Workshop on Beam Cooling and Related Topics 2011, COOL'11
September, 12-16, 2011
Dubna, Alushta, Crimea, Ukraine

Electron cooling performance at IMP facility

Institute of Modern Physics, CAS
Lanzhou

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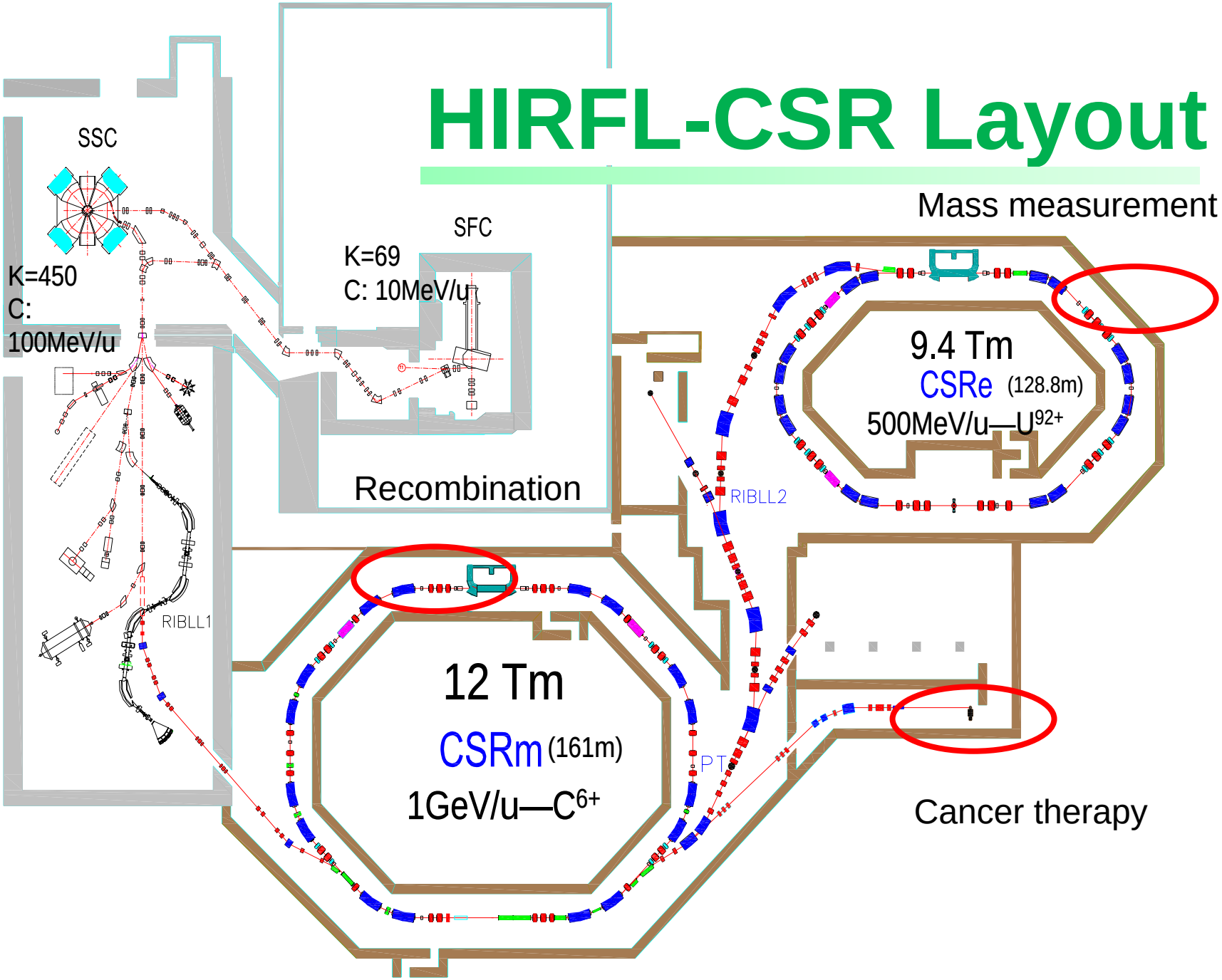
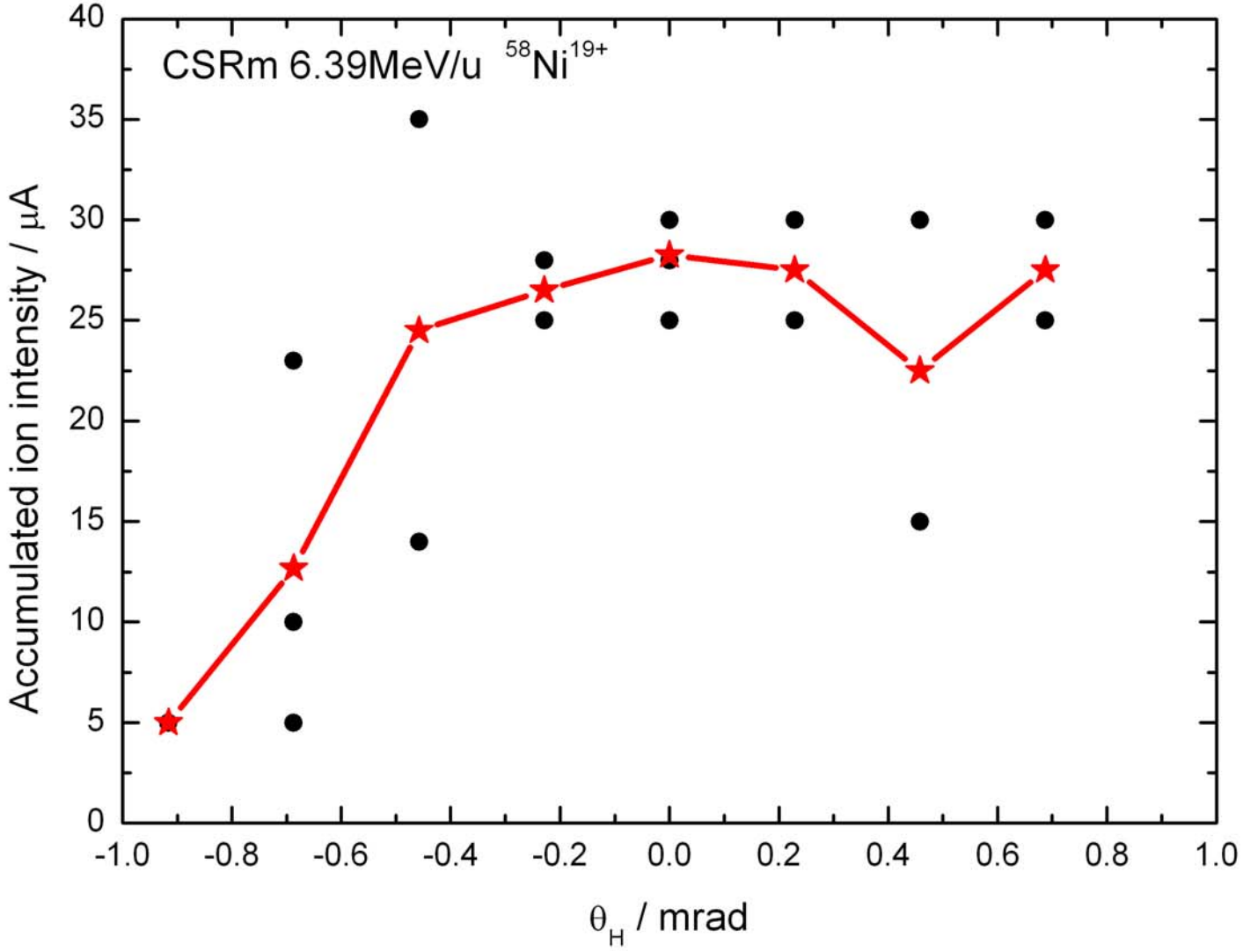
Main works in CSR

- Experiments on cancer therapy
- Cancer therapy
- Mass measurement
- $^{209}Bi^{36+}$ Accumulation and Acceleration in CSRm
- Recombination Experiments

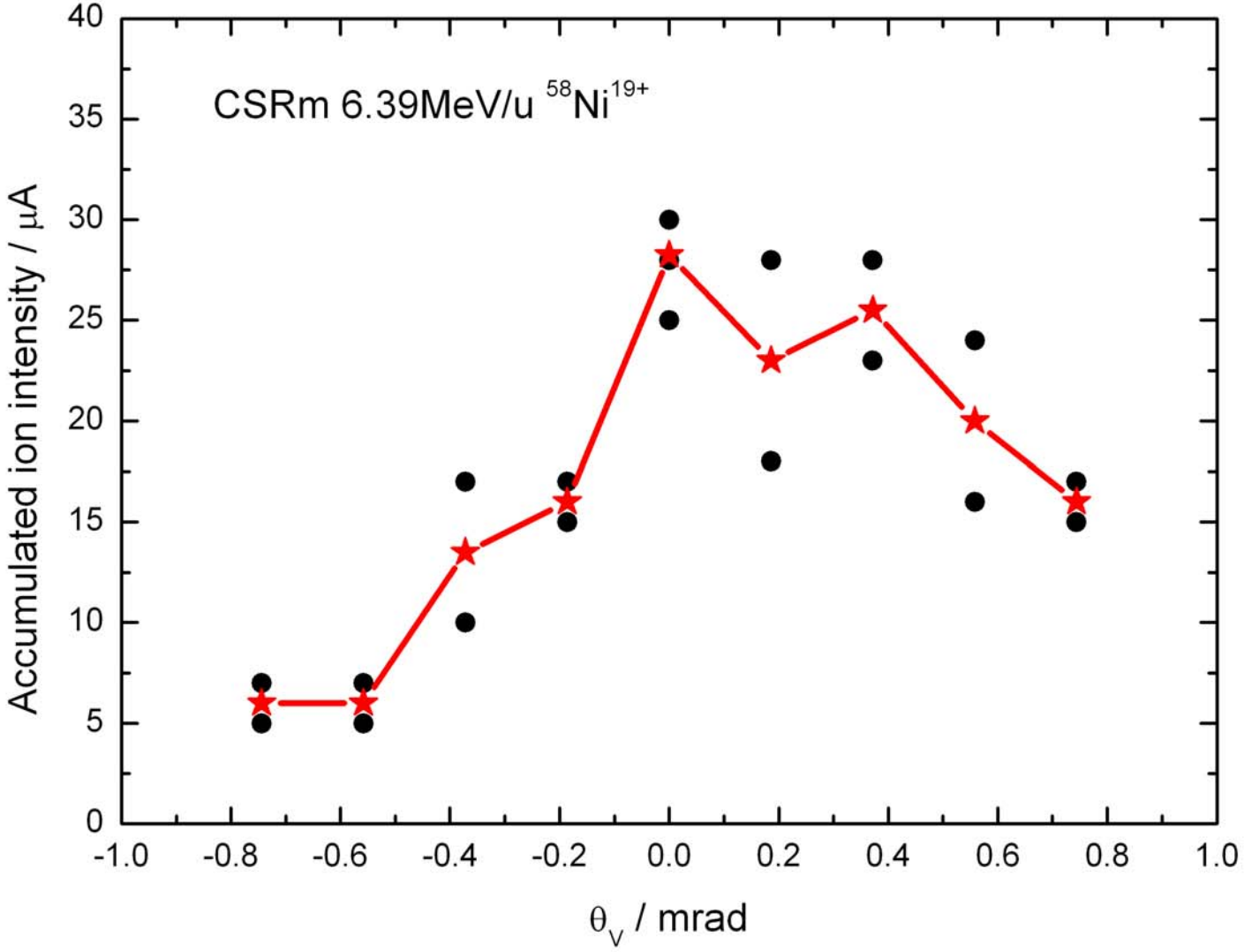
HIRFL-CSR Layout



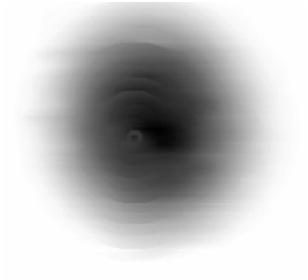
Beam Accumulation in CSRm

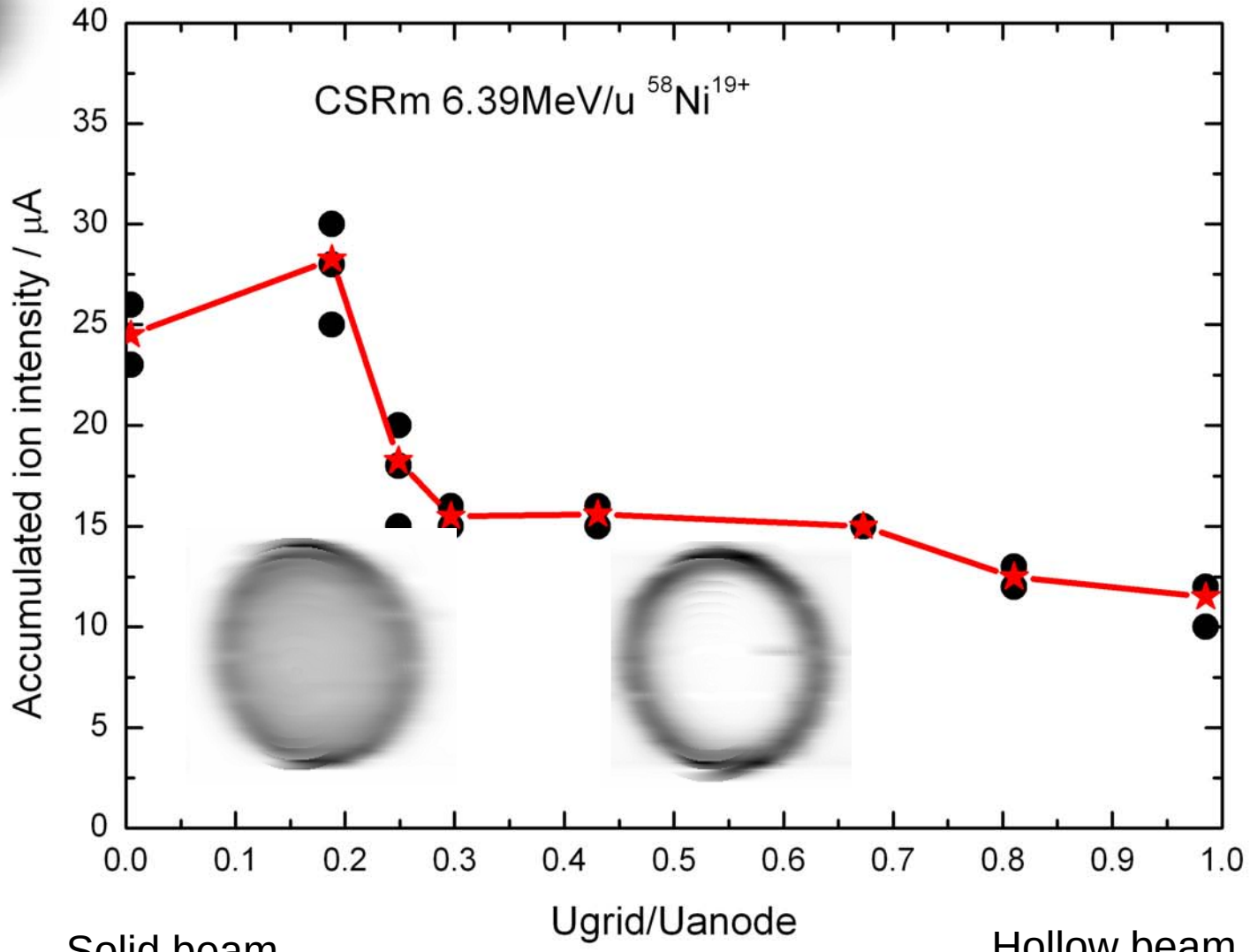


Accumulated ion intensity in 10s as a function of
related horizontal angle between ion and electron beams



Accumulated ion intensity in 10s as a function of related vertical angle between ion and electron beams





Solid beam

Hollow beam

Accumulated ion intensity in 10s as a function of profile of electron beam

0.33

0.67

0.22

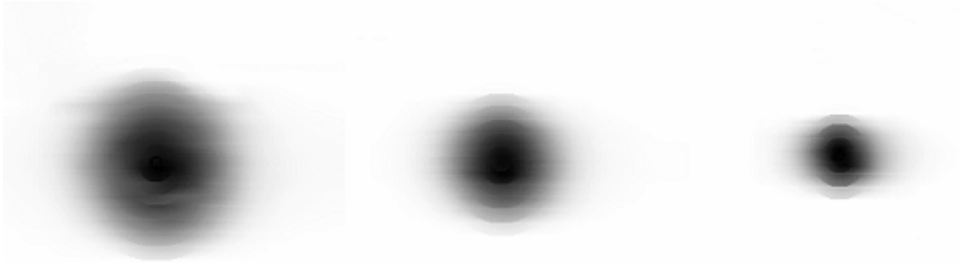
$U_{control}/U_{anode}$= 0.6/0.9 kV $U_{control}/U_{anode}$= 0.3/0.9 kV $U_{control}/U_{anode}$=0.2/0.9 kV

0.11

0

$U_{control}/U_{anode}$=0.1/0.9 kV $U_{control}/U_{anode}$= 0.05/0.9 kV $U_{control}/U_{anode}$= 0/1.4 kV

-0.07

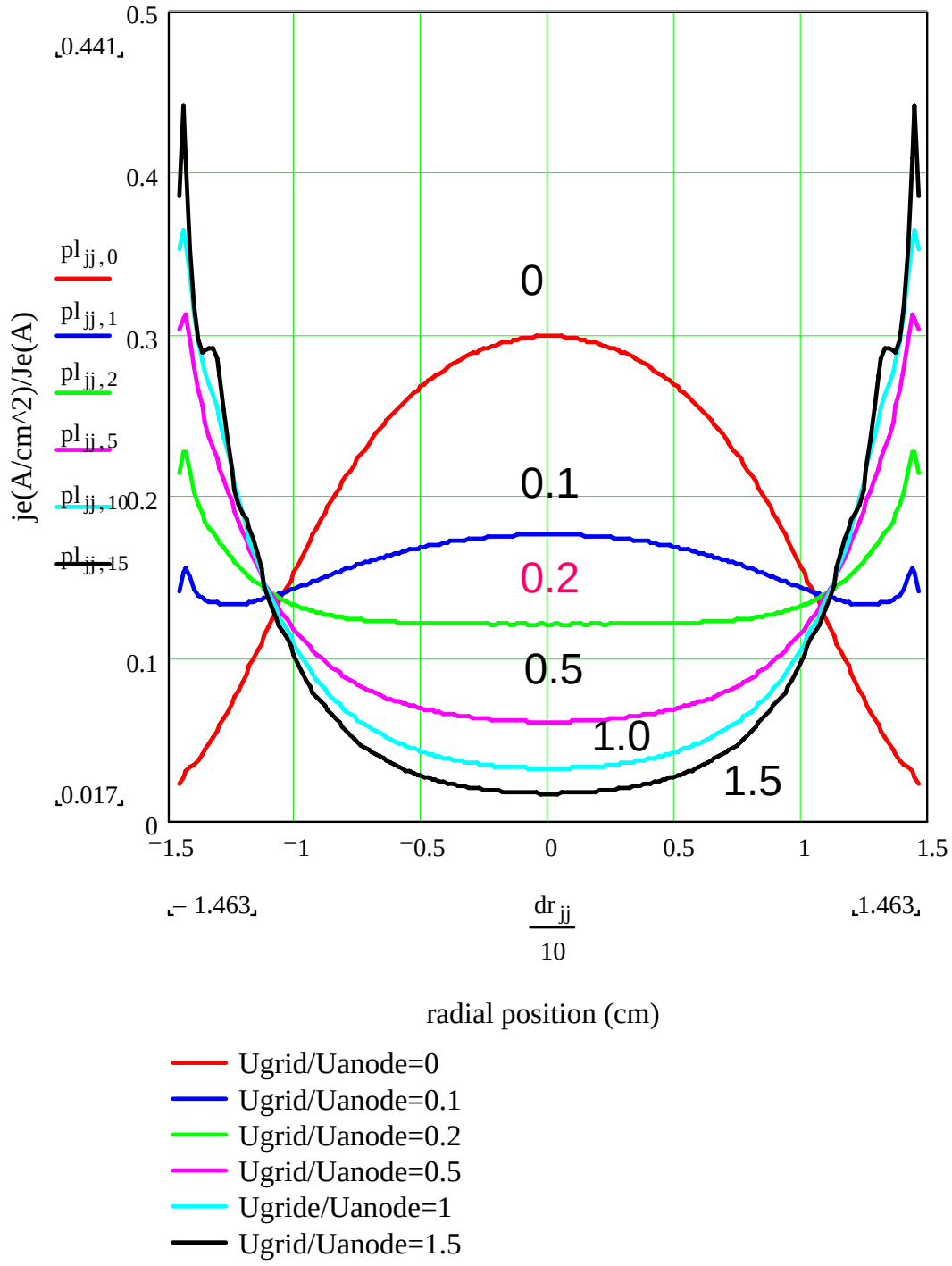


-0.2

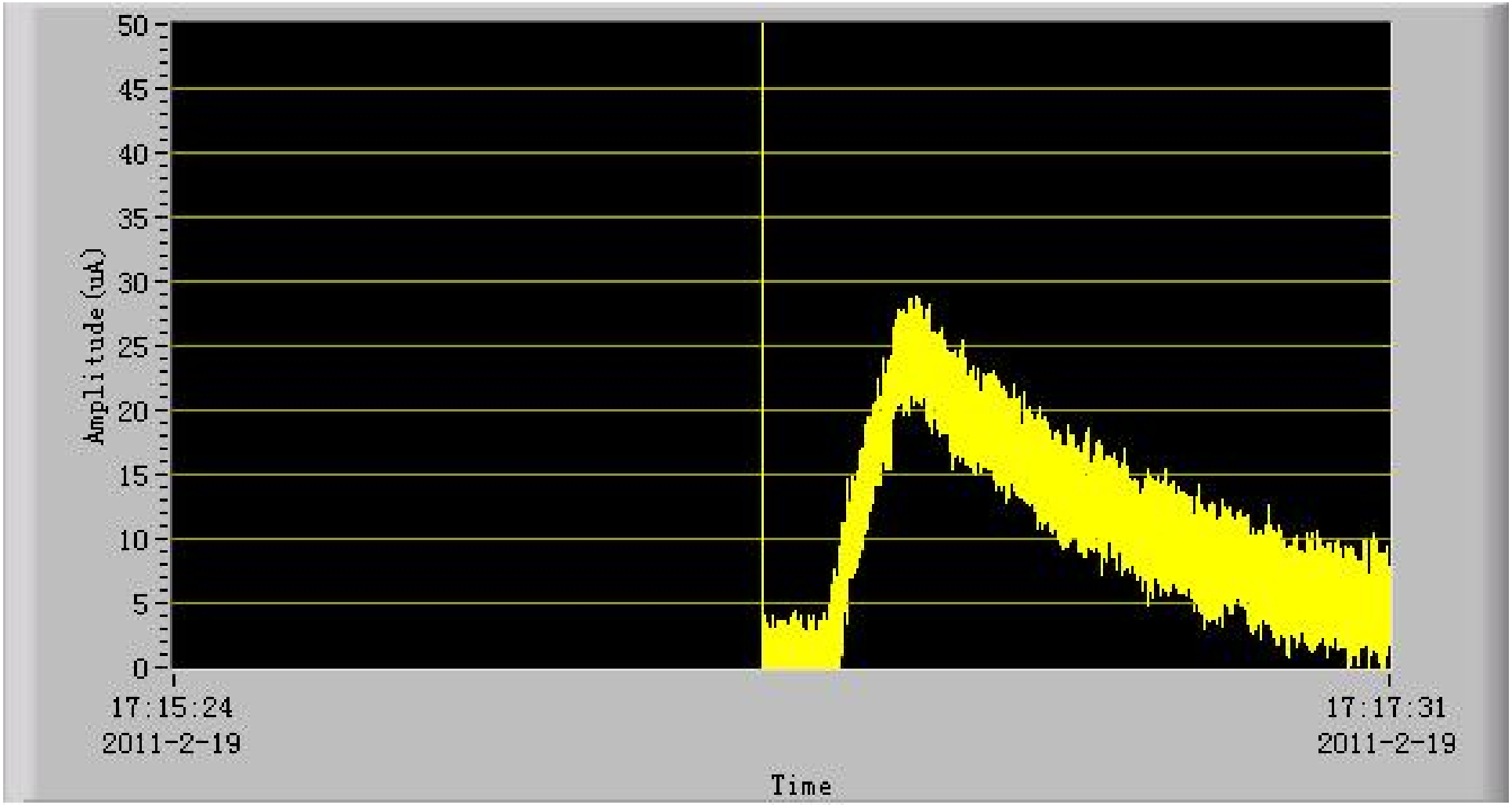
$U_{control}/U_{anode}$=–0.2/2.8 kV $U_{control}/U_{anode}$= -0.4/2.8 kV $U_{control}/U_{anode}$=–0.6/2.8 kV

-0.14

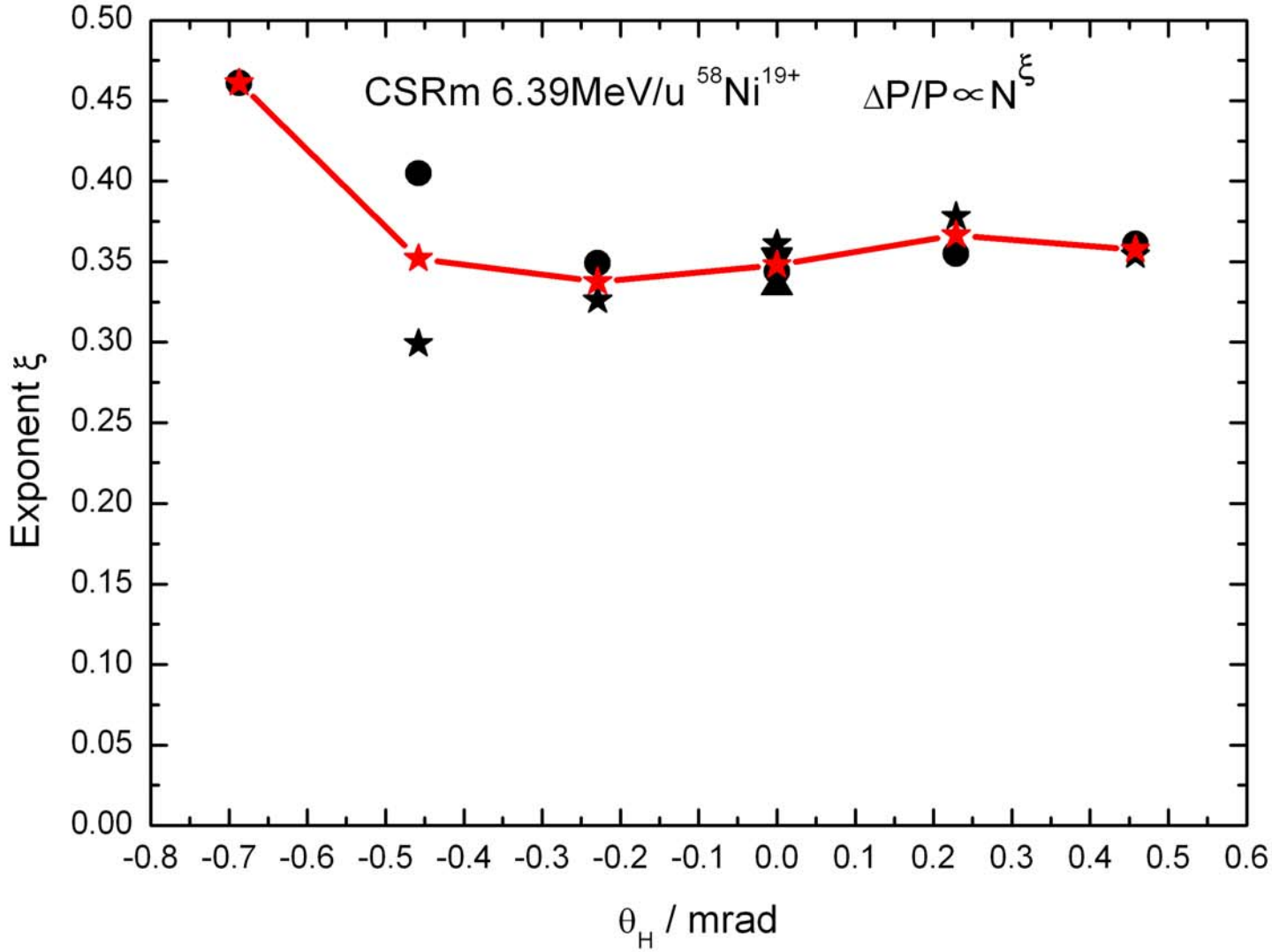
Electron beam profile


0.5
⌜0.441⌟
0.4
0.3
0.2
0.1
⌜0.017⌟
0
je(A/cm^2)/Je(A)
pl jj,0
pl jj,1
pl jj,2
pl jj,5
pl jj,10
pl jj,15
0
0.1
0.2
0.5
1.0
1.5
−1.5
−1
−0.5
0
0.5
1
1.5
⌜− 1.463⌟
dr jj / 10
⌜1.463⌟
radial position (cm)
Ugrid/Uanode=0
Ugrid/Uanode=0.1
Ugrid/Uanode=0.2
Ugrid/Uanode=0.5
Ugride/Uanode=1
Ugrid/Uanode=1.5

Exponent $\boldsymbol{\xi}$ **in** $\boldsymbol{\Delta}P/P \propto N^{\boldsymbol{\xi}}$



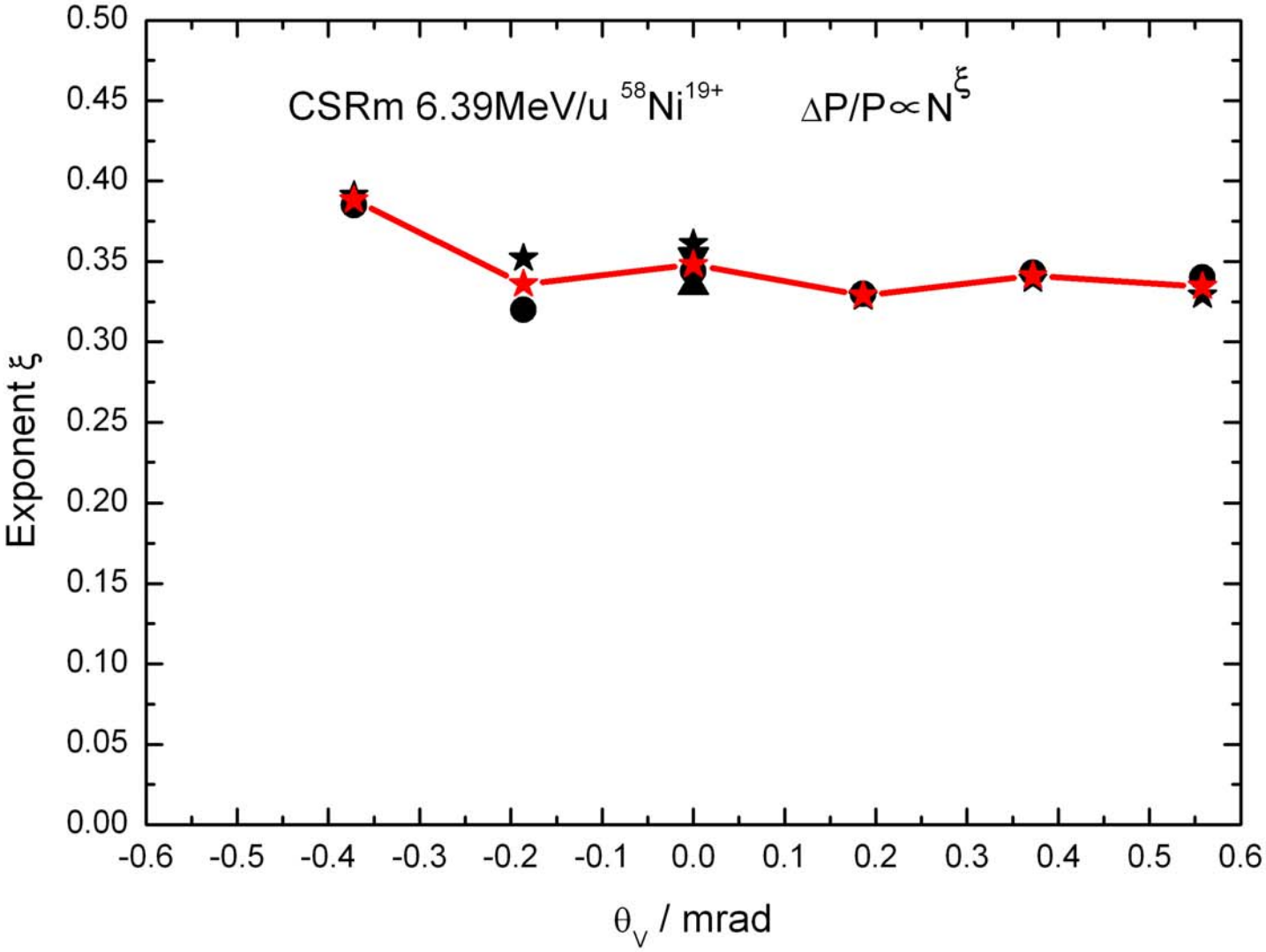
DCCT signal---Ion intensity decay during experiments



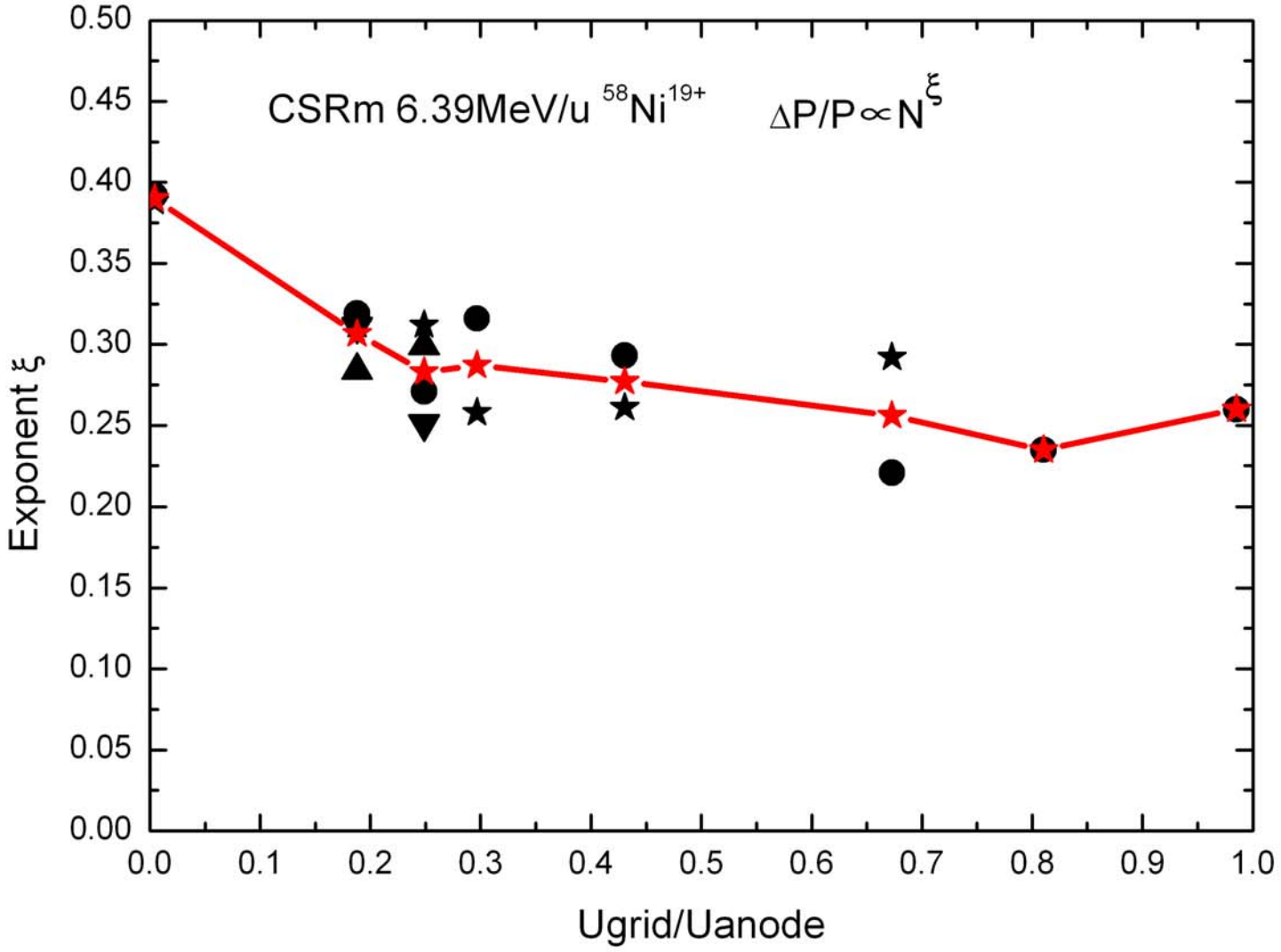
The momentum spread was scaled with the particle number as power law $\Delta P/P \propto N^{\xi}$

The exponent is the power coefficient **ξ**

The power coefficient as a function of
related horizontal angle between ion and electron beams



The power coefficient as a function of
related vertical angle between ion and electron beams



The power coefficient as a function of the profile of electron beam

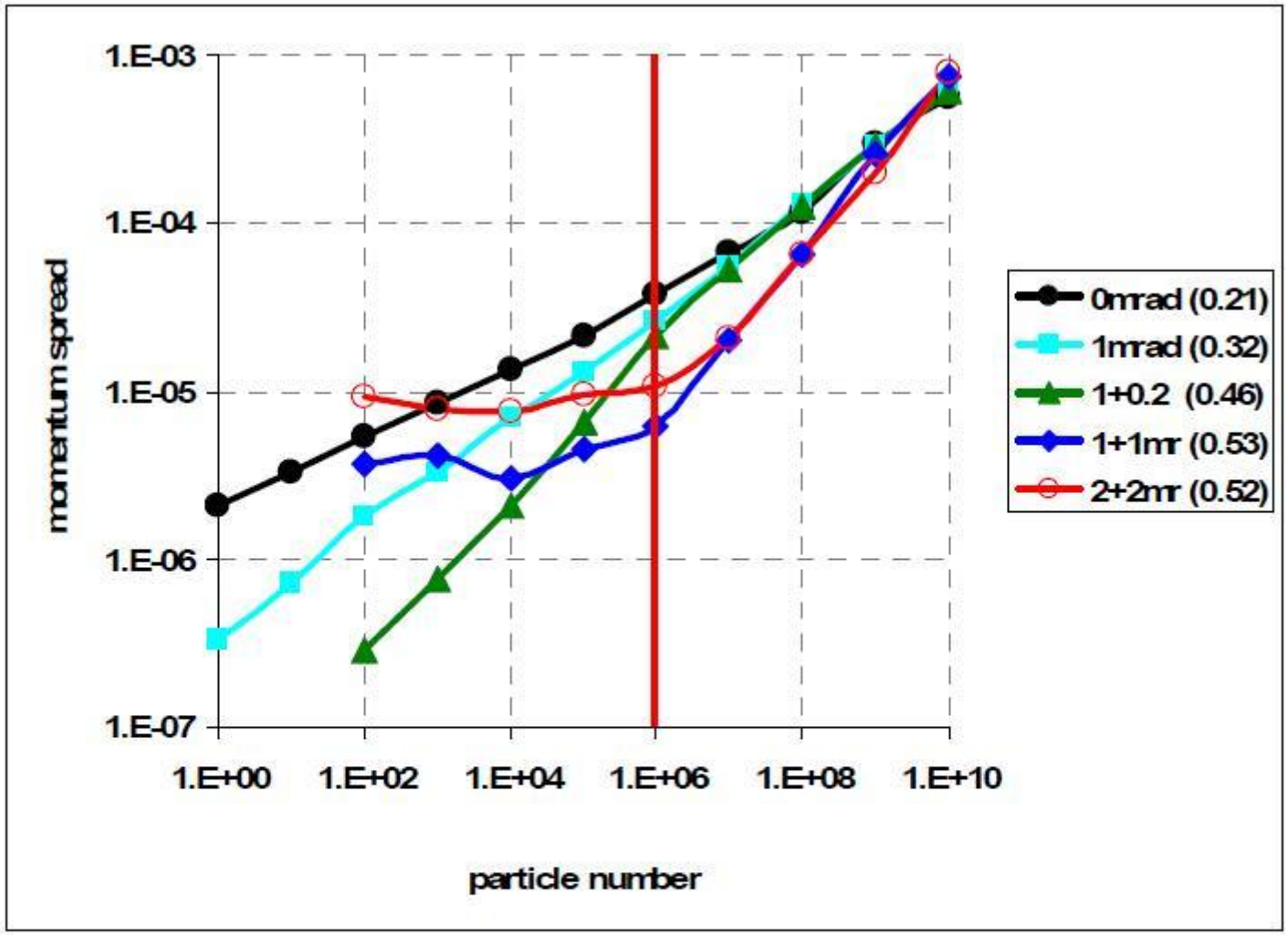
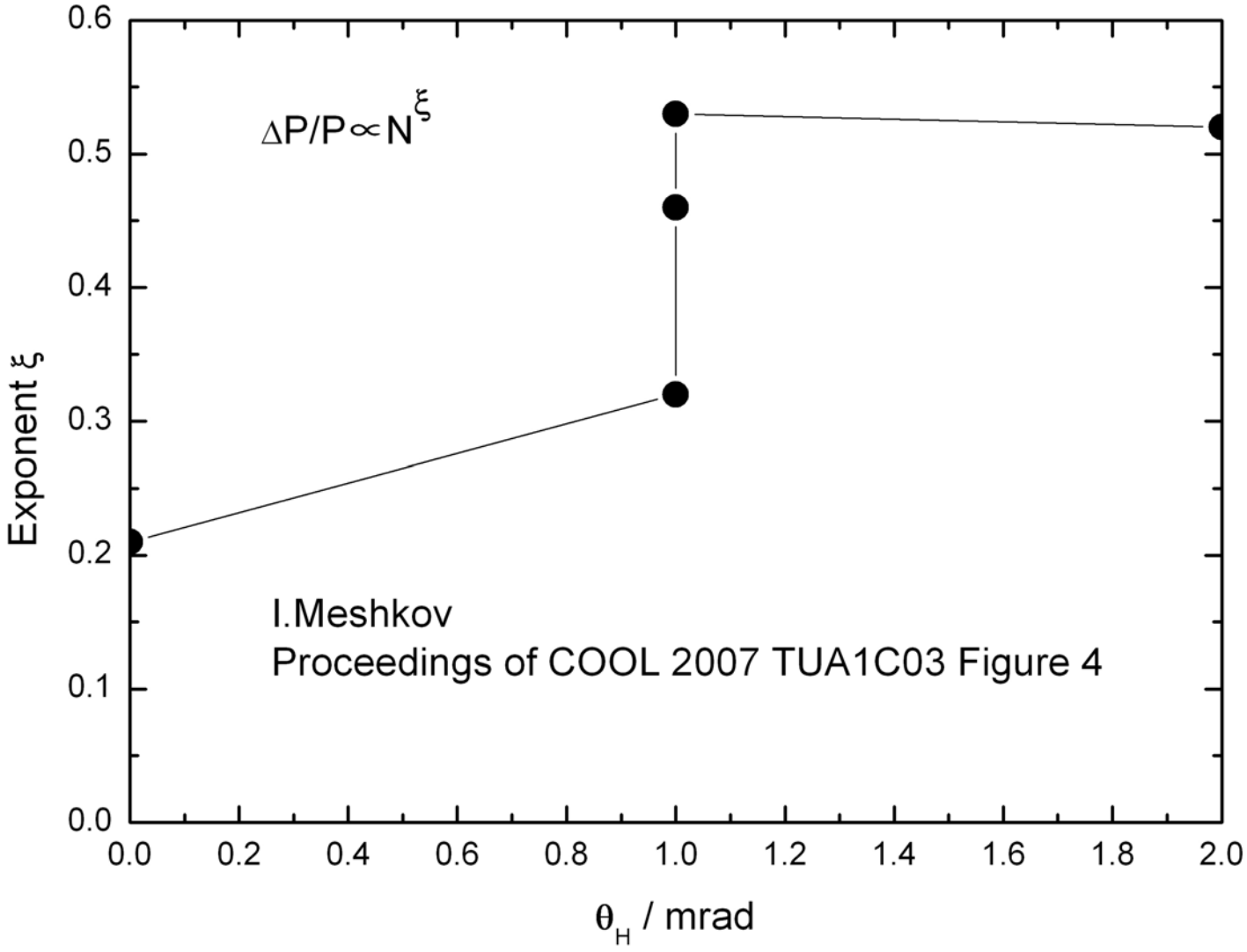
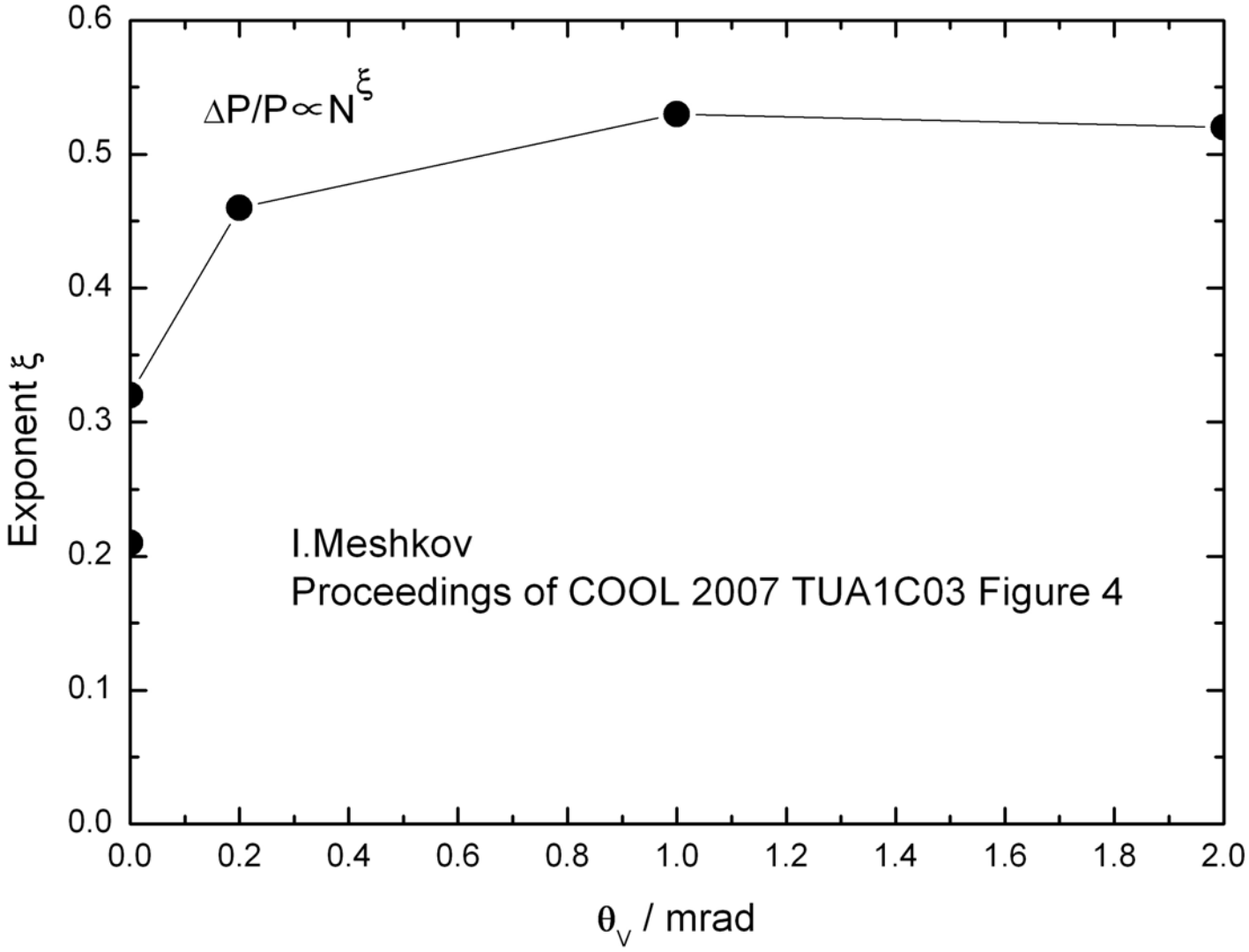


Figure 4: The dependence of the momentum spread on the particle number for different misalignments. I_e=25 mA, (0/0, 1/0, 1/0.2, 1/1 mrad, ξ=0.21, 0.32, 0.46, 0.53, 0.52).

I. Meshkov Proceedings of COOL 2007 TUA1C03



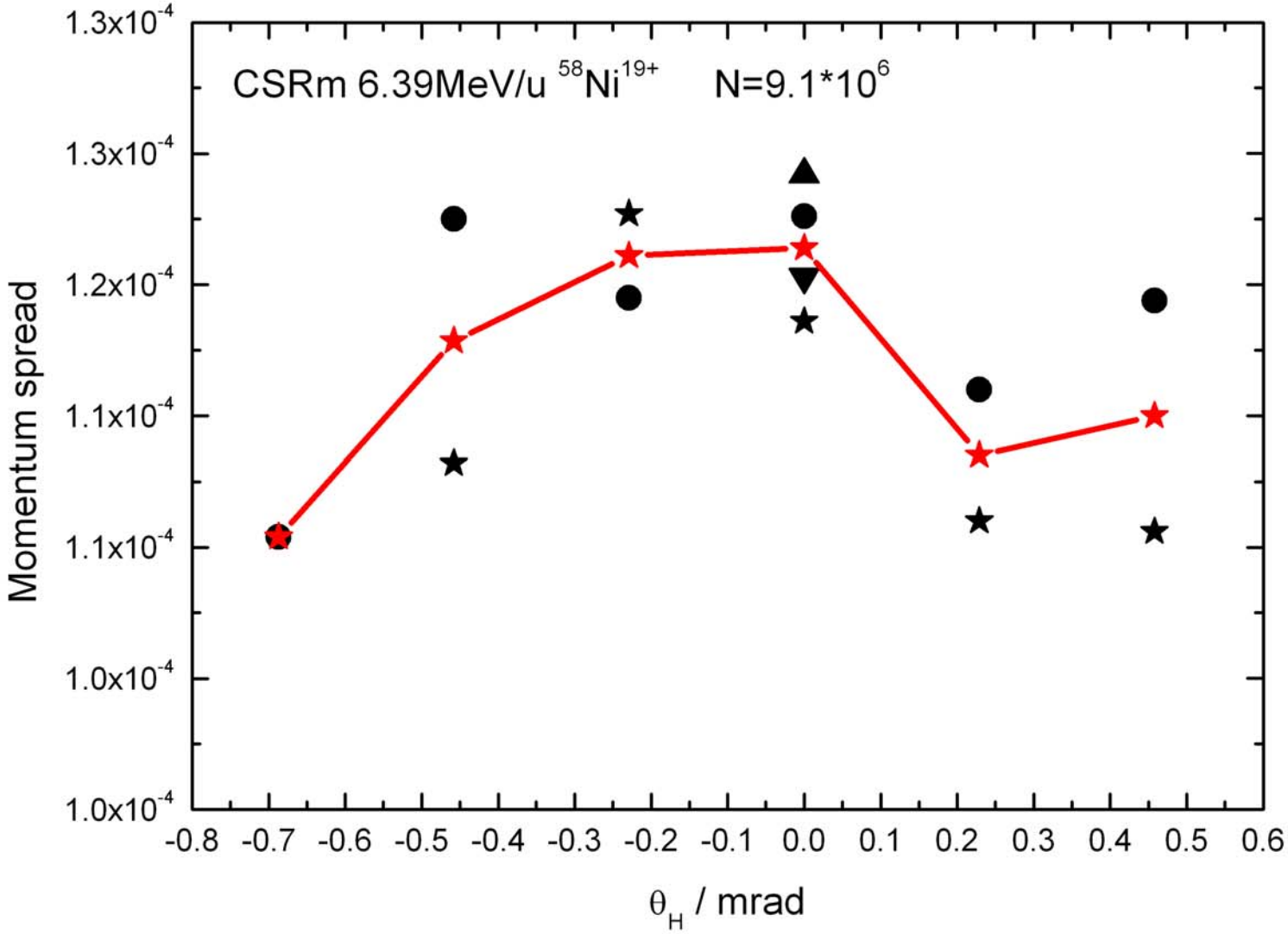
I. Meshkov Proceedings of COOL 2007 TUA1C03



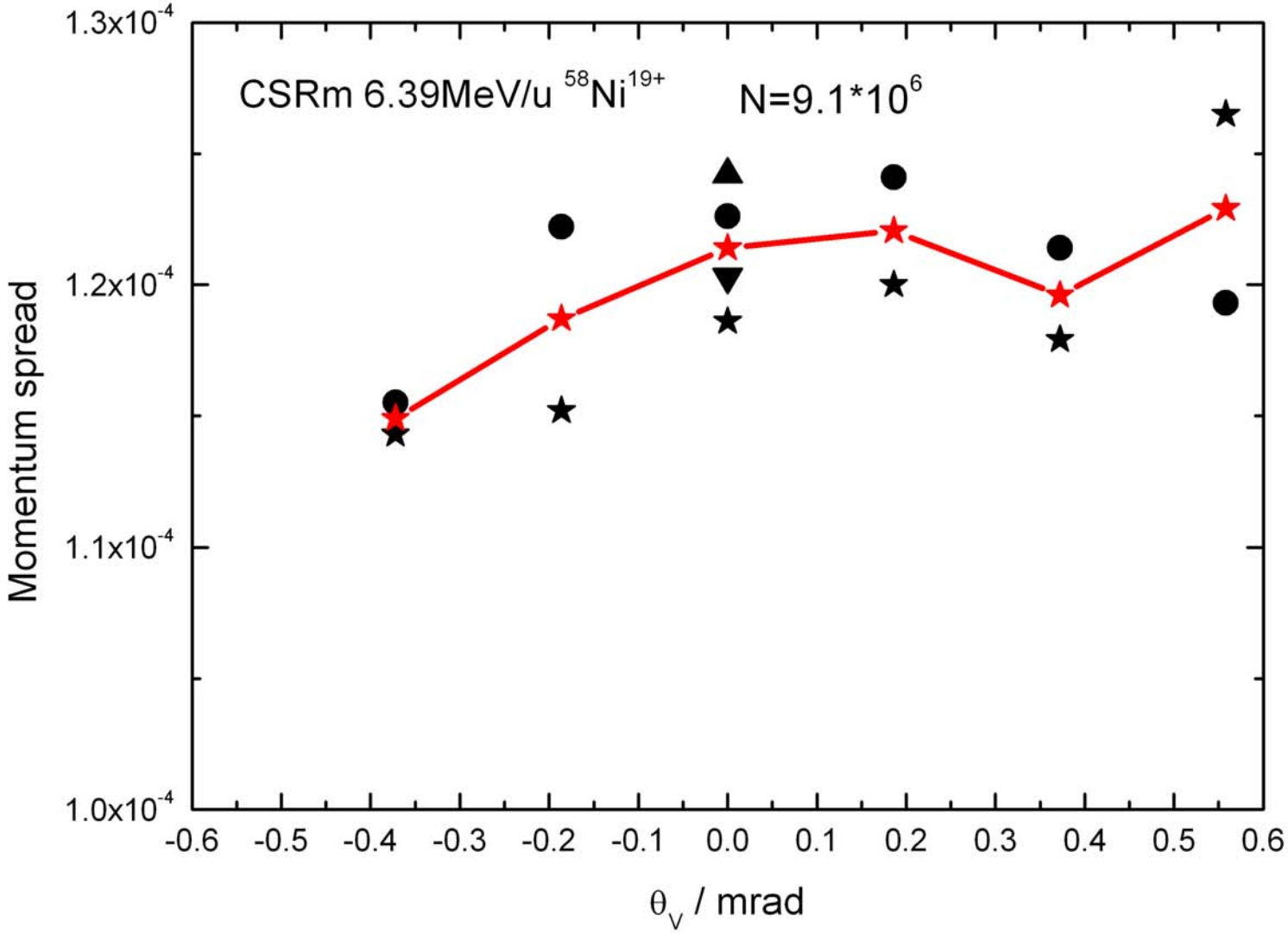
I. Meshkov Proceedings of COOL 2007 TUA1C03

Momentum Spread in the case of fixed particle number

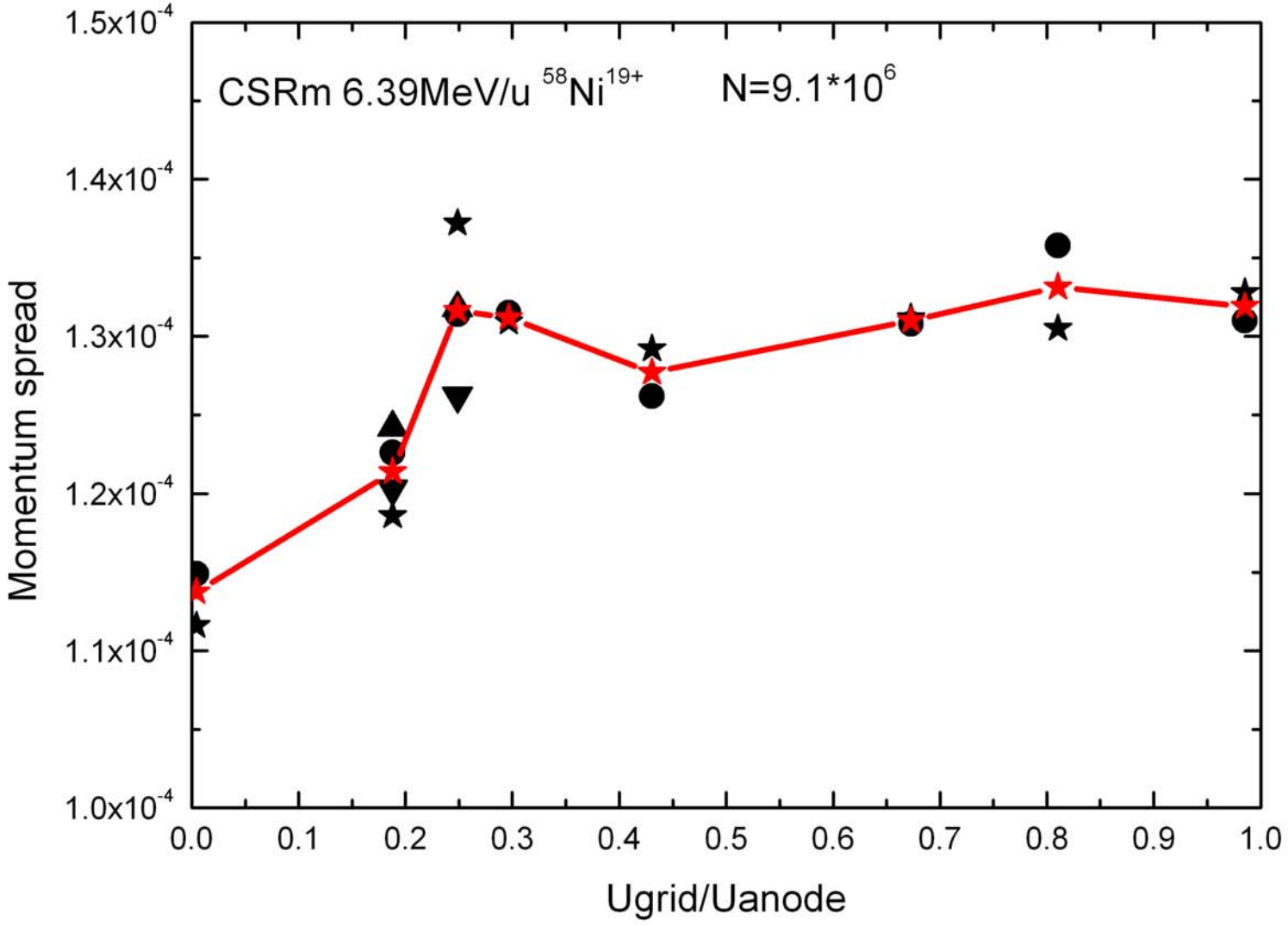
$N_{ion}=9.1*10^{6}$



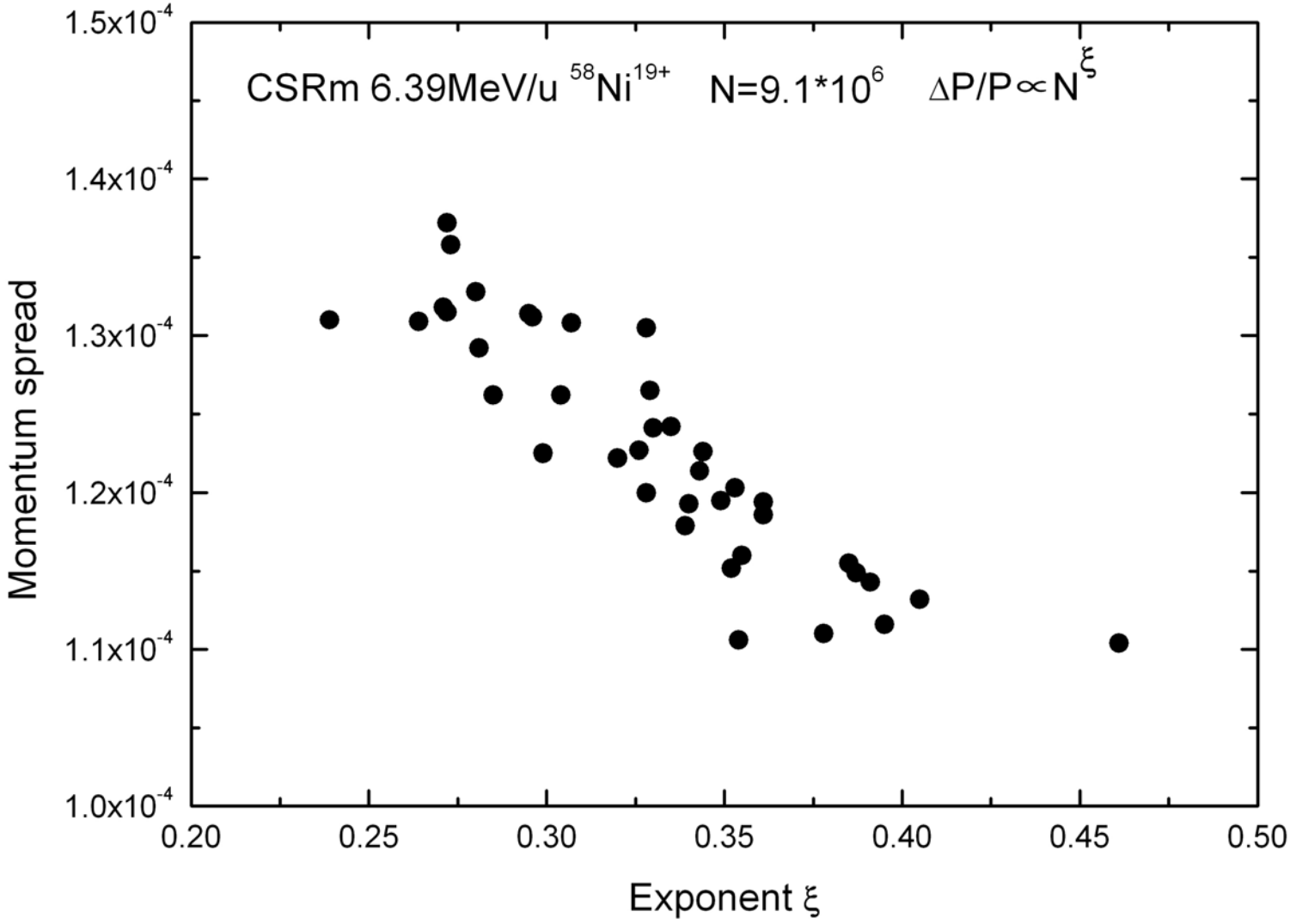
The momentum spread as a function of
related horizontal angle between ion and electron beams
in the case of fixed particle number N=9.1*10^6



The momentum spread as a function of
related vertical angle between ion and electron beams
in the case of fixed particle number N=9.1*10^6



The momentum spread as a function of
the profile of electron beam
in the case of fixed particle number N=9.1*10^{6}



The momentum spread as a function of
the exponent(power coefficient)
in the case of fixed particle number N=9.1*10^{6}

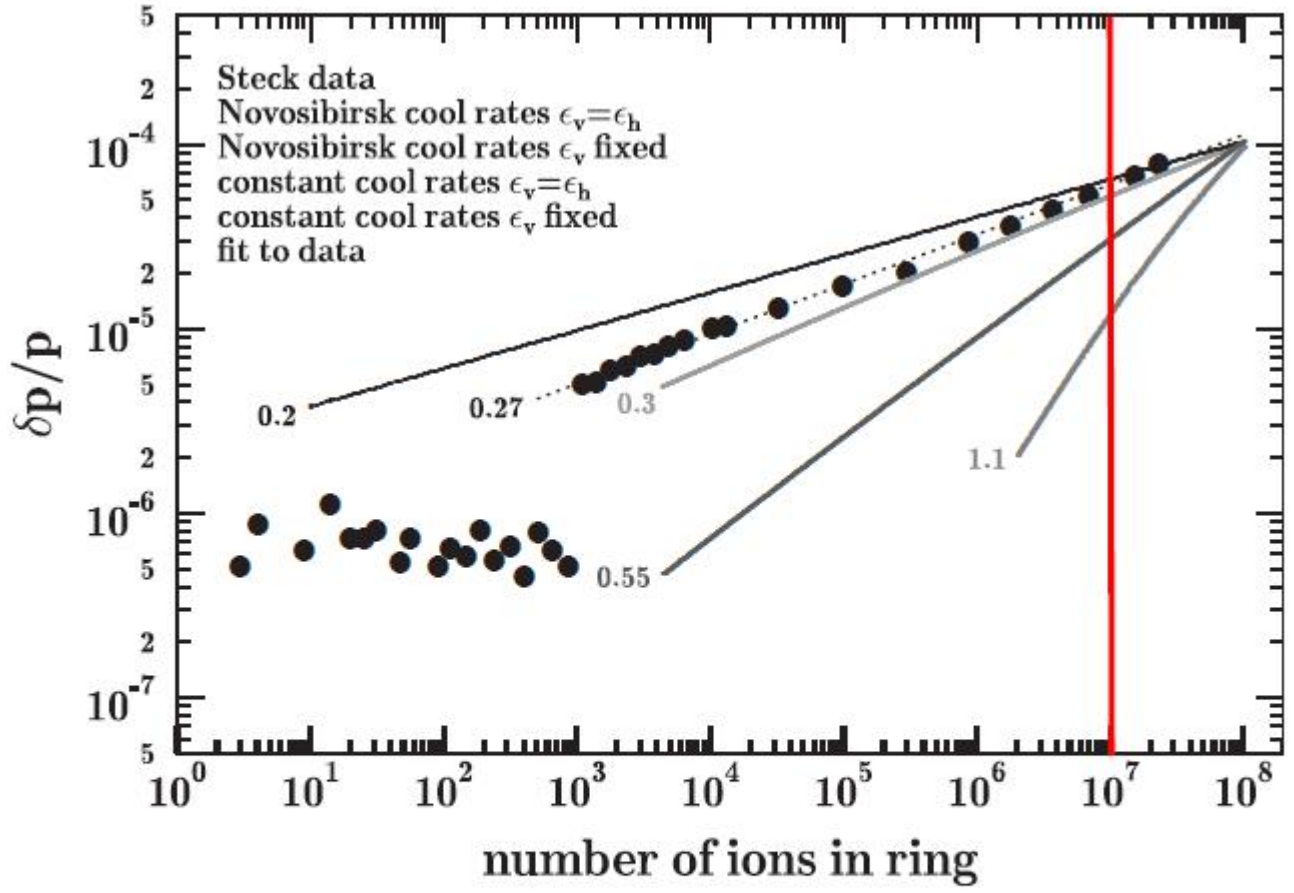
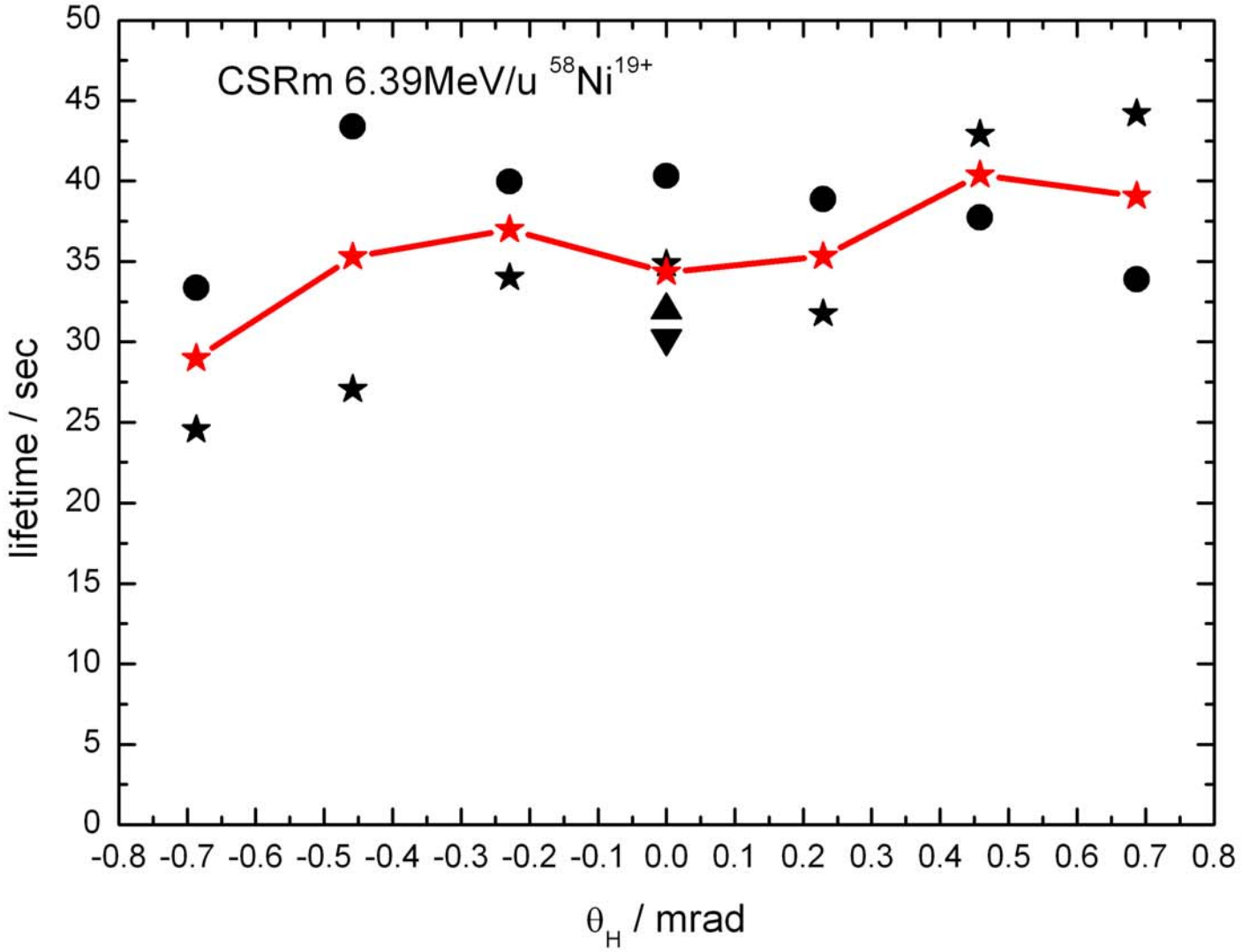


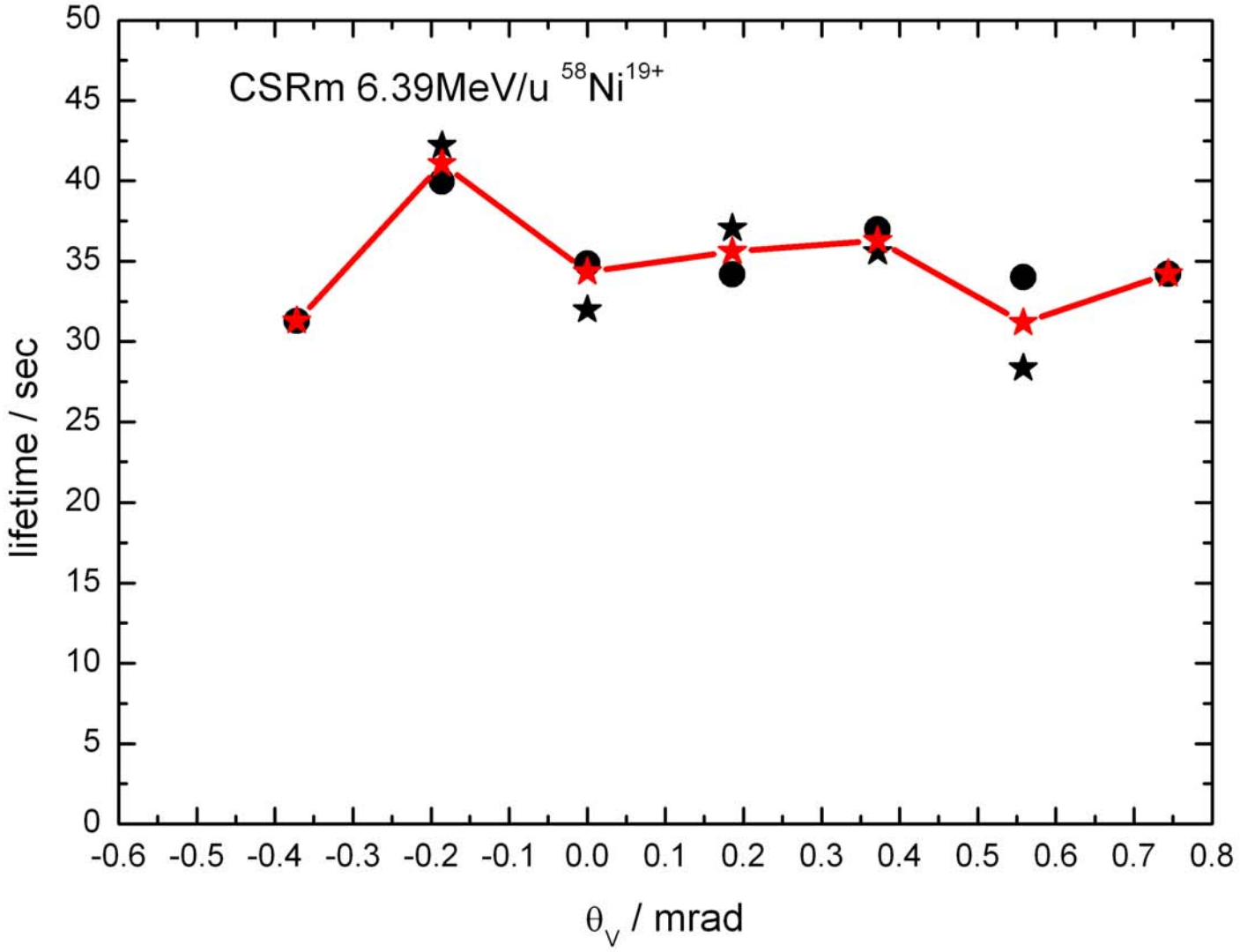
Fig. 1. Measured (dots [15]) and calculated (with the Piwinski approximation [6]) equilibrium momentum spreads in the ESR for U^{92+} at 360 MeV/u (the lower left dots are ultracold values [16]). Numbers indicate the slopes with current.

R.W. Hasse *NIMA*532(2004)451-453 Fig.1

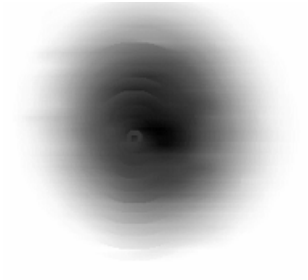
Lifetime

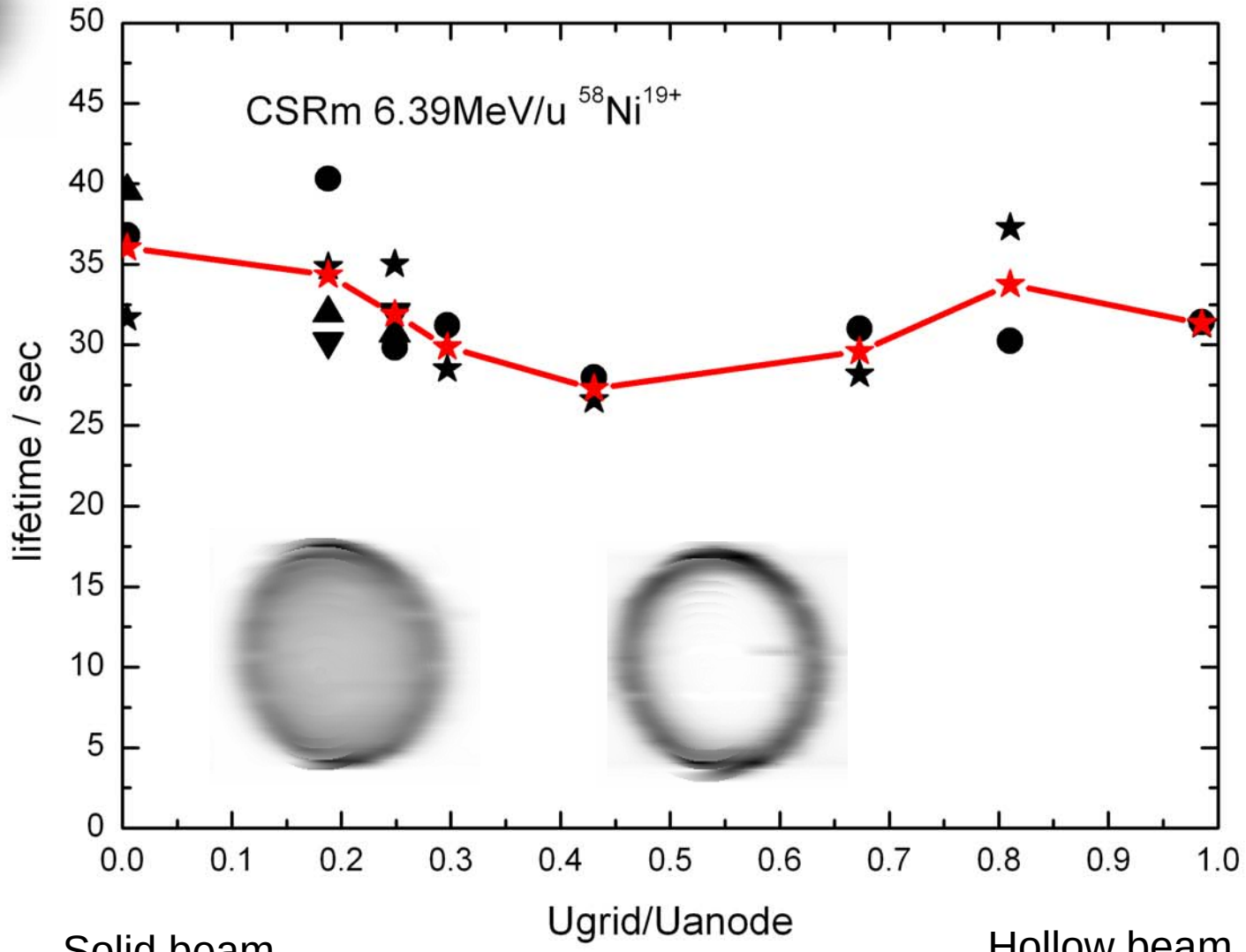


The lifetime of ion beam in the CSRm was derived from the signal of DCCT
The lifetime as a function of
related horizontal angle between ion and electron beams



The lifetime as a function of related vertical angle between ion and electron beams



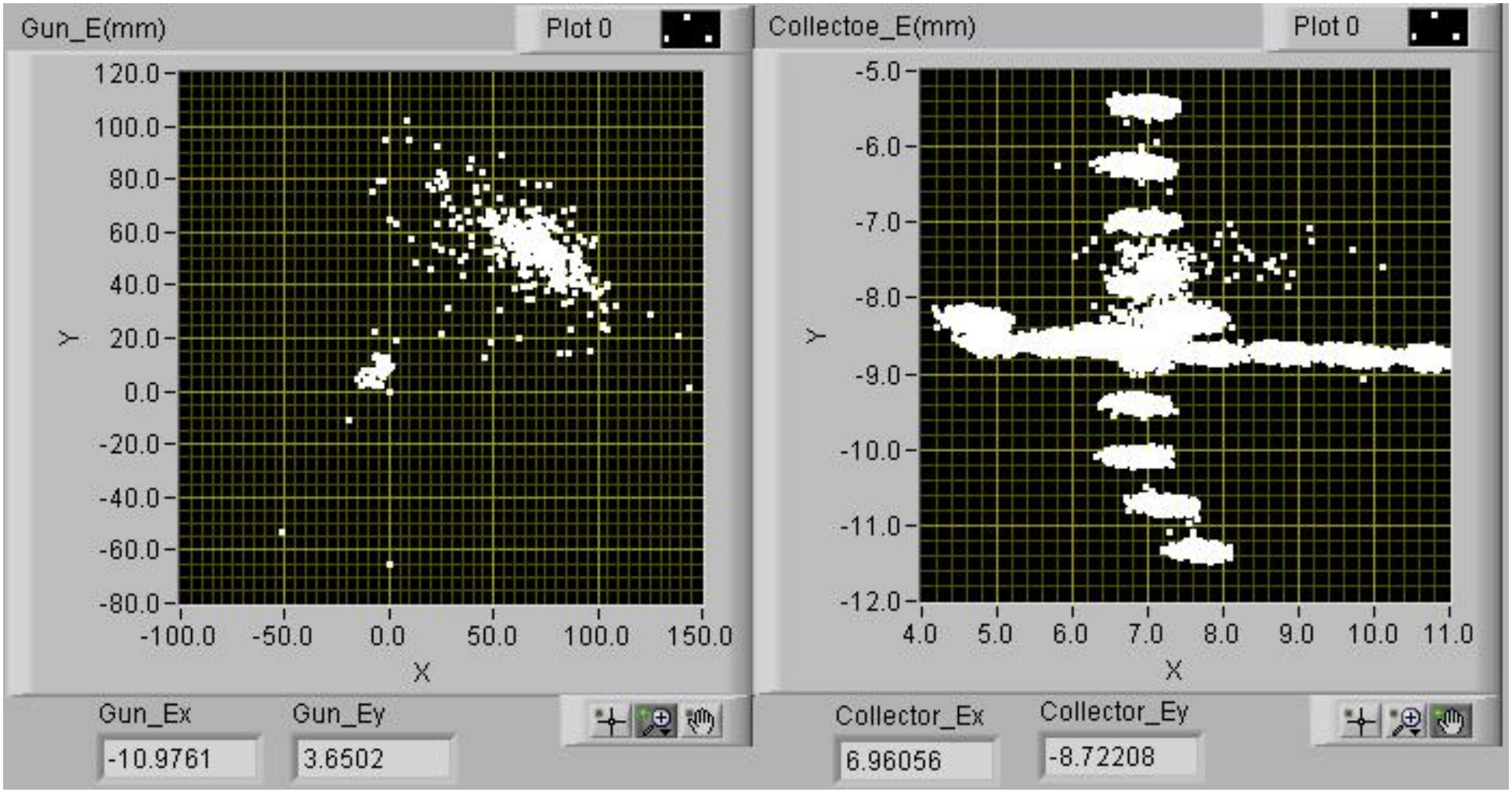


Solid beam

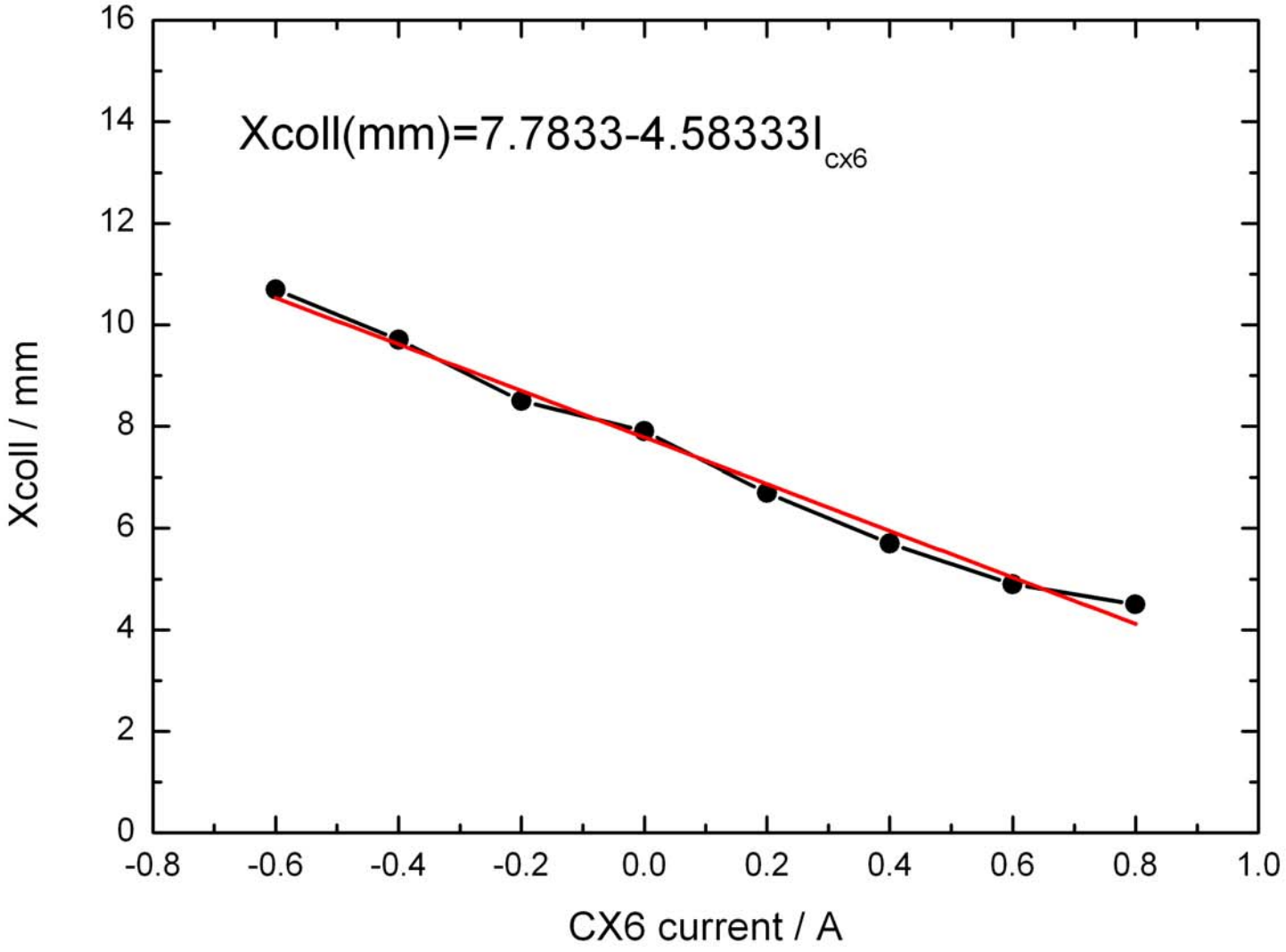
Hollow beam

The lifetime as a function of the profile of electron beam

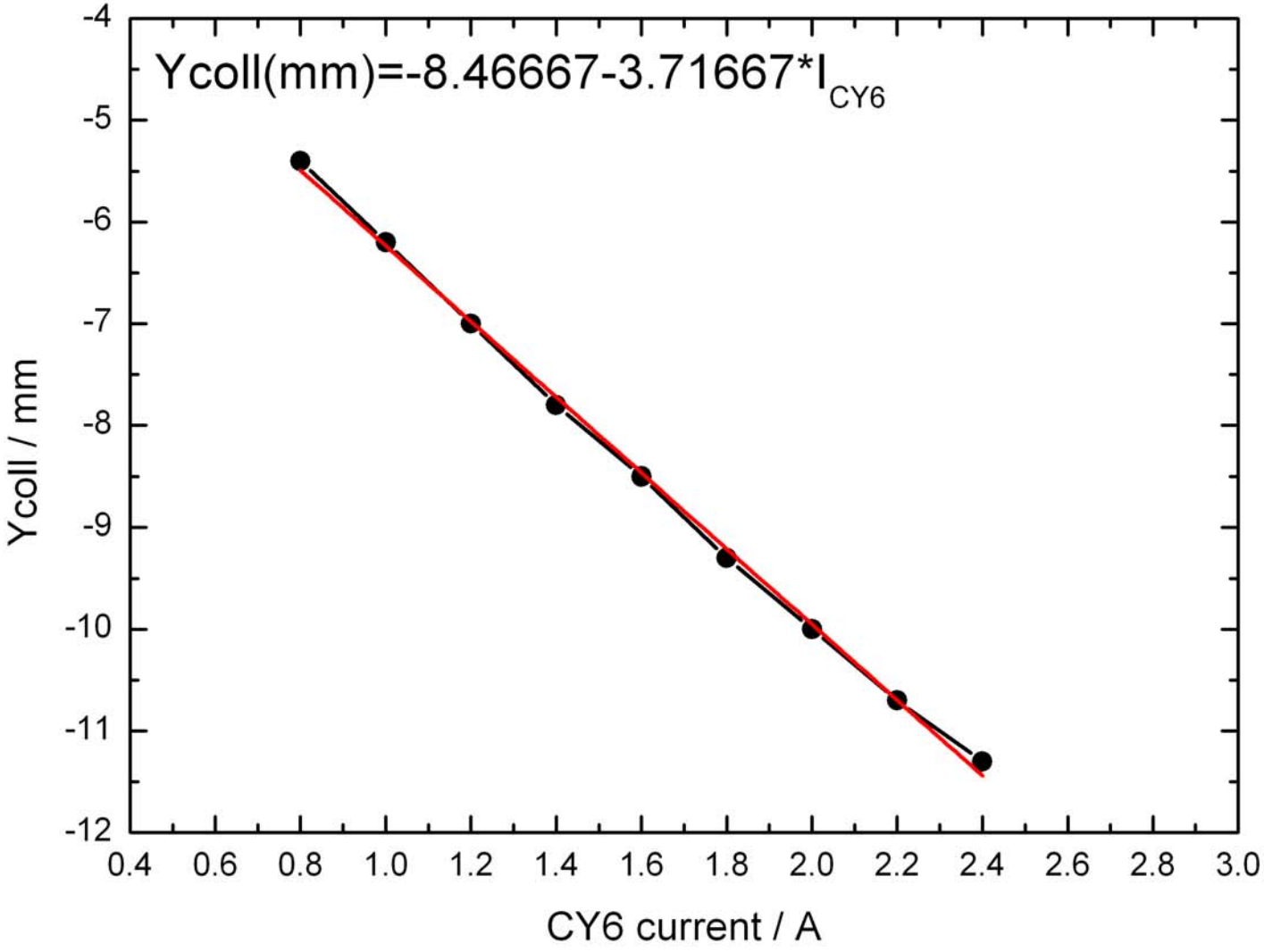
Beam positions



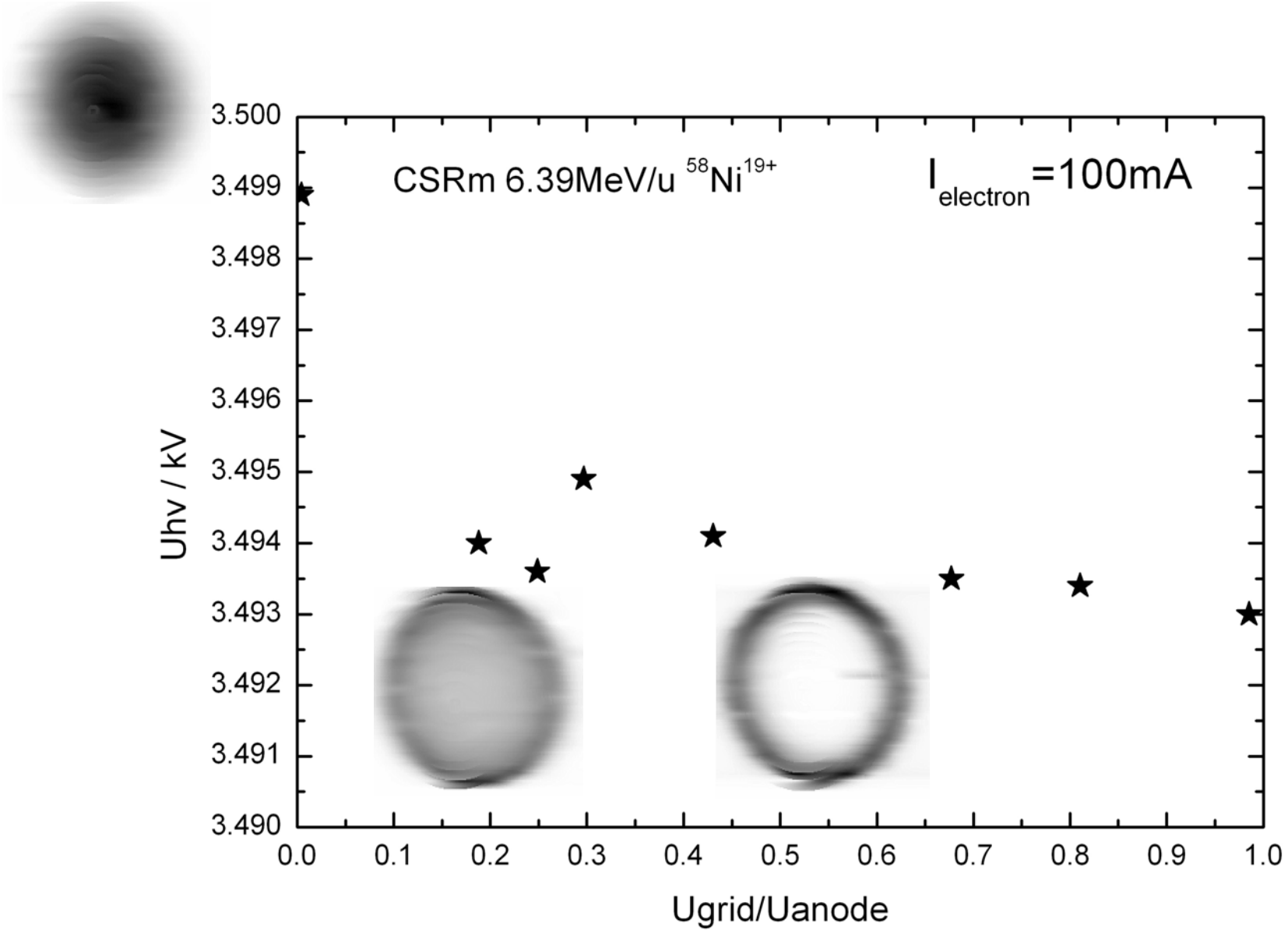
Electron beam position measurement results during experiments



Horizontal position of electron beam measured in the side of collector

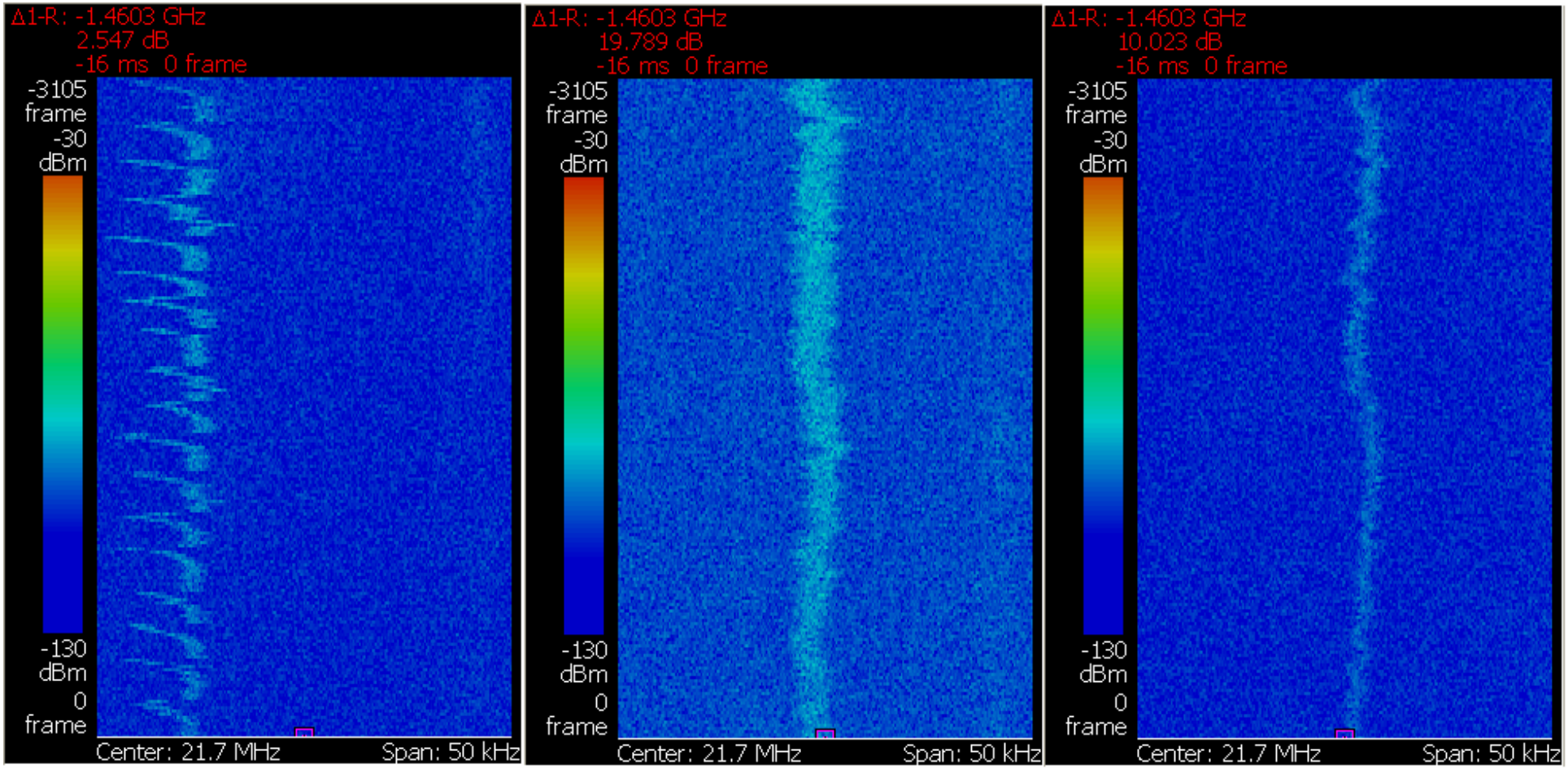


Vertical position of electron beam measured in the side of collector



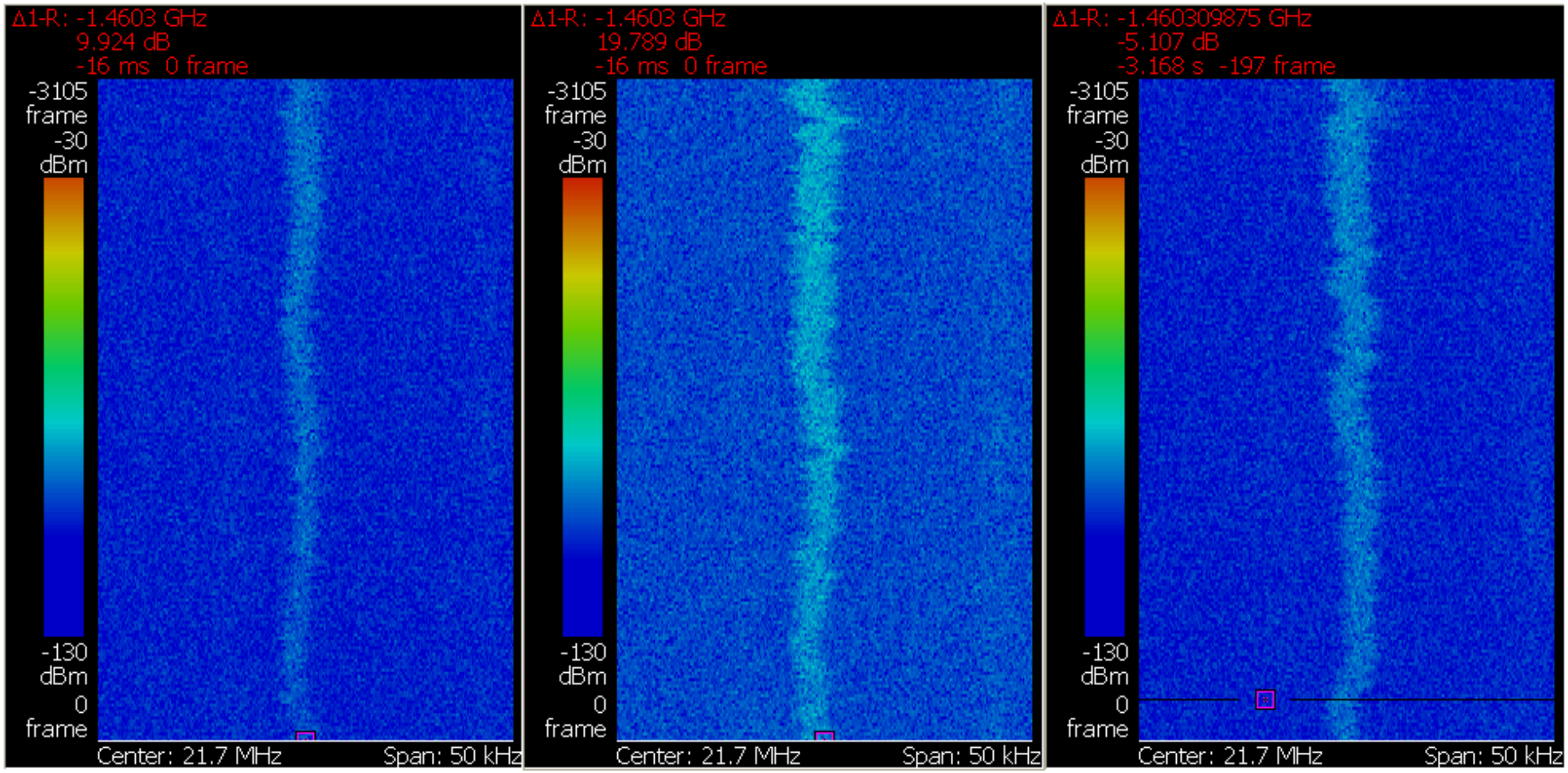
Optimal high voltage in the cases of the different electron beam profile

Beam Oscillation during Experiments



CX6=0.8A,	CX6=0.2A,	CX6=-0.4A,
CY6=1.6A,	CY6=1.6A,	CY6=1.6A,
θ_H=0.687mrad	θ_H=0.0mrad	θ_H=-0.687mrad
10.iqt	1.iqt	18.iqt

The central frequency of ion beam move to lower side,
And the longitudinal oscillation was observed
in the bigger misalignment in one direction.

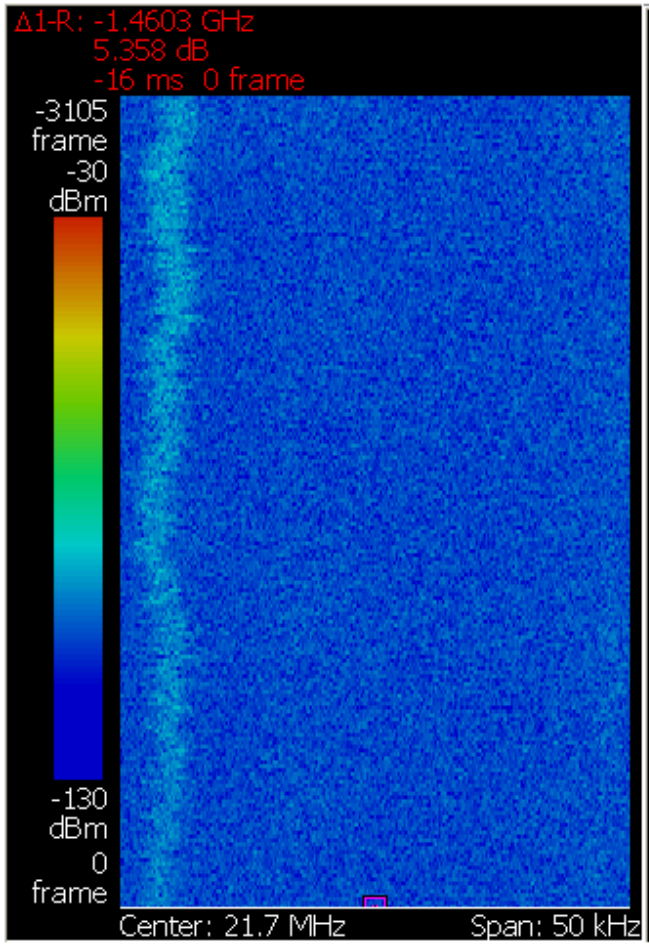


CX6=0.6A,
CY6=1.6A,
θ_H=0.458mrad
8.iqt

CX6=0.2A,
CY6=1.6A,
θ_H=0.0mrad
1.iqt

CX6=-0.2A,
CY6=1.6A,
θ_H=-0.458mrad
15.iqt

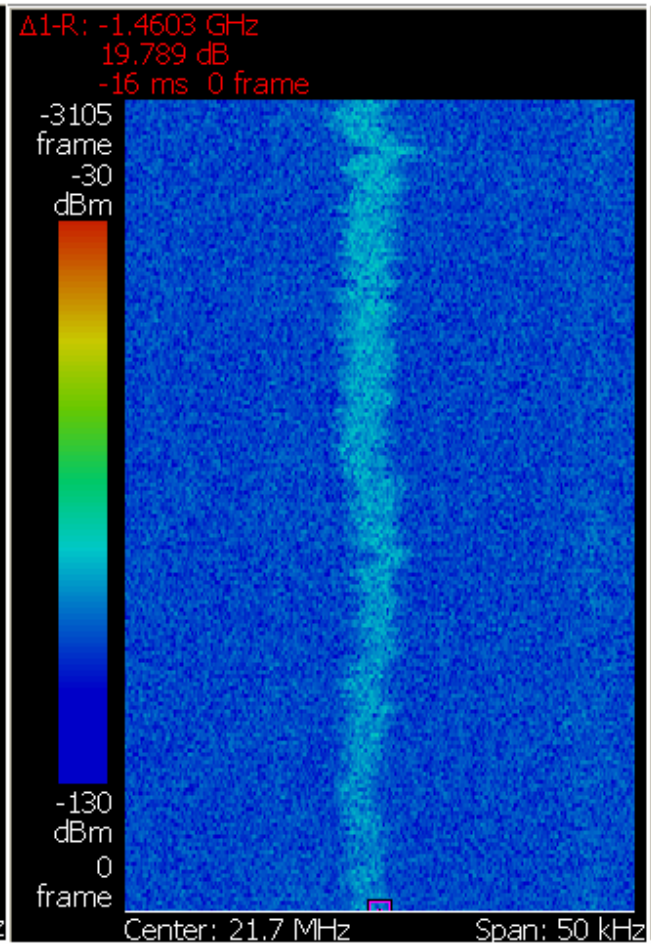
No obvious frequency shift and oscillation
in the case of a smaller misalignment in two directions.



CX6=0.2A,
CY6=2.4A,

θ_V=0.744mrad

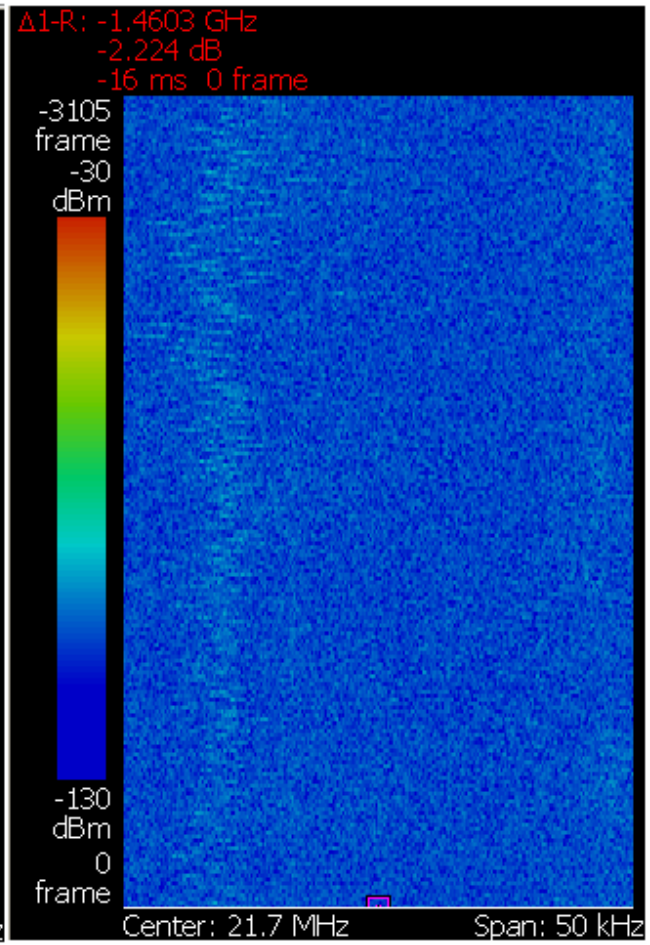
28.iqt



CX6=0.2A,
CY6=1.6A,

θ_V=0.0mrad

1.iqt

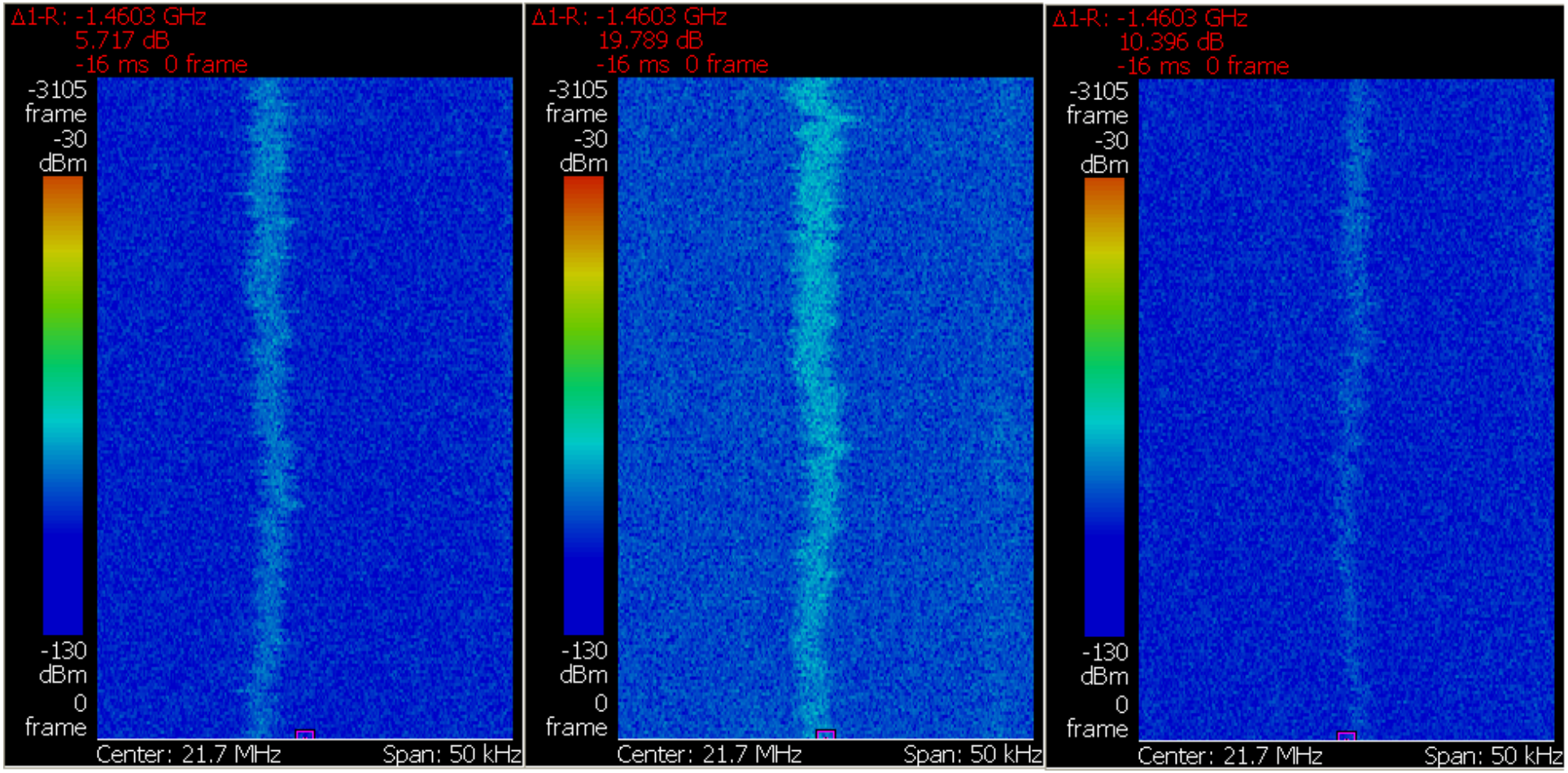


CX6=0.2A,
CY6=0.8A,

θ_V=-0.744mrad

36.iqt

The central frequency of ion beam move to lower side,
in the case of a bigger misalignment in two directions.
The frequency shift is not symmetrical !

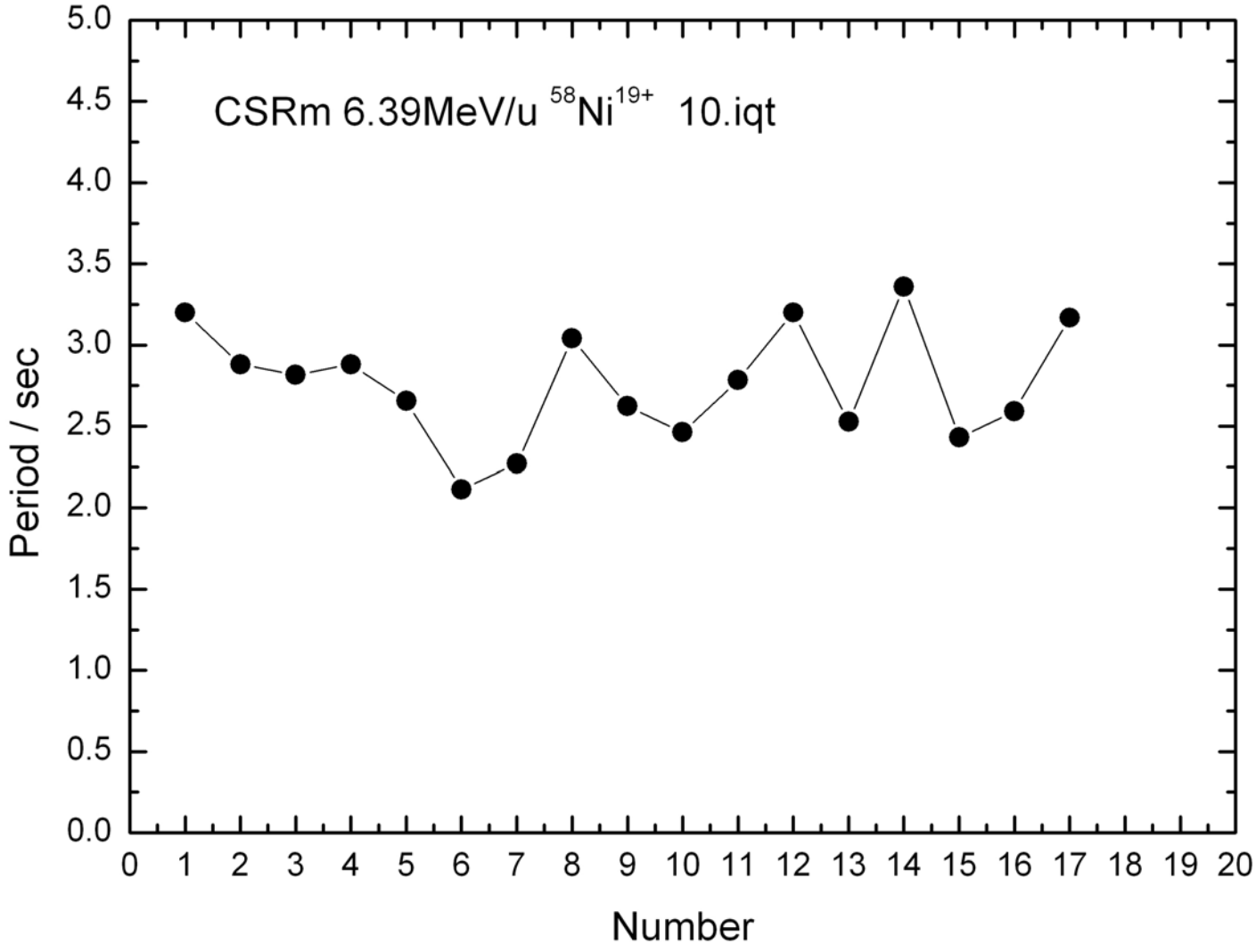


CX6=0.2A, CY6=2.2A,	CX6=0.2A, CY6=1.6A,	CX6=0.2A, CY6=1.0A,
θ_V=0.558mrad 26.iqt	θ_V=0.0mrad 1.iqt	θ_V=-0.558mrad 34.iqt

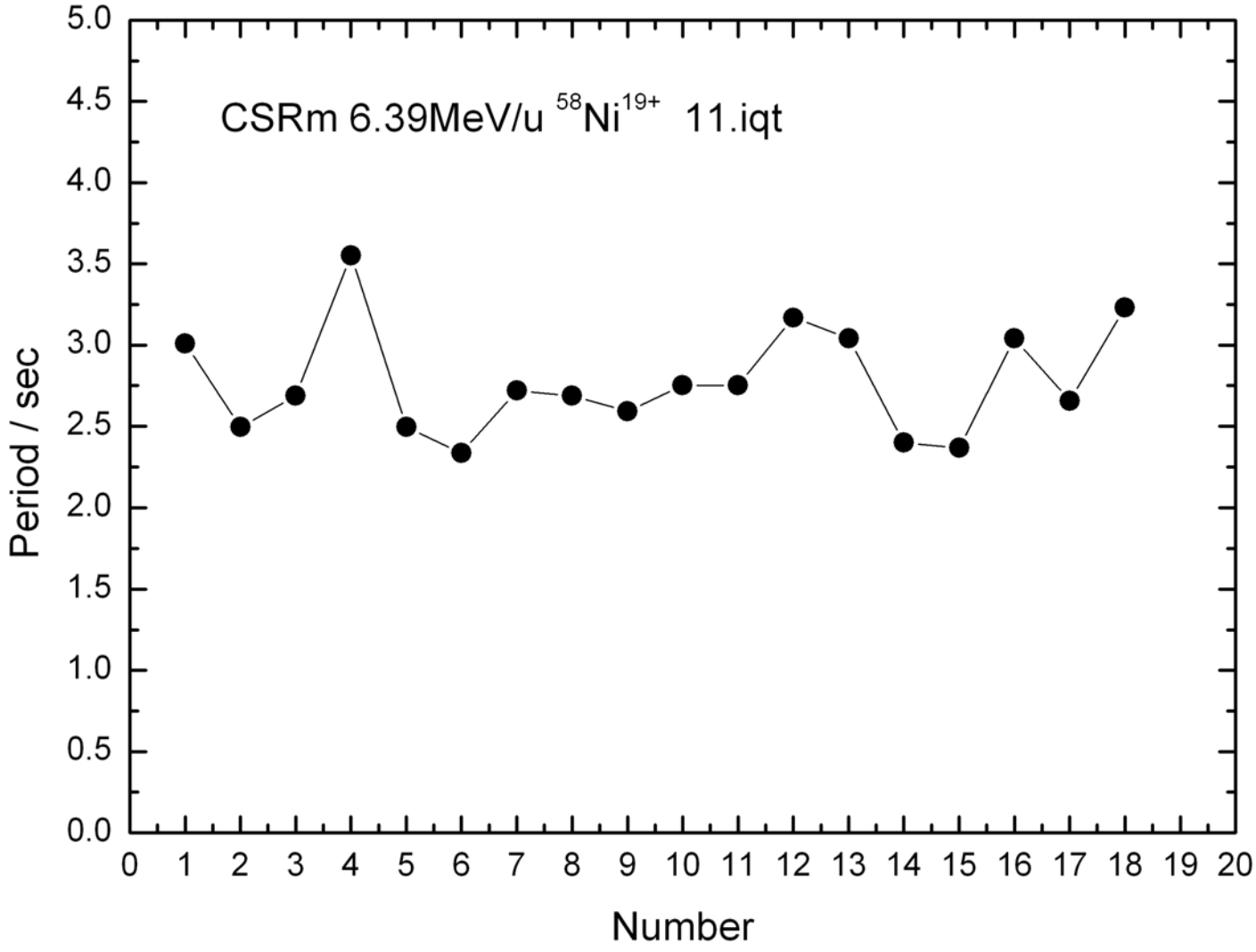
No obvious frequency shift and oscillation
in the smaller misalignment in two directions.

Question

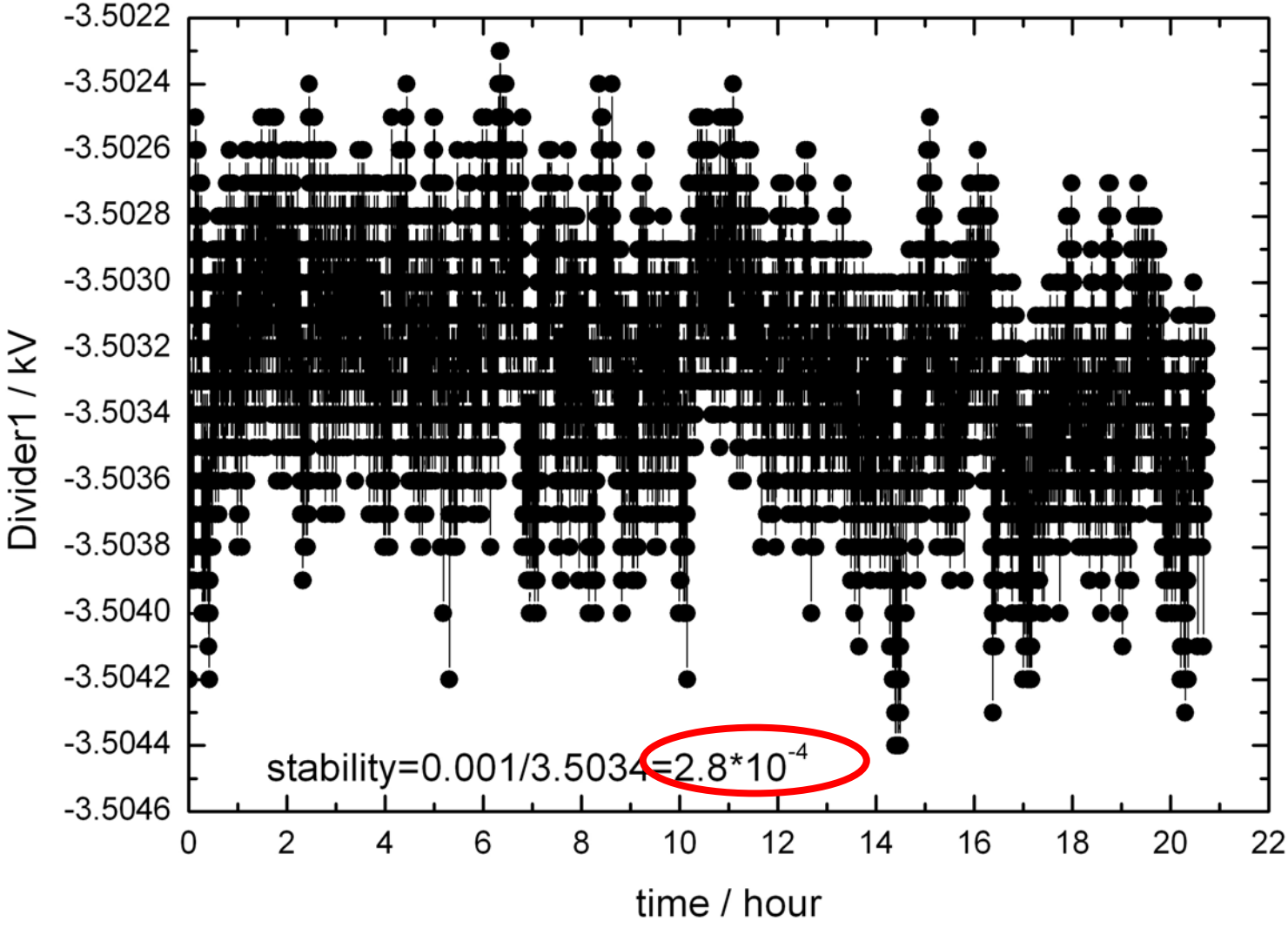
Why does the central frequency of ion beam shift to the same direction in the cases of a bigger misalignment angle at different vertical direction ?



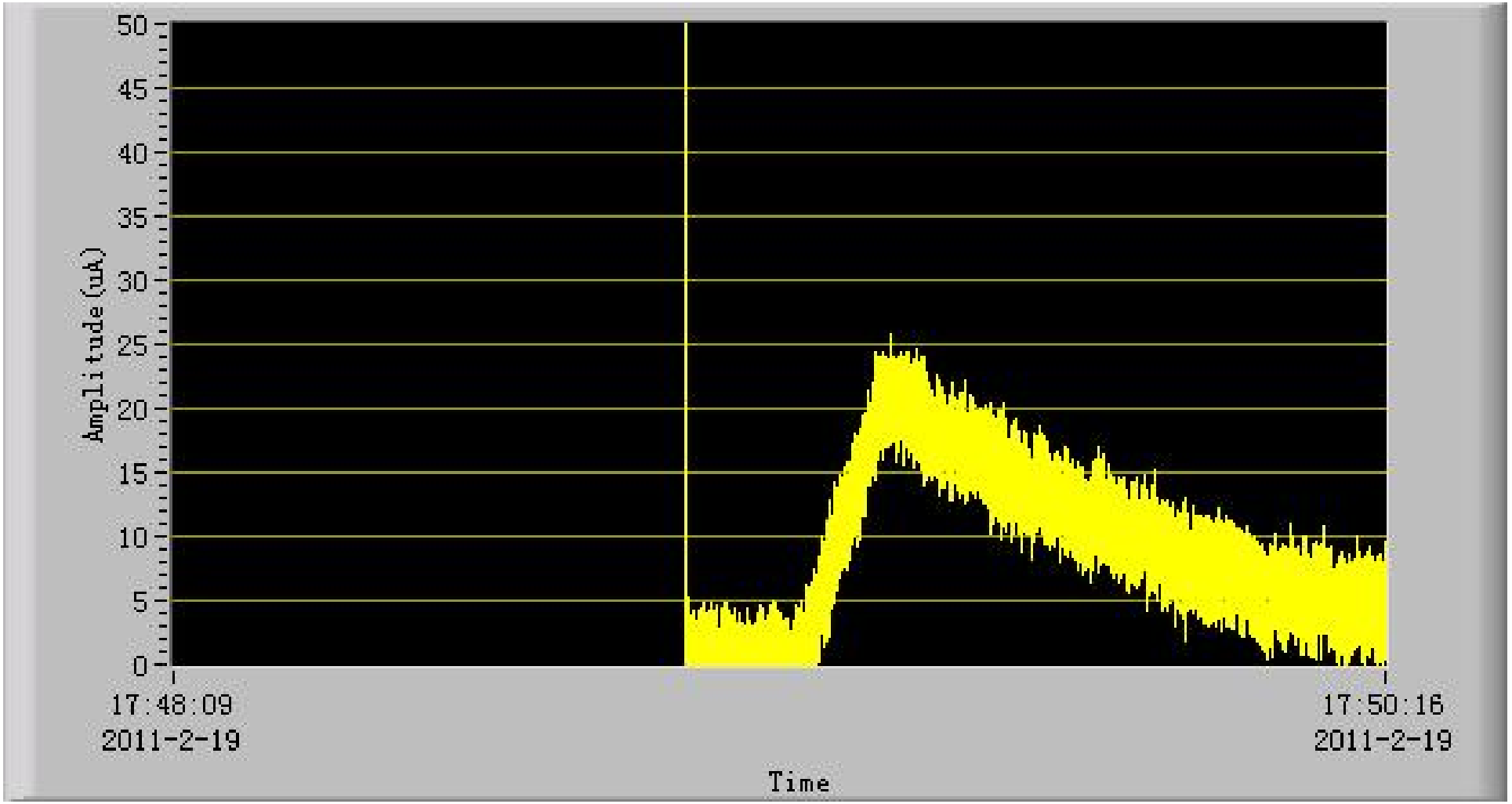
The periods of oscillation, the average value is 2.765sec



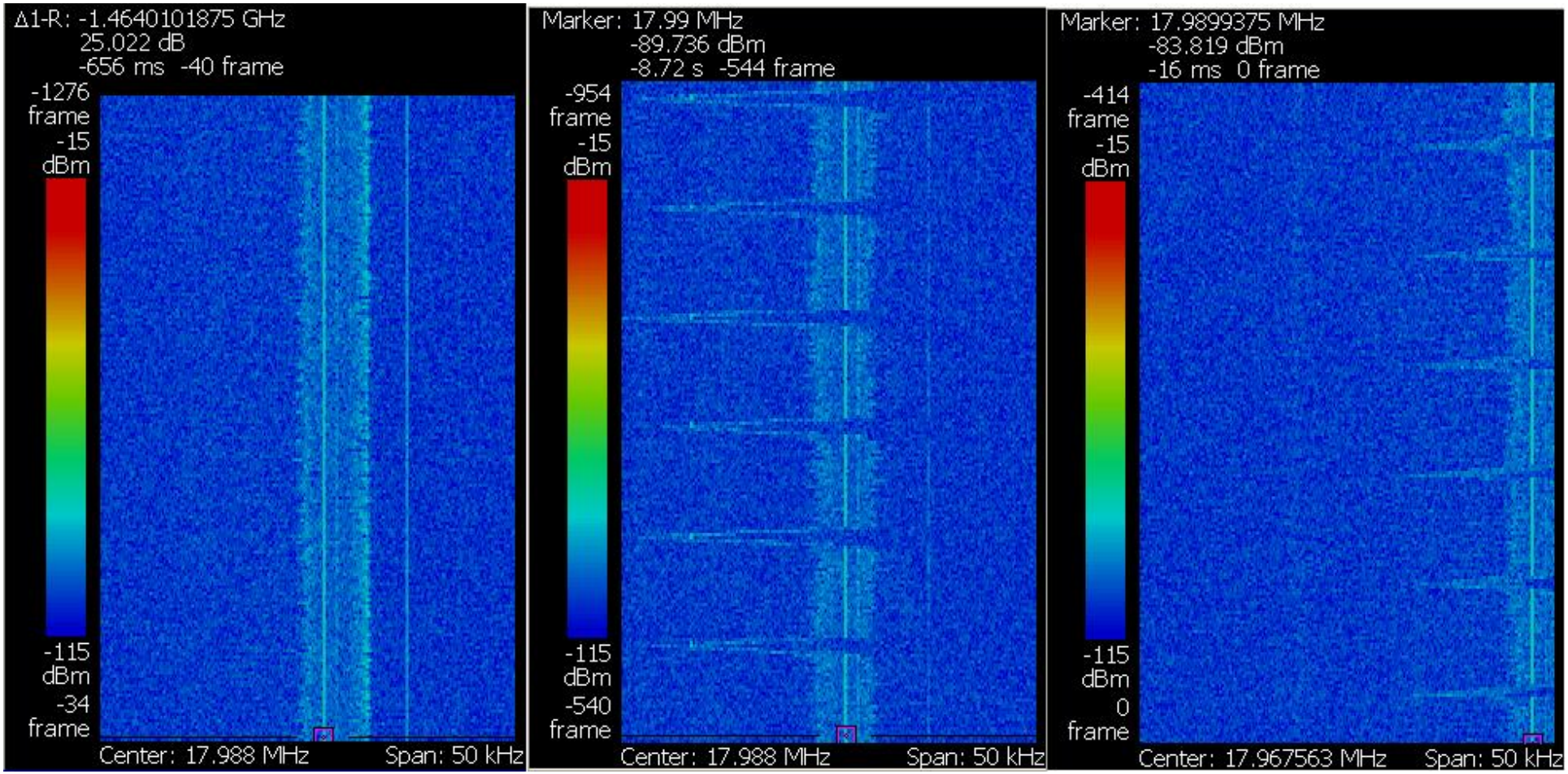
The periods of oscillation, the average value is 2.777sec



The stability of high voltage of cooler during experiments



There was no obvious ion beam loss during oscillation



Without modulation 10V-100ms-1000ms 20V-100ms-1000ms

Electron beam energy modulation

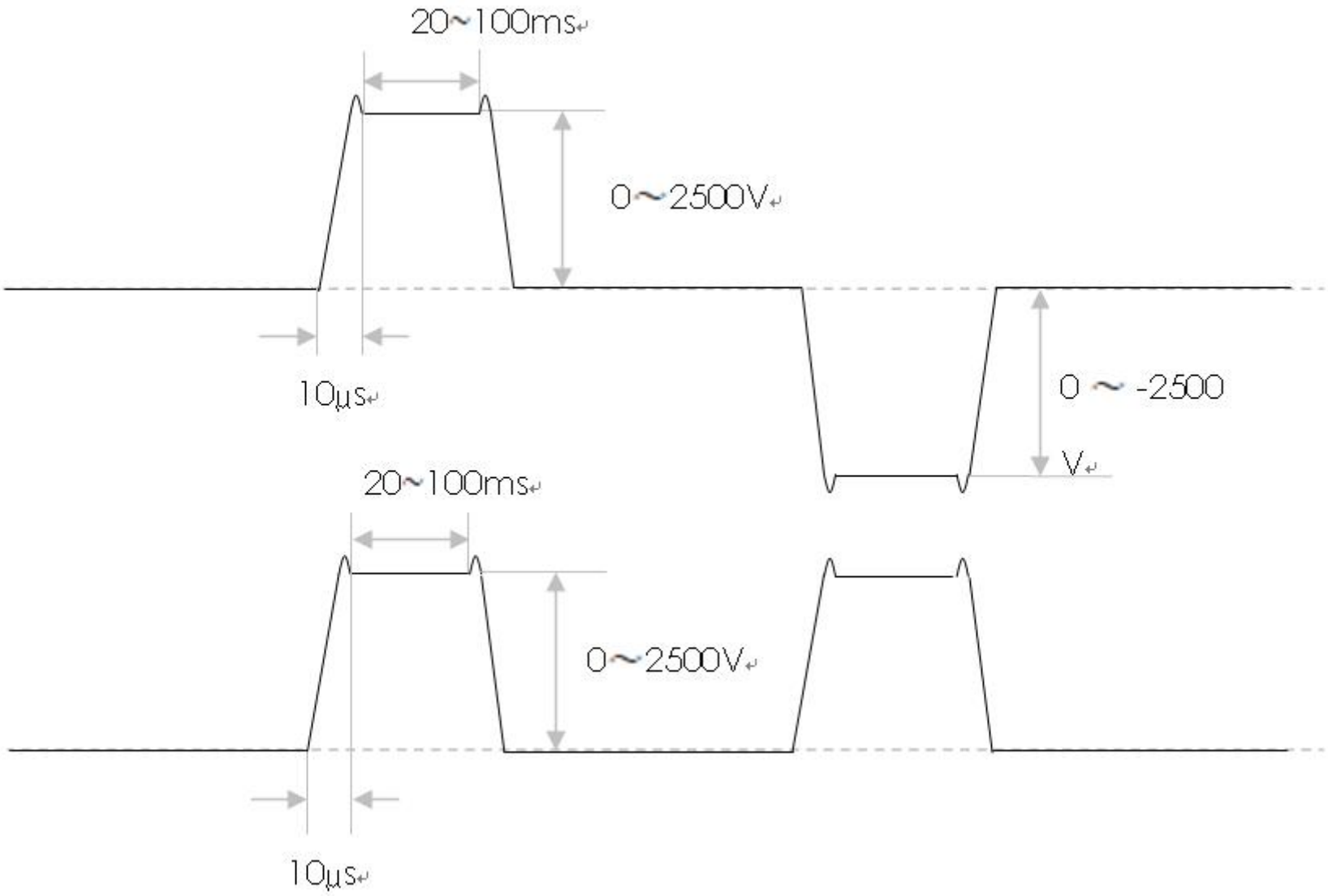
One conceivable explanation is that the high voltage of cooler was changed due to the electron beam hit in some place of cooler in the case of a bigger misalignment angle.

Magnetic Fields of Cooler

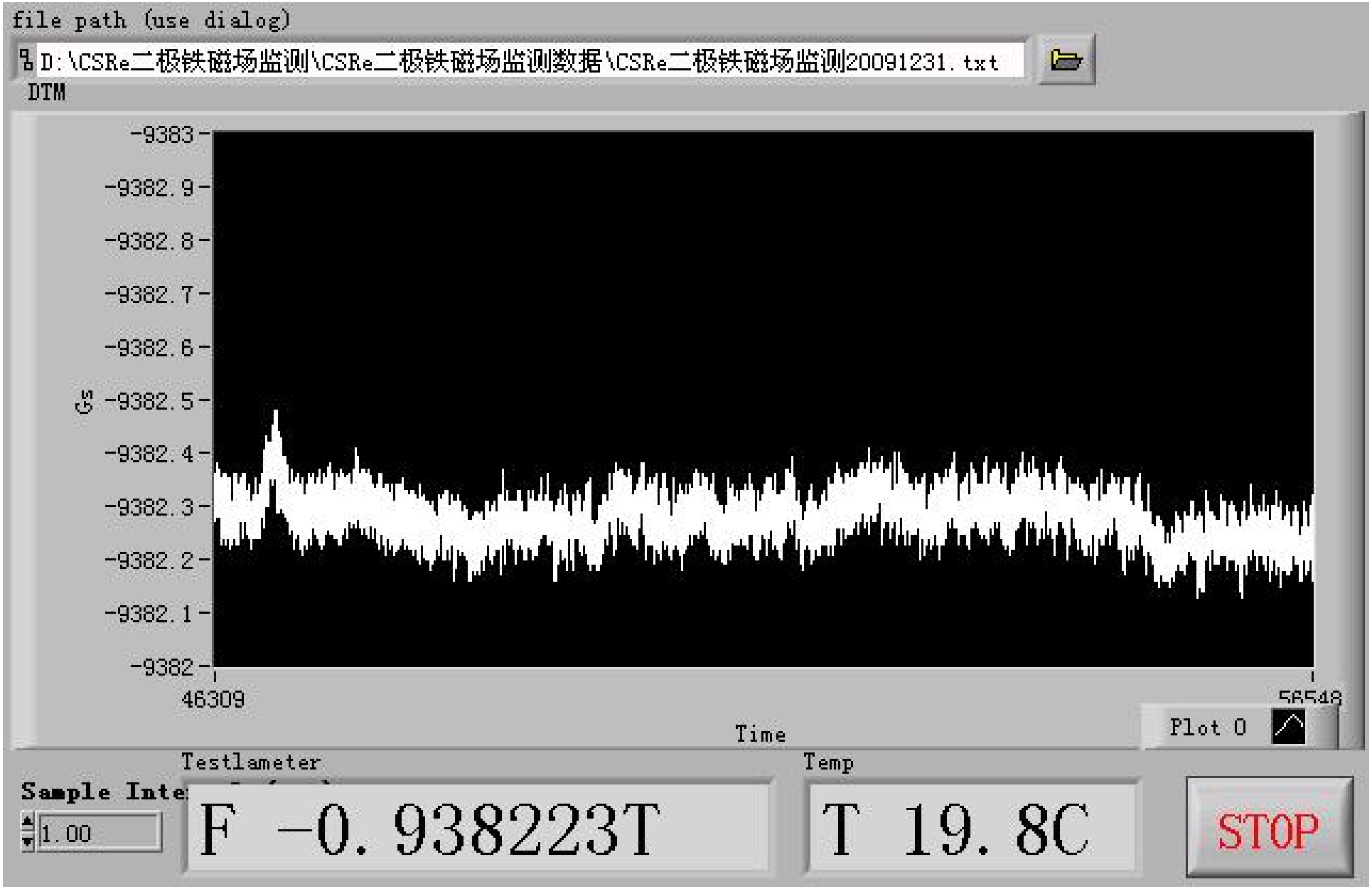
- $I_{cooling\ section}$=48A
- I_{toroid}=195A
- I_{gun}=780A
- $D_{cathode}$=29mm
- $B_{cooling\ section}$=375Gauss
- B_{toroid}=375Gauss
- B_{gun}=1625Gauss
- $D_{cooling}$=60mm

Upgrade and Improvement

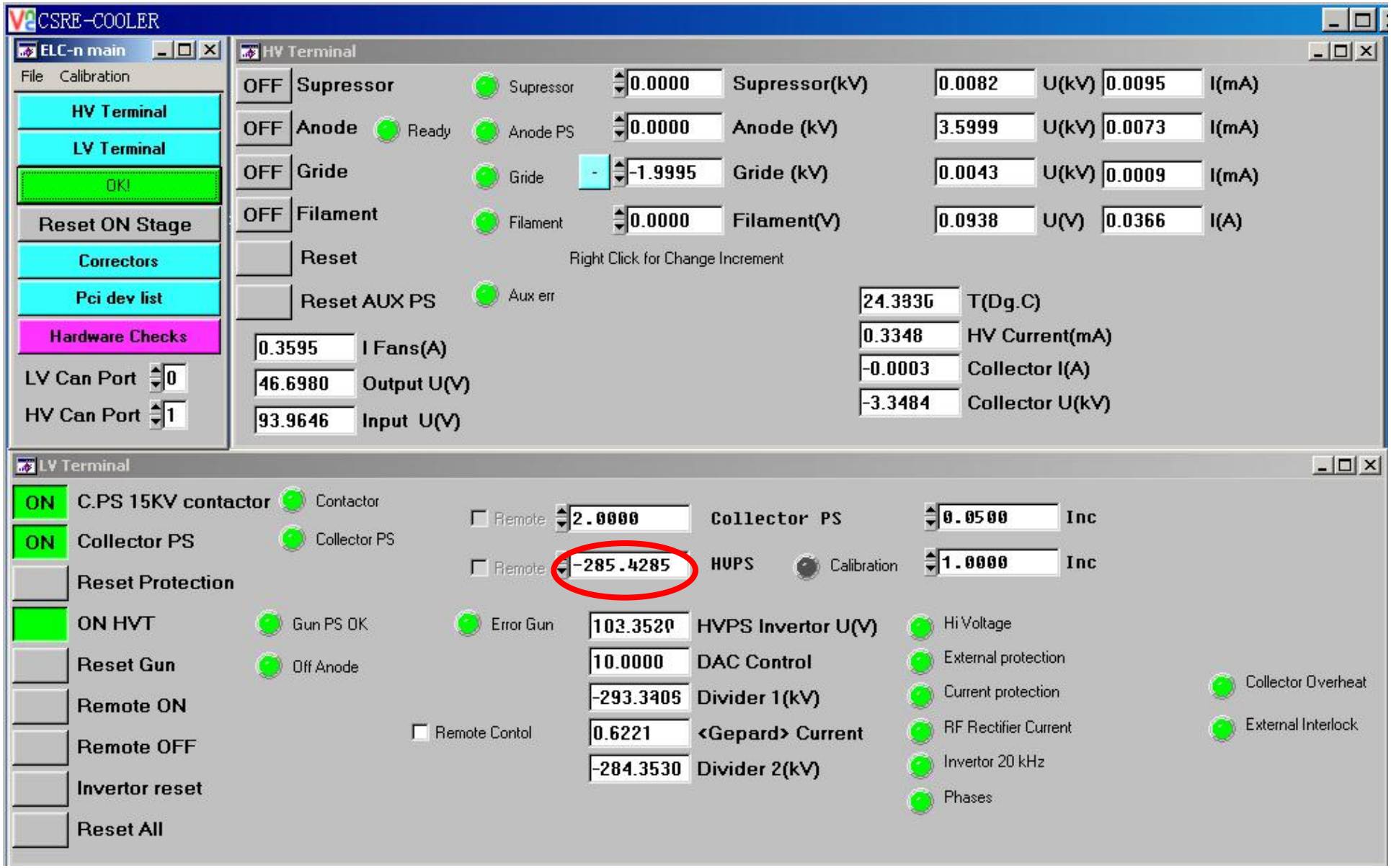
- Add energy modulation system for CSRm cooler
- Improve the stability of power supply for CSRe dipoles
- Temperature control for 300kV cooler
- High voltage of CSRe cooler approach to 285kV
- 14 days continuous work at 285kV



Electron energy modulation



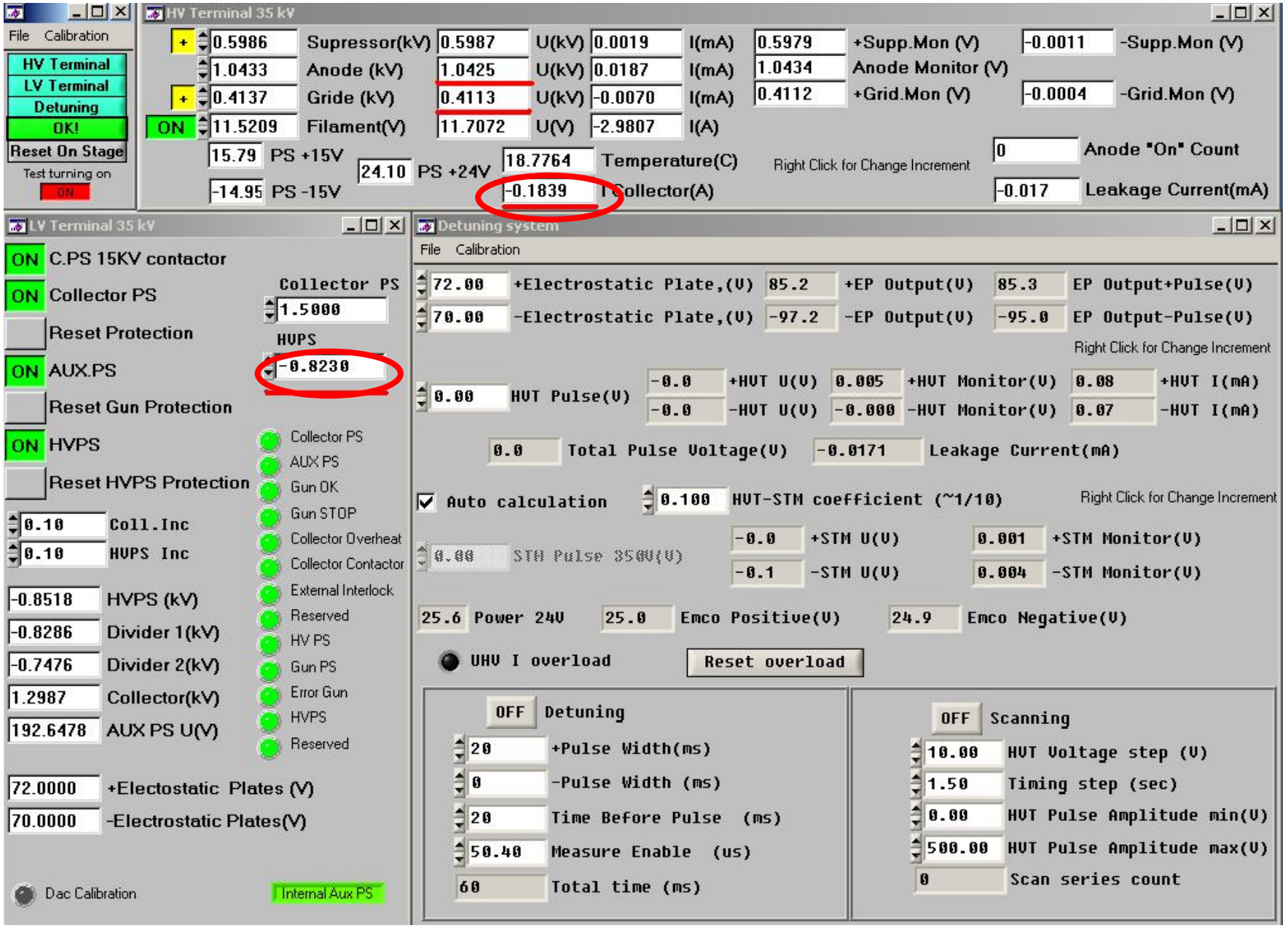
Monitoring of stability of dipole power supply in CSRe
And a slow feedback system was adapted.



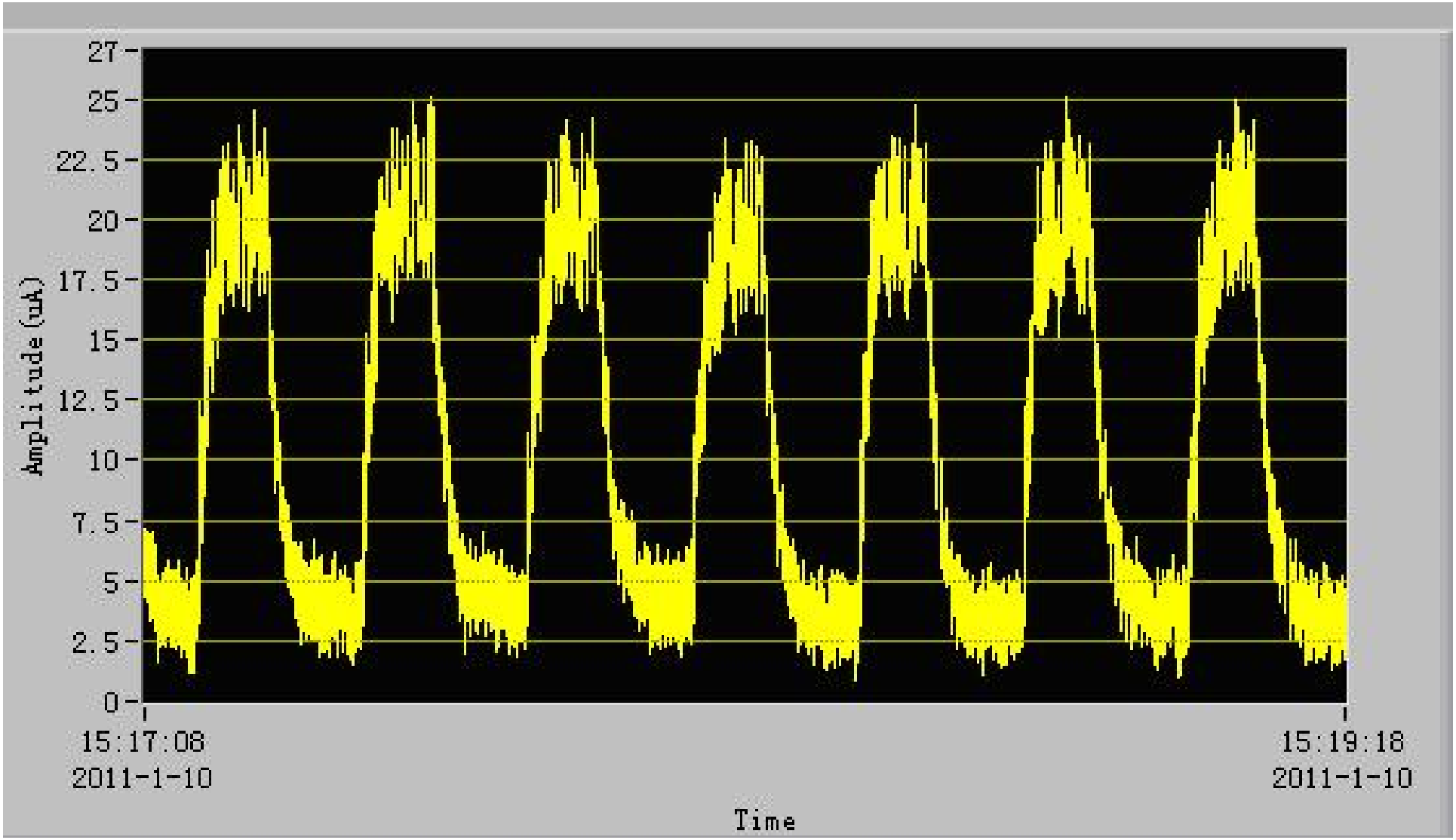
The high voltage of 300kV cooler in CSRe approach to 285kV

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

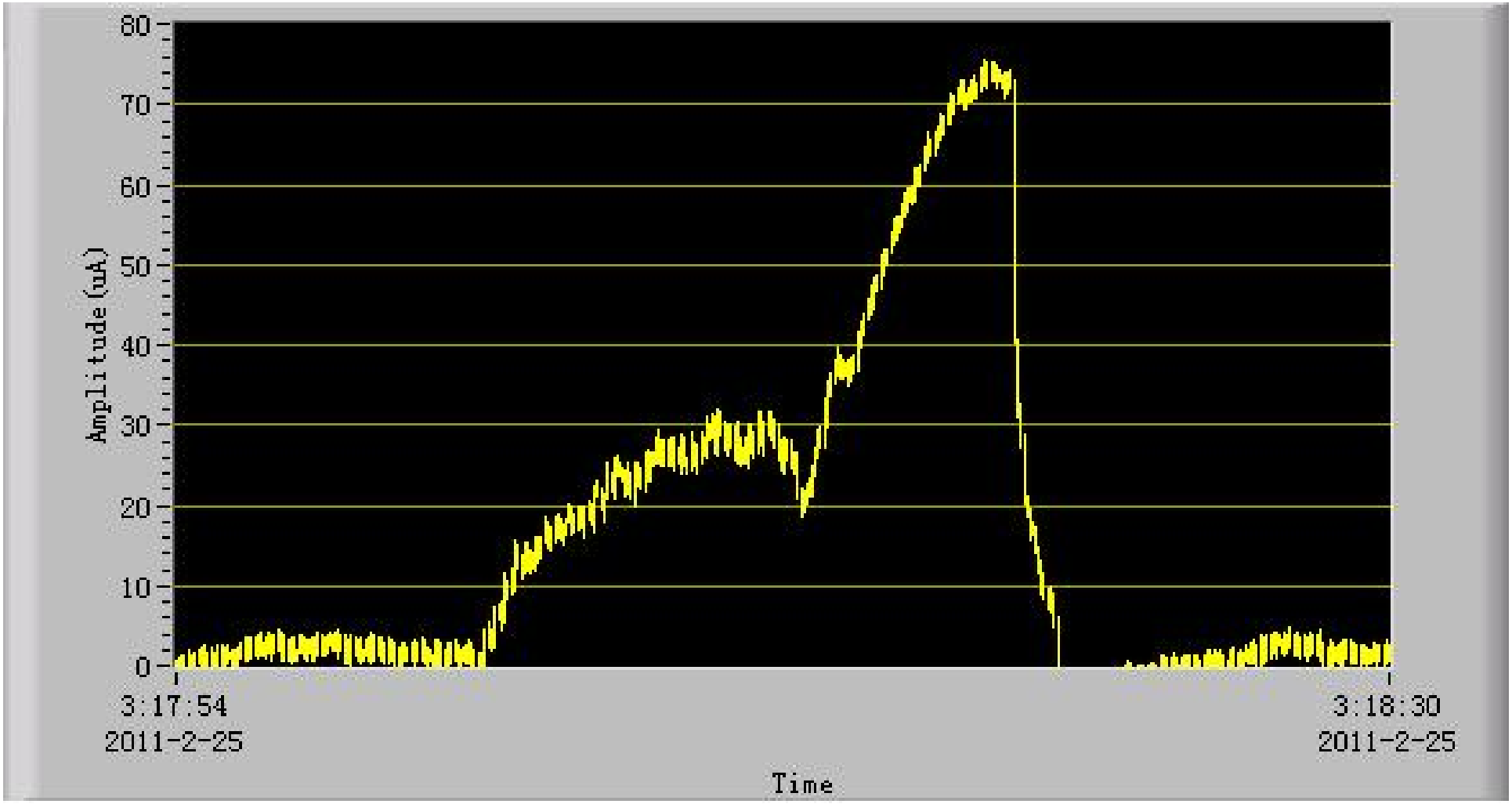
1.87MeV/u---170MeV/u



Electron cooler parameter preparative for 1.5MeV/u Bi

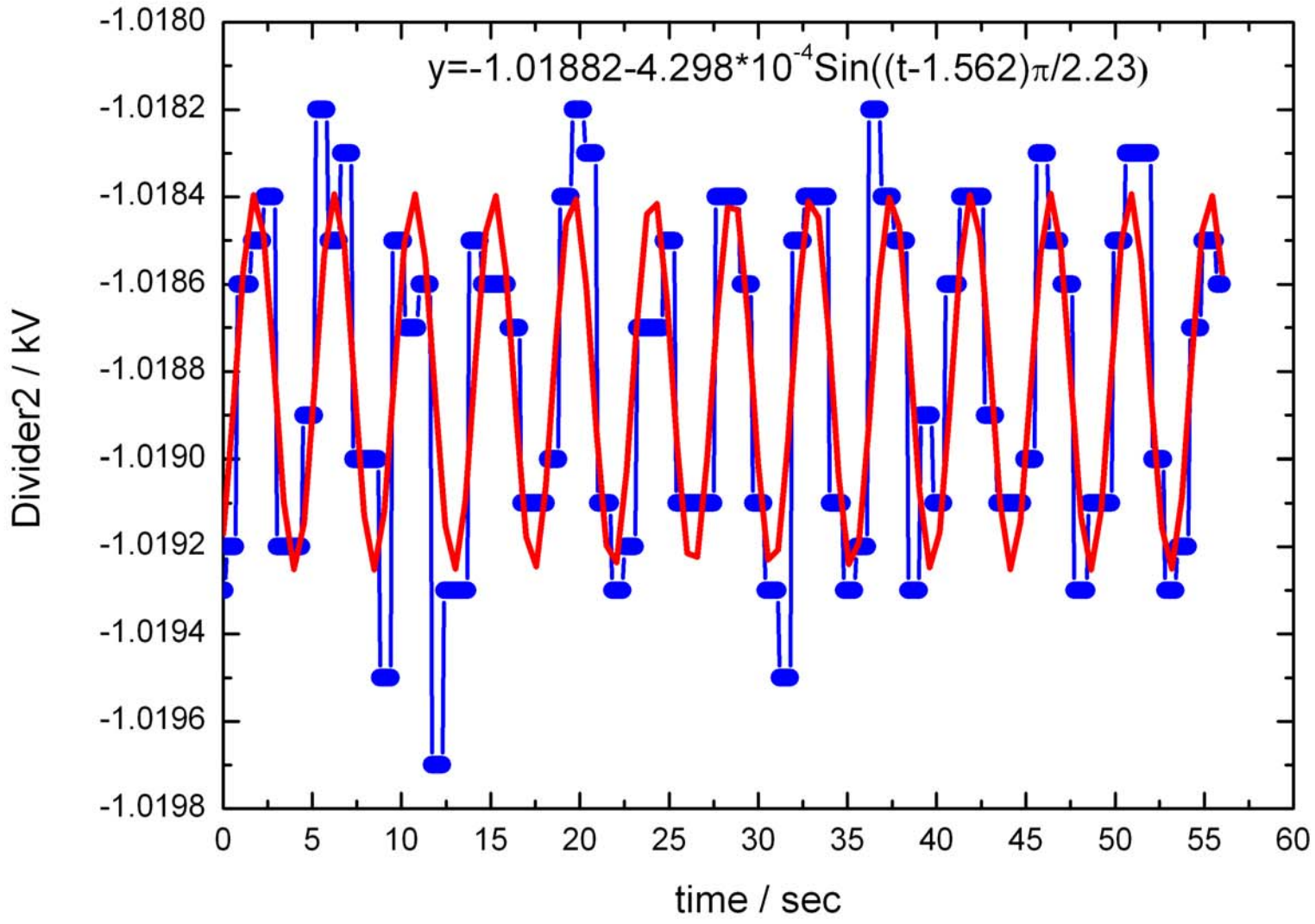


Bi beam accumulation with the help of electron cooling

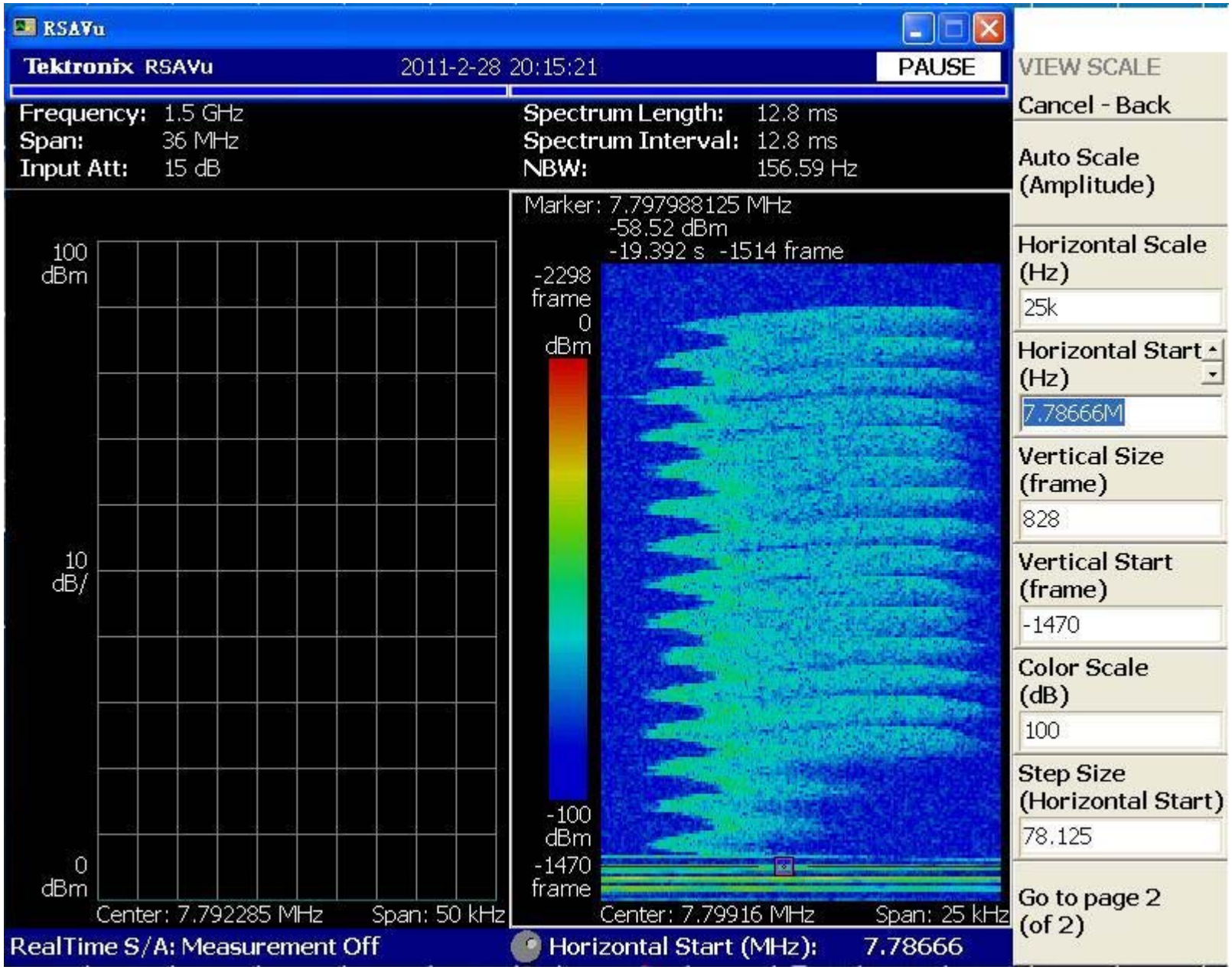


Bi beam accumulation and acceleration with the help of electron cooling

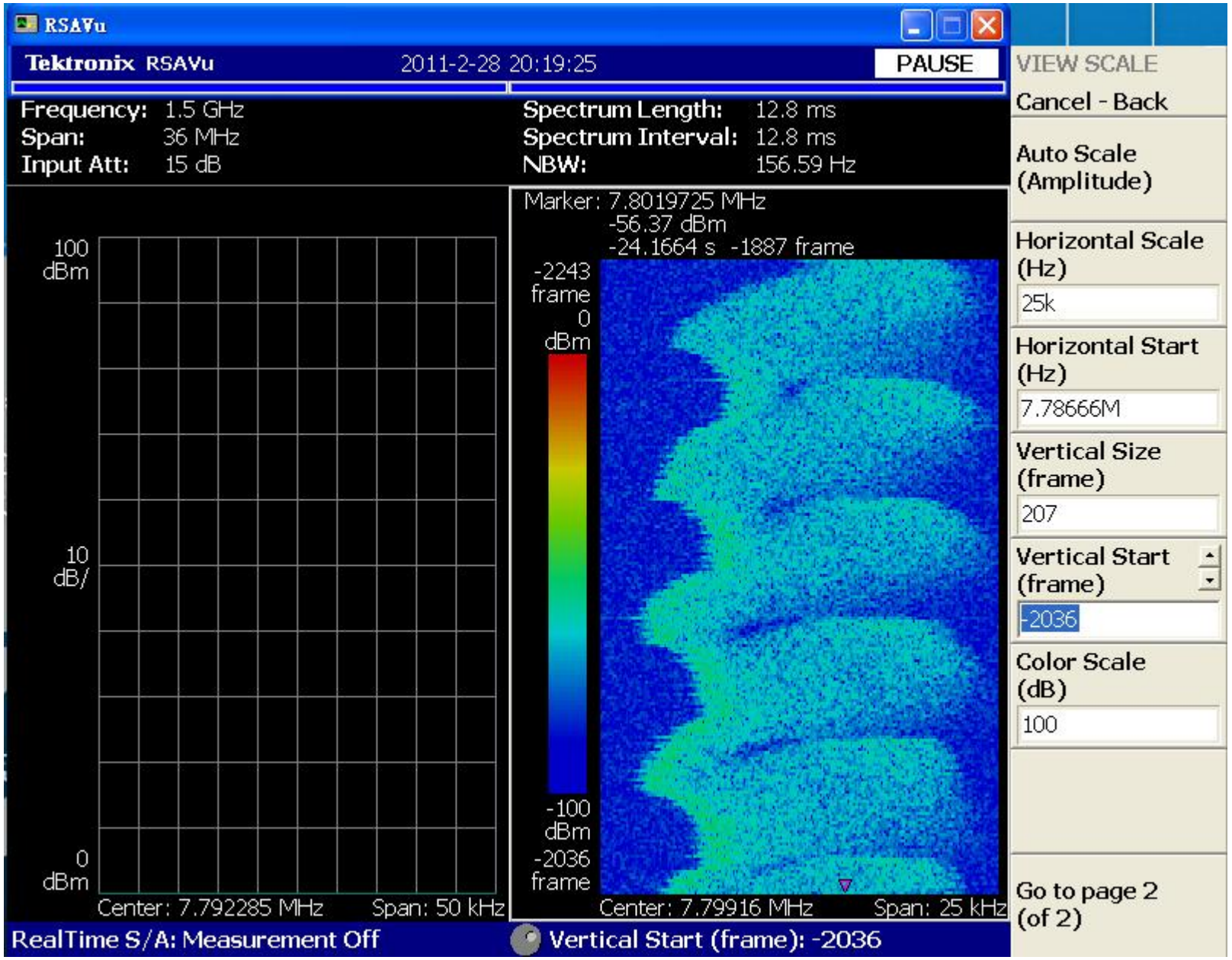
1.87MeV/u---170MeV/u



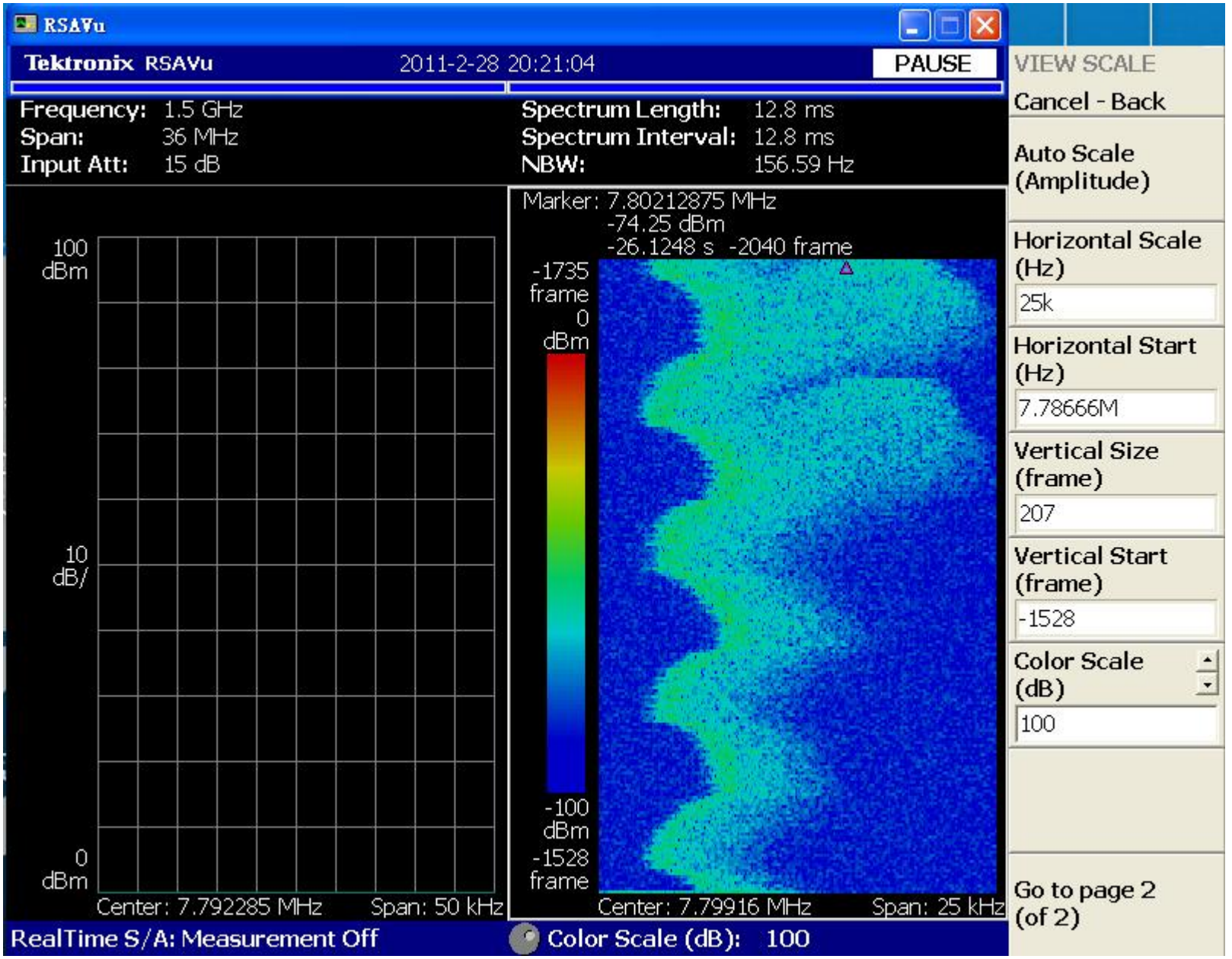
The stability of high voltage of electron cooler
The oscillation period is about 4.5sec



The observed oscillation during acuumulation
The oscillation period is about 0.6272 sec

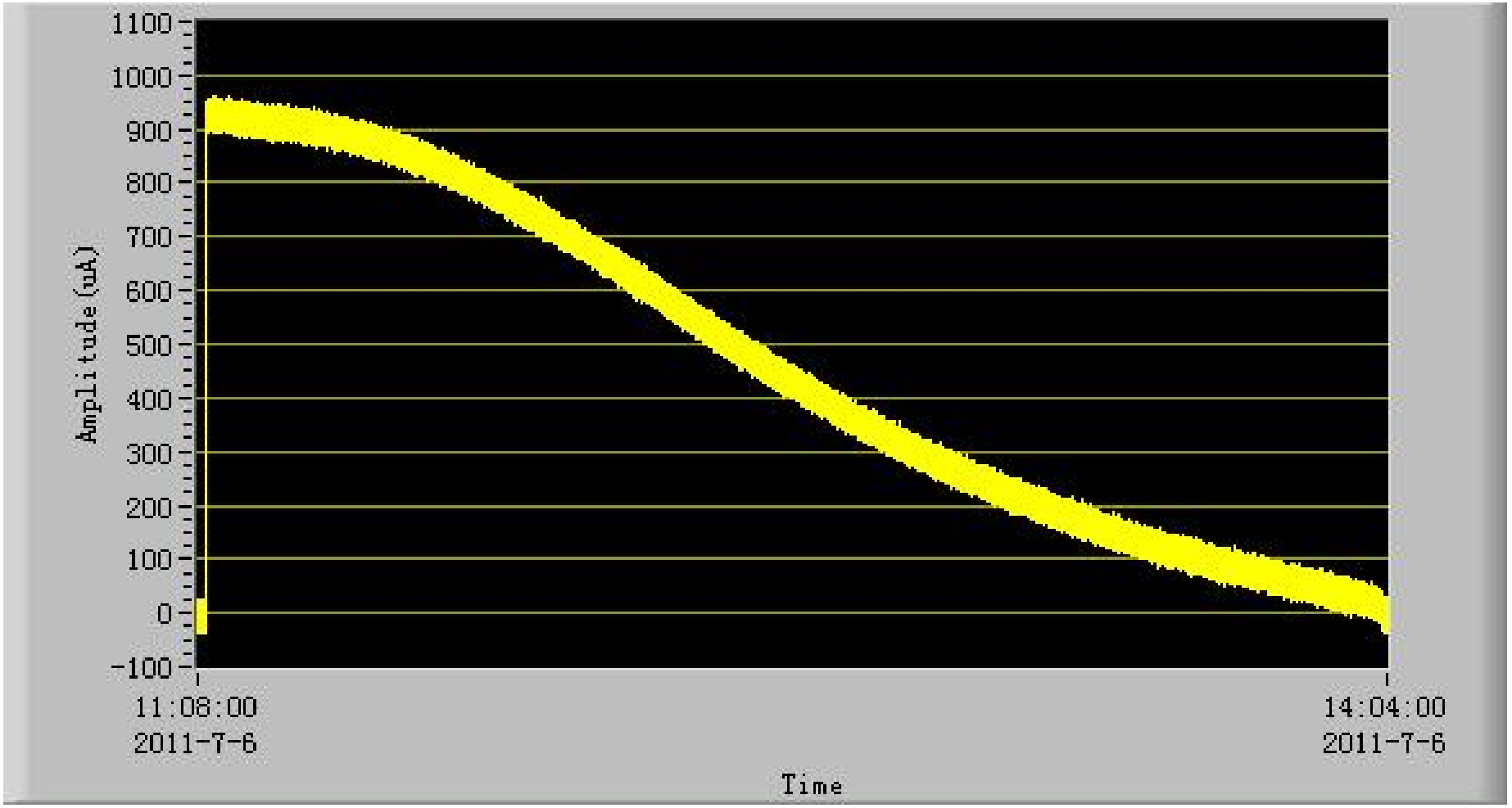


The beginning of injection and accumulation



The ending of injection and accumulation

10000sec slow extraction



200MeV/u $^{12}C^{6+}$ 10000 seconds slow extraction from CSRm

Summary

- The 35kV cooler can work at the lower energy(<1kV).
- The 300kV cooler can work at the higher energy(~285kV, 520MeV/u).
- The oscillation of ion beam was not caused by the instability of high voltage of cooler.
- Partial hollow electron beam is helpful to ion beam accumulation.
- A longitudinal oscillation signal was observed from Schottky probe during experiments.

Visit JINR in 1996 before COOL’96

Visit BINP in 1999

Thanks for the help from cooling community!

Welcome to IMP