Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

THz光を用いた分光研究とcERLへの期待

Shin-ichi KIMURA

UVSOR Facility, Institute for Molecular Science,

and School of Physical Sciences, The Graduate University for Advanced Studies,

Okazaki 444-8585, Japan

Acknowledgments

Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

M. Katoh, M. Adachi, H. Zen,
M. Shimada, Y. Taira,
K. Imura @ UVSOR Facility

M. Hosaka, N. Yamamoto,
Y. Takashima
@ Nagoya University

T. Takahashi
@ Kyoto University

C. Evain, C. Szwaj, S. Bielawski,
T. Tanikawa
@ Université des Sciences et Technologies de Lille, FRANCE

P. Probst, A. Scheuring, K. Il'in,
S. Wünsch, M. Siegel
@ KIT, GERMANY

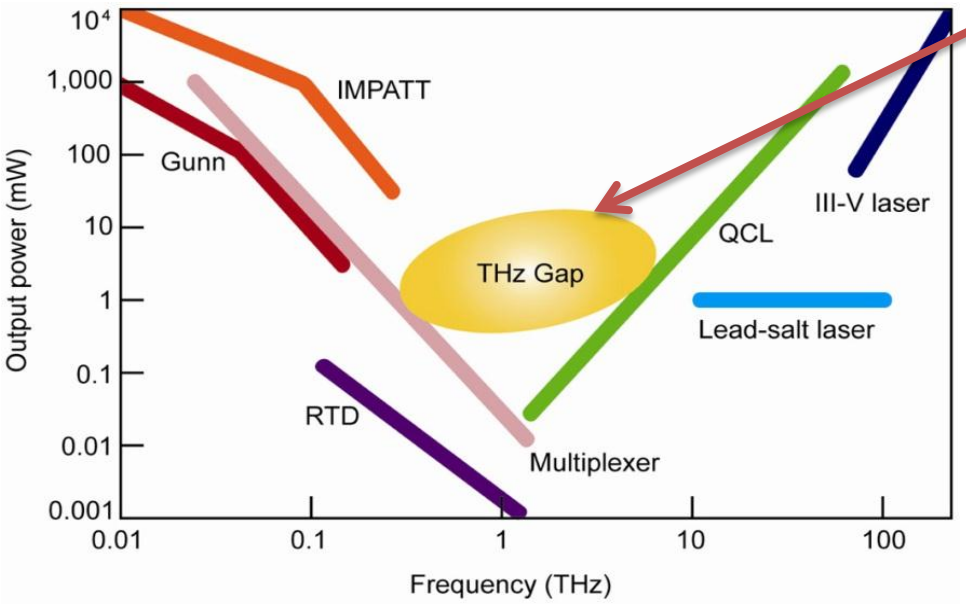
Financial support
Quantum Beam
Technology Program
(FY2008-2012)
of MEXT, Japan.

Outline

- IR/THz Synchrotron Radiation to Coherent Synchrotron Radiation (CSR)
  - What's THz?
  - IR/THz-SR
  - Present status of THz-CSR at UVSOR-III
- CSR from cERL
  - Expected average/peak intensity
  - Proposal scientific program
  - Other intense THz source project in the world
- Conclusion

Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

Terahertz



No intense light source in THz

1 THz
= 4.13 meV
= 52 K
= 300 μm
= 33.3 cm^{-1}

Radio wave — "THz gap" — Optics

THz

Microwave | millimeter wave | sub-mm wave | infrared | visible | ultraviolet | X-ray

0.001 0.01 0.1 1 10 100 1000 10000 [THz]

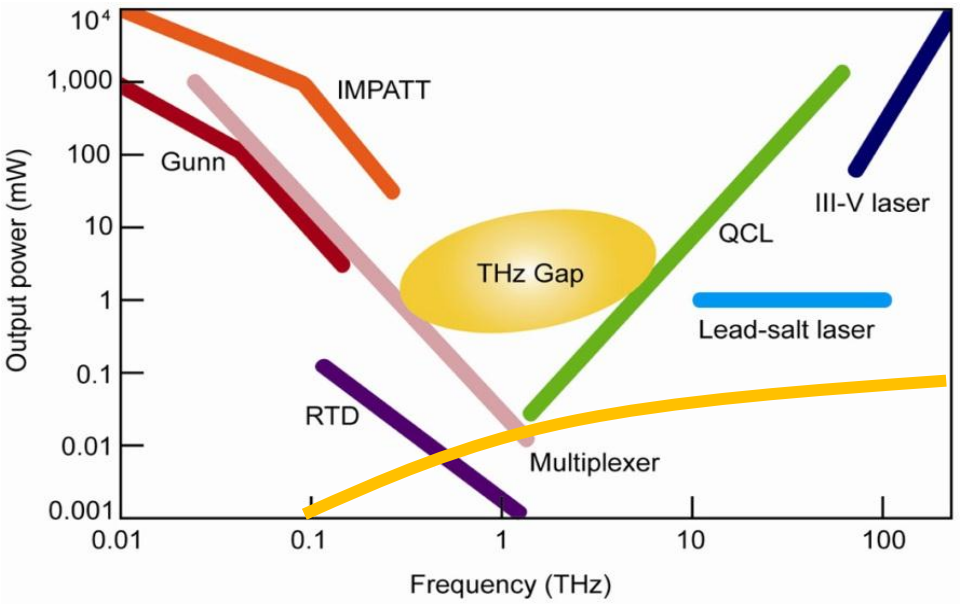
SC gap RT molecule Si gap

many elementary excitations …

Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

Terahertz

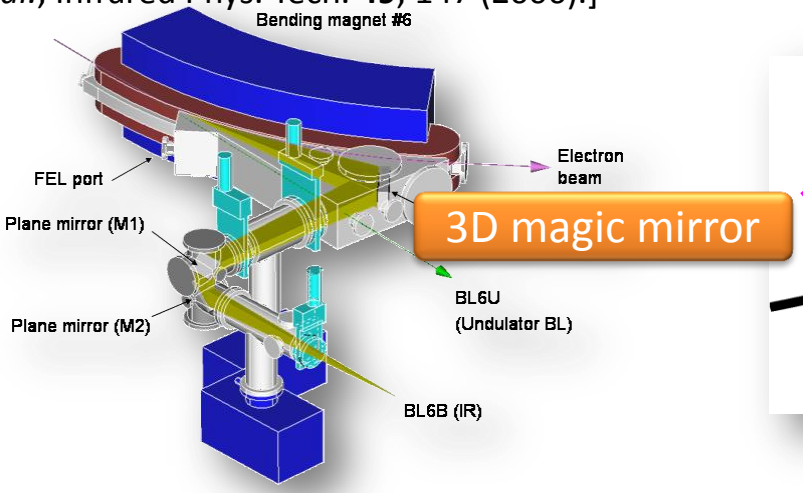


1 THz
= 4.13 meV
= 52 K
= 300 μm
= 33.3 cm^{-1}

BL6B @ UVSOR-II

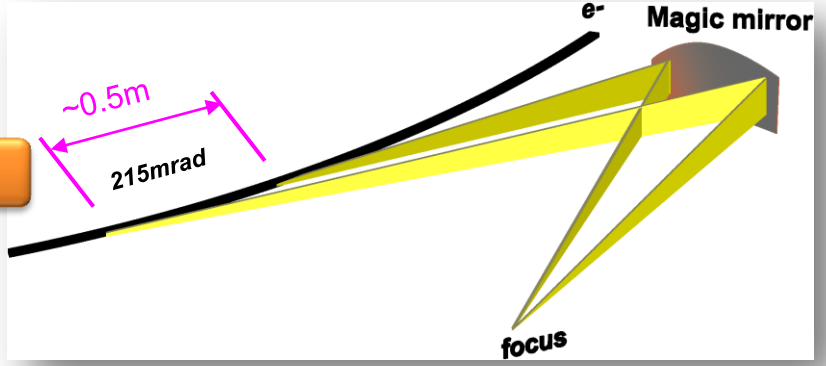
The highest-flux IR/THz BL

[SK *et al.*, Infrared Phys. Tech. **49**, 147 (2006).]

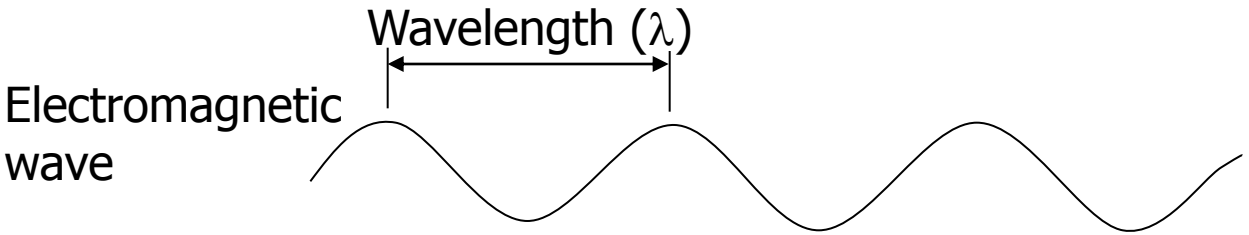


3-dimensional magic mirror

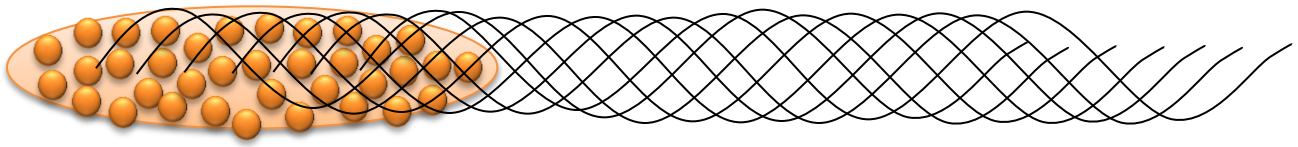
[SK et al., NIMA **467-468**, 437-440 (2001).]



What's coherent synchrotron radiation (CSR) ?



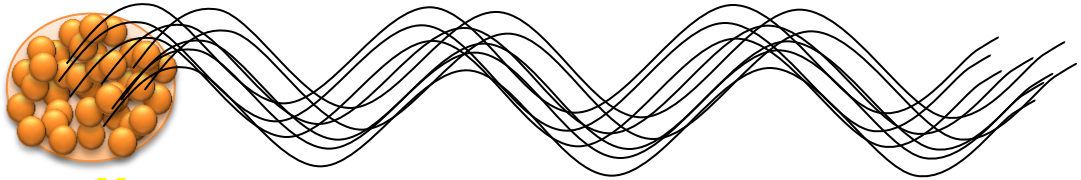
Bunch length » λ [normal synchrotron radiation]



→ incoherence

+

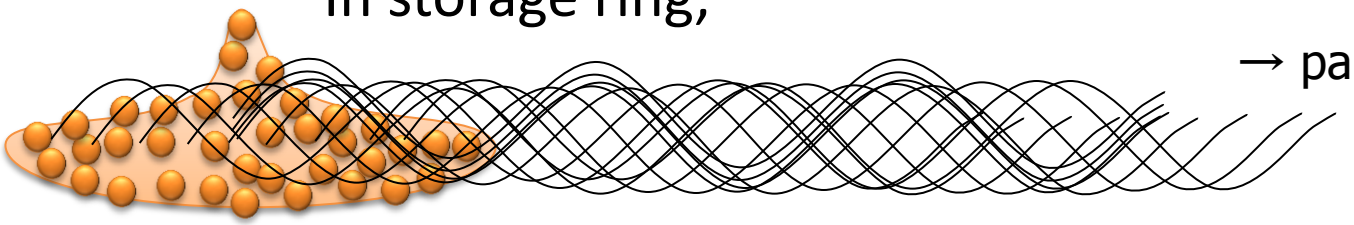
Bunch length ≤ λ [linac, energy recovery linac,,,,]



→ full coherence

=

In storage ring,

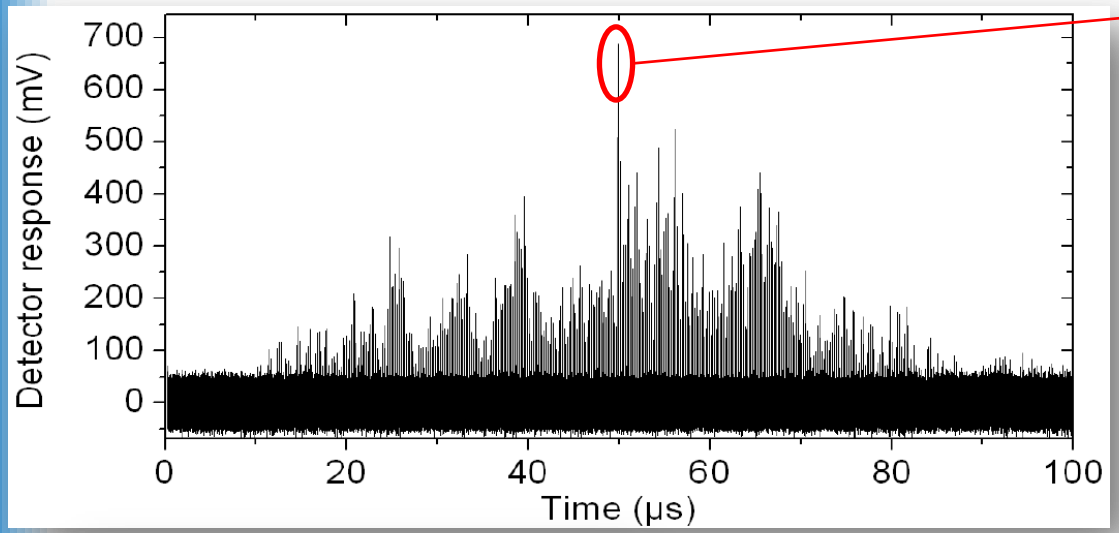


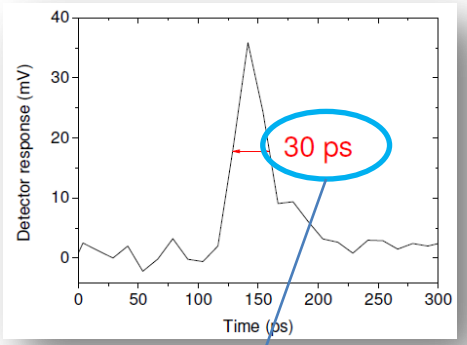
→ partial coherence

Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

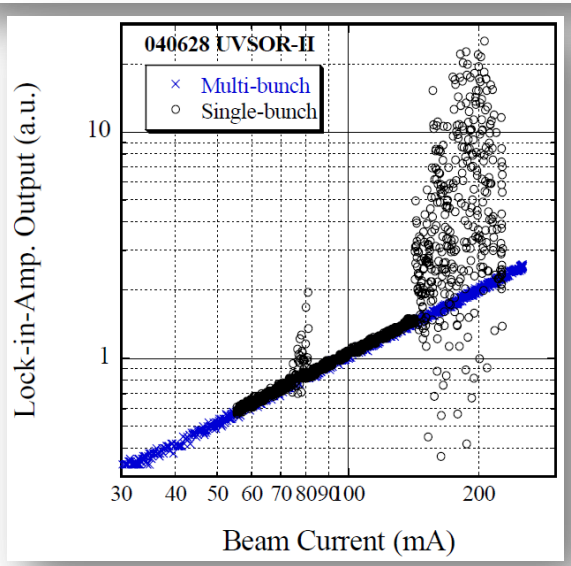
Bursting emission at UVSOR-II

Time structure of THz bursting detected by YBCO detector.
[P. Petra, SK *et al.*, submitted to IEEE Trans. THz Sci. Tech.]





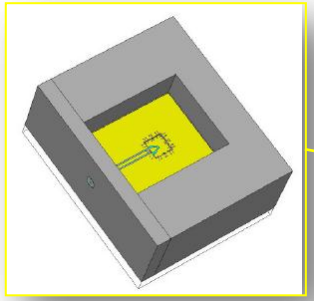
~several 100 ps



[Y. Takashima, SK *et al.*, JJAP **44**, L1131 (2005).]

LN_2-cooled YBCO detector
[P. Probst *et al.*, APL **98**, 043504 (2011).]

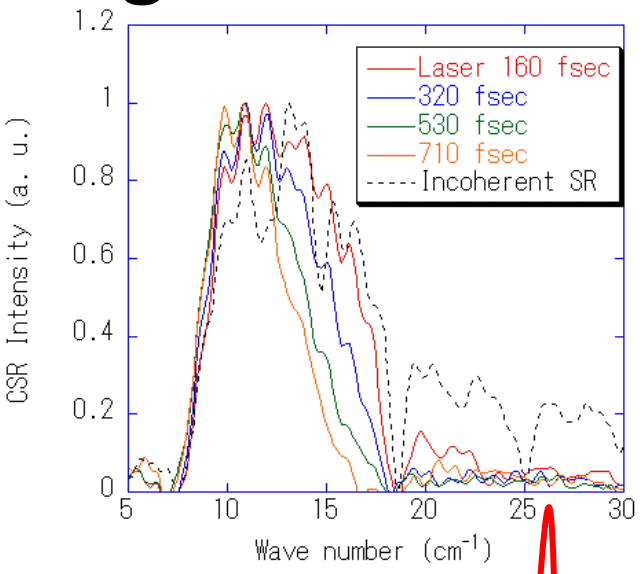
Karlsruhe Institute of Technology

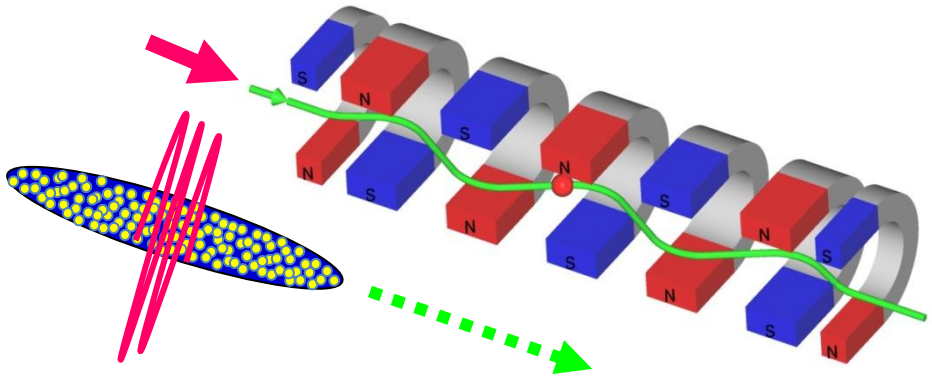


Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

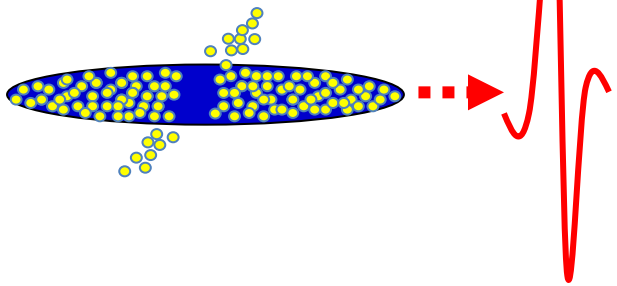
THz CSR via Laser Bunch Slicing at UVSOR-II

[Y. Takashima, SK *et al.*, Jpn. J. Appl. Phys. **44** (2005);
M. Shimada, SK *et al.*, Jpn. J. Appl. Phys. **46**, 7939 (2007);
M. Shimada, SK *et al.*, Phys. Rev. Lett. **103** (2009).]





Pulse laser



CSR

Normal (Incoherent) SR

Coherent SR

SR Power emitted by an electron bunch

$$P = P_0(N_e + N_e^2 F_e)$$

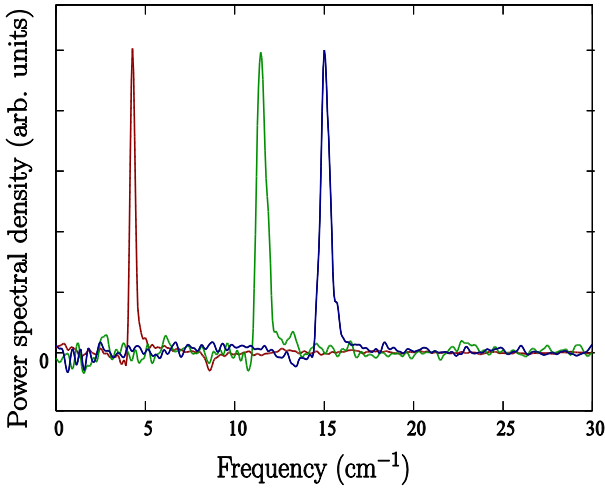
$$F_e = \left(\int \cos(2\pi z/\lambda) S(z) dz\right)^2$$

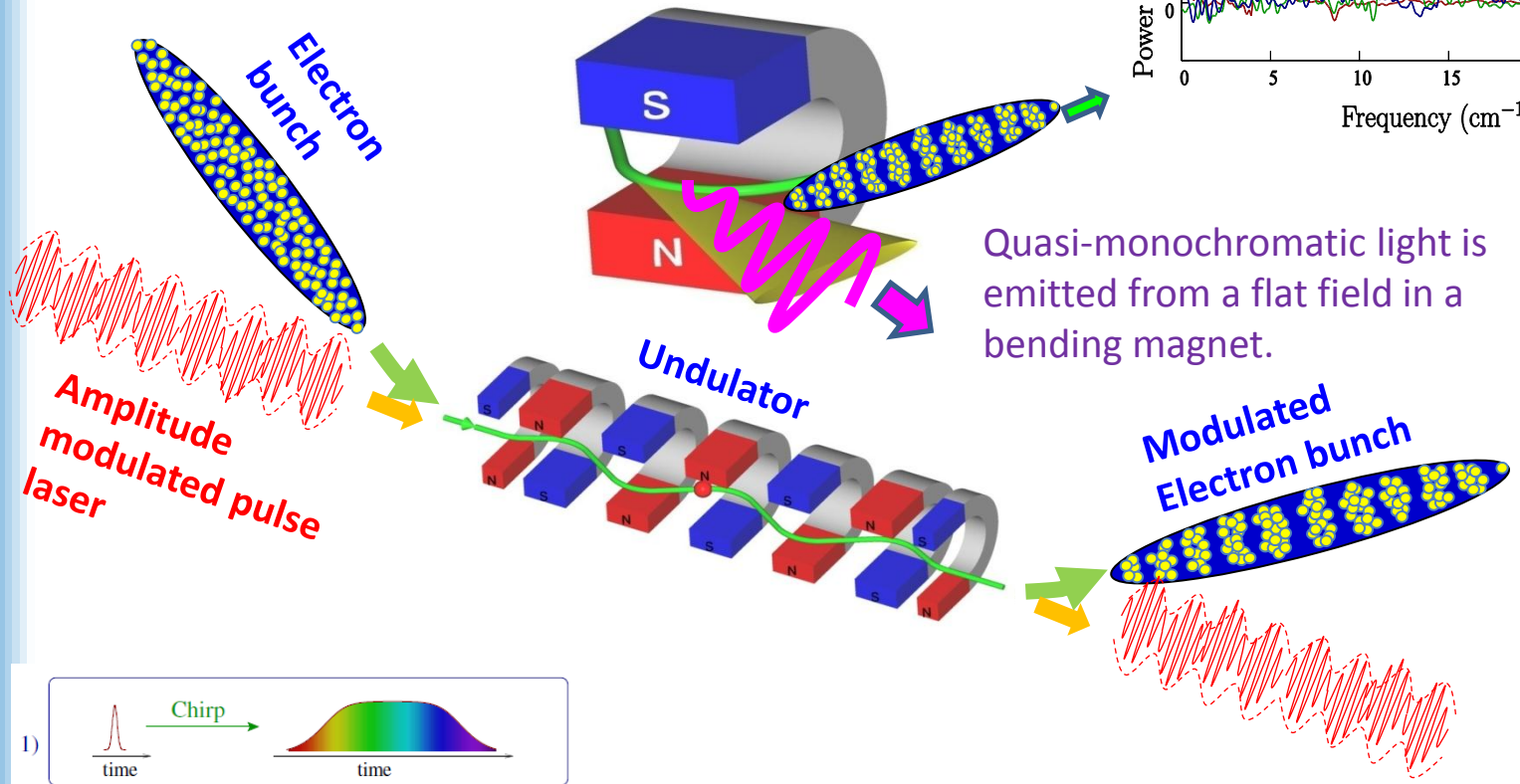
P_0; SR power from a single electron
N_e; Number of electrons in a bunch
F_e; Form factor of electron bunch
S(z); Longitudinal density distribution of electron bunch

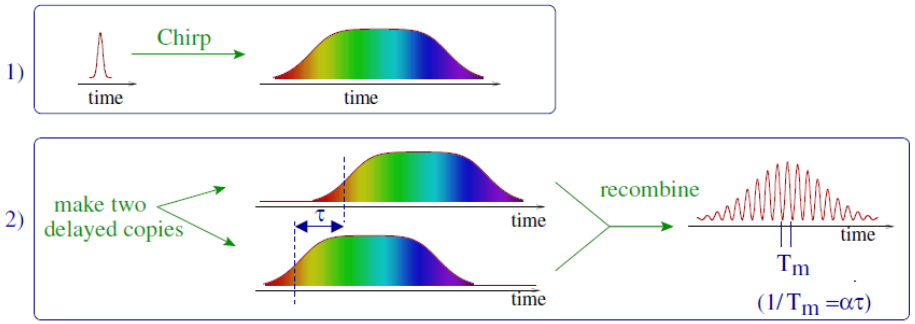
Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

Quasi-monochromatic CSR generated by amplitude-modulated pulse laser

[S. Bielawski, SK et al., Nature Physics, **4**, 390 (2008).]





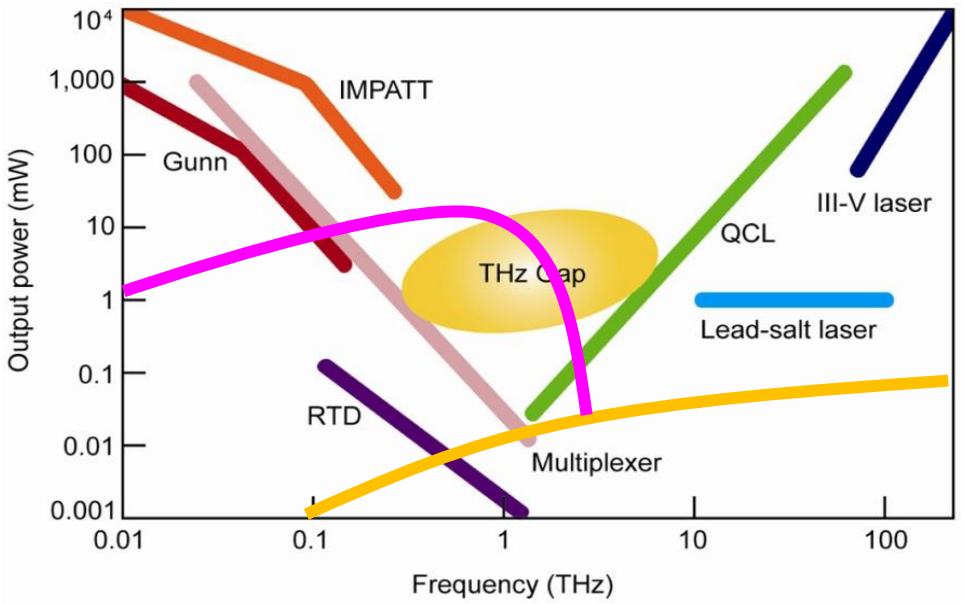


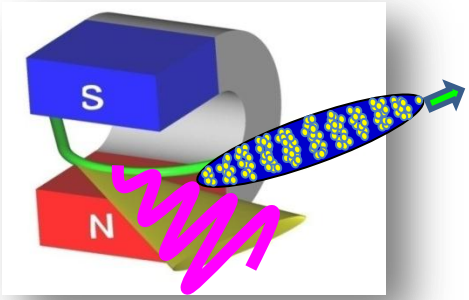
- ✓ Peak power => 10,000 times of "normal" SR
- ✓ Peak wavenumber : controlled by Michelson delay → Tunable

Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

Terahertz



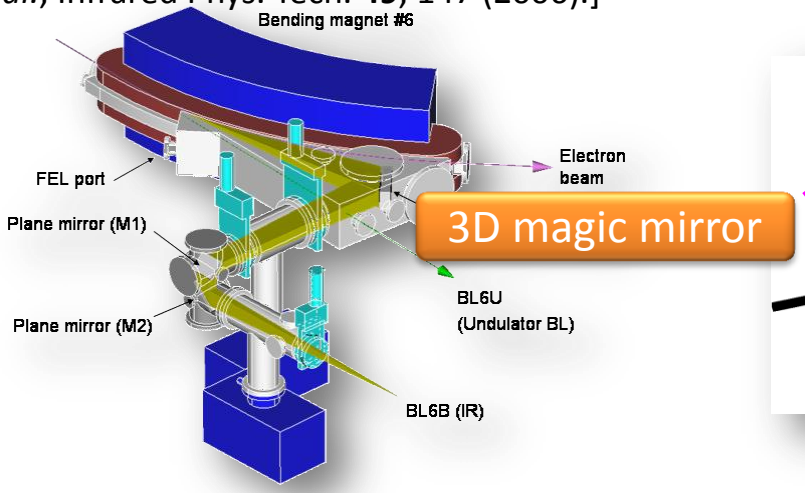


1 THz
= 4.13 meV
= 52 K
= 300 μm
= 33.3 cm^{-1}

BL6B @ UVSOR-III

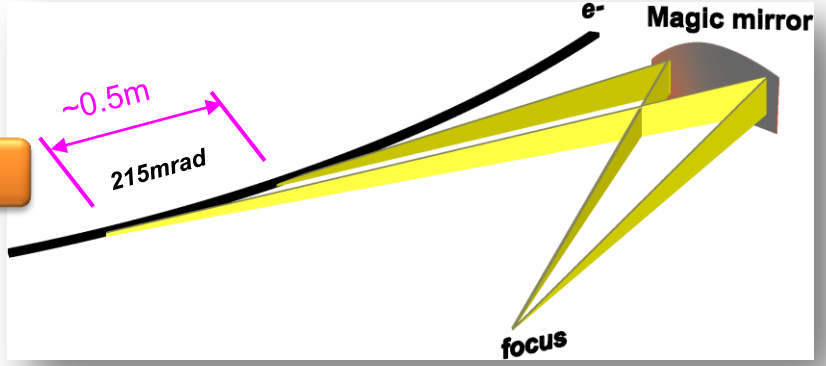
The highest-flux IR/THz BL

[SK *et al.*, Infrared Phys. Tech. **49**, 147 (2006).]

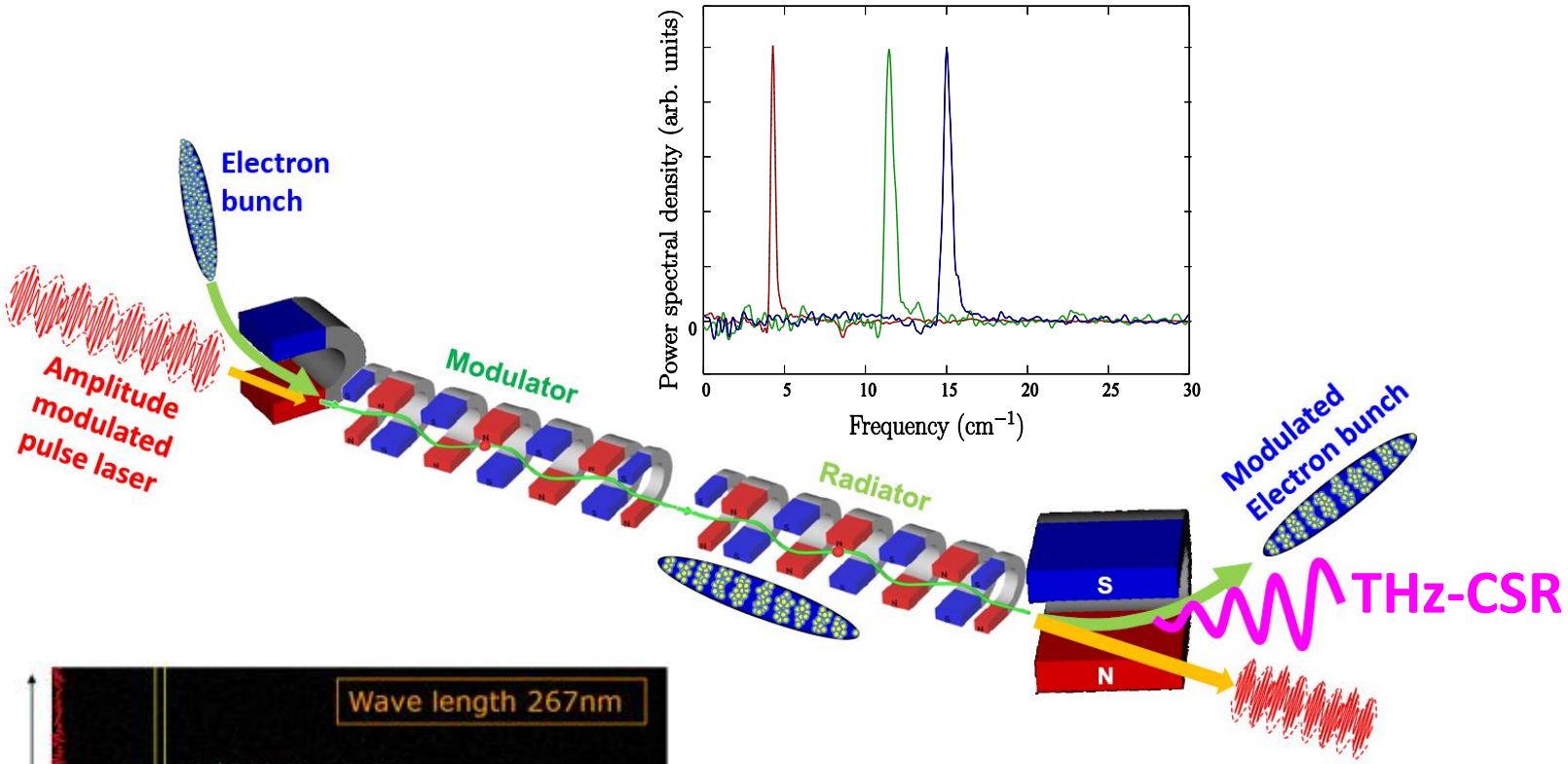


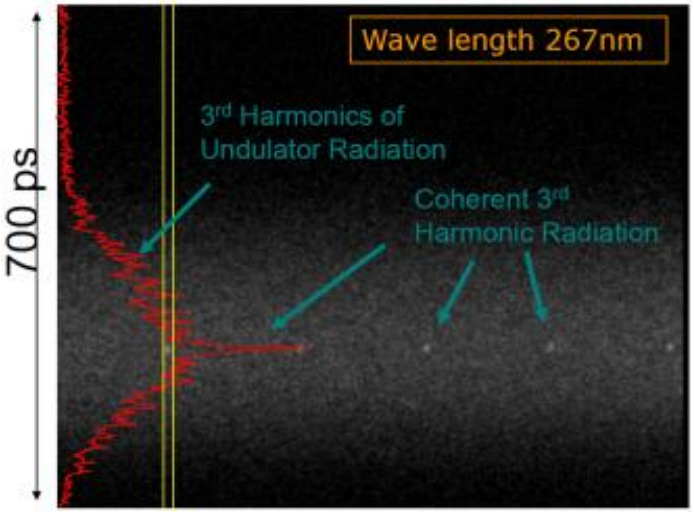
3-dimensional magic mirror

[SK et al., NIMA **467-468**, 437-440 (2001).]



Combination of THz-CSR and Coherent Harmonic Generation (CHG) in the VUV region





[M. Labat et al., Euro. Phys. J. D **44**, 187 (2008);
T. Tanikawa et al., Appl. Phys. Express **3**, 122702 (2010).]

Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

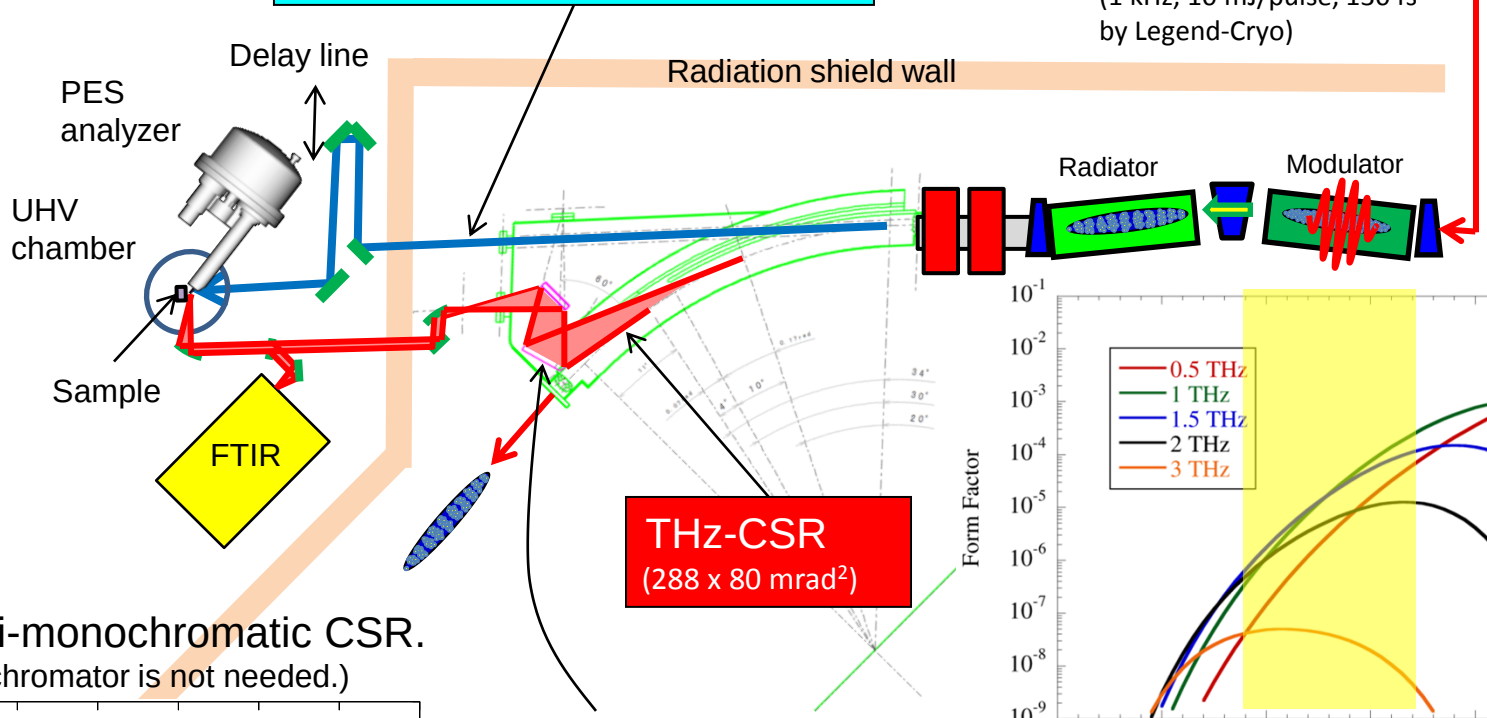
Quantum Beam Technology Program

THz pump–PES probe (TP^{3}S) beamline at UVSOR-III

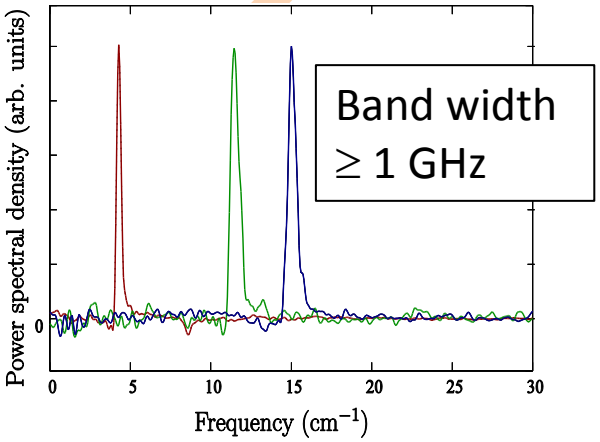
Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

VUV-CHG [6-th CHG ($h\nu \sim 9$ eV) is expected. $\Delta h\nu \leq 10$meV]

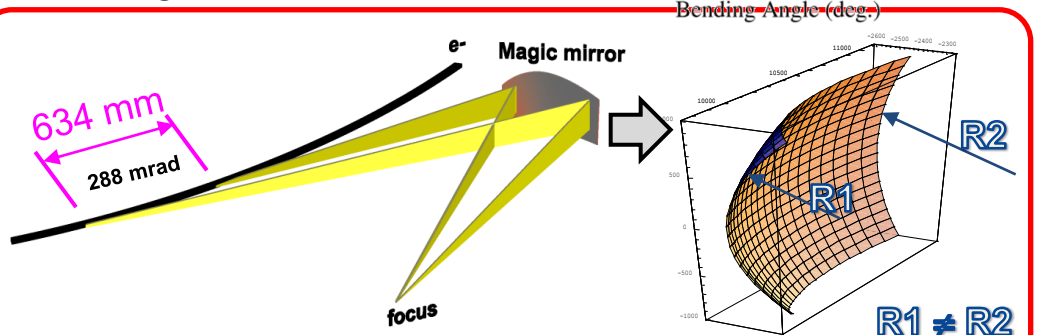
Ti:Sa laser
(1 kHz, 10 mJ/pulse, 130 fs by Legend-Cryo)



Quasi-monochromatic CSR.
(Monochromator is not needed.)



3D-magic mirror

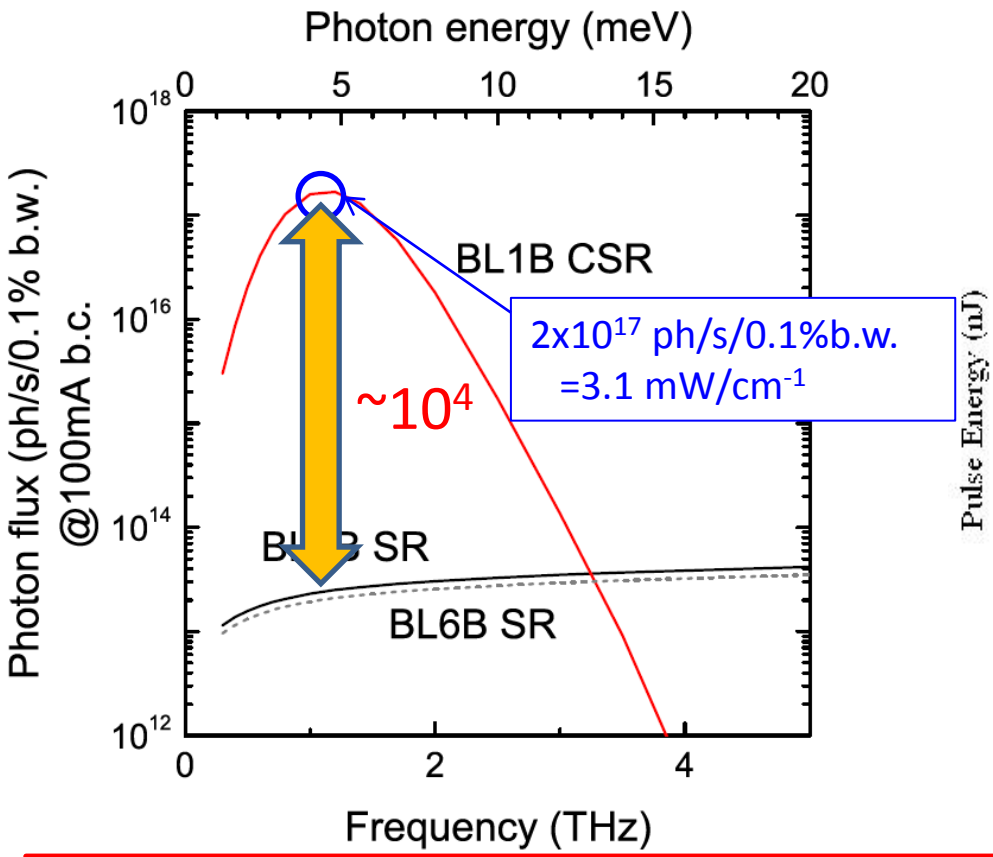


[S. Kimura et al., NIMA **467-468**, 437 (2001).]

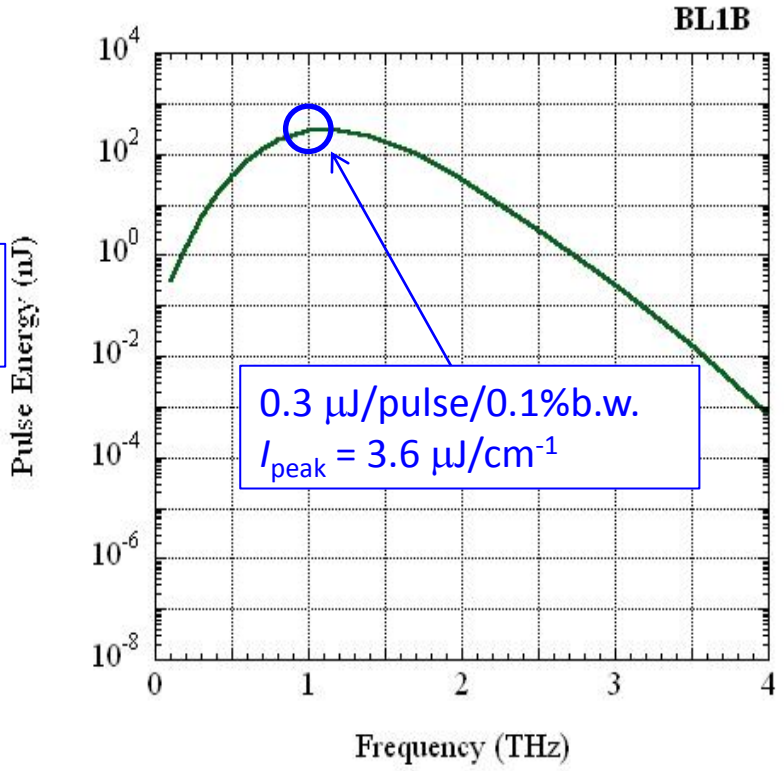
Photon flux and peak power of THz-CSR

(Calculated by M. Hosaka)

Average photon flux



Peak power

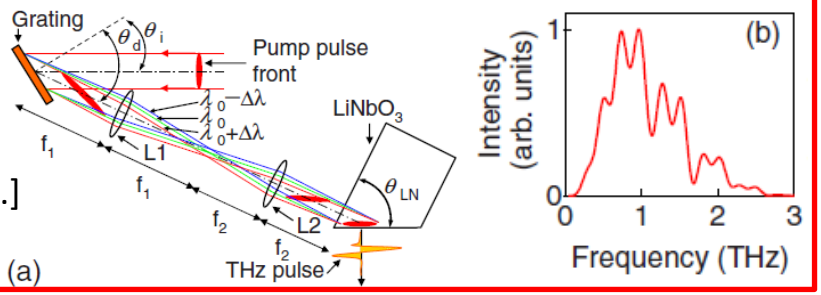


cf.) Highest peak power of laser THz source :

2 μJ/pulse ← white light

[H. Hiroi et al., APL **98**, 091106 (2011);
Nature Commun. **2**, 594 (2011).]

~ 0.005 μJ/pulse/0.1%b.w. @ 1 THz



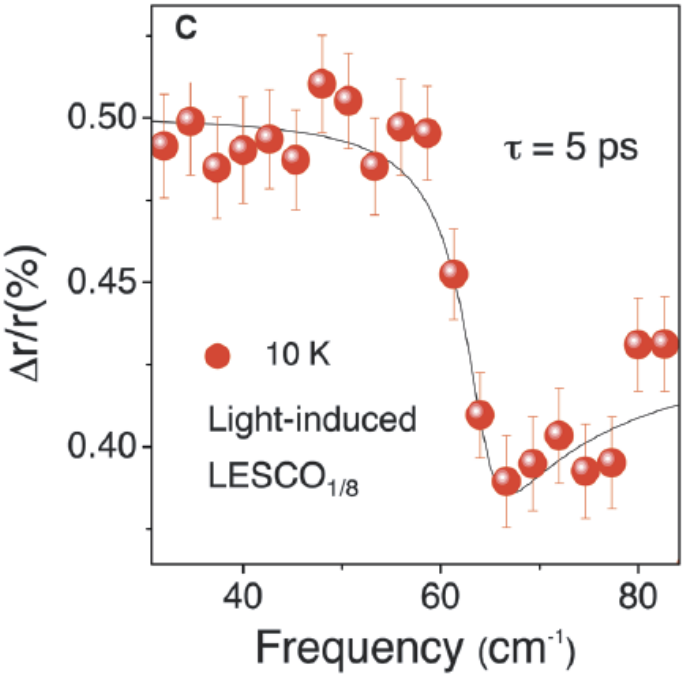
Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

Previous THz/IR pump experiments

THz-pump – THz-TDS probe

THz-induced Josephson plasma of LSCO

[D. Fausti et al., Science **331**, 189 (2011).]

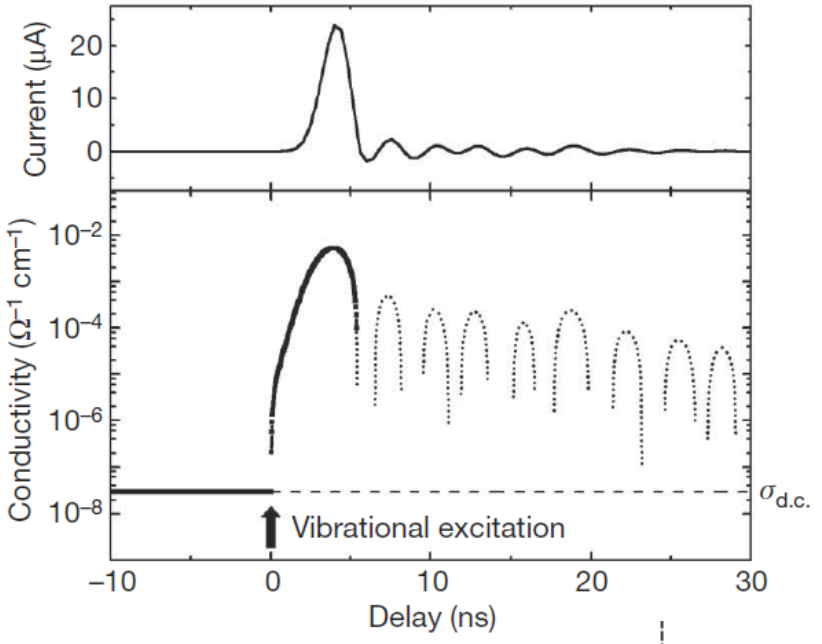


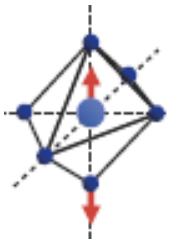
Pump: 16 μm (12 THz, 40 meV)

THz-pump – transport probe

THz-induced MIT of $Pr_{0.7}Ca_{0.3}MnO_3$

[M. Rini et al., Nature **449**, 72 (2007).]





Pump: 17 THz (71 meV)

Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

Compact Energy Recovery Linac @ KEK

First beam injection: 4th Quarter 2013
First light: in 2014 (?)

By M. Shimada

horizontal acceptance		300	mrad			
current		10	mA			
	electron energy [MeV]	electron charge [pC]	bunch length [ps]	CSR pulse energy [J/pulse]	CSR pulse peak power [W]	CSR average power [W]
case 1	60	77	0.1	5.89E-06	2.50E+07	7.65E+02
case 2	60	500	1	1.12E-05	4.74E+06	2.24E+02
case 3	200	200	0.1	4.00E-05	1.70E+08	2.00E+03
case 4	200	1000	1	4.47E-05	1.90E+07	4.47E+02

Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

CSR @ J-lab. ERL

[Nature **420**, 153 (2002).]

Jefferson Lab

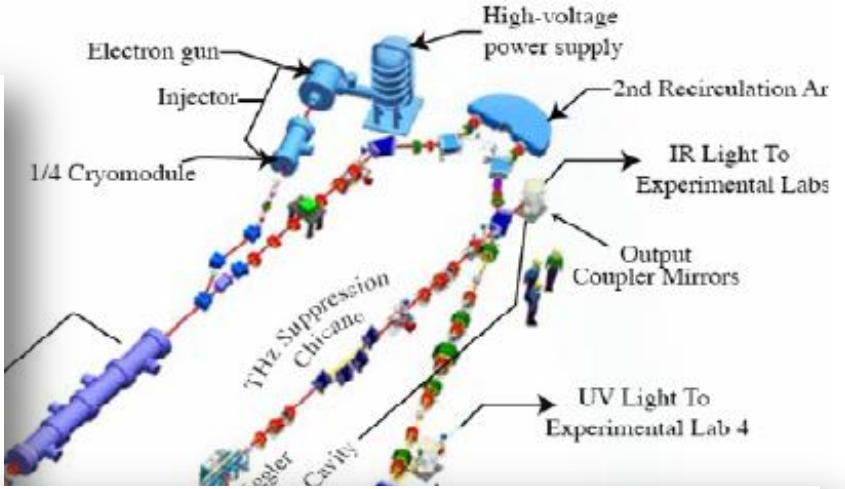
High-power terahertz radiation from relativistic electrons

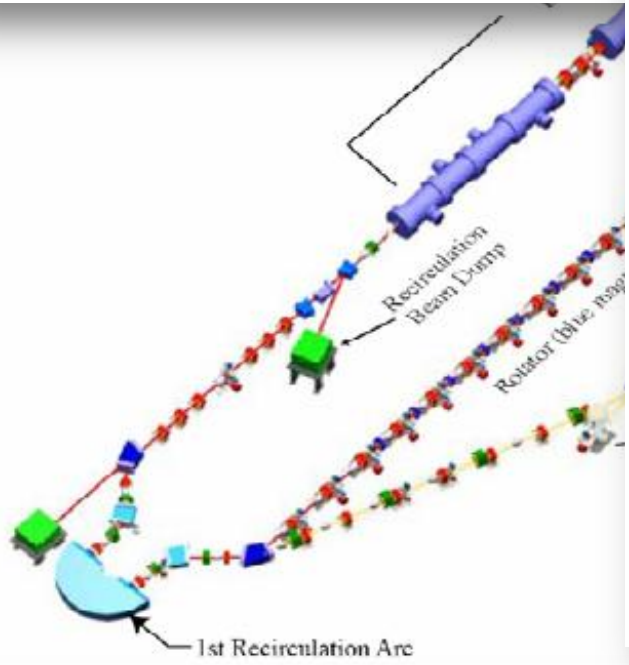
G. L. Carr*, Michael C. Martin†, Wayne R. McKinney†, K. Jordan‡, George R. Neil‡ & G. P. Williams‡

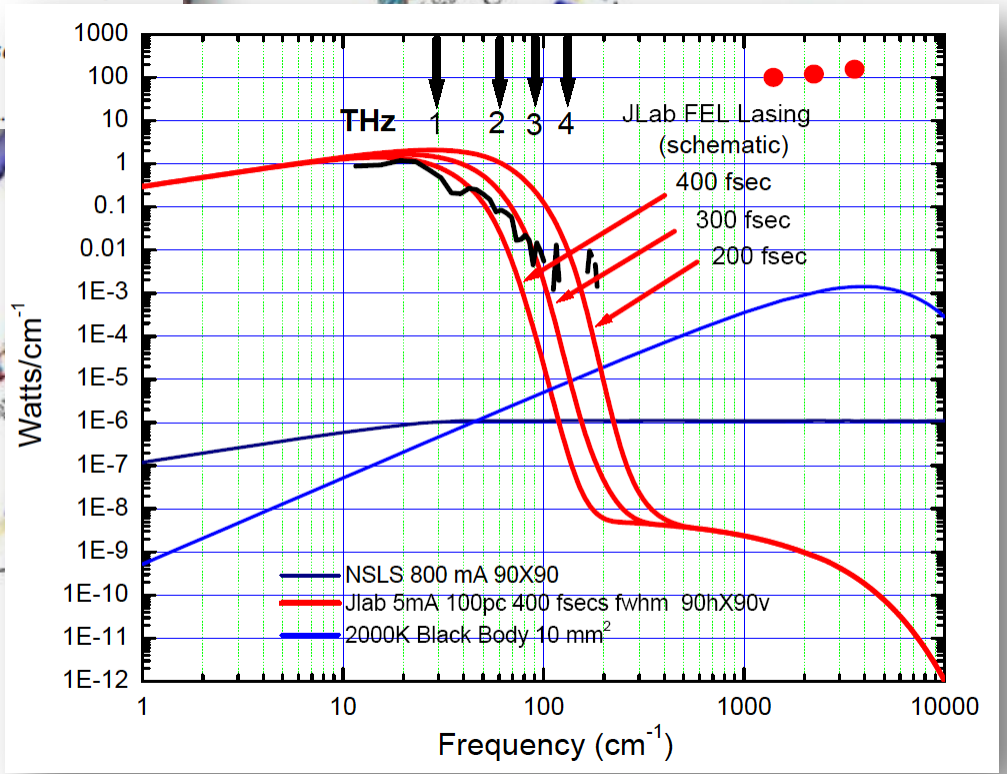
* *National Synchrotron Light Source, Brookhaven National Laboratory, Upton, New York 11973, USA*

† *Advanced Light Source Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*

‡ *Free Electron Laser Facility, Jefferson Laboratory, 12000 Jeffers Newport News, Virginia 23606, USA*



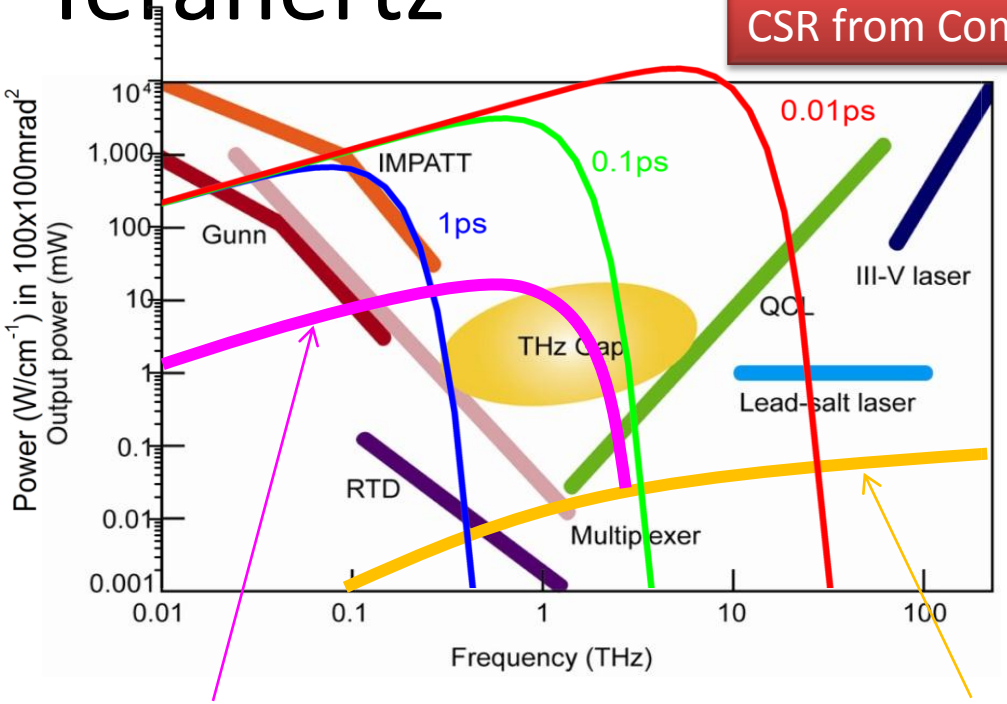




Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

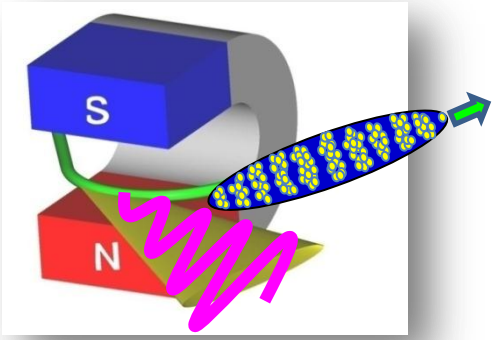
Terahertz



CSR from Compact ERL

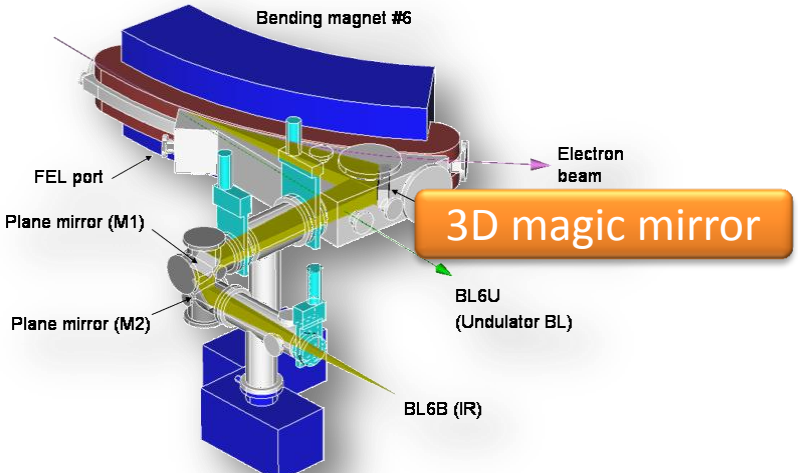
1 THz
= 4.13 meV
= 52 K
= 300 μm
= 33.3 cm^{-1}

Laser-slicing CSR



BL6B @ UVSOR-III

The highest-flux IR/THz BL



Expected scientific programs

THz pump- ??? probe

(QP, Phonon,,,)

- LCS X/SX probe
  - Diffraction
  - XANES/DXAFS
  - Imaging
  - (AR)PES
- THz-TDS probe
  - Absorption/reflection
- Laser probe
  - Absorption/reflection
  - ARPES
- + Laser pump + LCS X probe (by Nakamura)

THz-probe

- SNOM
- Wide region imaging
- Combination with x-ray imaging (absorption, phase contrast)

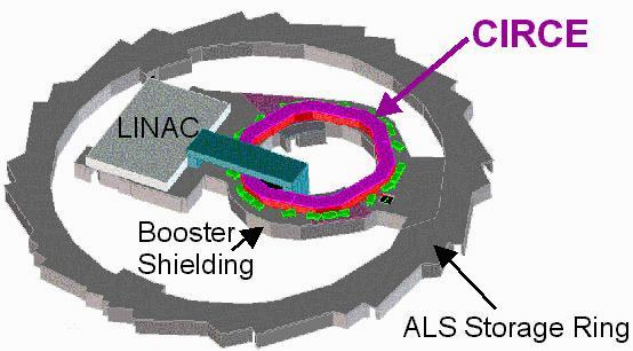
Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

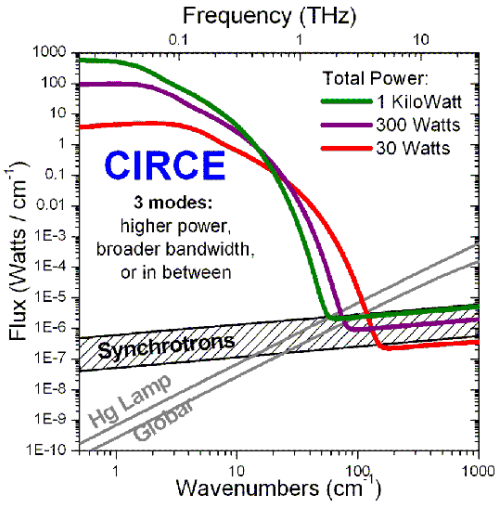
Other CSR source projects

Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN

CIRCE Coherent InfraRed CEnter @ ALS

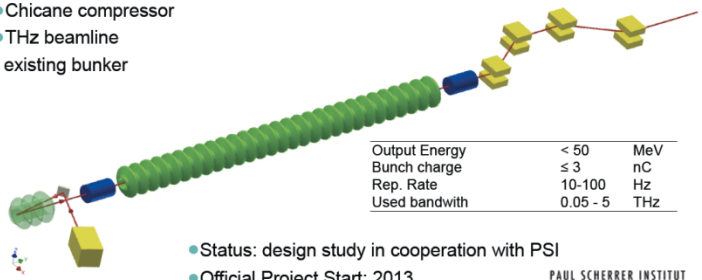
[http://circe.lbl.gov/]





FLUTE: A Test Experiment

- Allow small scale tests of THz generation, compression, radiation transport and instrumentation, ...
- Outline:
  - Photo injector (CTF 3 type)
  - S band normal conducting linac
  - Chicane compressor
  - THz beamline
- Use existing bunker



Output Energy	< 50	MeV
Bunch charge	≤ 3	nC
Rep. Rate	10-100	Hz
Used bandwith	0.05 - 5	THz

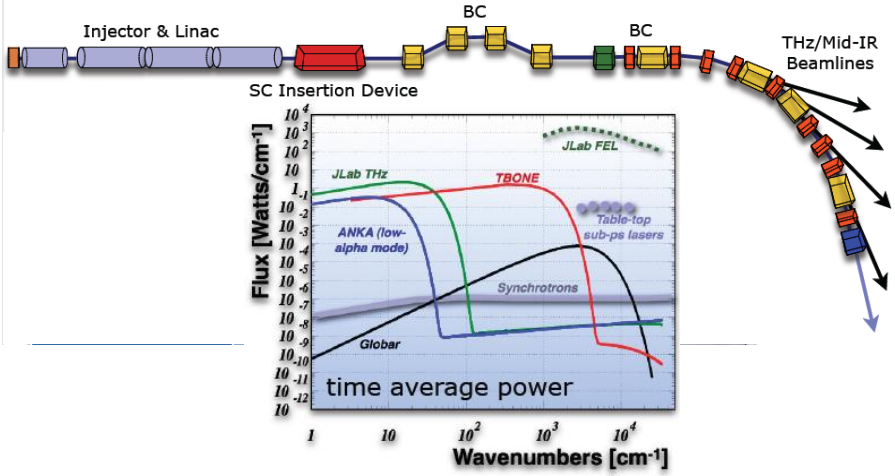
- Status: design study in cooperation with PSI
- Official Project Start: 2013

PAUL SCHERRER INSTITUT PSI

[http://www.isa.au.dk/meetings/esls2011/talks/ses6/2011-ESLS-Schuh.pdf]

TBONE @ ANKA

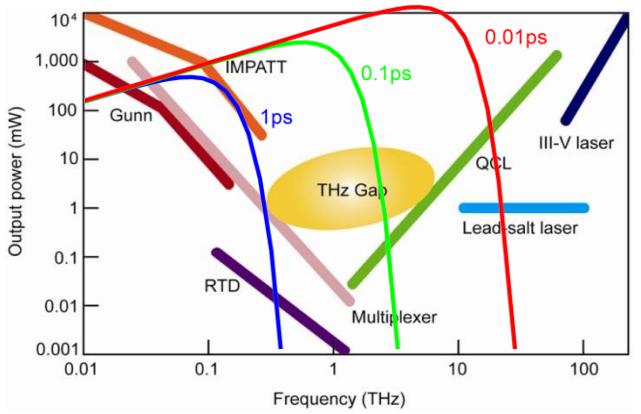
[http://ankaweb.fzk.de/conferences/TBONE/Home.html]

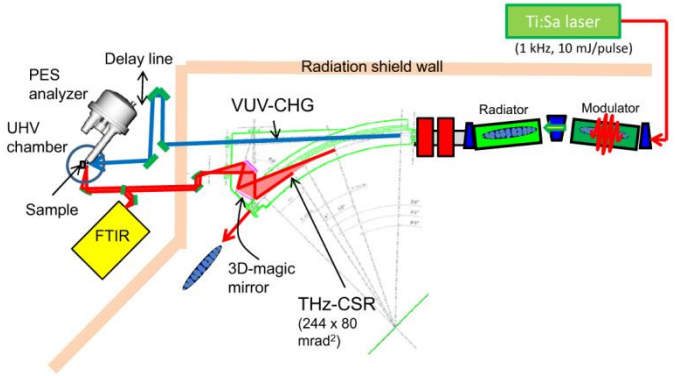


Conclusion

IR/THz-SR and THz-CSR activities at UVSOR-III, and expected intense THz from cERL are introduced.

- THz-CSR from cERL can bridge the THz gap.
- THz-pump PES-probe spectroscopy (TP^3S) was desired at UVSOR-III.
  - The beamline was constructed and the test experiment will be performed .
- New experiments can be desired using cERL.





Shin-ichi KIMURA [kimura@ims.ac.jp]
UVSOR Facility, Institute for Molecular Science, JAPAN