Beam Instability Phenomena Observed at HIRFL-CSR in the Presence of Electron Cooling

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Main works in CSR

- Experiments on cancer therapy (15% of beamtime)
- Cancer therapy (5% of beamtime)
  (Total / **73patients**(from 2009), **Last year / 21patients**)
- **Mass measurement (next step:SMS)**

(high-precision Schottky Mass Spectroscopy)

- H_2^+ Accumulation and Acceleration in CSRm
- $^{238}U^{32+}$ Accumulation and Acceleration in CSRm
- Recombination Experiments (5% of beamtime)

***Physical Review Letters*, 109, 102501 (2012)**

Progress of HIRFL-CSR was reported by Dr. Y J Yuan at STORI'11 in Italy

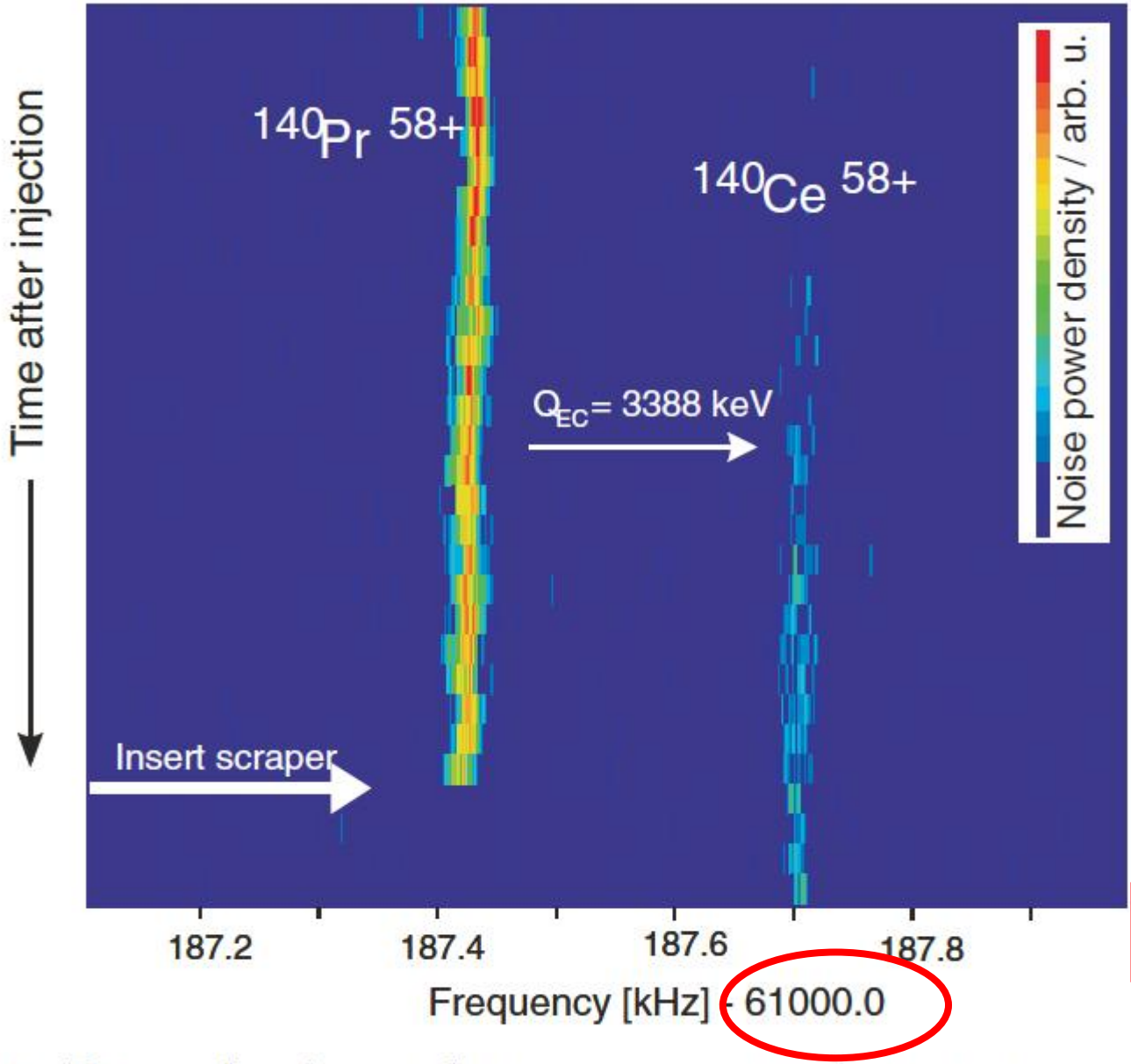
Requirements

- High precision
- High stability
- High intensity
- High resolution

$$\Delta f/f = 1*10^{-6}$$

Reference

- GSI results
- $\Delta f/f=5*10^{-7}$



Span 1kHz

Fig. 5. Principle of providing pure isomeric beams via scraping off a component of the cooled circulating beam.

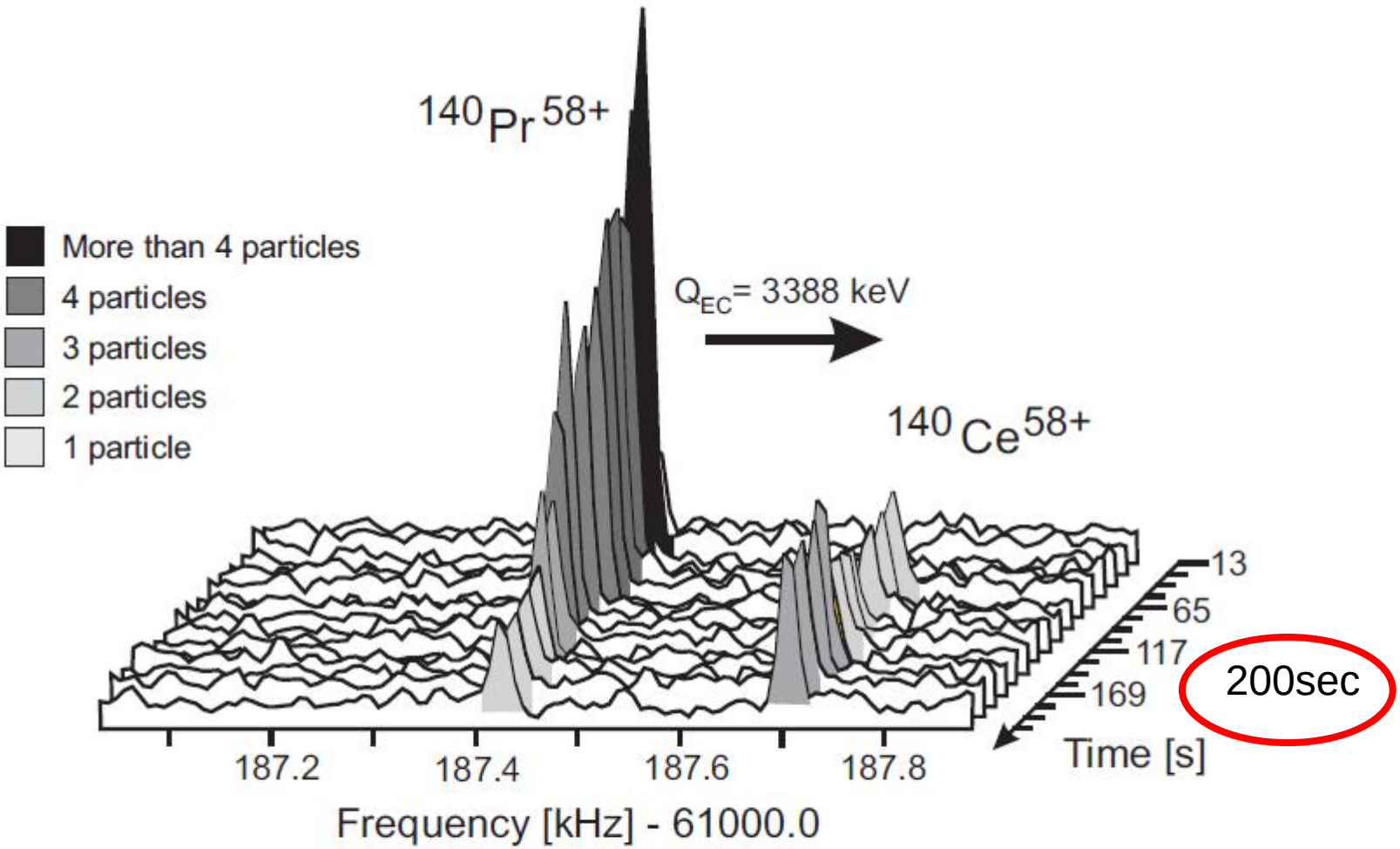
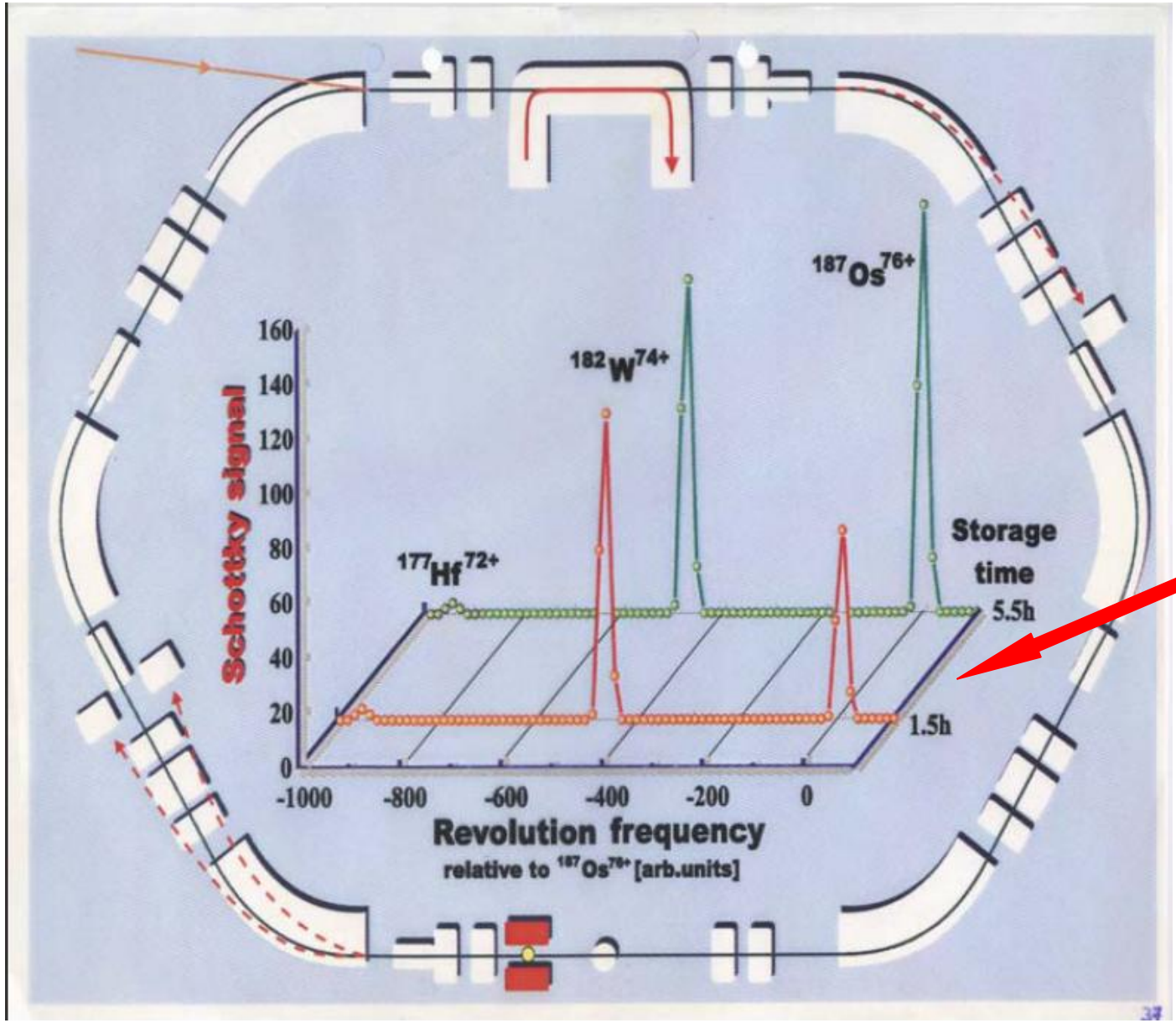
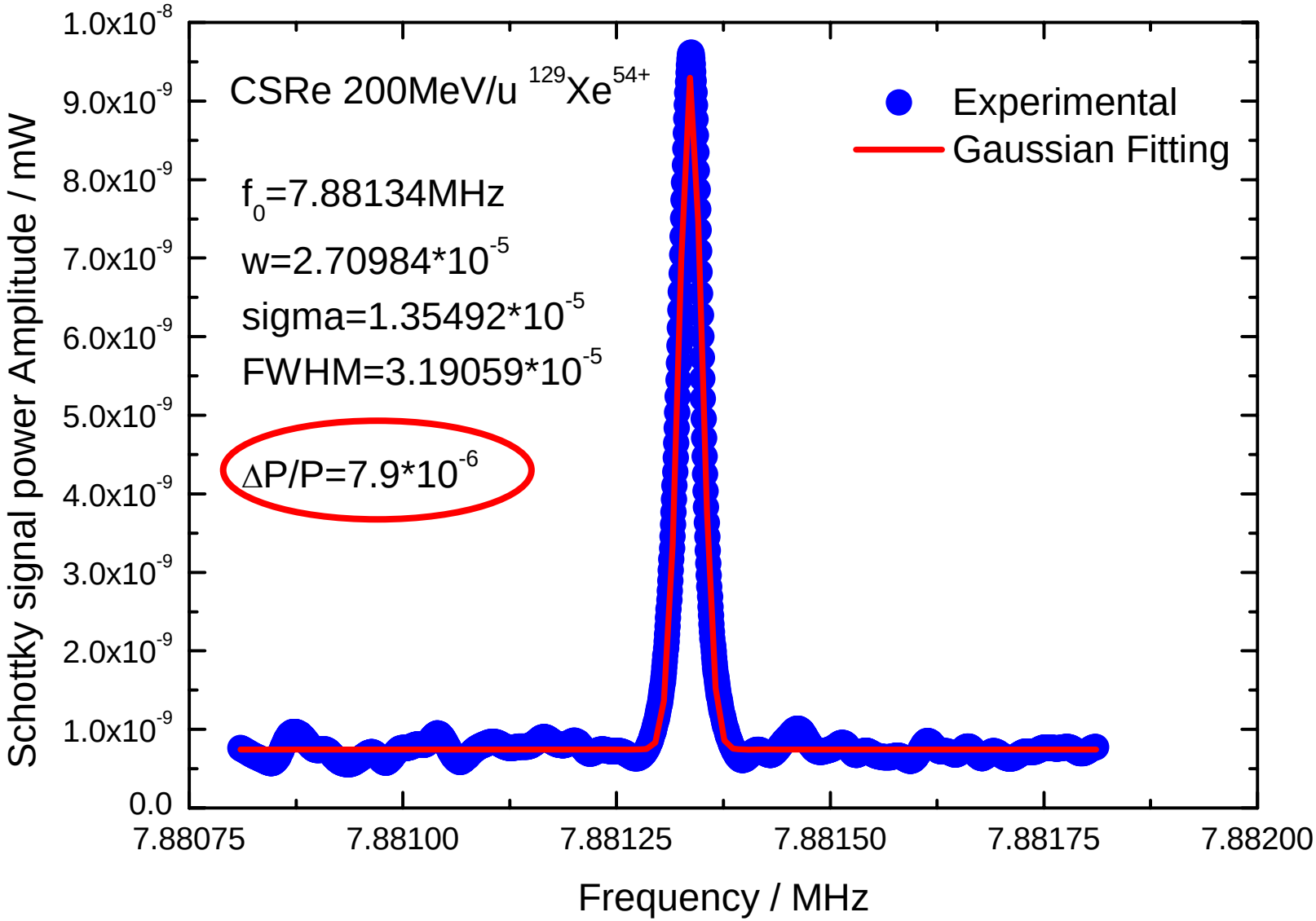


FIG. 5: A series of subsequent-in-time Schottky frequency spectra of mother $^{140}Pr^{58+}$ and daughter $^{140}Ce^{58+}$ ions. About six mother nuclei were initially stored. Two out of them decayed via nuclear electron capture into $^{140}Ce^{58+}$. The correlated intensity changes are clearly seen. Other ions decayed via β^+ decay or were lost e.g. due to interaction with the residual gas.



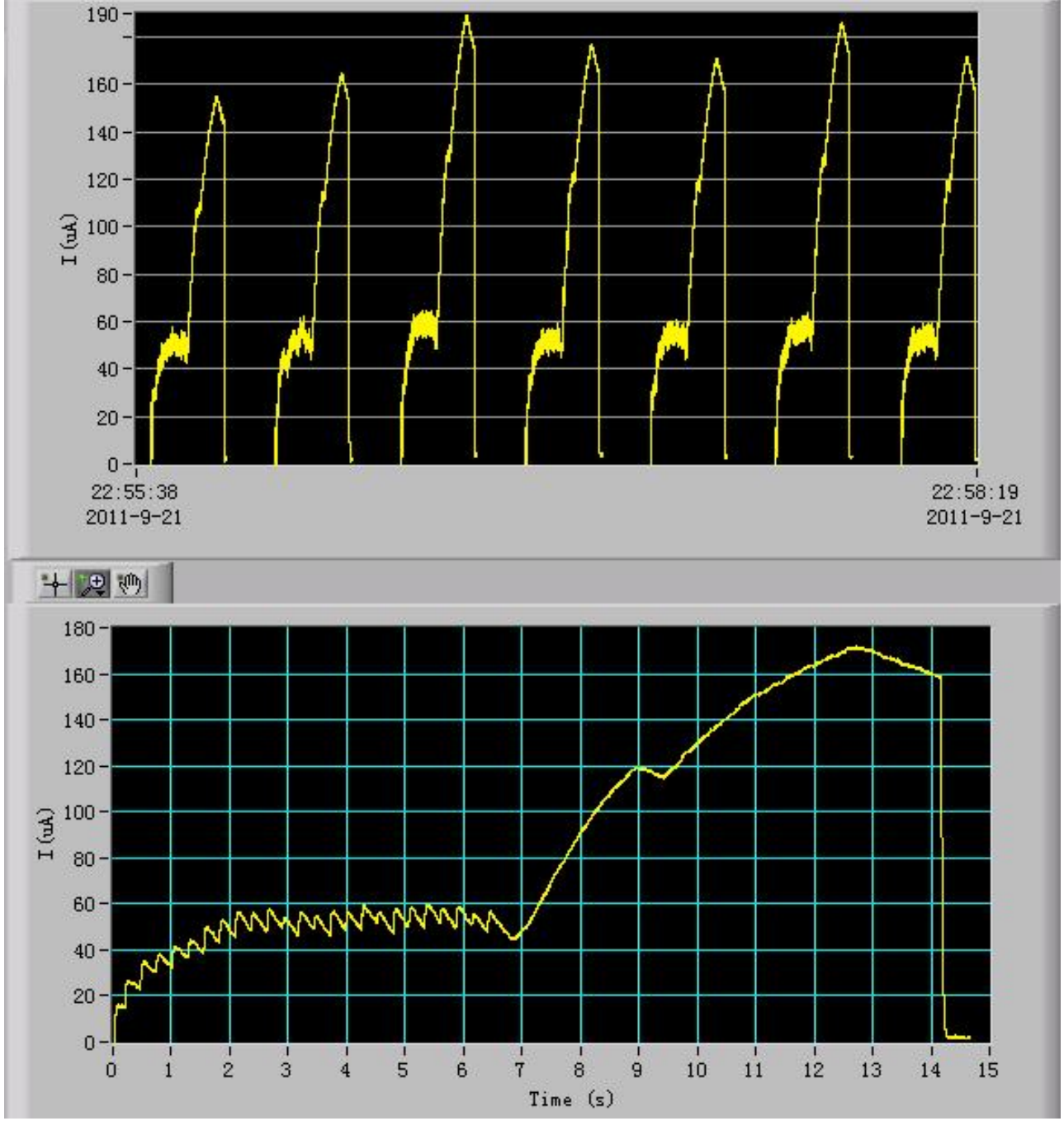
Long time stability



The best result from CSRe

$^{238}U^{32+}$ Accumulation and Acceleration in CSRm

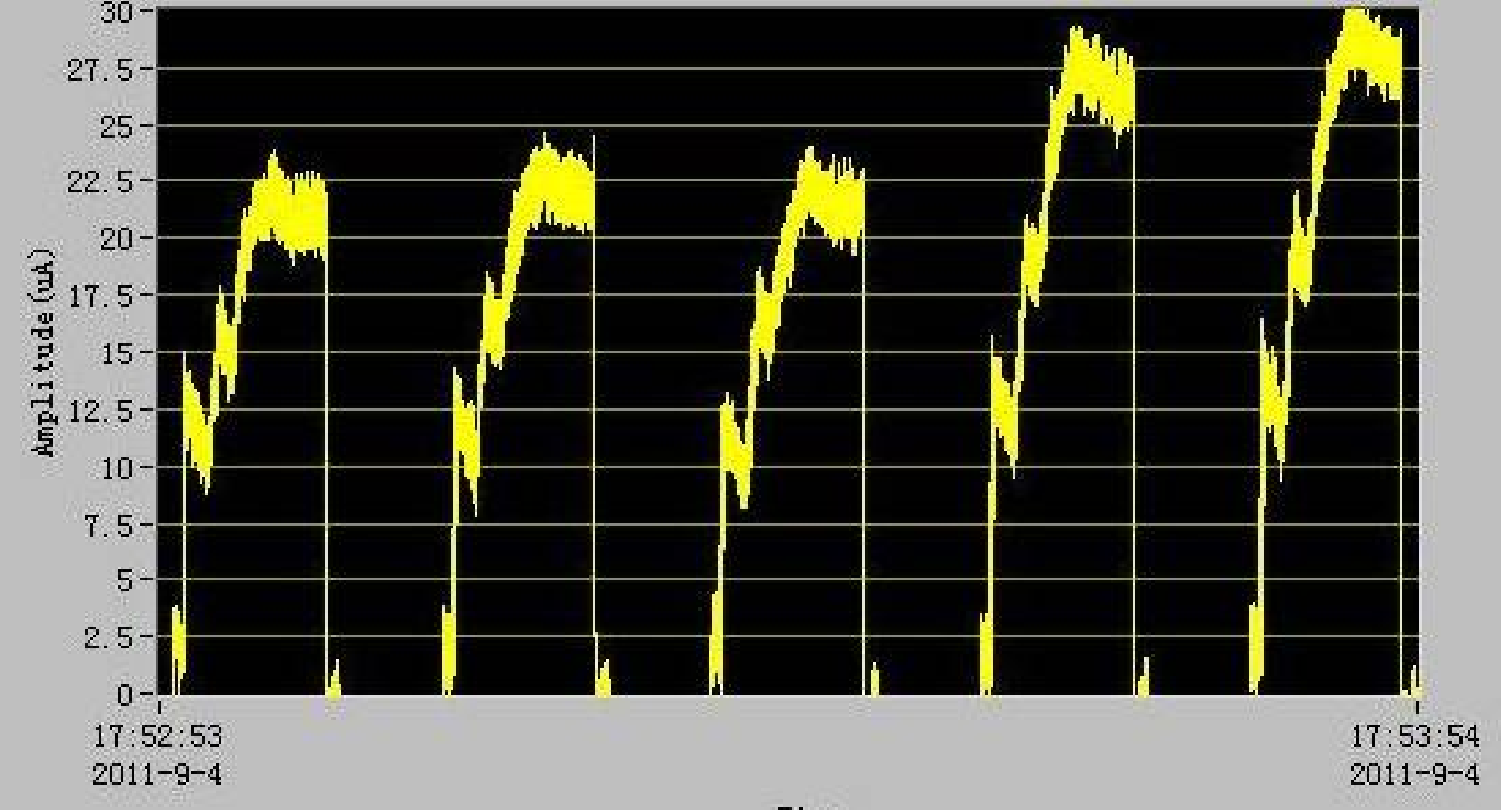
1.2MeV/u---100MeV/u



Accumulation and Acceleration of $^{238}U^{32+}$ 1.2MeV/u to 100MeV/u

H_2^+ Accumulation and Acceleration in CSRm

10MeV/u---400MeV/u

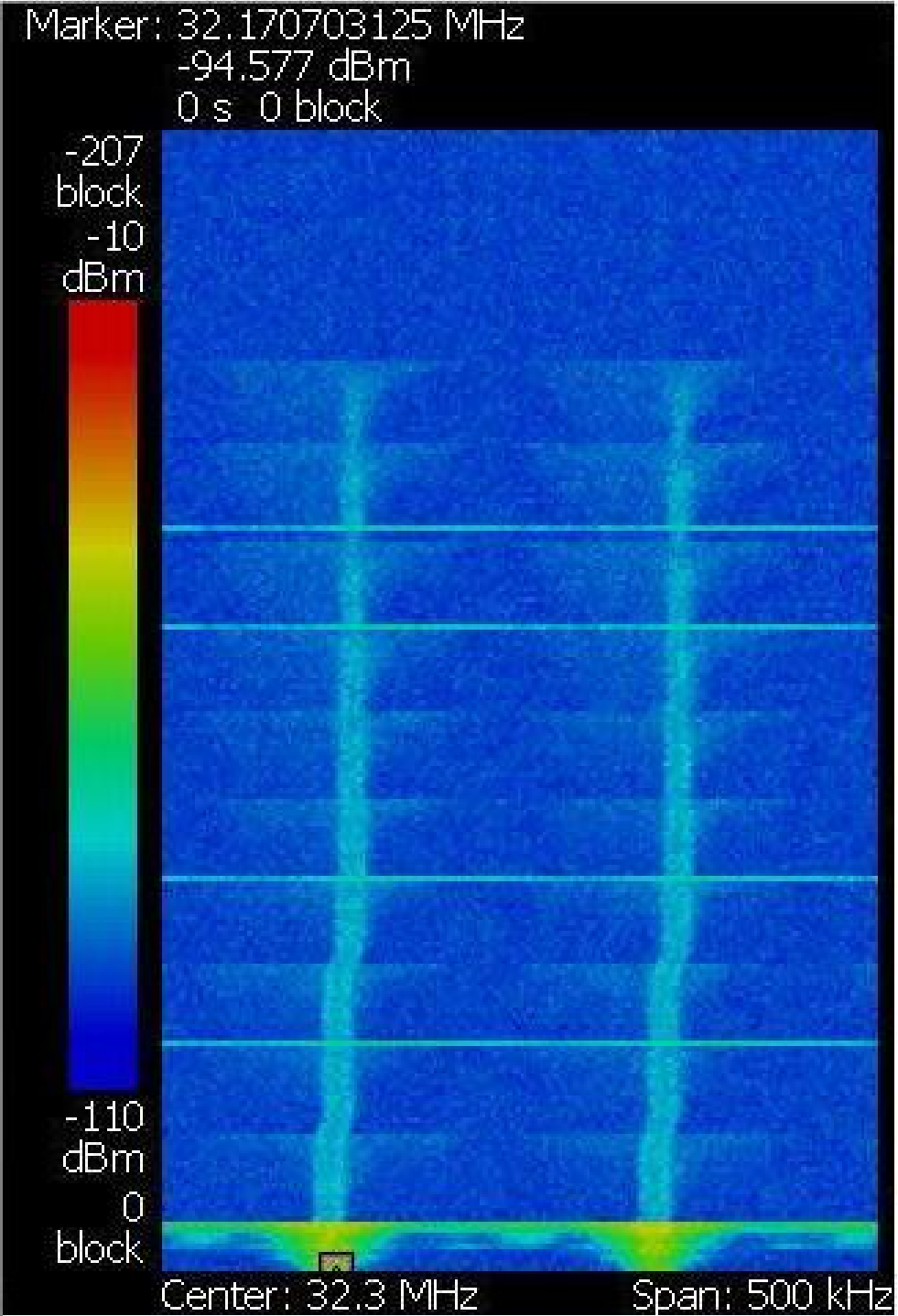


Accumulation and Acceleration of H^{+}_{2} from 10MeV/u to 400MeV/u
No obvious accumulation under the electron cooling

Beam Instability Phenomena Observed at HIRFL-CSR in the Presence of Electron Cooling

Accumulation

- Energy stability of injector
- Position and angle of ion beam
- Stability of dipole field in CSRm
- Stability of quadrupole in CSRm
- HV stability of electron cooler
- Corrector stability in CSRm



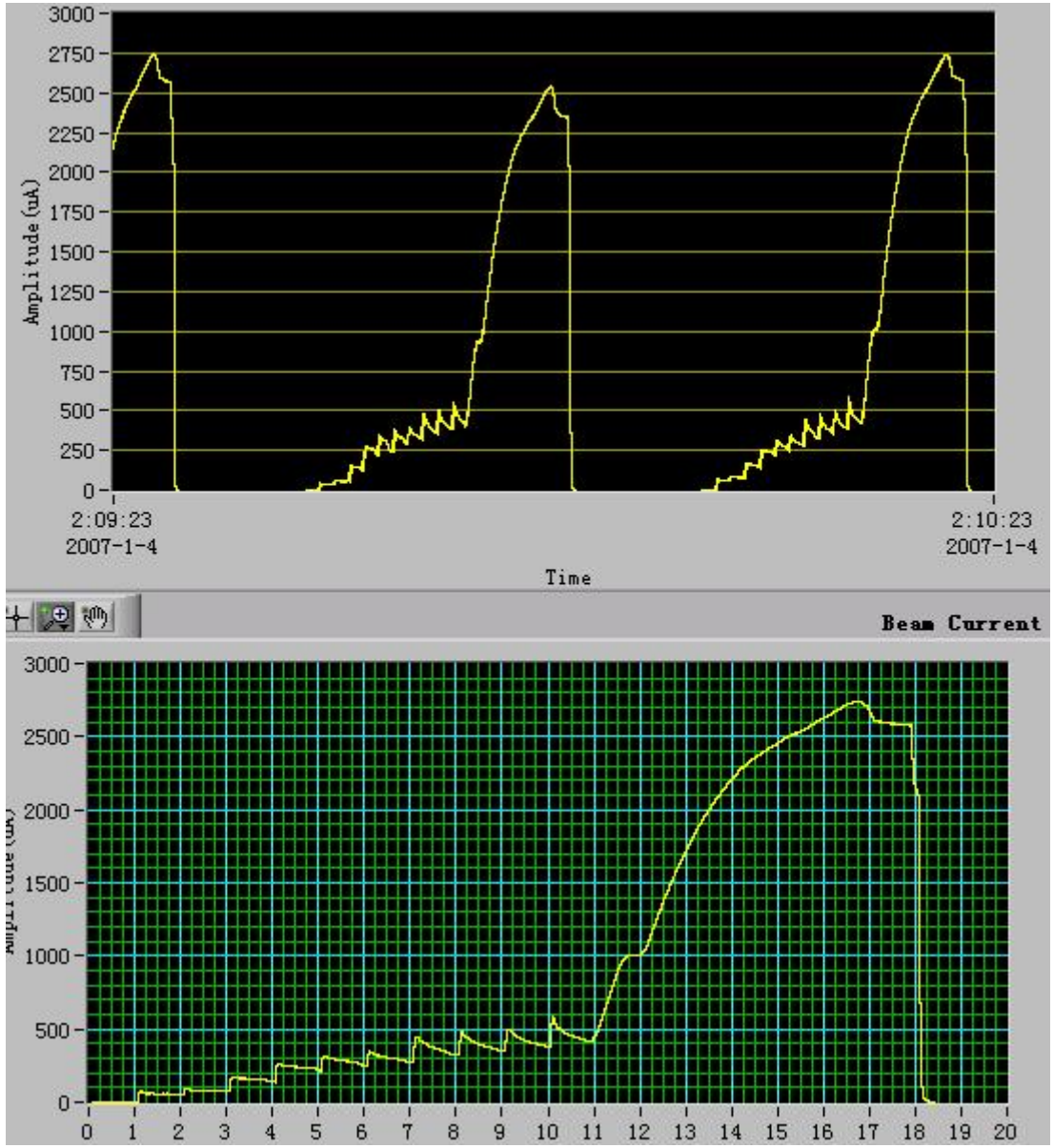
January 4 2007
Accumulation and Acceleration
Of $^{12}C^{6+}$ under electron cooling
7MeV/u----1000MeV/u

Stripping injection

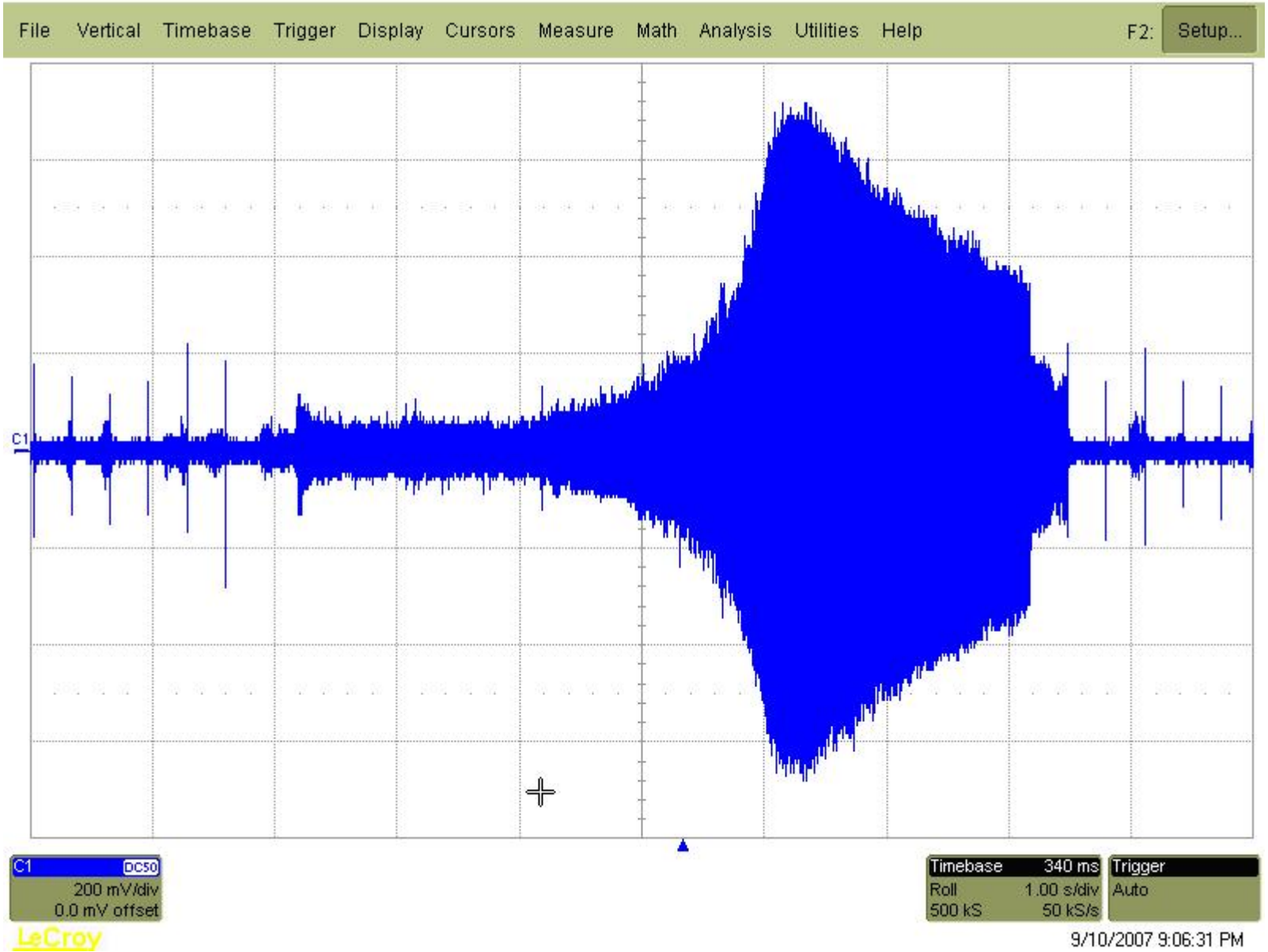
(1)There was no obvious sideband signal between the neighbor harmonic.
(2)Almost symmetrically cooled to the centre.
(3)The intensity of signal increased with the injection.
(4)The central frequency slightly shifted to the left (smaller side).

Reasonable work-point setting
Enough longer lifetime
No obvious beam loss

Ion energy
Electron energy
The field of dipole of the CSRm ring
The frequency of RF
Matched well each other!



DCCT signal of CSRm $^{12}C^{6+}$ 7MeV/u----1000MeV/u



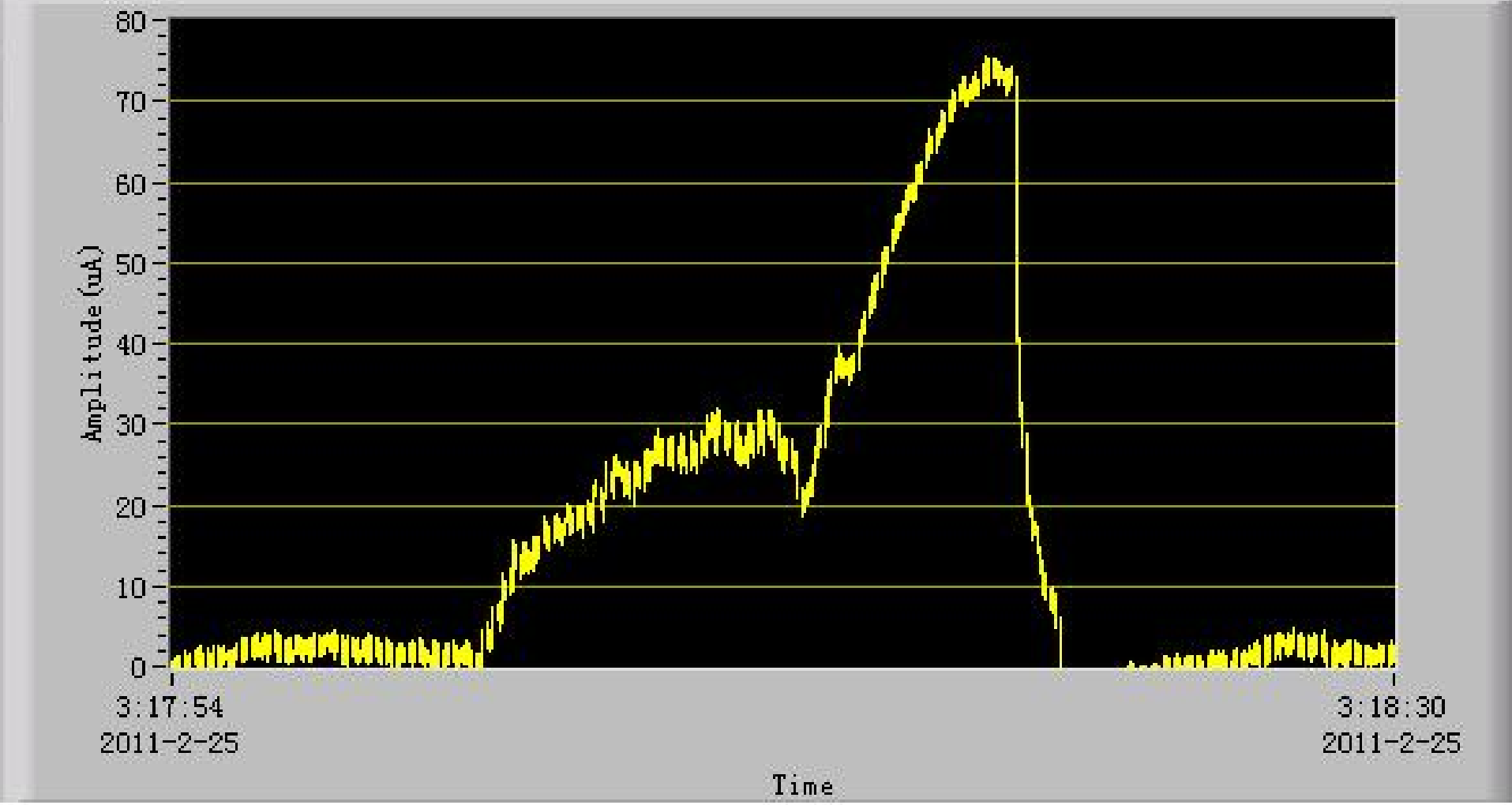
The signal from one electrode of beam position monitor during beam instability
It seem that the beam blow-up, the size became bigger

The corresponding beam intensity signal from DC current transformer during beam instability.

The beam intensity not increased duratively. Saturation was achieved.The sudden drop happened when achieved a certain value, and not all particle lost, only partial lost, and then Increased again with new injection.

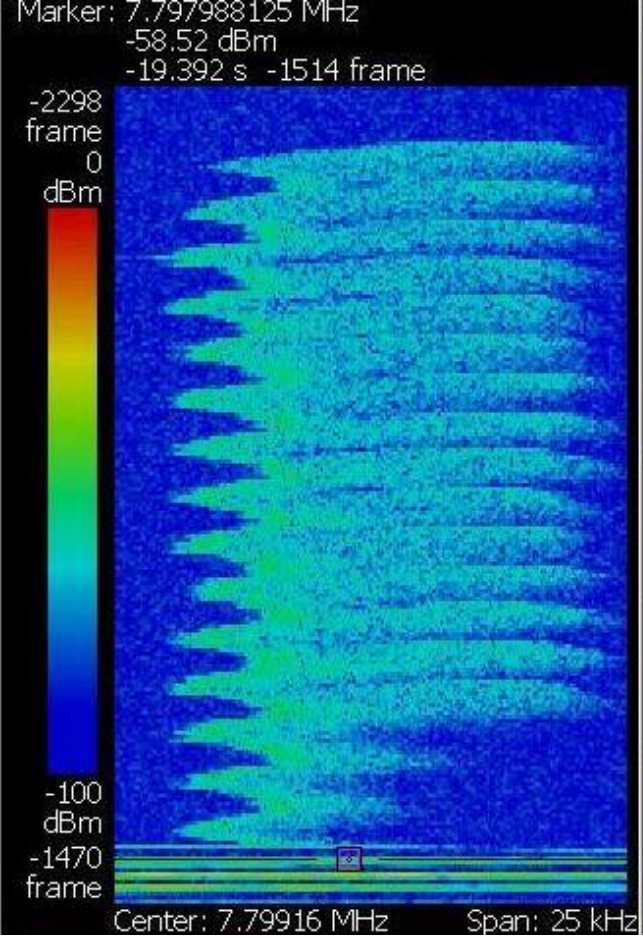
$^{209}Bi^{36+}$ Accumulation and Acceleration in CSRm

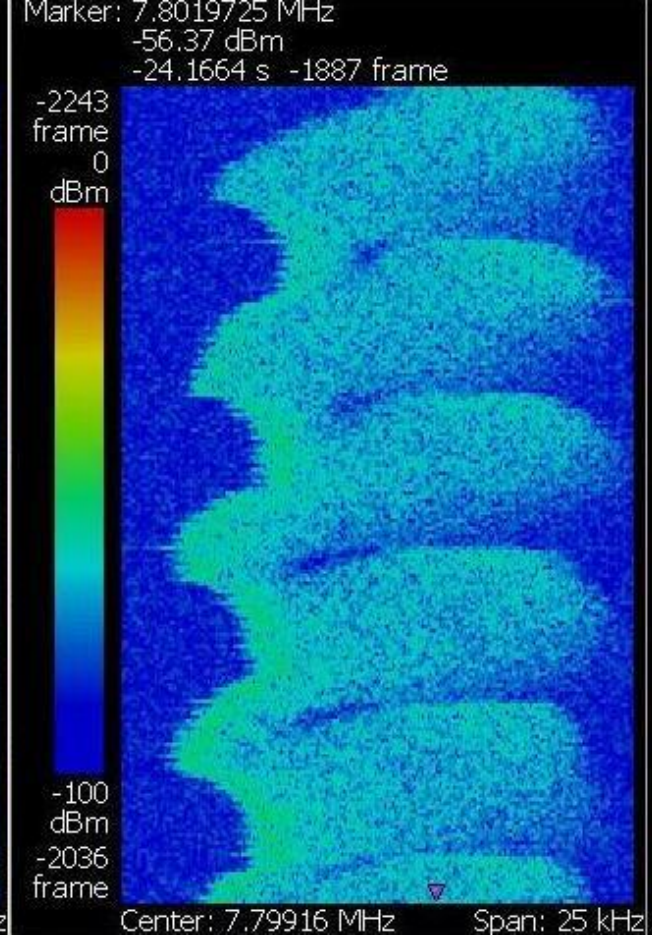
1.87MeV/u---170MeV/u

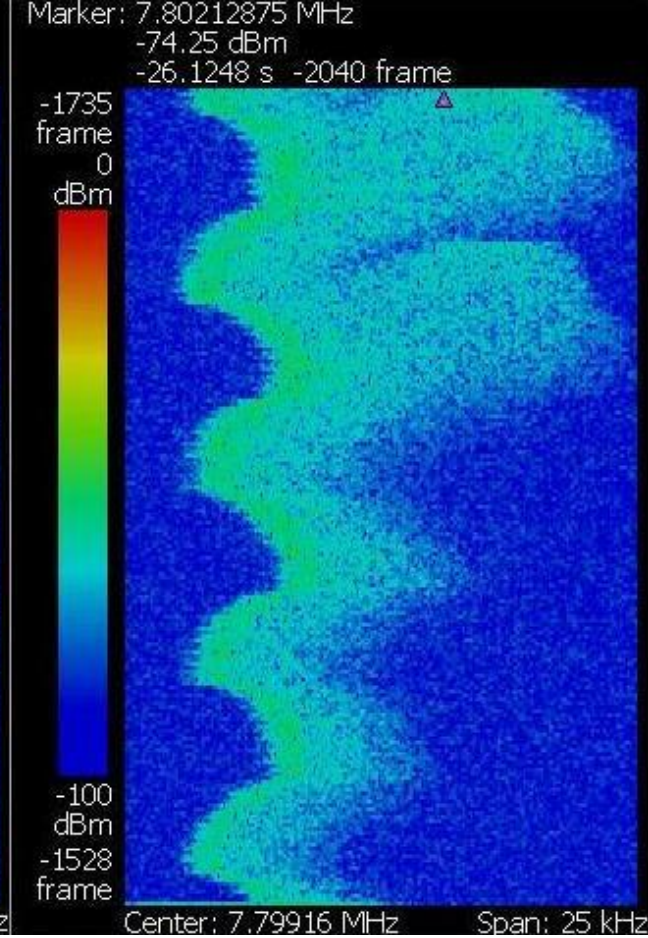


Bi beam accumulation and acceleration with the help of electron cooling

1.87MeV/u---170MeV/u



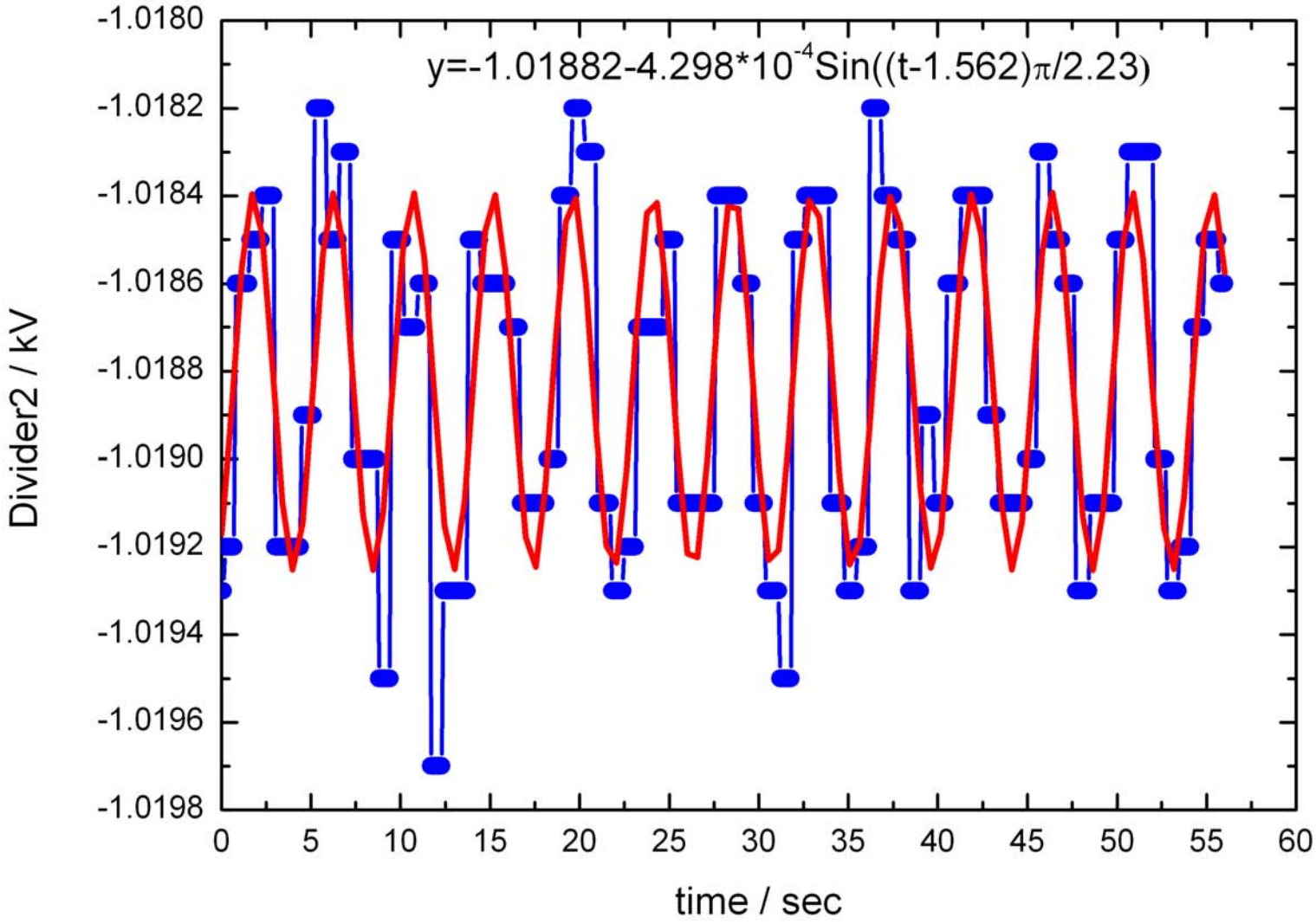




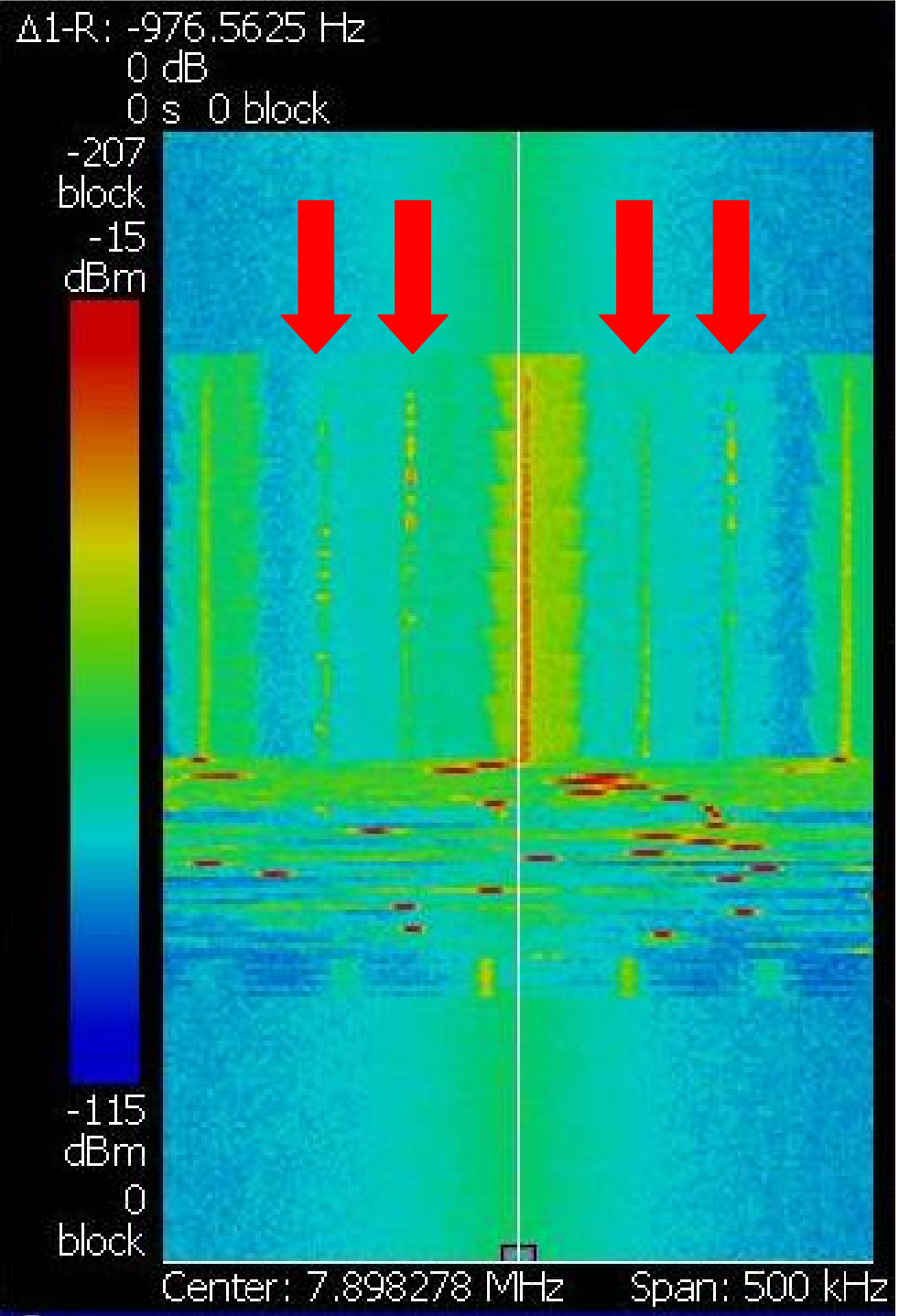
Left: whole injection,
Middle: the beginning of injection and accumulation
Right: he ending of injection and accumulation

Feb 25 2011 CSRm
$^{209}Bi^{36+}$ *1.87MeV/u---170MeV/u*

The observed oscillation during accumulation, The oscillation period is about 0.6272 sec



The stability of high voltage of electron cooler
The oscillation period is about 4.5sec



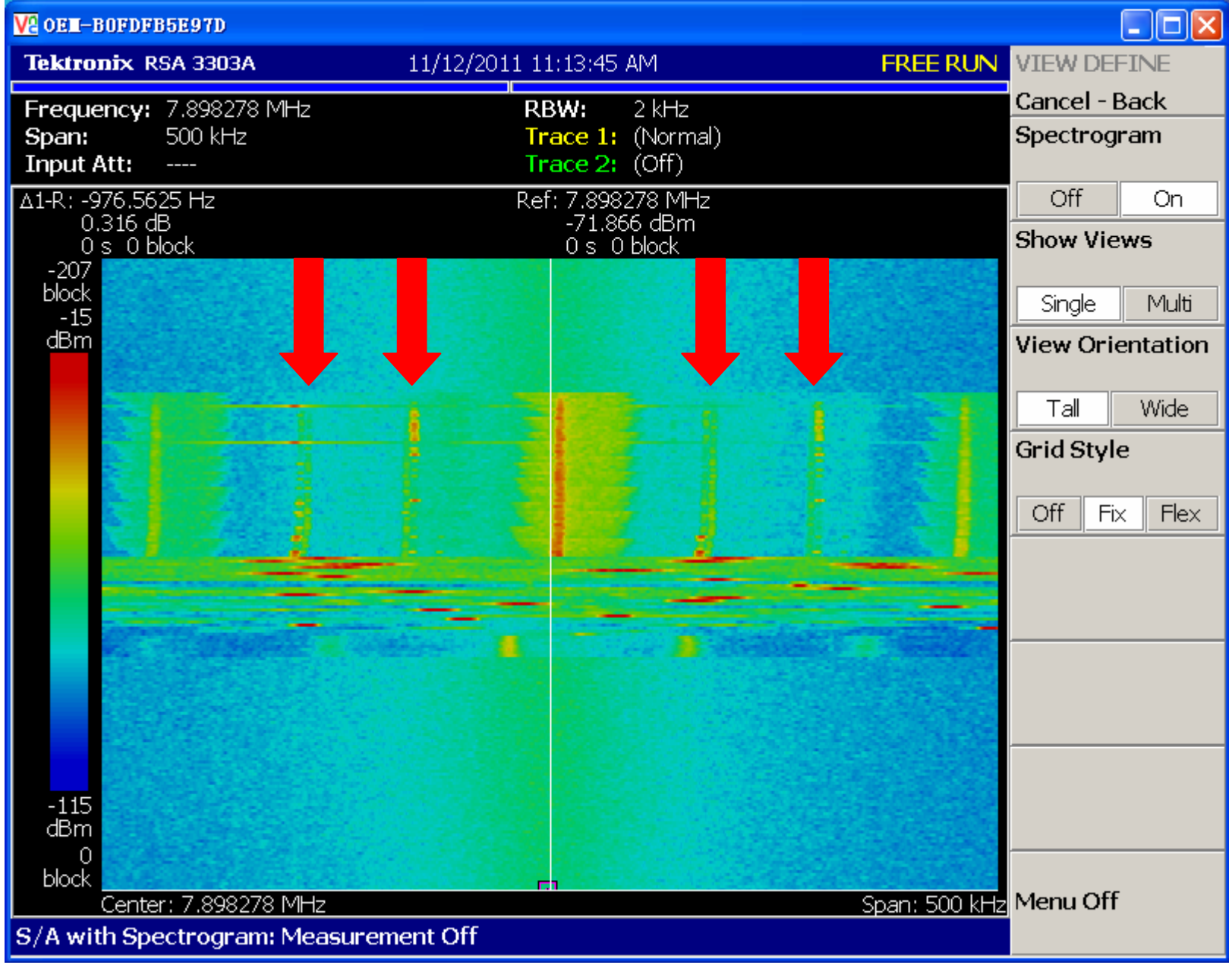
December 12 2011
Accumulation and Acceleration
Of $^{12}C^{6+}$ under electron cooling
7MeV/u

Stripping injection

(1)There was obvious sideband signal between the neighbor harmonic.
(2)Not symmetrically cooled to the centre.
(3)The intensity of signal increased with the injection.
(4)The central frequency did not shifted.

Unreasonable work-point setting
Obvious beam loss when stronger sideband

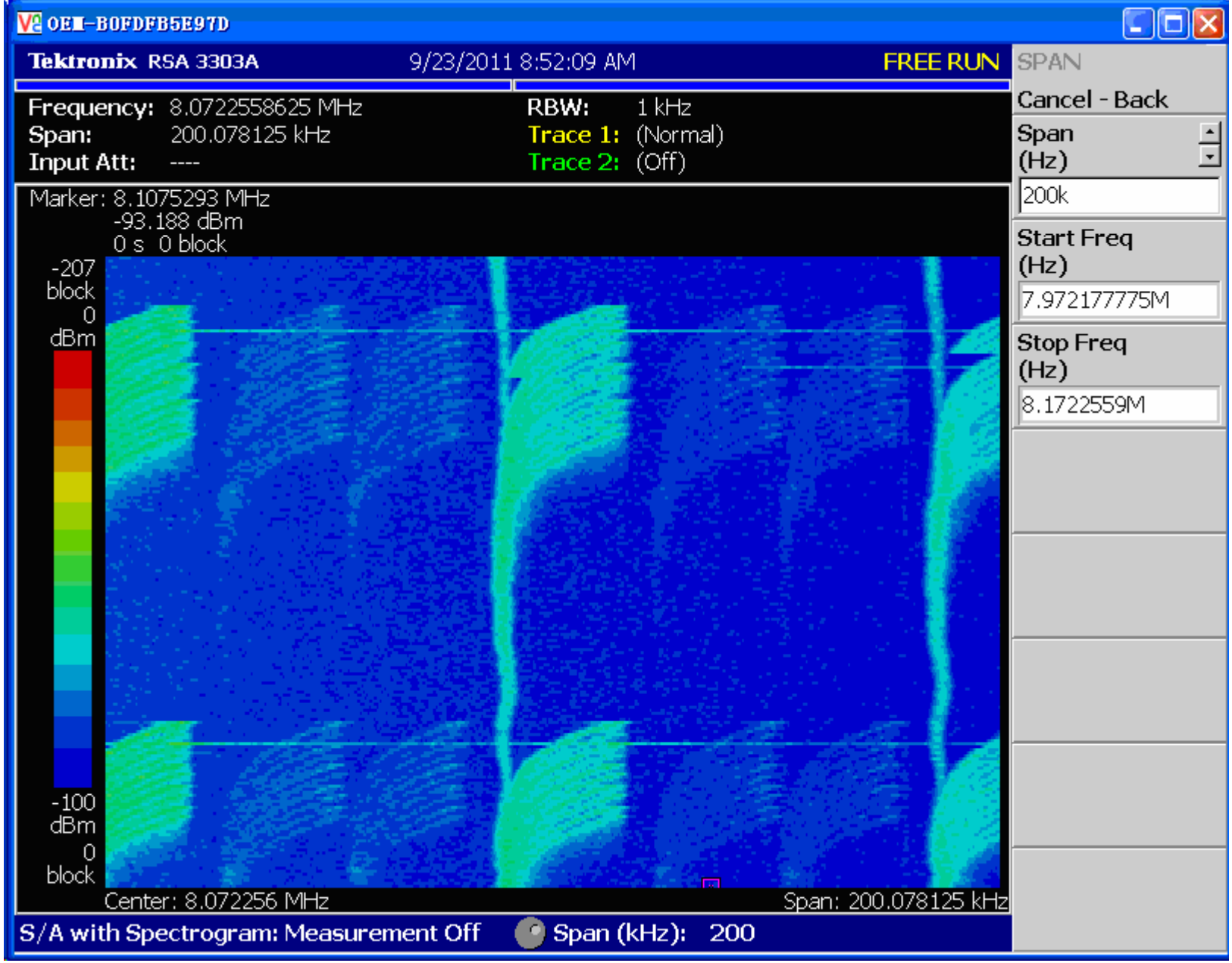
Ion energy
Electron energy
The field of dipole of the CSRm ring
The frequency of RF



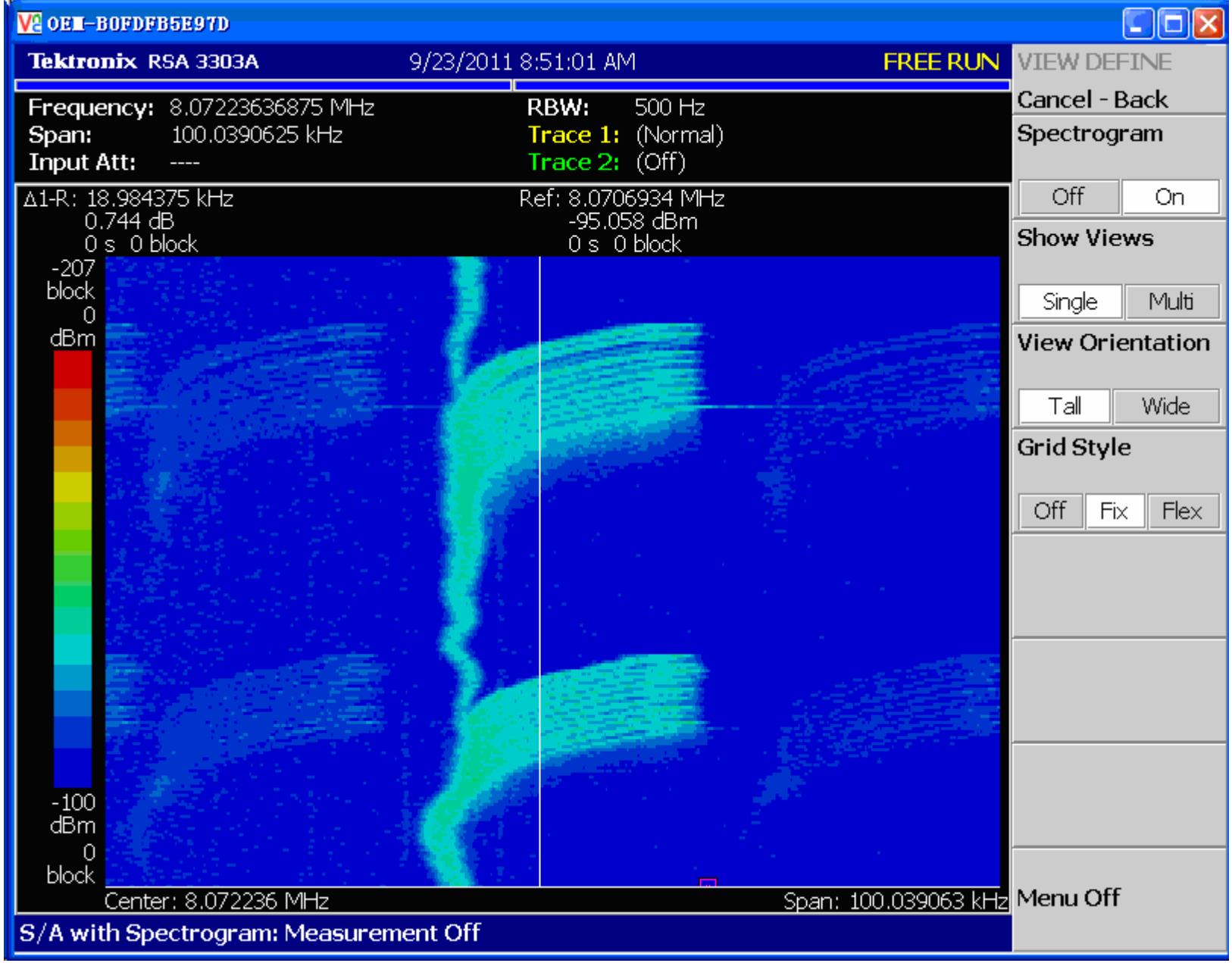
The Schottky signal with obvious sideband

$^{238}U^{32+}$ Accumulation and Acceleration in CSRm

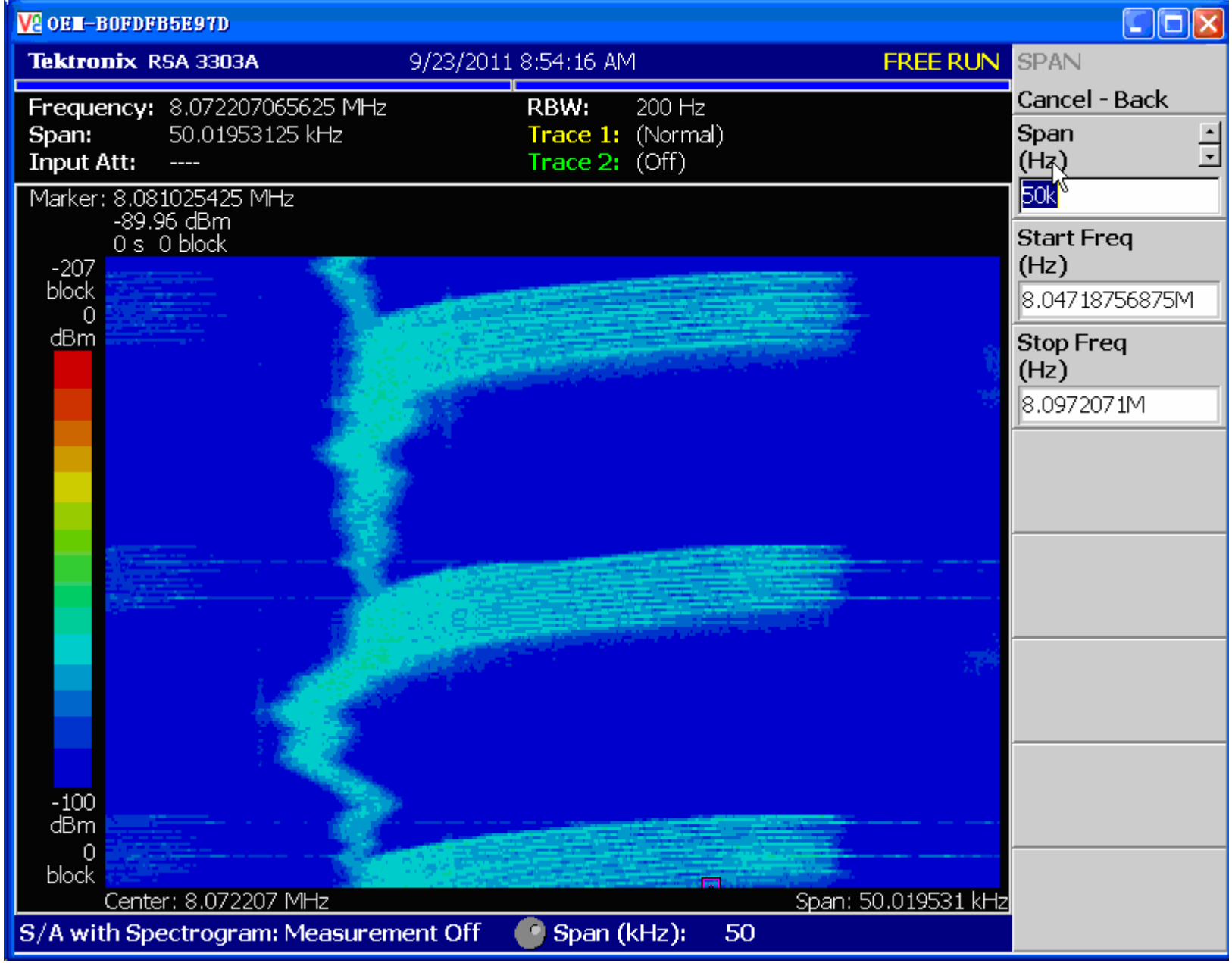
1.2MeV/u---100MeV/u



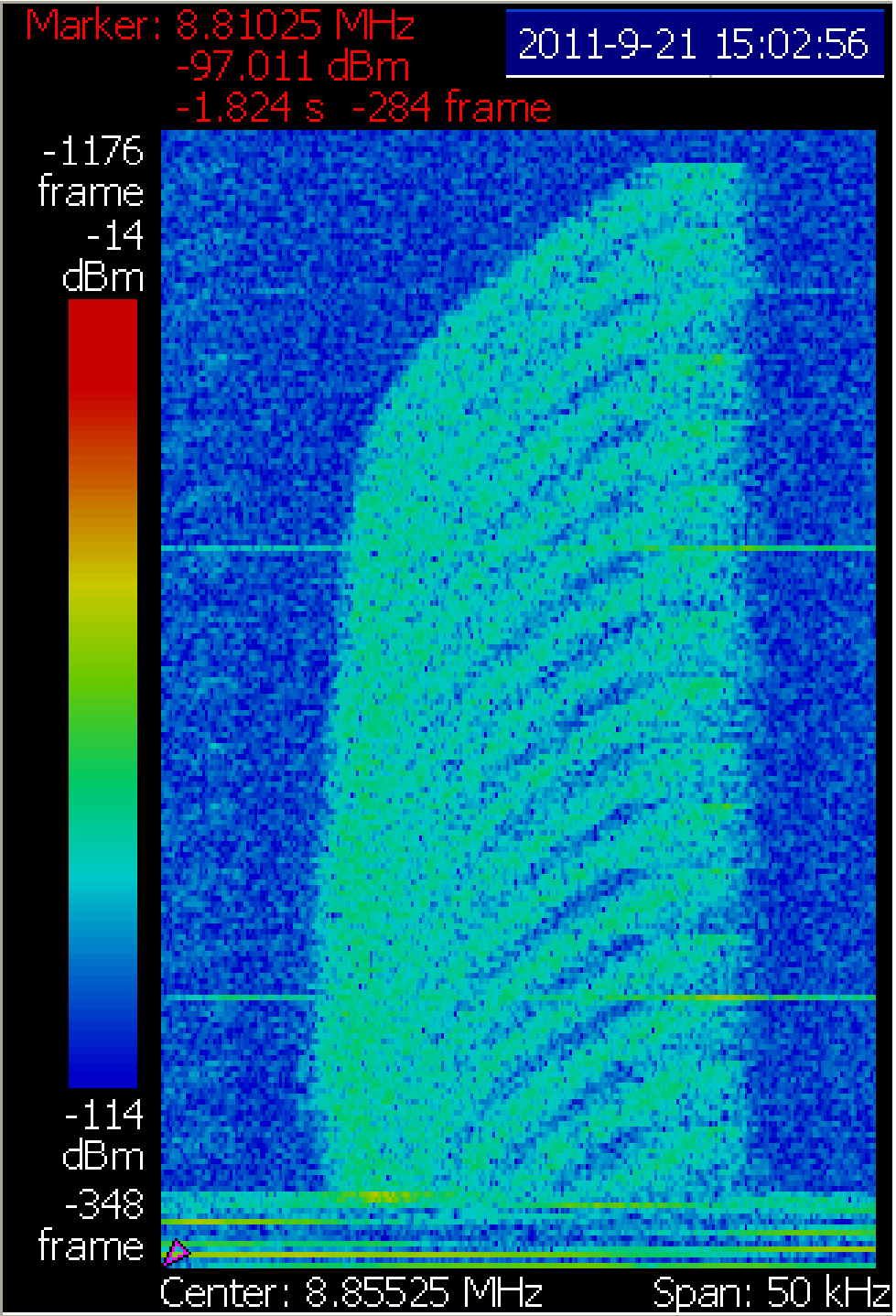
The Schottky signal with obvious sideband $^{238}U^{32+}$ Span=200KHz



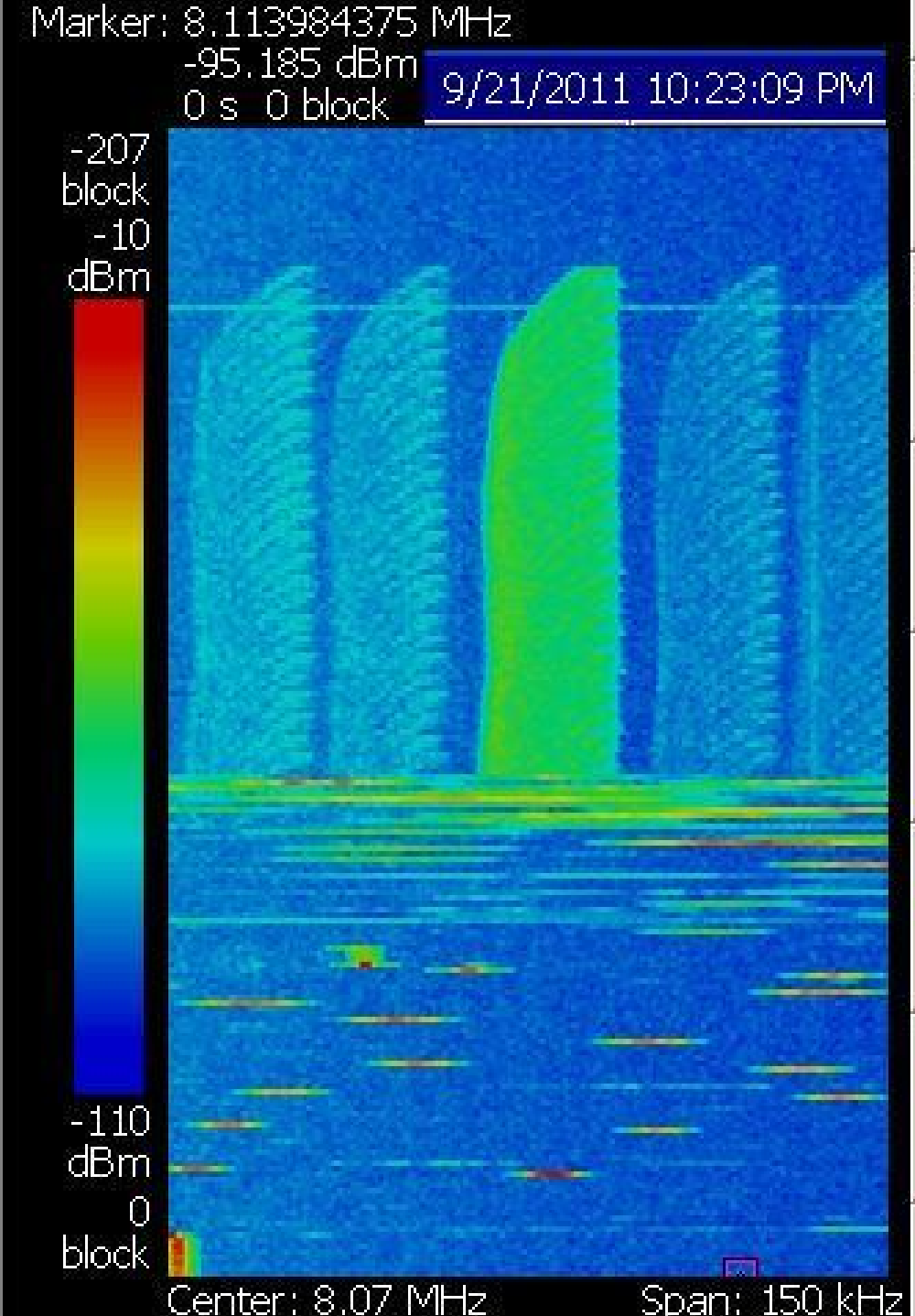
The Schottky signal with obvious sideband $^{238}U^{32+}$ Span=100KHz



The Schottky signal with obvious sideband $^{238}U^{32+}$ Span=50KHz



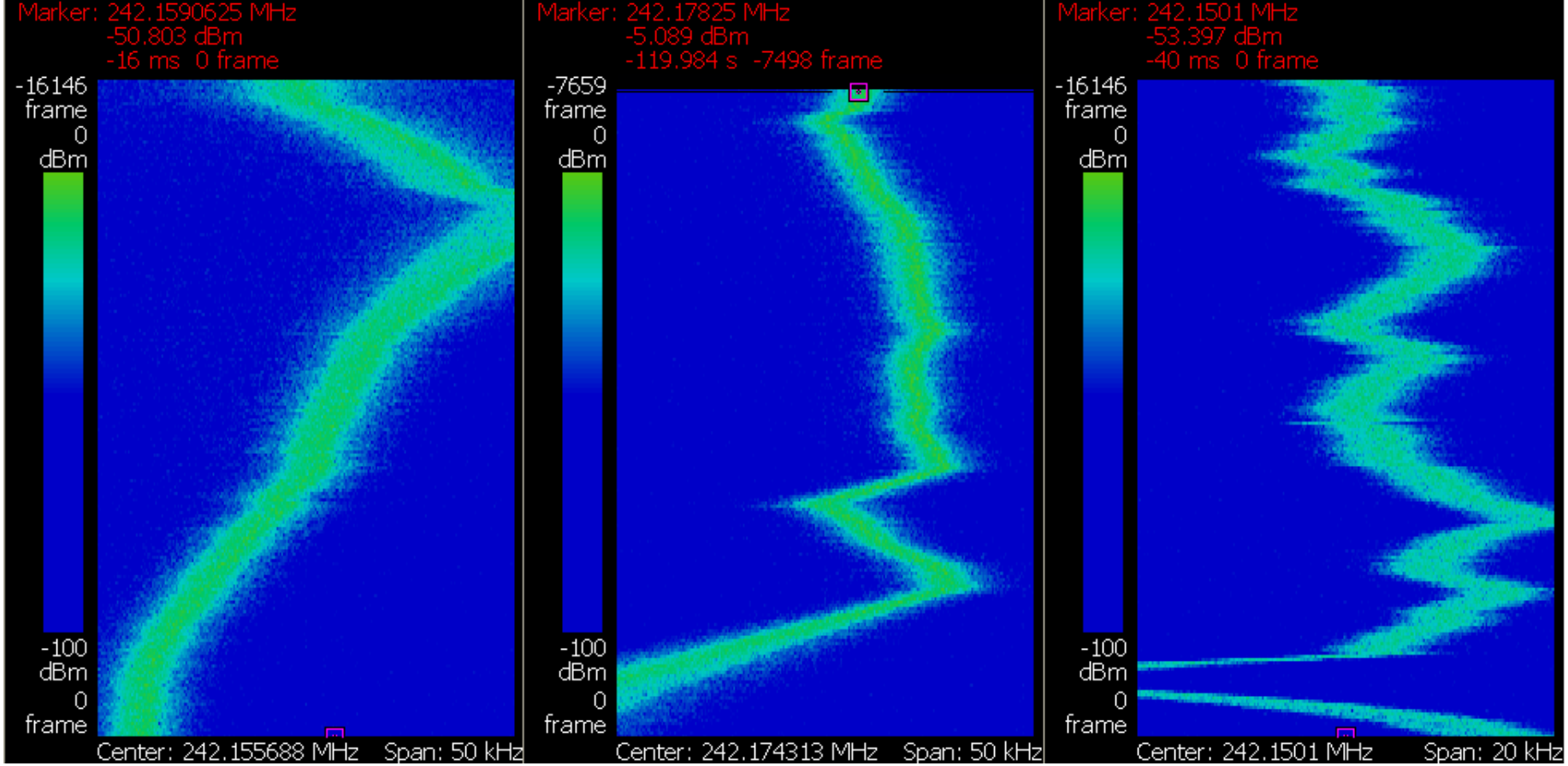
If adjust the electron energy to the center or left side, there was no Accumulation!



There were obvious sideband around the centre signal.

After cooling

- Stability of dipole field in CSRe
- Stability of quadrupole in CSRe
- HV stability of electron cooler
- Corrector stability in CSRe



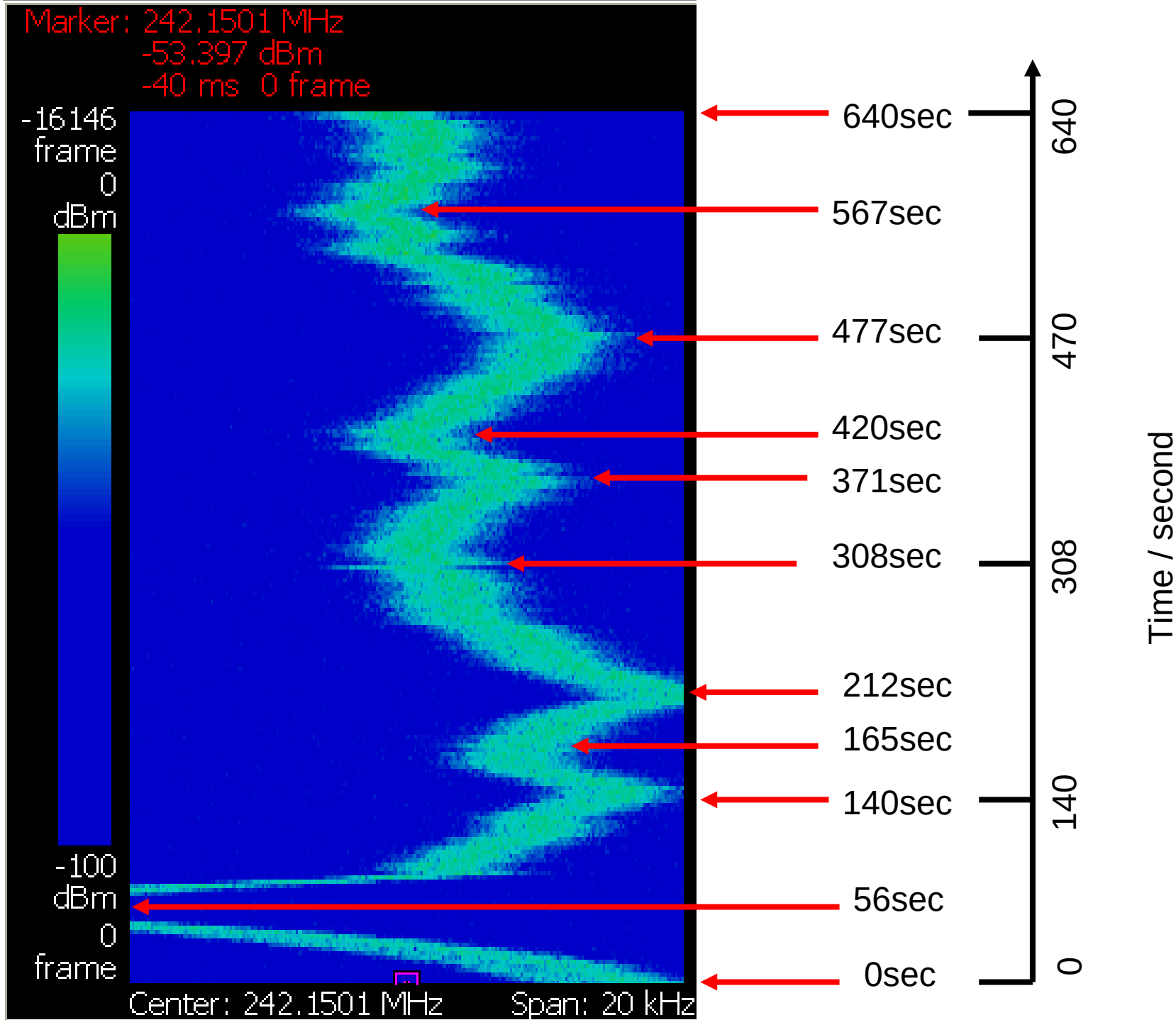
January 8 2012 CSRe

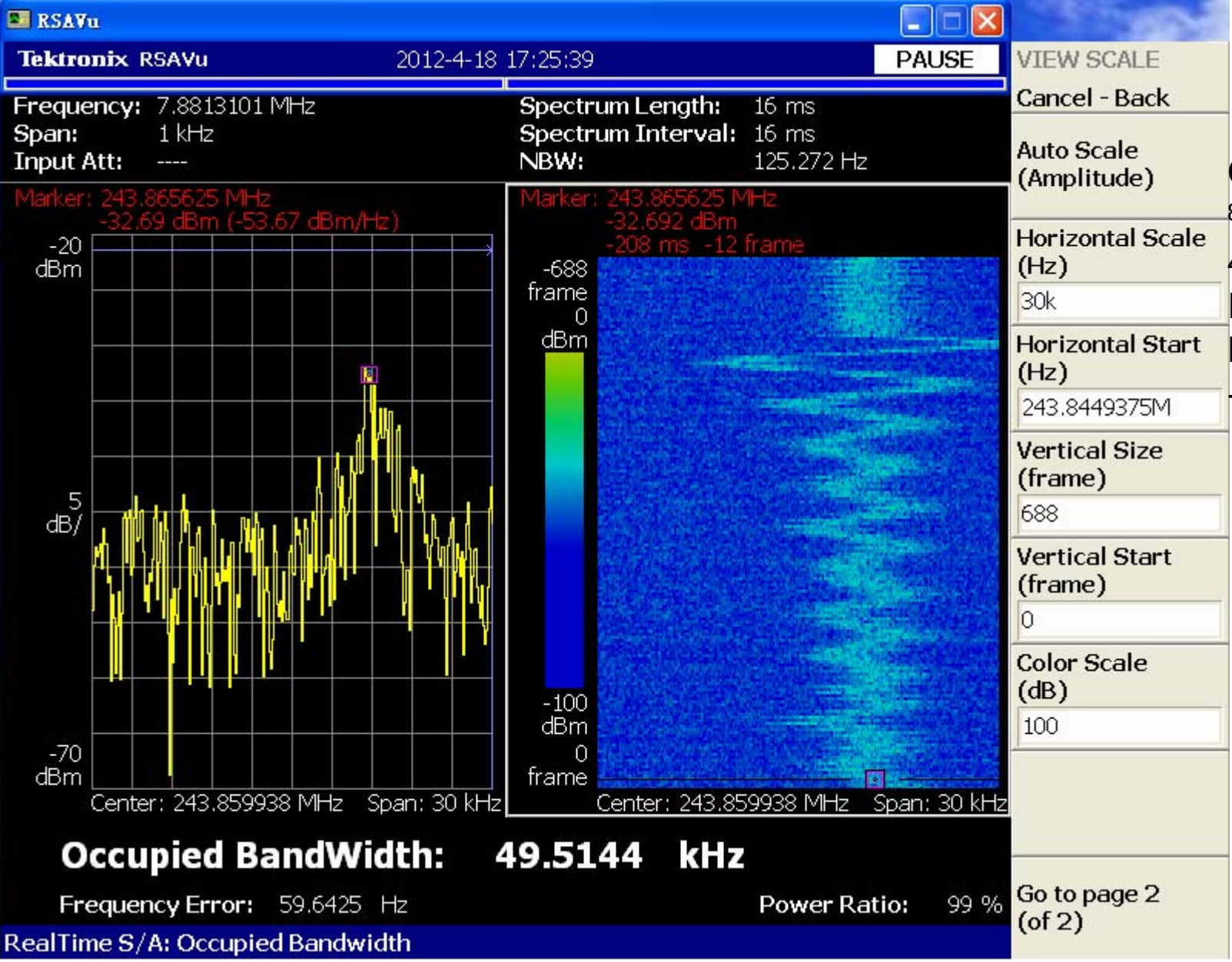
$^{86}Kr^{36+}$ 200MeV/u

Normal Mode

$\Delta f/f_0 = \pm 25kHz/242MHz = \pm 1/10*10^{-3} = \pm 1*10^{-4}$

The Schottky spectrum of ion beam after cooling equilibrium in CSR experimental ring

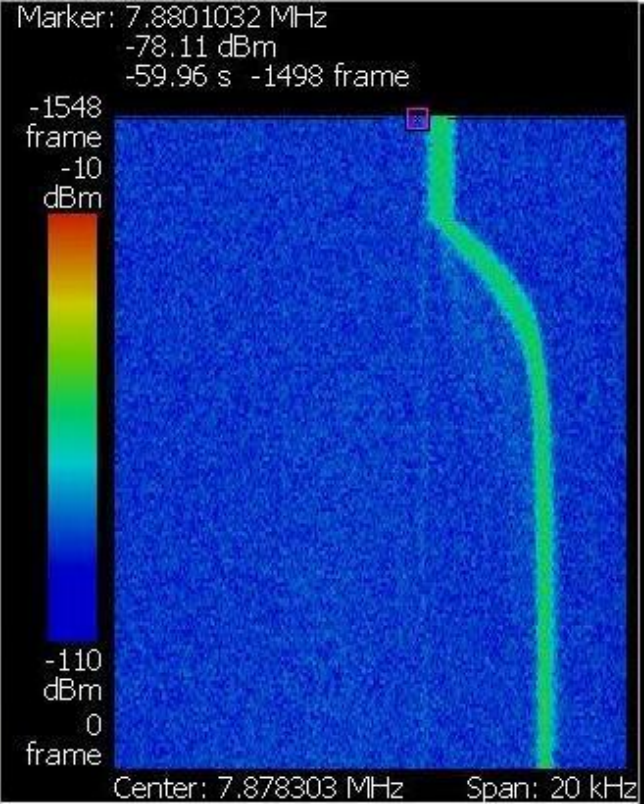

January 8 2012 CSRe $^{86}Kr^{36+}$ 200MeV/u Normal Mode
Marker: 242.1501 MHz
-53.397 dBm
-40 ms 0 frame
-16146
frame
0
dBm
-100
dBm
0
frame
Center: 242.1501 MHz
Span: 20 kHz
640sec
567sec
477sec
420sec
371sec
308sec
212sec
165sec
140sec
56sec
0sec
640
470
308
140
0
Time / second

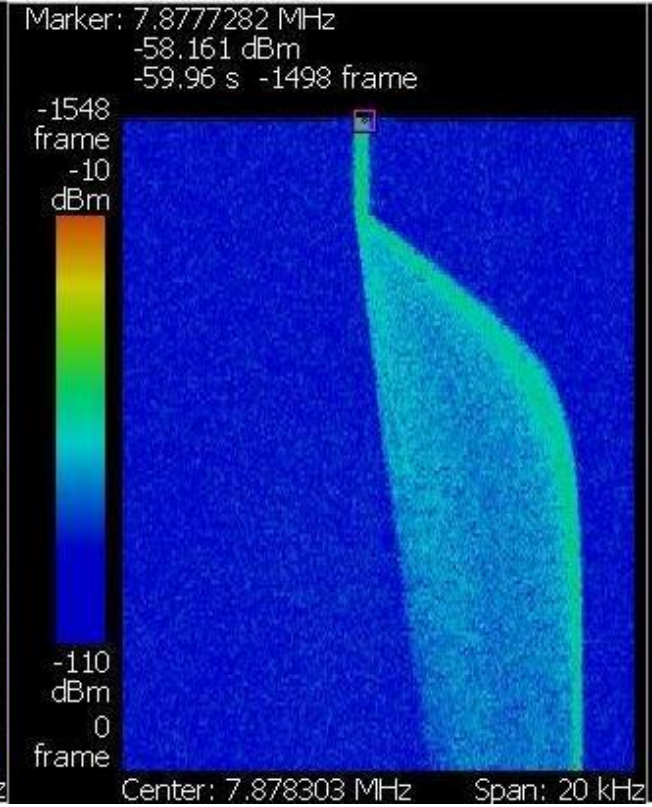


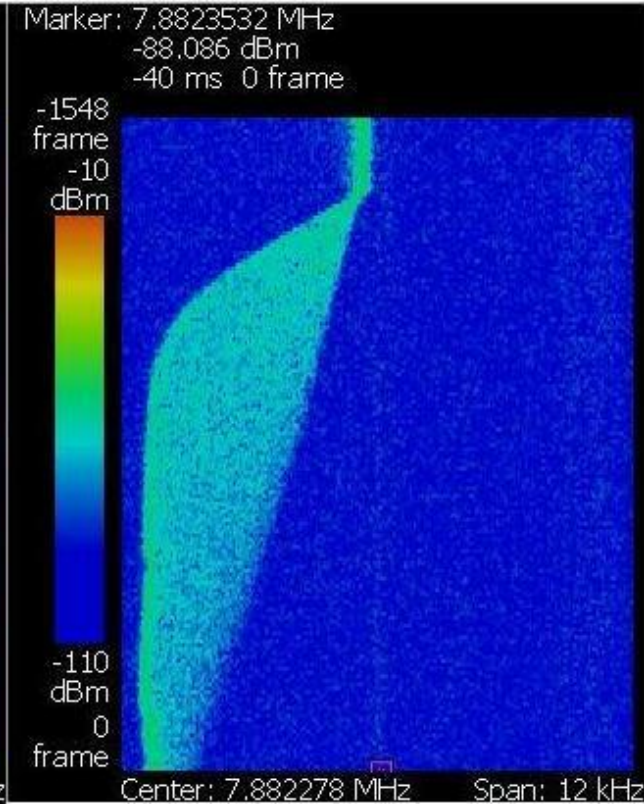
CSRe
$^{86}Kr^{36+}$
434.8MeV/u
Isochronous
Magnetic rigidit
---10.19T.m

The Schottky spectrum of ion beam **in the absent of** electron cooler at the **isochronous operation mode** in CSR experimental ring

Instability
During the cooling force measurement



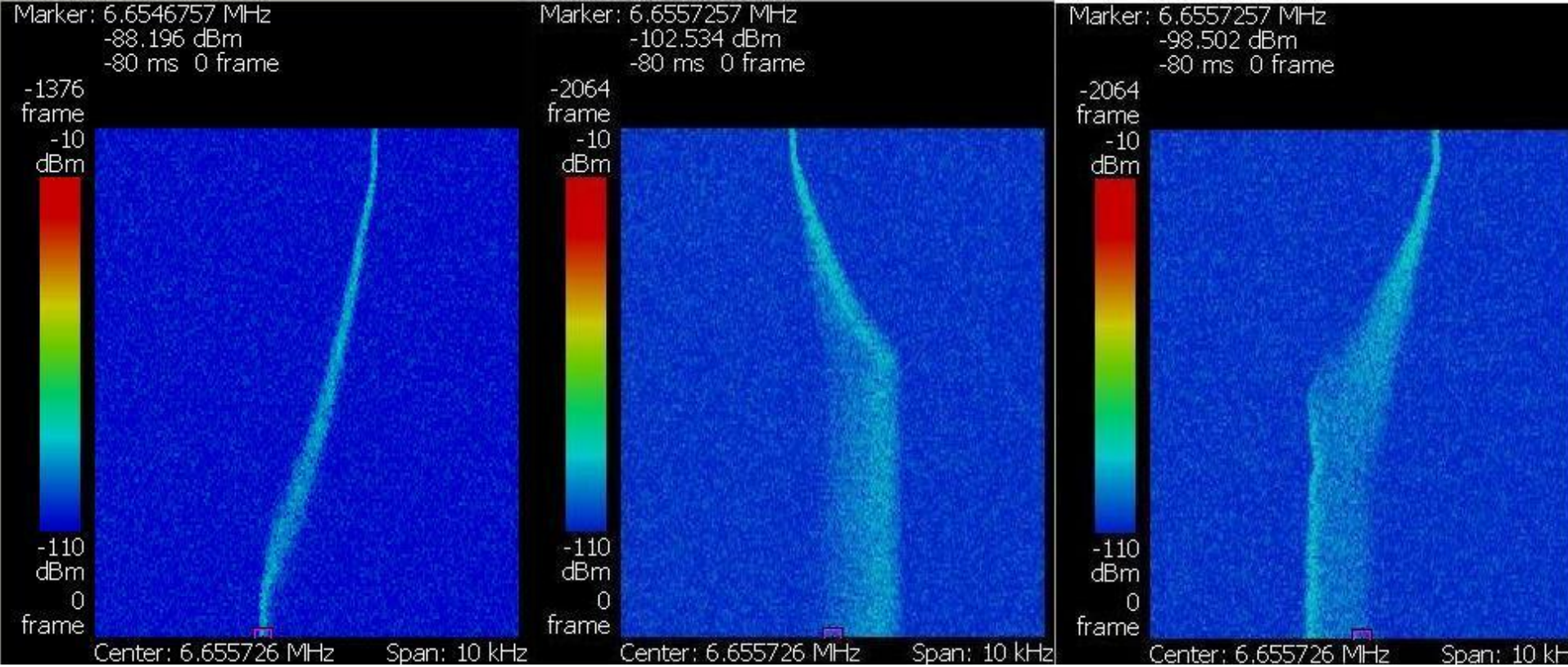




Left---standard Schottky signal during cooling force measurement, optimal toroid field
Middle---smaller toroid field than optimal one, Electron energy:108.96keV--109.16keV
Right--- smaller toroid field than optimal one, Electron energy:108.96keV---108.76keV.

Feb. 2 2010 200MeV/u $^{129}Xe^{54+}$ CSRe Internal target mode

The Schottky spectrum of 200MeV/u $^{129}Xe^{54+}$
during cooling force measurement in CSR experimental ring.



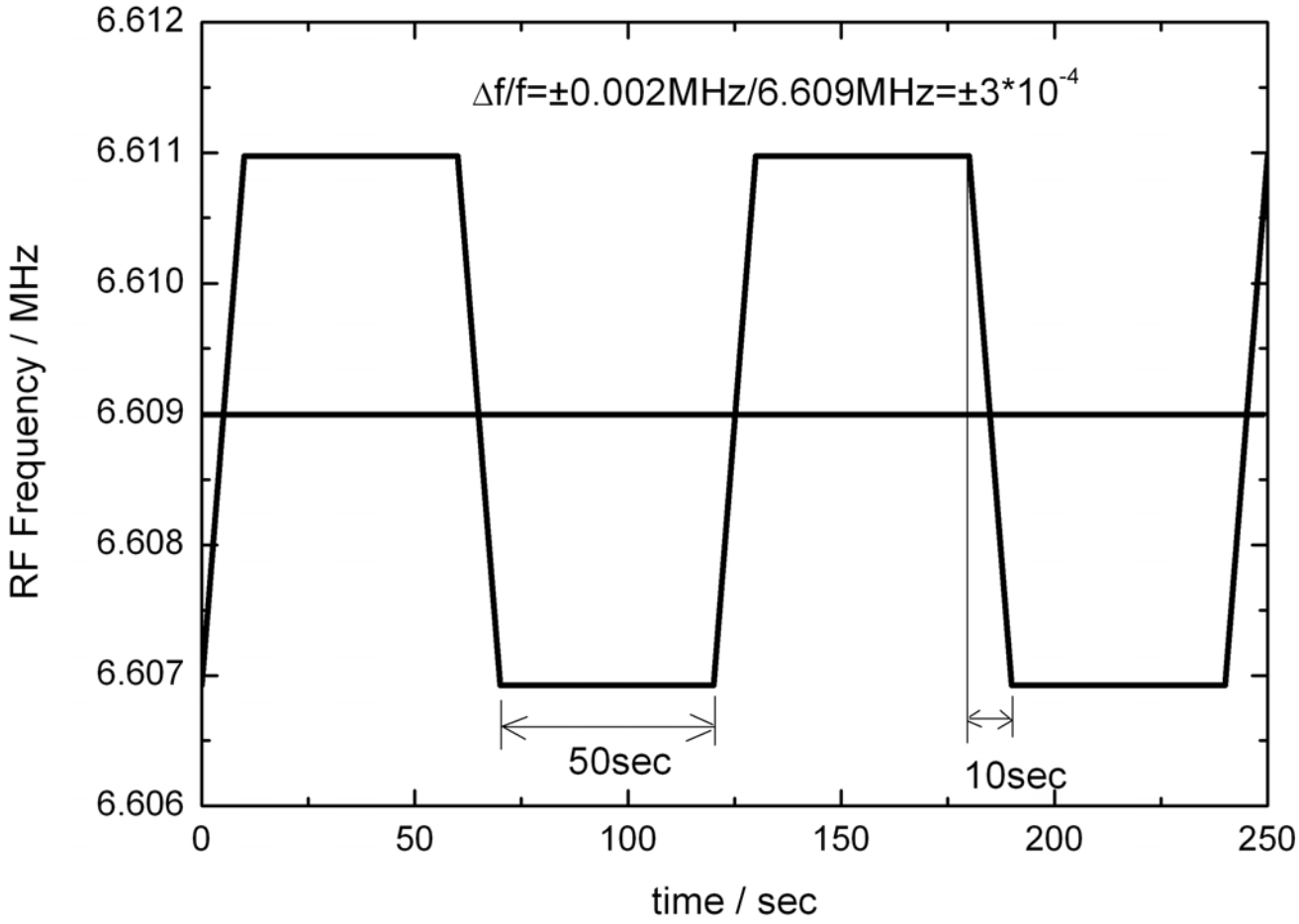
Left---no angle between ion and electron beams,
Middle---with an angle in vertical direction,
Right---with an angle in vertical direction, opposite electron energy change.

The Schottky spectrum of 400MeV/u $^{12}C^{6+}$
during cooling force measurement in CSR experimental ring.

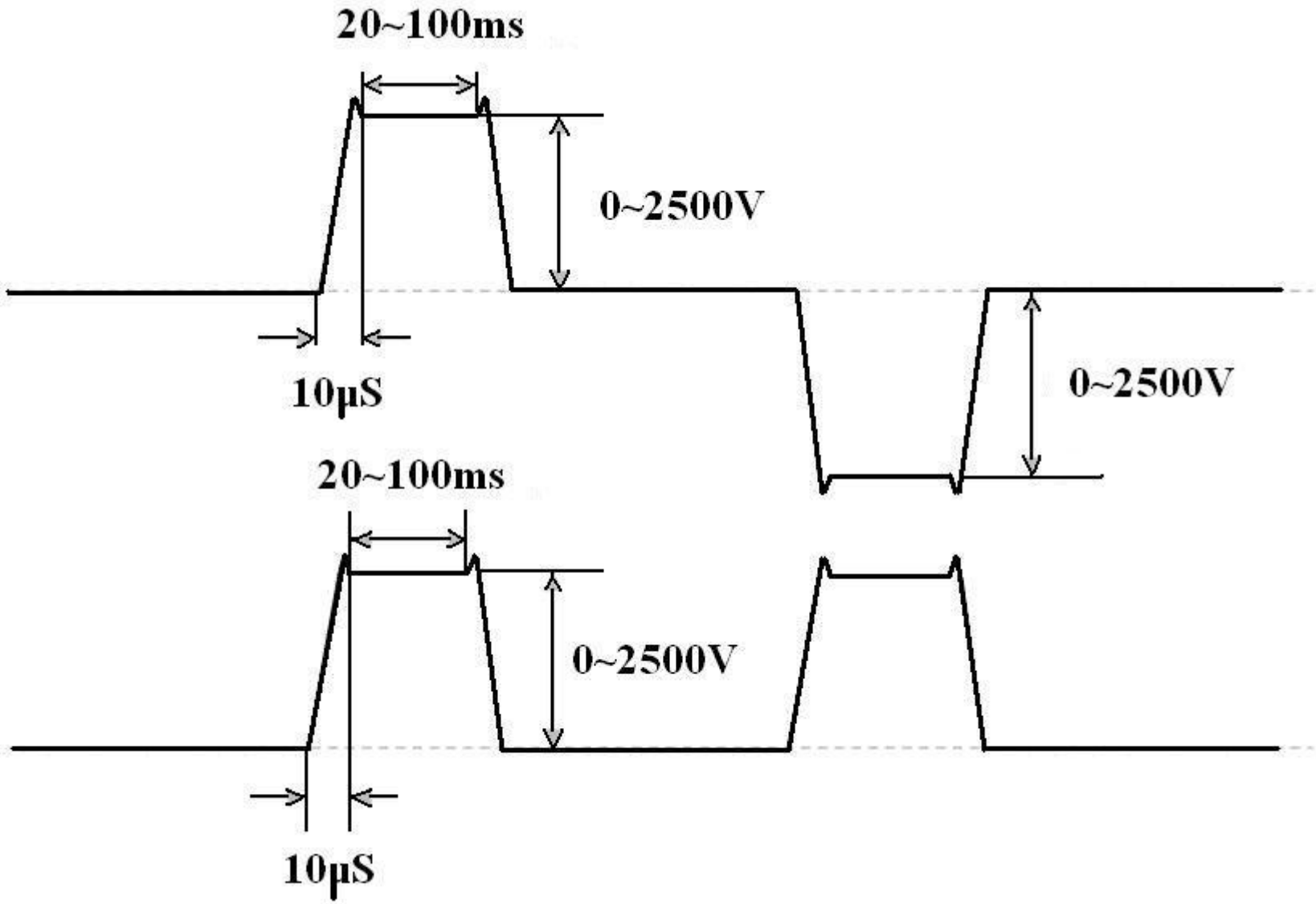
Example of external modulation

- Fast modulation
- Slow modulation

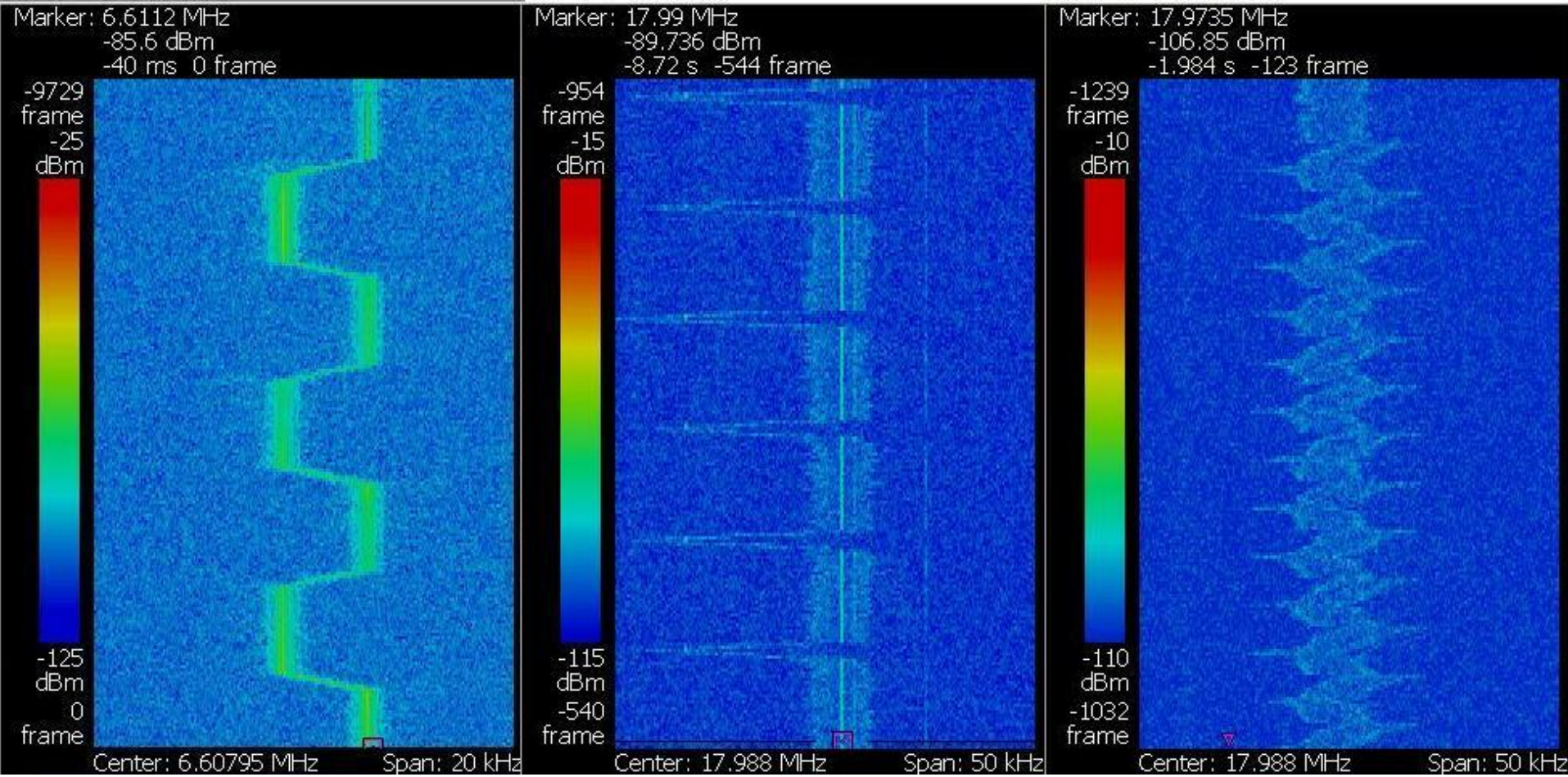
They are helpful to understand the change in the Schottky signal.



Waveform of RF frequency modulation



Waveform of electron energy modulation



Left---the action of the change of RF frequency
Middle---the action of the unilateral change of electron energy
Right--- the action of the bilateral change of electron energy

The Schottky spectrum of ion beam under the action of external factor.

For high solution mass measurement

$$\Delta f/f_0 = \pm 1*10^{-6}$$

$$\Delta f/f_0 = \pm 250Hz/242MHz = \pm 1*10^{-6}$$

Schottky signal of beam in CSRe

at 242MHz main frequency

span= 1kHz

FWHM：full width at half maximum

Δf=250Hz

Summary

- Study the source and mechanism of instability in the future.
- Seek the solution (method) to suppress and eliminate the instability.
- Improve the stability of machine.
- Increase the intensity of accumulated beam in CSRm.

Thank You !

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