Observation of THz CSR Burst at UVSOR-II

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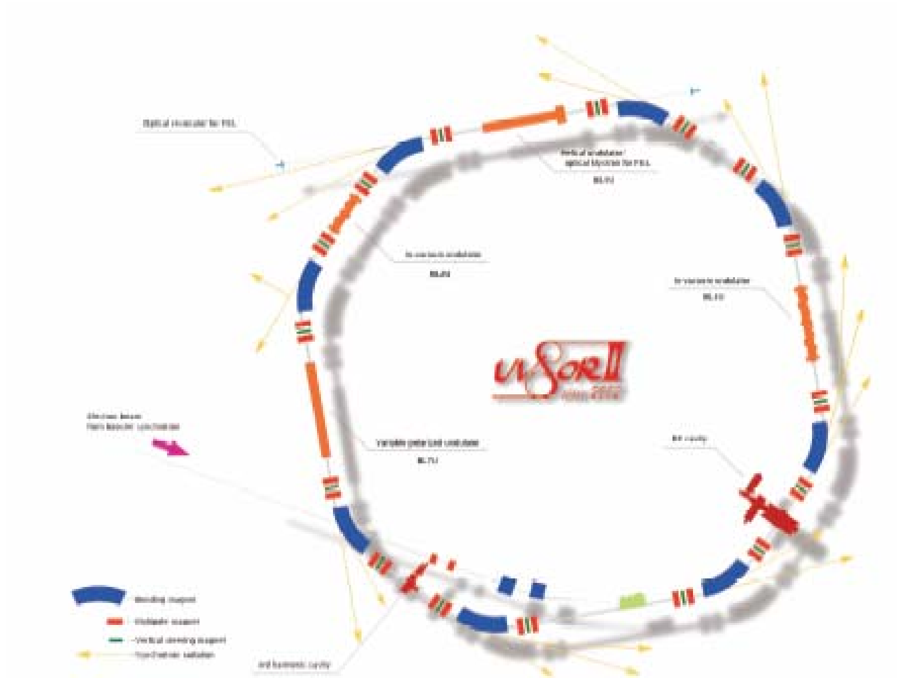
OUTLINE

- Accelerators, Infrared/THz beam line, detectors…
- Observation of THz CSR burst before / after RF cavity upgrade
  - Intensity of THz CSR burst
  - Temporal structure of burst train and of single burst
  - Condition for bursting
- Measurement with THz diode detector with high temporal resolution
- Effect of laser bunch slicing on THz CSR burst

UVSOR-II Accelerators

- **UVSOR promotes a research of THz CSR. There are two topics.**
  - **THz CSR burst due to the beam instability**
    (This talk)
  - **Laser bunch slicing**
    (by Mochihashi in the next session.)

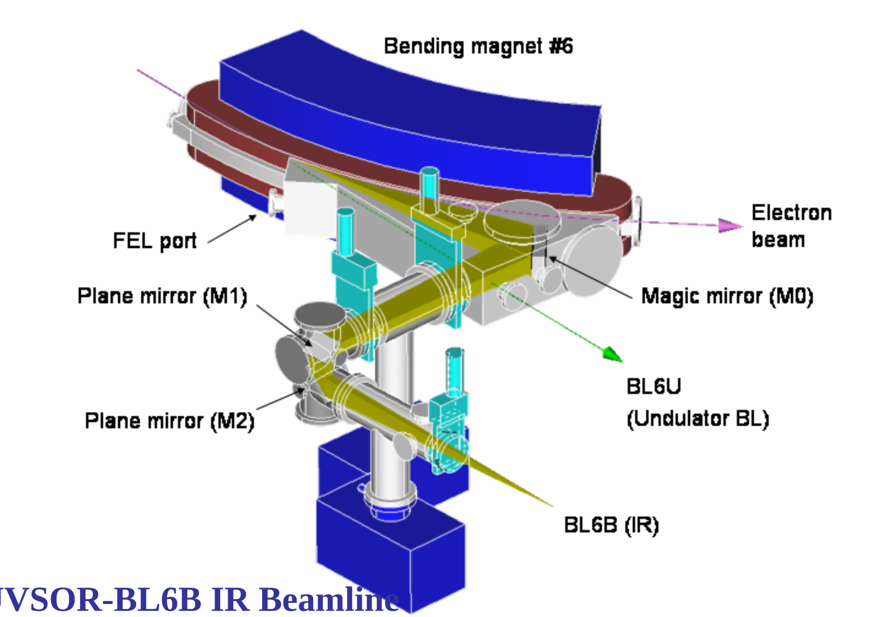


Specific at the THz CSR burst experiments

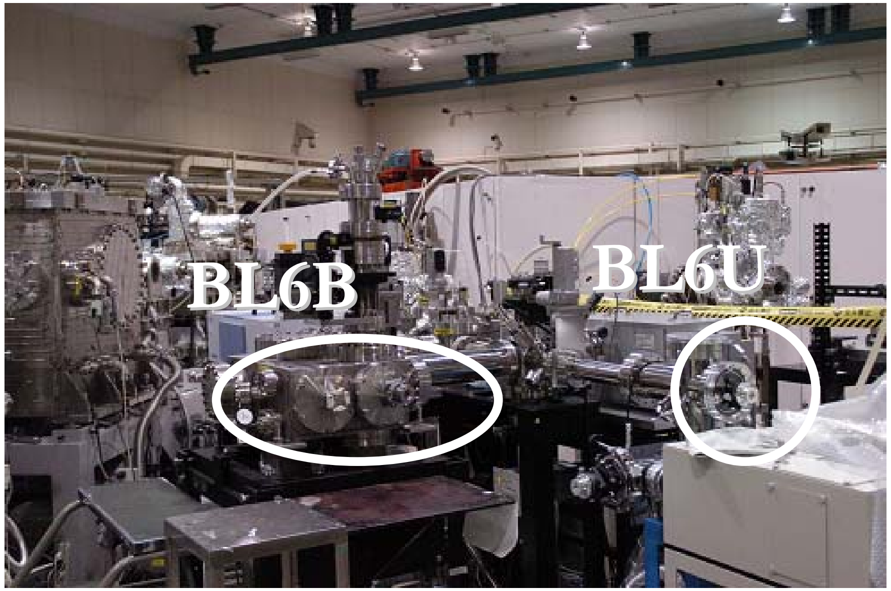
Electron Energy	600 MeV
Circumference	53.2 m
Natural Emittance	17.5 nm-rad
Natural Energy Spread	3.4×10^{-4}
Natural Bunch Length (rms)	~105.2 ps
RF Frequency	90.1 MHz
Synchrotron Frequency	14.4 kHz
Momentum Compaction Factor	0.028
Damping time	20 ms

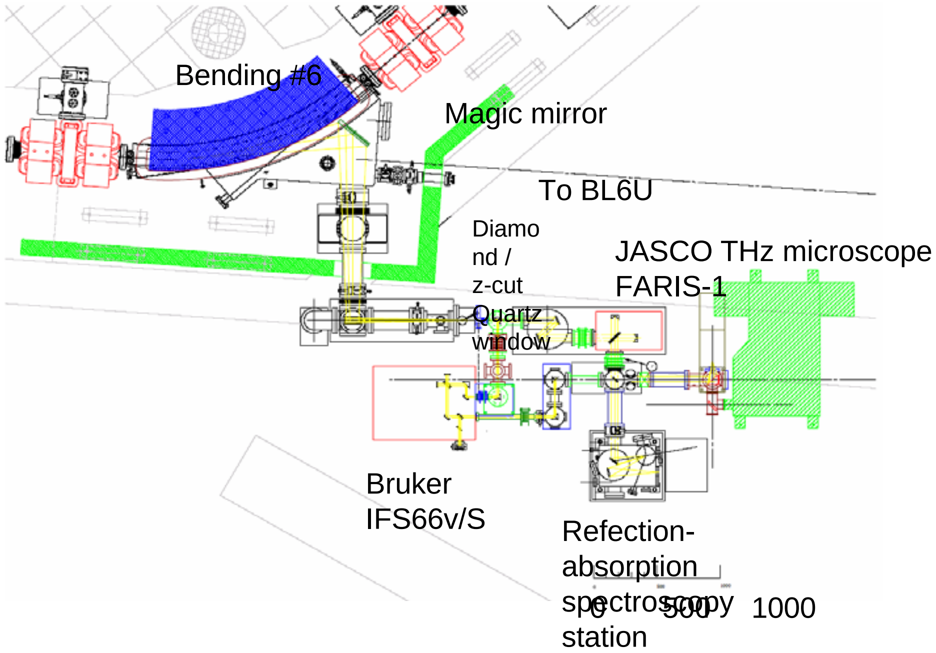
(before upgrade of RF cavity at 2005)

Beamline for THz



UVSOR-BL6B IR Beamline
S. Kimura et al., AIP Conf. Proc. 705 (2003)





Solid Angle

- BL6B 215×80 mrad^2
- BL6U 7×7 mrad^2

- The large solid angle of BL6B is realized by a magic mirror.
- BL6U is a monitor beamline.

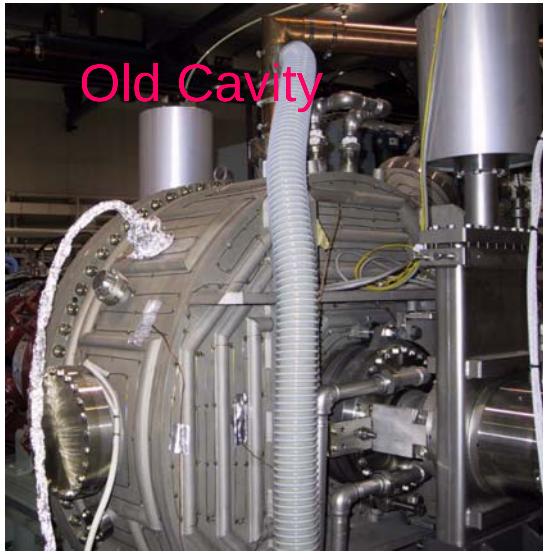
THz detectors

	Hot electron bolometer (InSb)	THz diode detector (Schottky)
Time resolution	1.6 μs (~ 10 revolution of UVSOR-II)	~ 100 ps
Spectral range	3cm^{-1}～50cm^{-1} (including the effect of the beamline optics, BL6B)	7.3cm^{-1}～11cm^{-1}
Sensitivity	5×10^5 V/W	~3×10^3 V/W
Operation temperature	4K (cooled by Liq. He)	Room temperature

- THz diode detector has a high time resolution and works at the room temperature.
- The sensitivity of the bolometer is much higher than THz diode detector

Virginia Diodes, Inc.

Upgrade of RF Cavity (2005)



After upgrade of RF cavity, the characters of the THz CSR burst has changed.

- Threshold
- time structure of burst train and the single pulse etc…

	Before Upgrade	After Upgrade
RF Frequency	90.1 MHz	90.1 MHz
RF Voltage	55 kV	150~200 kV
Synchrotron Frequency	14.4 kHz	19.4 kHz
RMS Bunch Length	105.2 ps	78.1 ps
Quality Factor	8000 (unloaded)	23800 (unloaded)
Shunt-impedance	500 kΩ	2.9 MΩ

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Before RF cavity upgrade

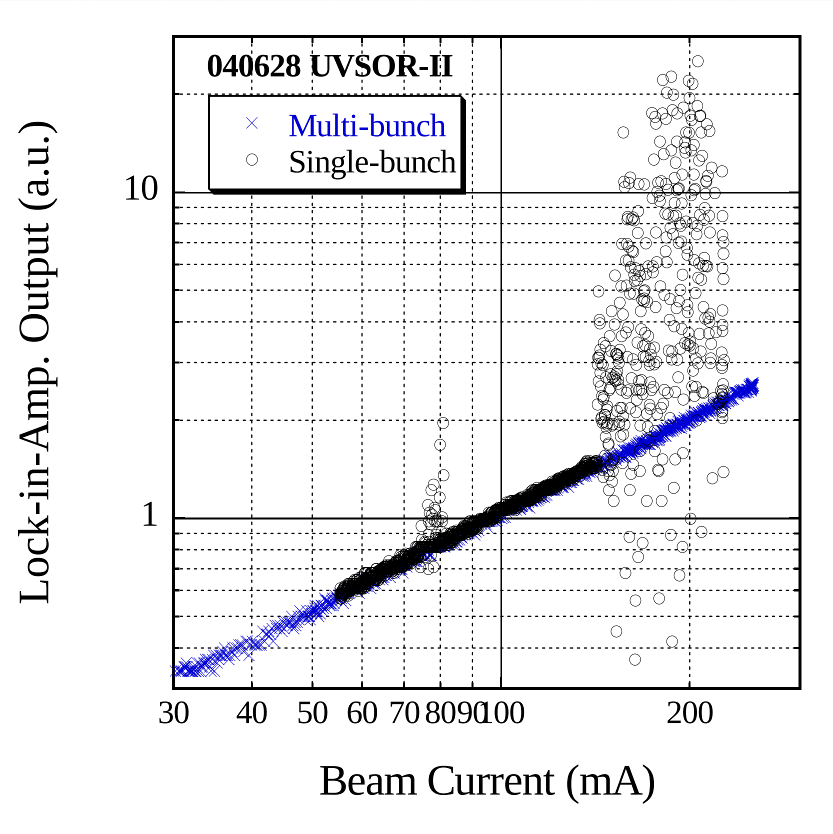
Measurement of intensity of THz burst

Y. Takashima et al. JJAP 44(35), 2005, 1131

- Average intensity is measured by using lock-in-amp and mechanical chopper with 100 Hz.
- Multi-bunch mode is proportional to the beam current.

- There is two current regions of THz burst, 80 mA and 140 ~ mA.
- Peak intensity of burst is 10^5 times larger than normal SR.

(raw data does not show here)



Average intensity of terahertz radiation with a multi-bunch and single-bunch mode

Time structure of terahertz burst train

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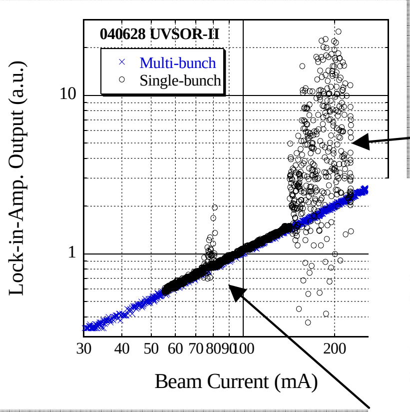
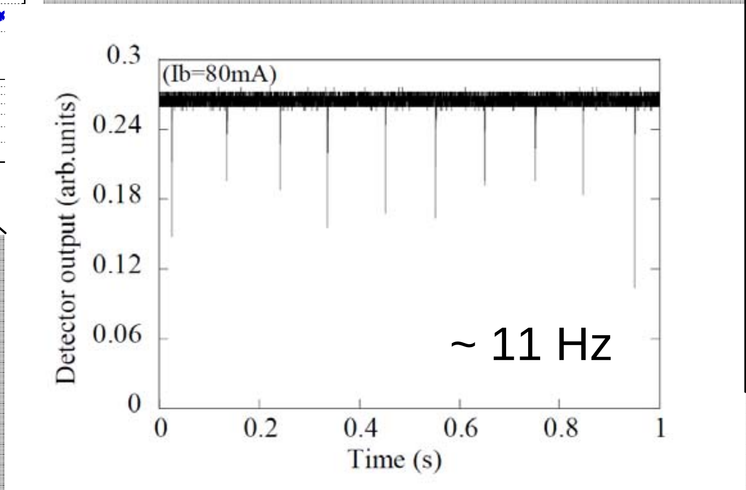
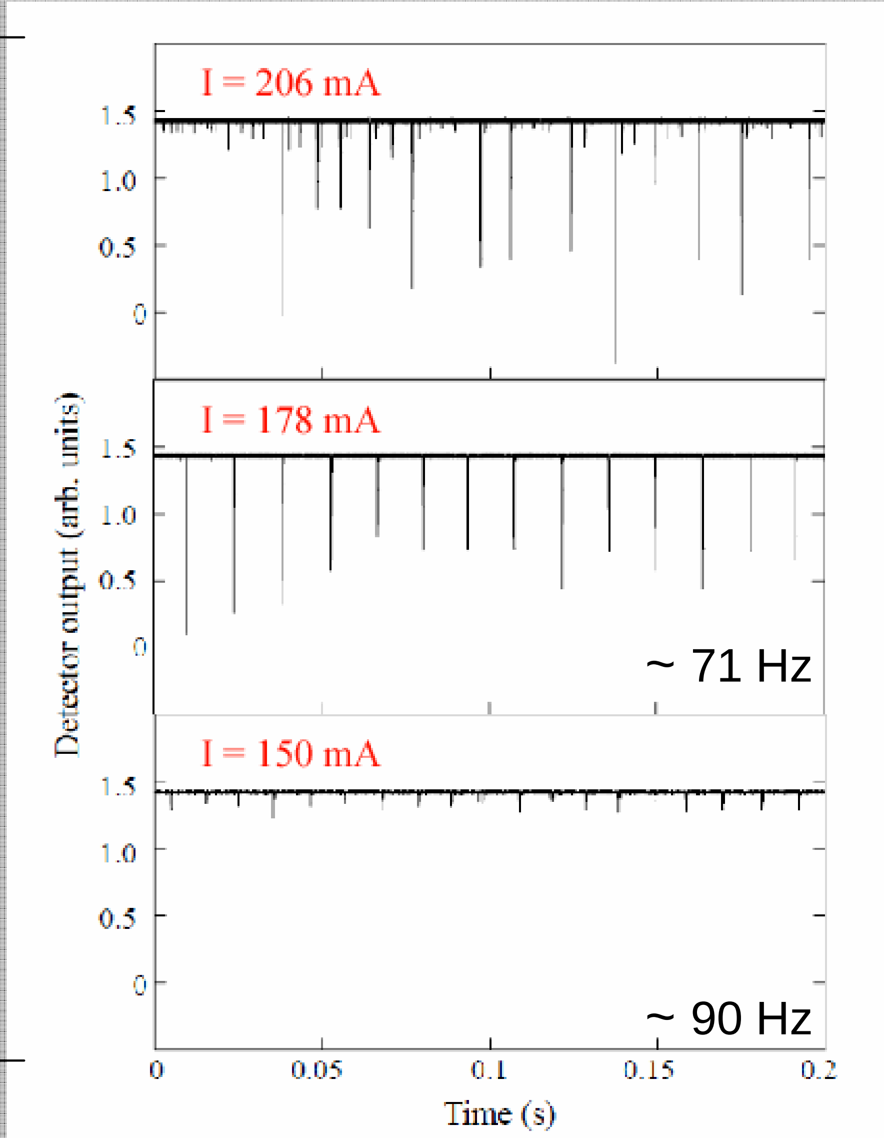
- Intensity of the burst CSR is stronger at the higher beam current.
- The burst appear chaotically at extremely high beam current of 206 mA while quasi-periodically at the lower current.
- The repetition of the burst at 80 mA is lower than at the current over the second threshold.







Time structure of a single pulse of the burst

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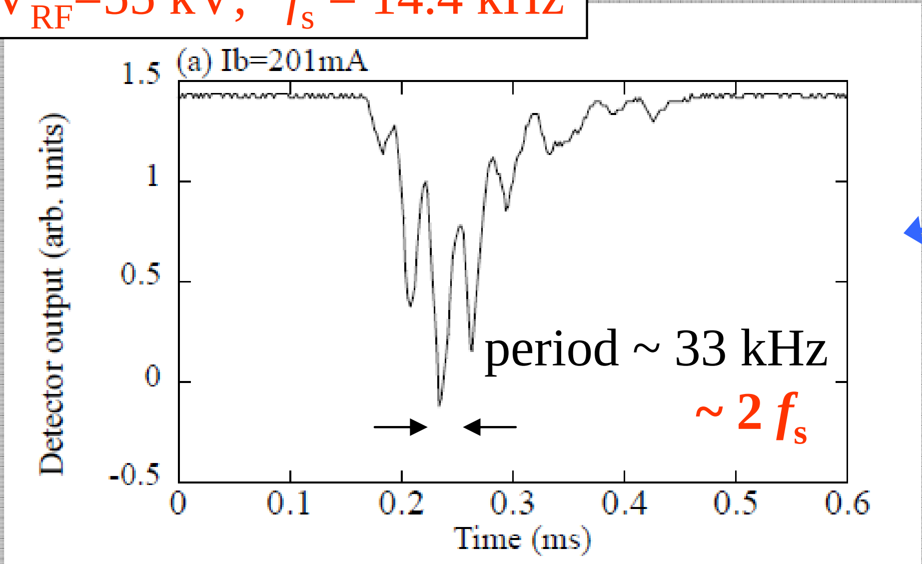
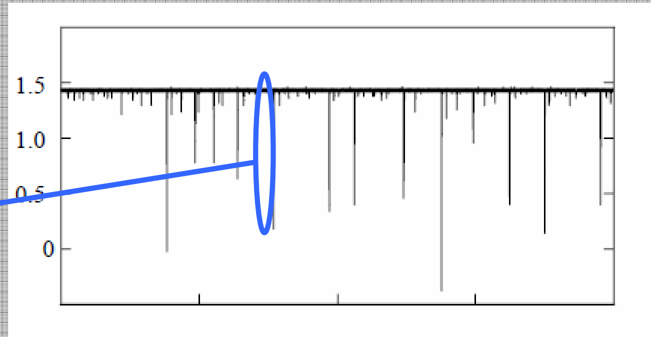
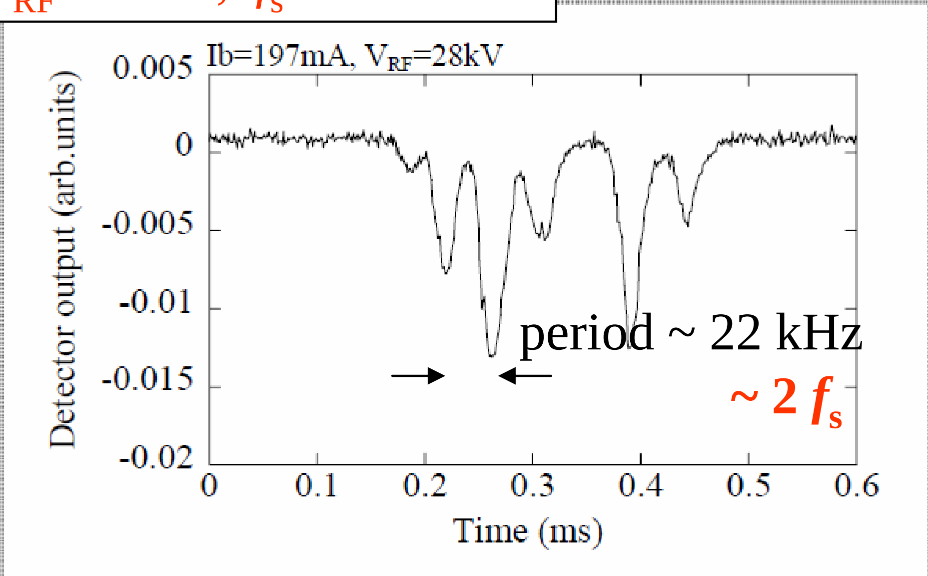
V_{RF}=55 kV, f_s = 14.4 kHz





V_{RF}=28 kV, f_s = 10.3 kHz



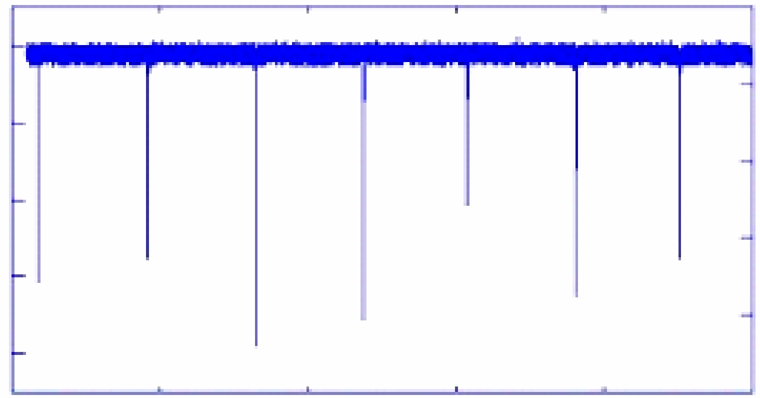
- Time period in the single burst pulse with V_{RF} of 55 kV is near to the twice of the synchrotron frequency f_s, 14.4 kHz.
- When V_{RF} is 28 kV, f_s changes into 10.3 kHz, which is near to half of 22 kHz.

Synchrotron frequency seems to have strong relationship with burst.

Relationship between THz Bursts and rms bunch length

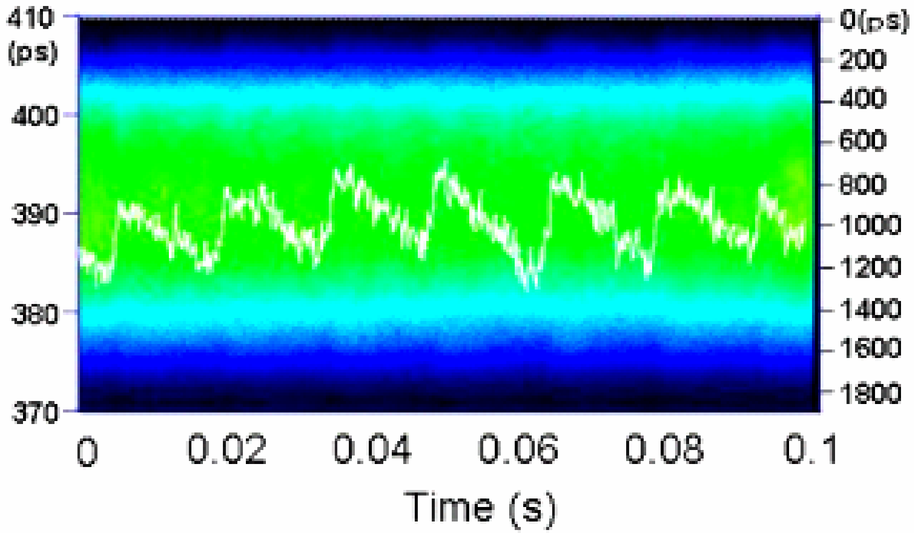
The beam current is 177 mA

• THz Bursts signals detected by the InSb bolometer



• Rms bunch length (white line) and the THz CSR burst simultaneously measured by a streak camera

(Color image is the raw data of the streak camera.)



Response of a streak camera synchronized with the signal of the bolometer.

The variation of the rms bunch length is associated with the burst occurrence.

After RF cavity upgrade

Effect of beam instability on the THz CSR burst

- After upgrade of RF cavity, THz CSR burst occurs when vertical beam instability is monitored.

Stable electron beam

Unstable electron beam

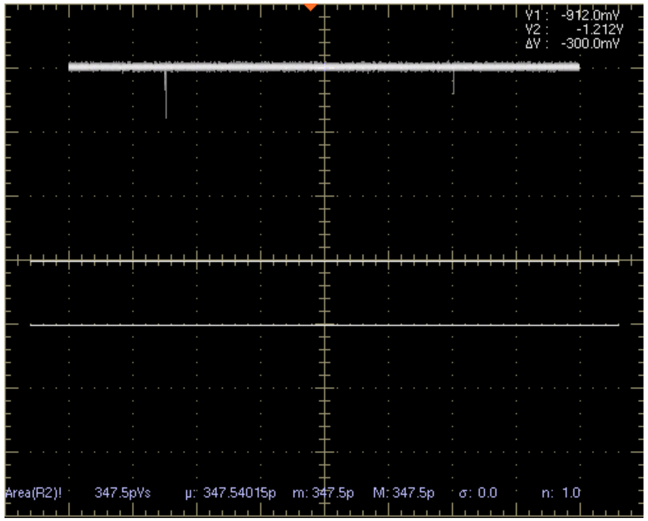
Horizontal

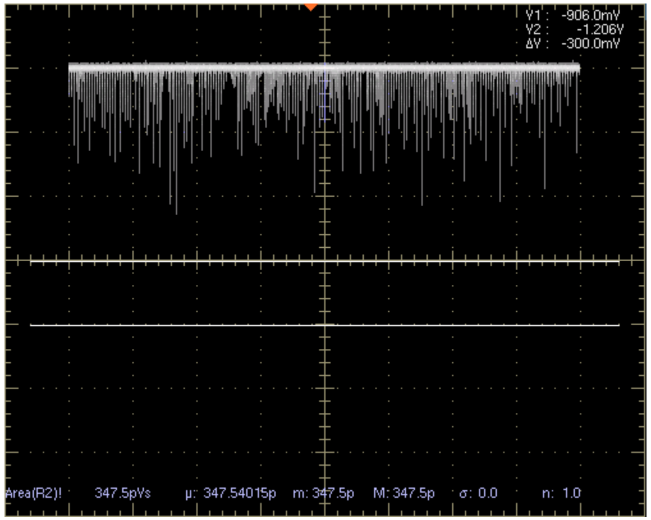
Vertical

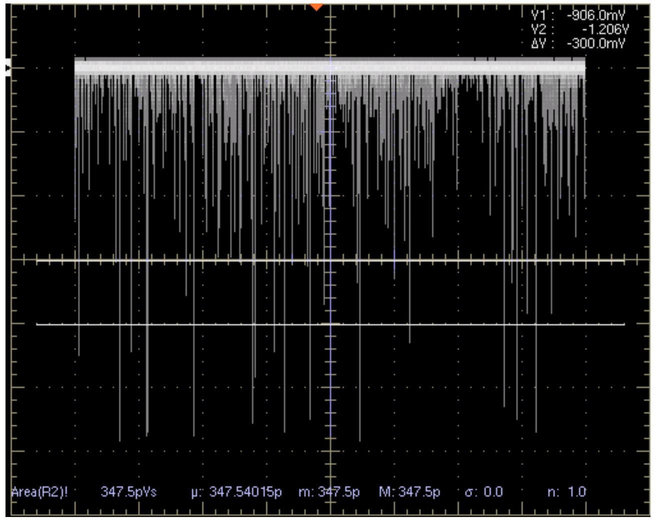
- The direction of the monitor camera is rotated at 90 degree.
- Beam instability to the vertical direction is observed with high current or high RF voltage.

Intensity of THz CSR burst

- The intensity of THz CSR burst increase at the higher RF voltage
- High RF voltage is assumed to induce transverse beam instability and THz CSR burst occurs.







RF voltage 57.9 kV
Current 65.7mA

RF voltage 89.5 kV
Current 65.5mA

RF voltage 121 kV
Current 65.0mA

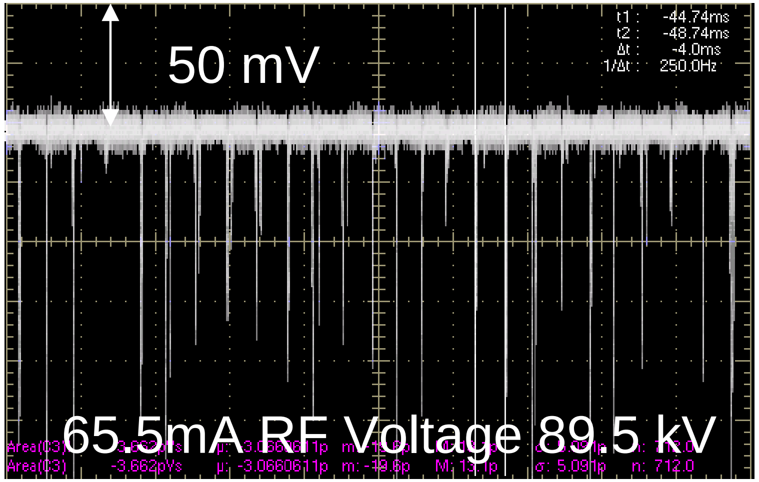
Time structure of the burst train with various RF voltage

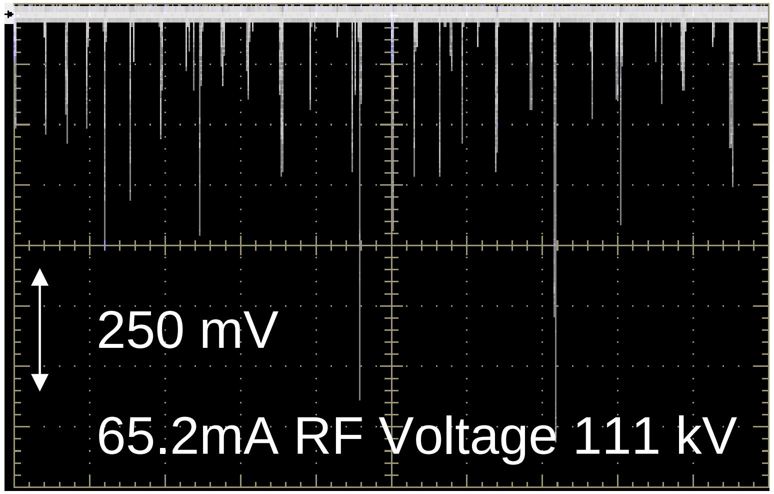
- The burst occurs periodically when the RF voltage is low.
- When the RF voltage is high, the burst train turn into chaotic.

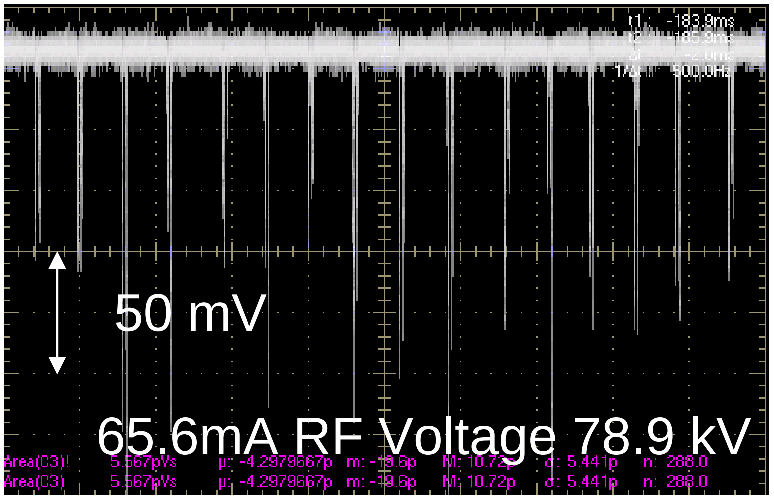
These features are almost the same with before RF upgrade.

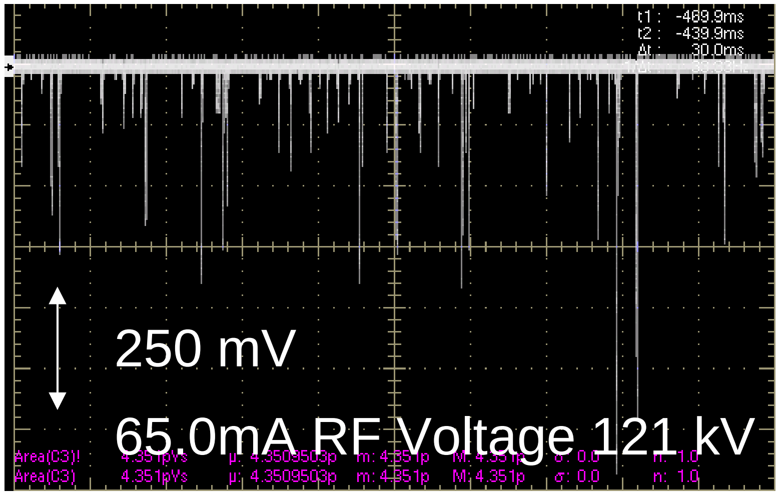
But…

- The single pulse of the burst does not contain the structure with synchrotron frequency.









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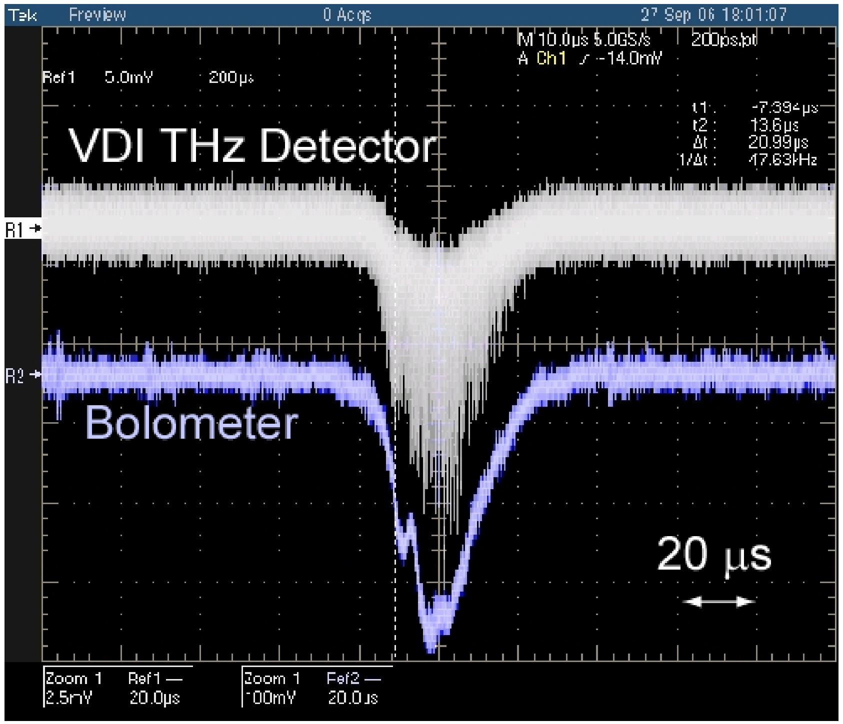
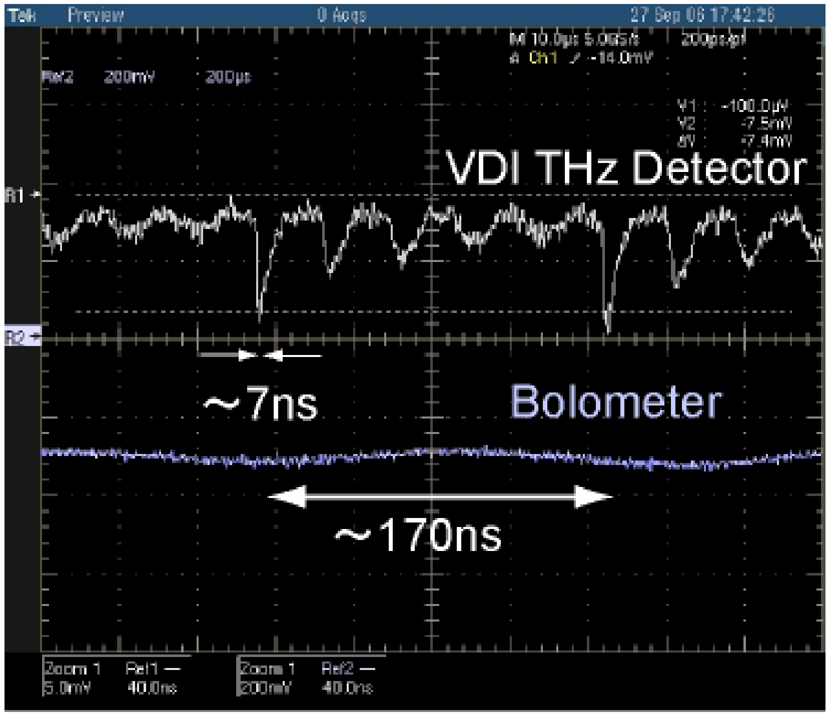
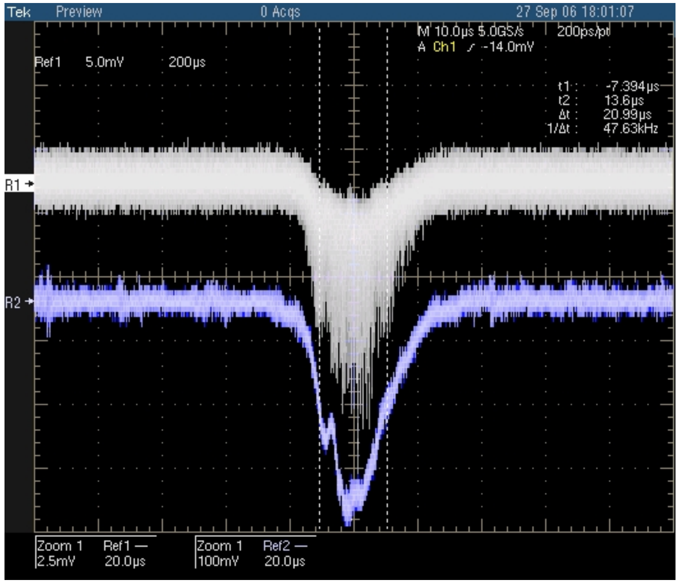
Response of the bolometer and VDI terahertz diode detector

- The envelope of the time development of the diode detector are consistent with the bolometer.
- Temporal resolution of VDI detector is shorter than revolution frequency of 5.6 MHz (170 ns).

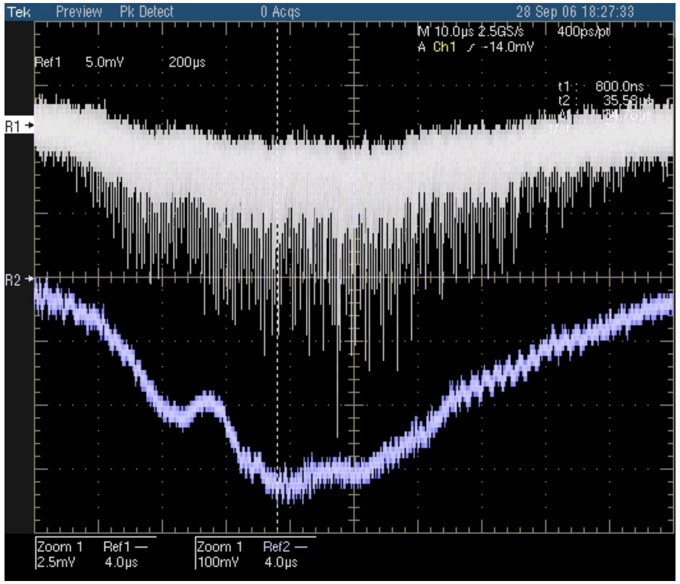




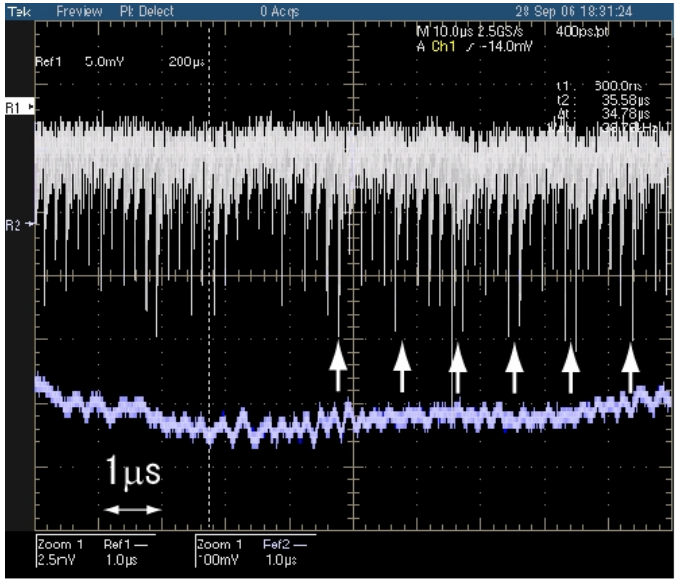
Time structure of the THz CSR burst measured by bolometer and THz diode detector



Scale 20μsec



Scale 4μsec



Scale 1μsec

Close UP

- The rapid time development can be observed by the THz diode detector. At the left image, we can see a sort of time structure, which could not be resolved by the bolometer.
  - Blue : Bolometer
  - White : THz diode detector

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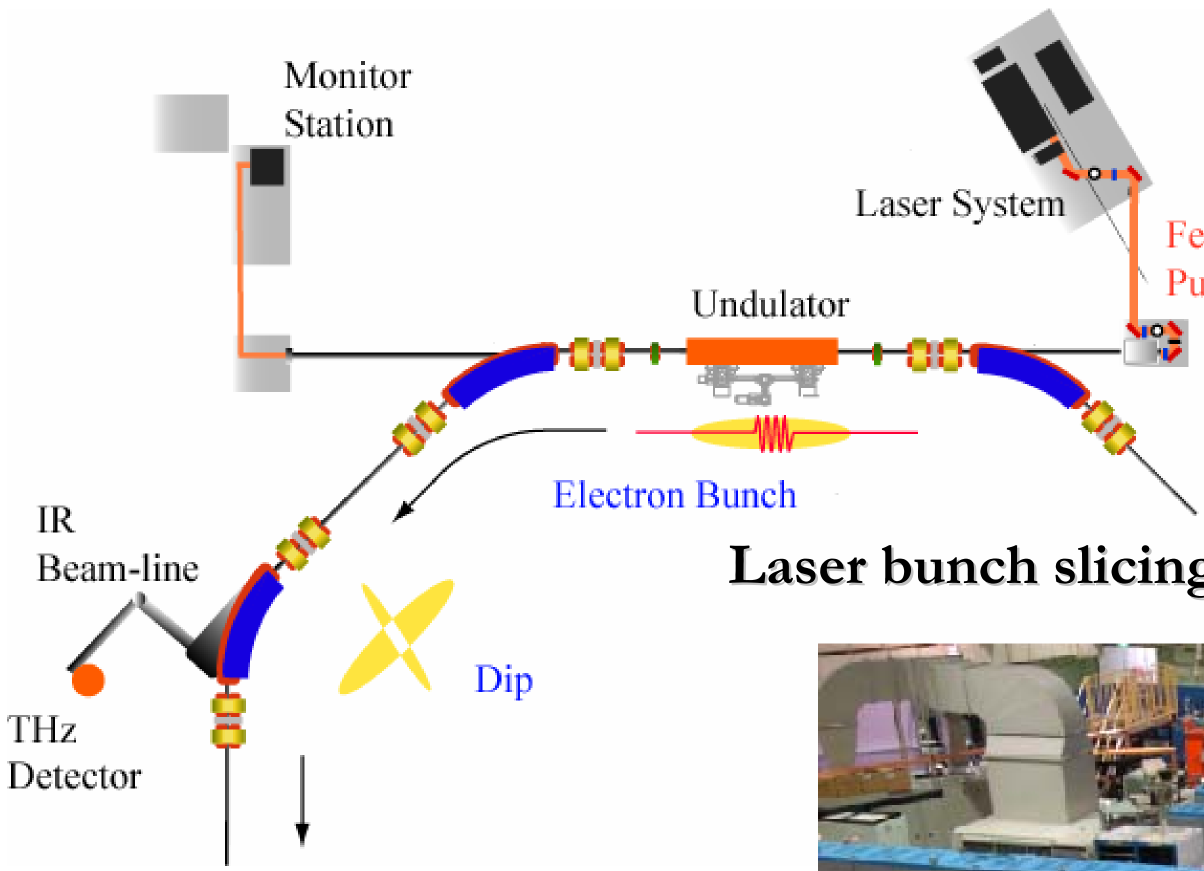
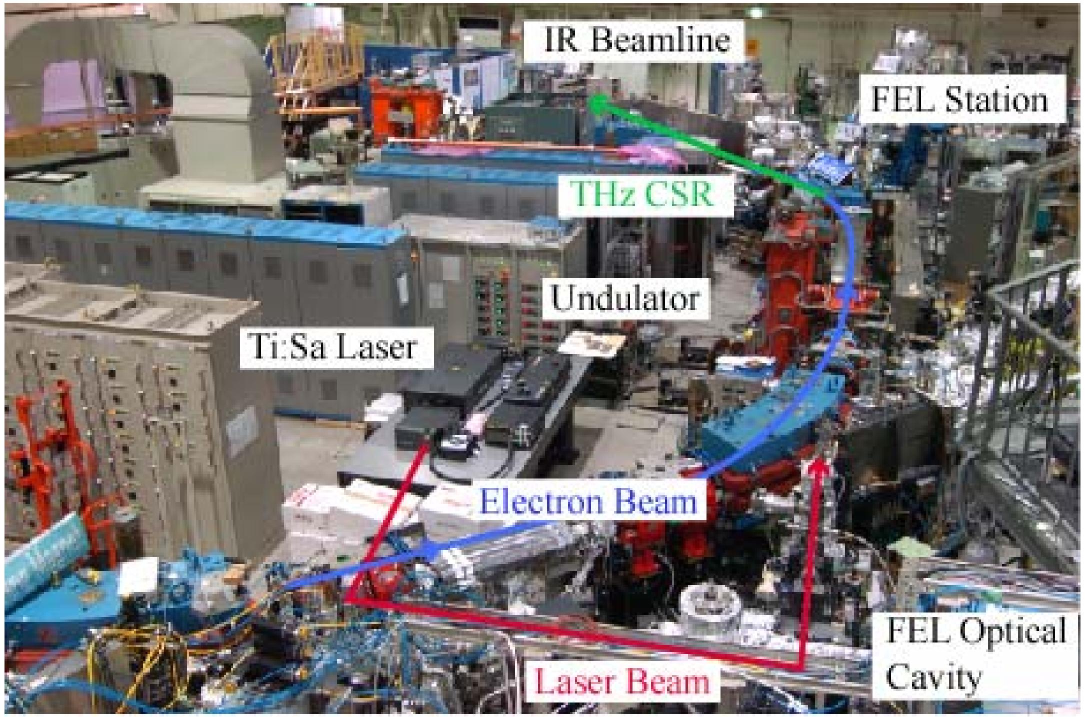
Does laser bunch slicing induce bursting ？



Laser bunch slicing system at UVSOR-II

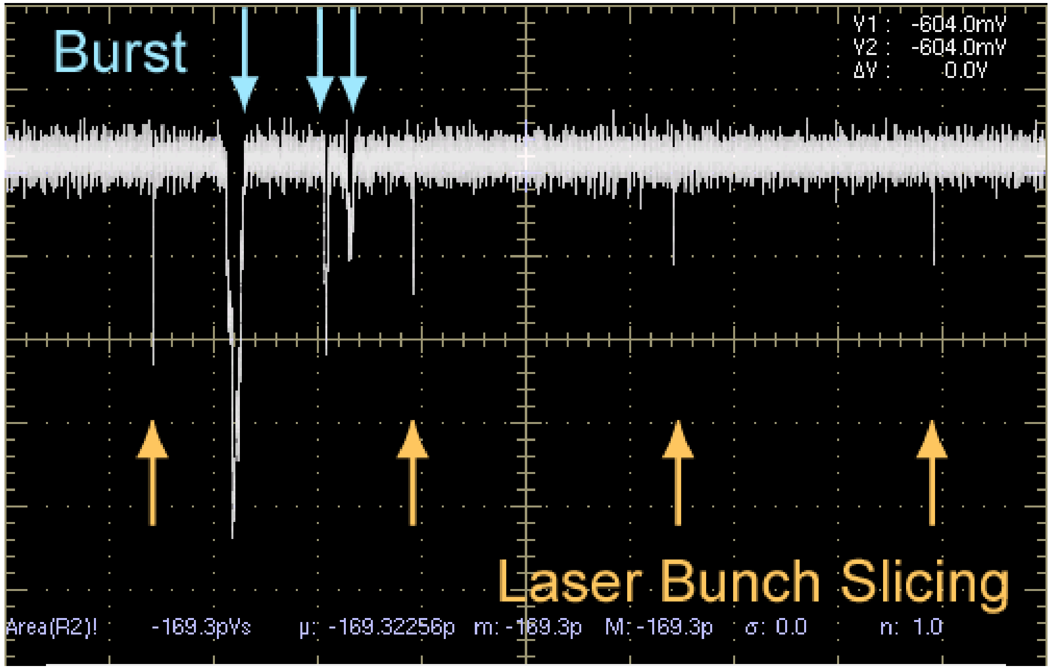


Laser Parameters

Pulse Energy	2.5 mJ/pulse
Pulse Width	130 fs ~2ps
Rep. Rate	1 kHz
(synchronized with 90.1 MHz)	
Wavelength	790 – 810 nm

Laser bunch slicing with high current

- Laser bunch slicing is performed while bursting.



- At UVSOR-II, the laser bunch slicing does not induce burst in terahertz region unlike other storage ring.

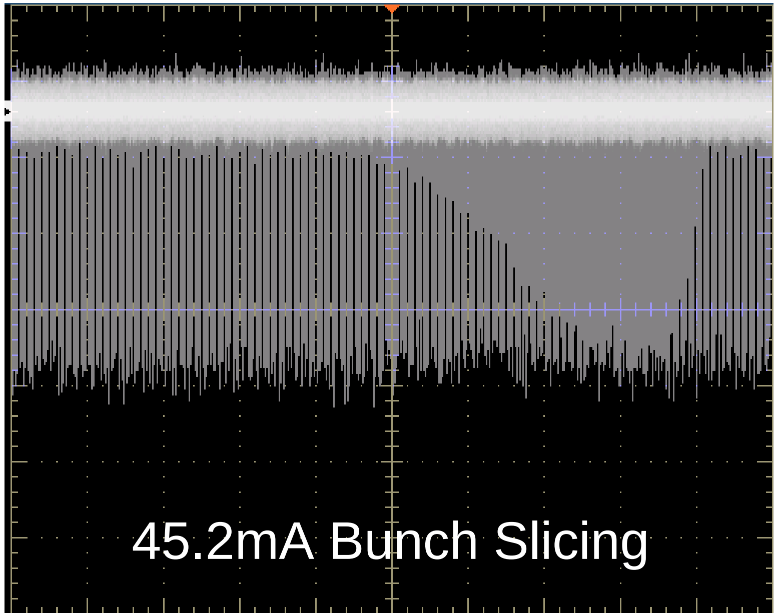
Conclusion

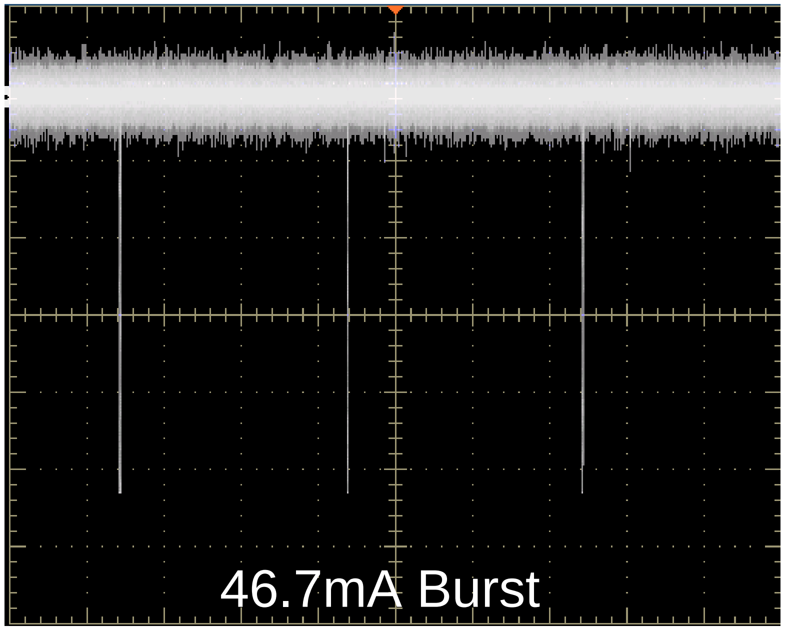
- 2004-2005
  - We observed two thresholds for the THz CSR bursts.
  - Time structure is strongly associated with the synchrotron frequency.
  - Time trains of the burst is quasi-periodic at the lower beam current but turn into chaotic at the higher beam current
  - Enhance of the intensity of the THz CSR is strong at the lower THz frequency (<10 cm^{-1})

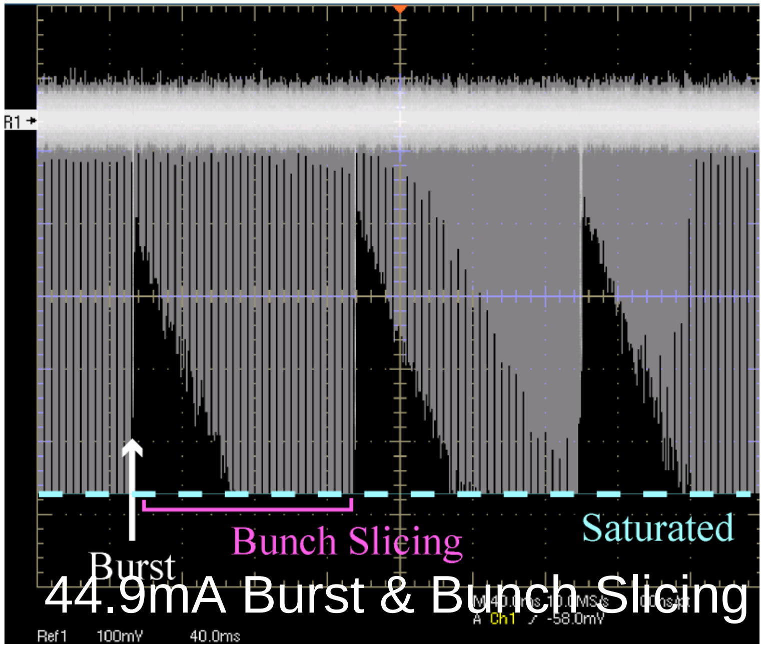
- 2006-2007
  - THz CSR burst is associated with the vertical beam instability and RF cavity after the upgrade of RF cavity.
  - There is possibility to observe the rapid time structure of the burst by the THz diode detector.
  - Laser bunch slicing does not induce the THz CSR burst.

Laser bunch slicing and observation of terahertz burst (preliminary)

- Some example of the bolometer signals in the same current region. In some cases, there is no burst but signal of laser bunch slicing. In the other cases, we observe only THz CSR burst with around 8 kHz.
- At 44.9 mA, THz CSR of both burst and laser bunch slicing are observed. Repetition of the burst pulse of 8 kHz does not change. The laser bunch slicing decrease just after bursting because of the beam instability.







Intensity of THz CSR burst with low-pass filter

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The intensity of burst is expressed as follows,

$$P_{burst}(k) = N[1+(N-1)F(k)]p(k)$$

$$F(k) = \left| \int Q(z) e^{ikz} dz \right|^2$$

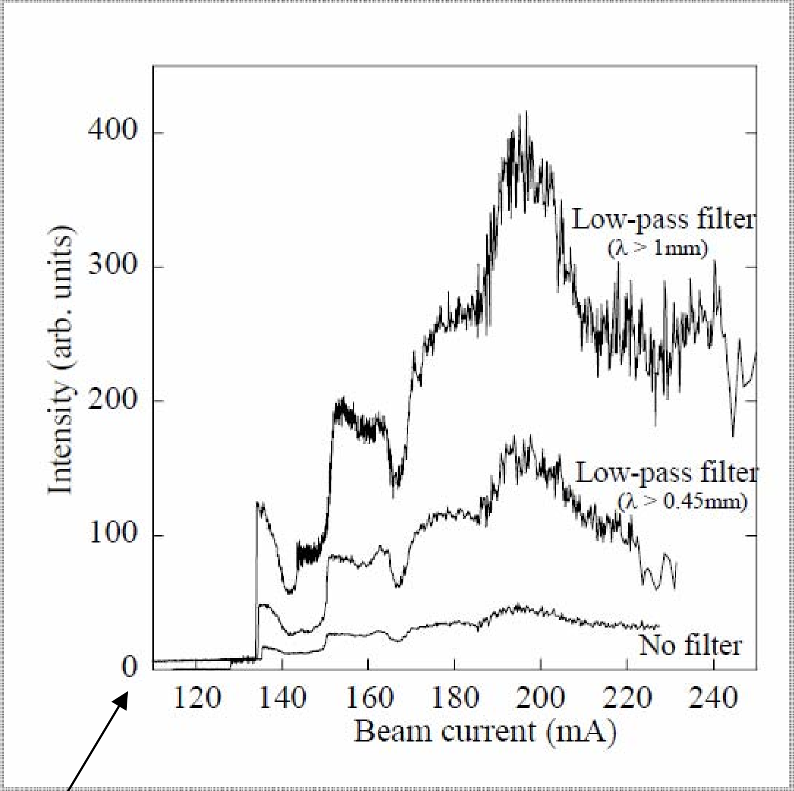
$Q(z)$: longitudinal electron density distribution
$F(k)$: Form factor
(Square of Fourier Transformation of $Q(z)$)

The ratio of the average burst intensity to the incoherent SR with a current of 130 mA is plotted.

$$Ratio\ of\ \ Intensity \equiv \overline{P}_{burst}(I) / \overline{P}(130\,mA)$$

- "*Ratio of Intensity*" is larger with lower THz frequency (less than 10 cm^{-1}).
- There is no significant difference of the current dependency in terms of wavelength of the burst CSR.
- Average intensity is measured by using lock-in-amp and mechanical chopper with 11 Hz.

Average burst intensity normalized by incoherent SR (130 mA)



Normalized at the 130 mA, where THz CSR burst does not appear