
G. L. Carr*, Michael C. Martin†, Wayne R. McKinney†, K. Jordan‡, George R. Neil‡ & G. P. Williams‡

** National Synchrotron Light Source, Brookhaven National Laboratory, Upton, New York 11973, USA*
† Advanced Light Source Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
‡ Free Electron Laser Facility, Jefferson Laboratory, 12000 Jefferson Avenue, Newport News, Virginia 23606, USA



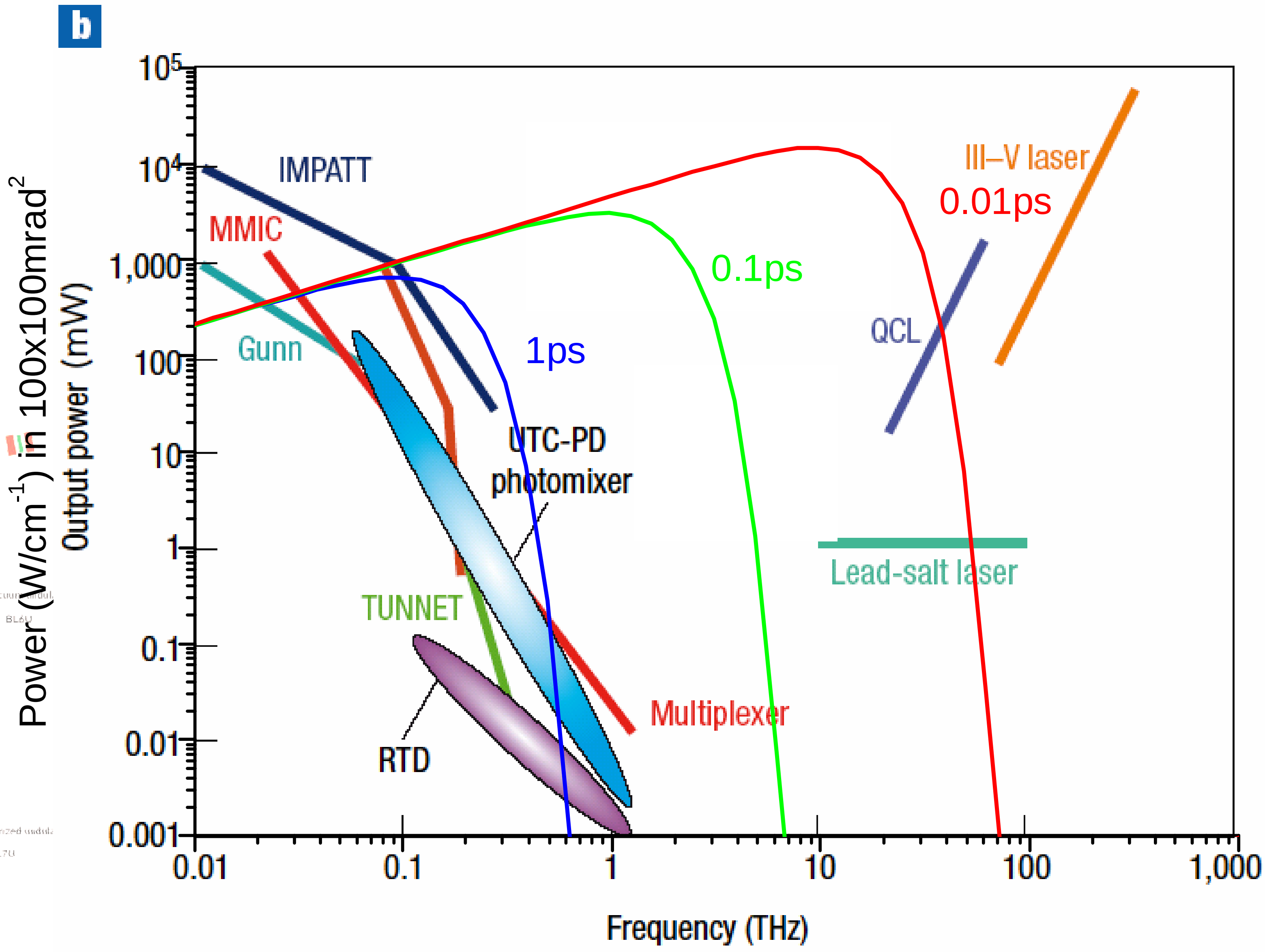
Intense CSR from ERL @ KEK





[K. Harada @ KEK]

High power CW THz sources



[M. Tonouchi, nature photonics **1**, 97 (2007).]

Conclusion + outlook

- Present THzSR + IRSR
  - High intensity + high brilliance.
  - Applications are mainly conventional use.
  - New advanced spectroscopies were produced.

- Future
  - We need intense IR + THz light.
    - Further advanced spectroscopy. (SNOM,)
    - THz pump – VIS, X-ray,,,, probe experiment.
    - Chemical reaction.
    - Etc.