Beam Commissioning of the KEK Digital Accelerator

Taiki Iwashita (KEK)

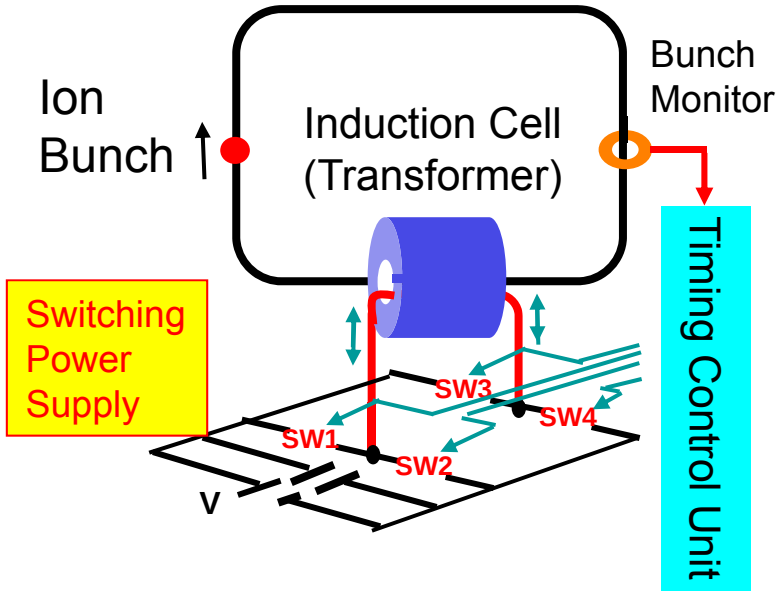
- Digital Accelerator
- KEK Digital Accelerator (KEK-DA)
- ECR ion source and Einzel Lenz chopper
- Injection Kicker
- Beam Bunch Observation
- Confine, Squeeze, Acceleration of the Beam
- Summary

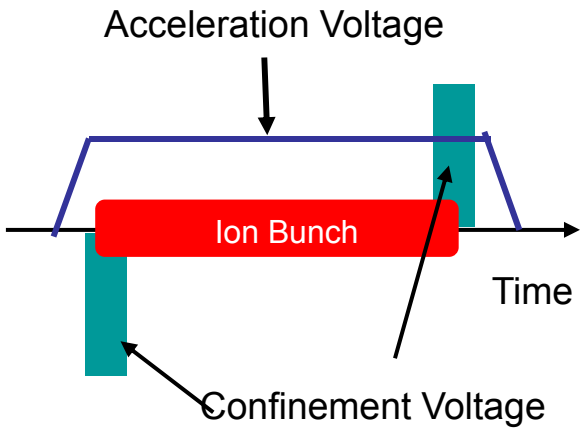
HIF-HEDEP US-Japan Workshop @ Osaka Univ. Oct. 12~14, 2011

KEK-DA Collaborators

- KEK ※T. Iwashita, T. Adachi, T. Arai, D. Arakawa, K. Okamura, E. Kadokura, M. Kawai, T. Kawakubo, T. Kubo, K. Koyama, H. Someya, A. Takagi, K. Takayama, H. Nakanishi, M. Hashimoto, M. Wake
- Sokendai (Graduate University for Advanced Studies) Leo Kwee Wah
- Nagaoka University of Technology W. Jiang
- Nippon Advanced Technology K. Okazaki
- Pulse Power Japan Laboratory A. Tokuchi

Digital Accelerator (DA)

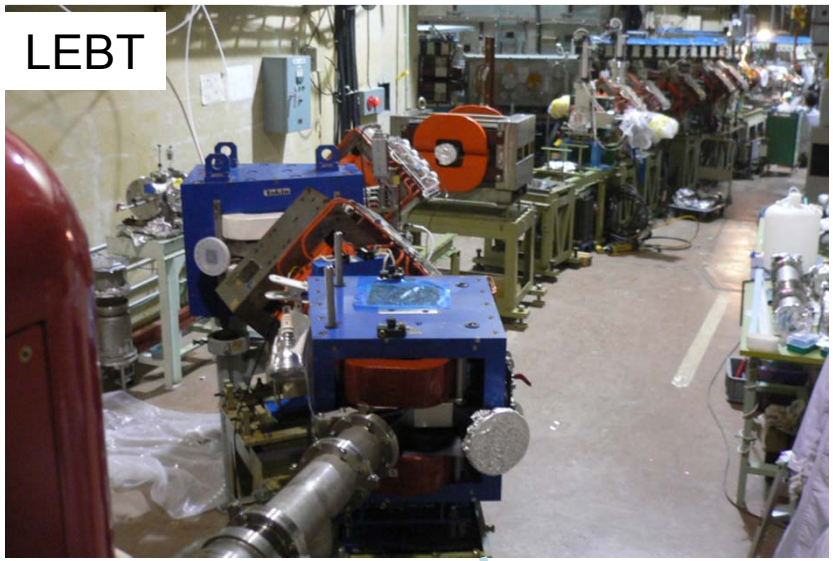


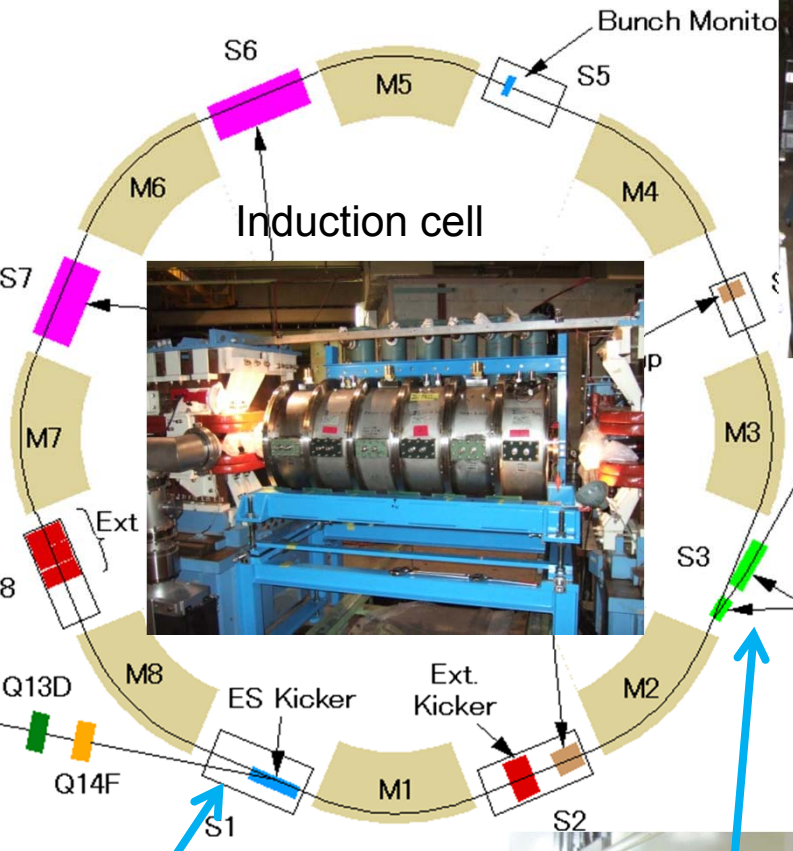


- Proposed by Takayama & Kishiro (KEK) in 2000
- Proof of principle experiments at KEK 12GeV PS in 2006
- RF cavity of conventional synchrotron is replaced by induction cell (Transformer)
- Switching power supply using high power MOS-FET is free from the limitation of band width of RF cavities and amps
- DA can accelerate all species of Ions without large injector → wide field of applications are expected
- Gate trigger signal is generated from bunch monitor signal
- Acceleration / Confinement are separeted function → Increase freedom of beam handling

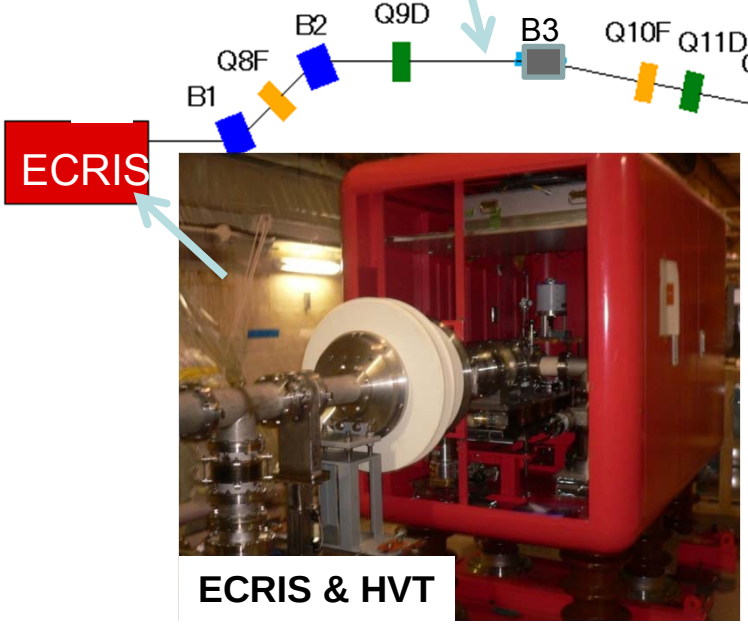
KEK Digital Accelerator

T. Iwashita *et al.*, *"KEK Digital Accelerator"* *Phys. Rev. ST-AB 14, 071301 (2011).*

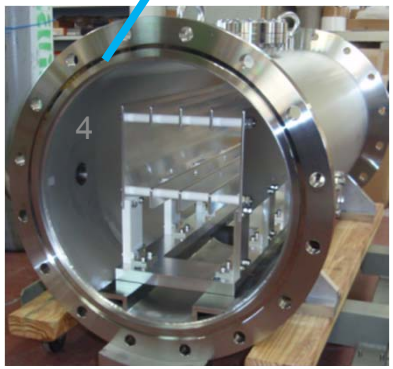


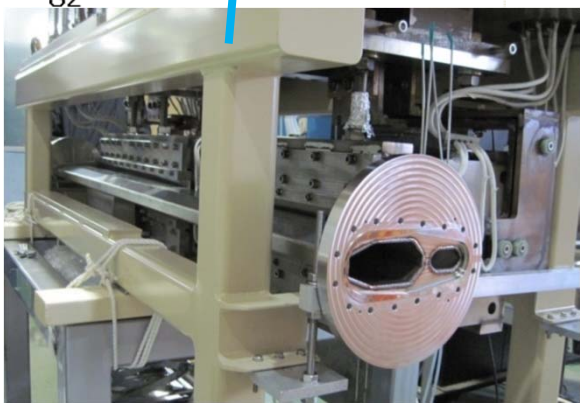


HEBT
Experiment Area
Beam Dump

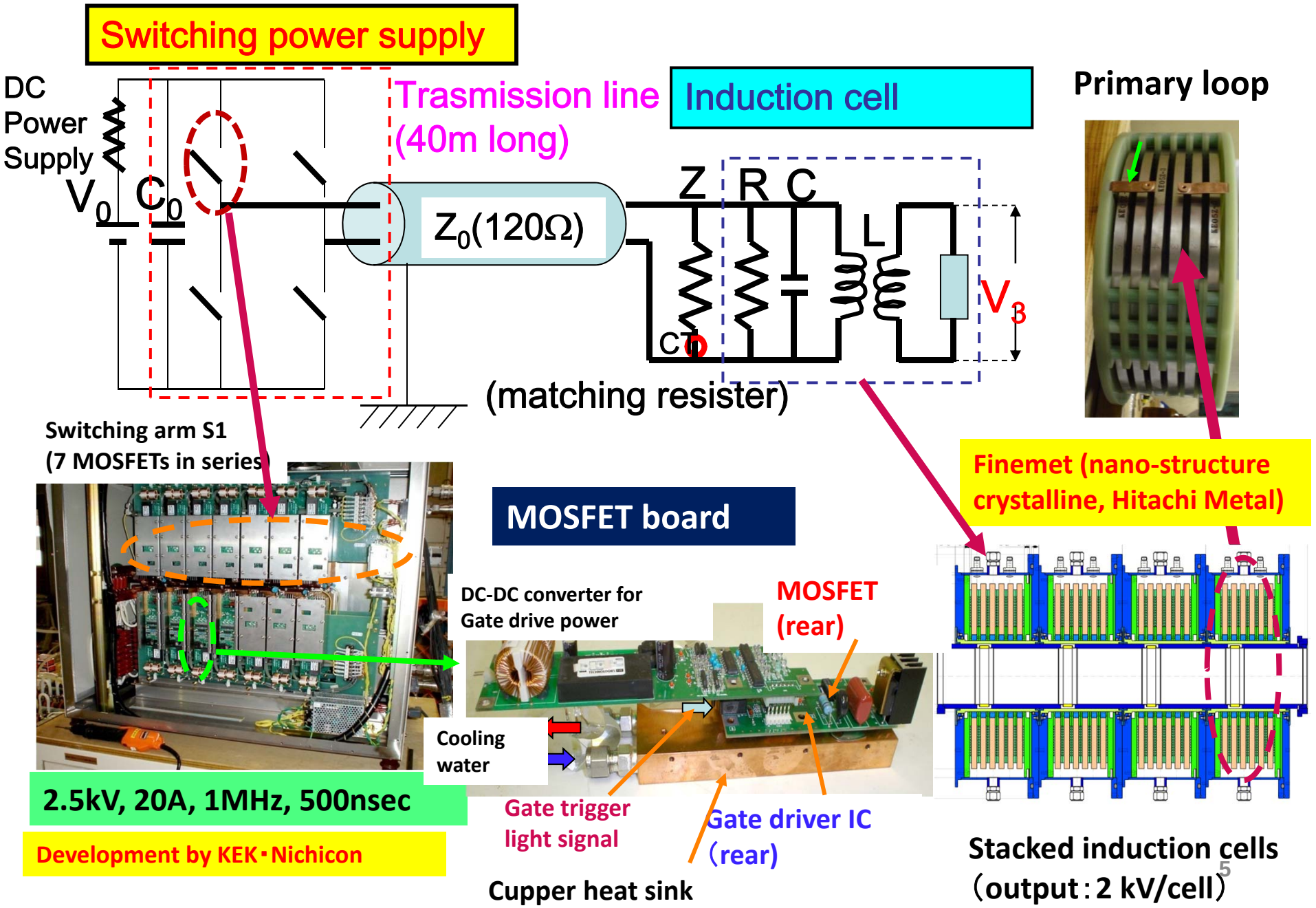


ECRIS & HVT

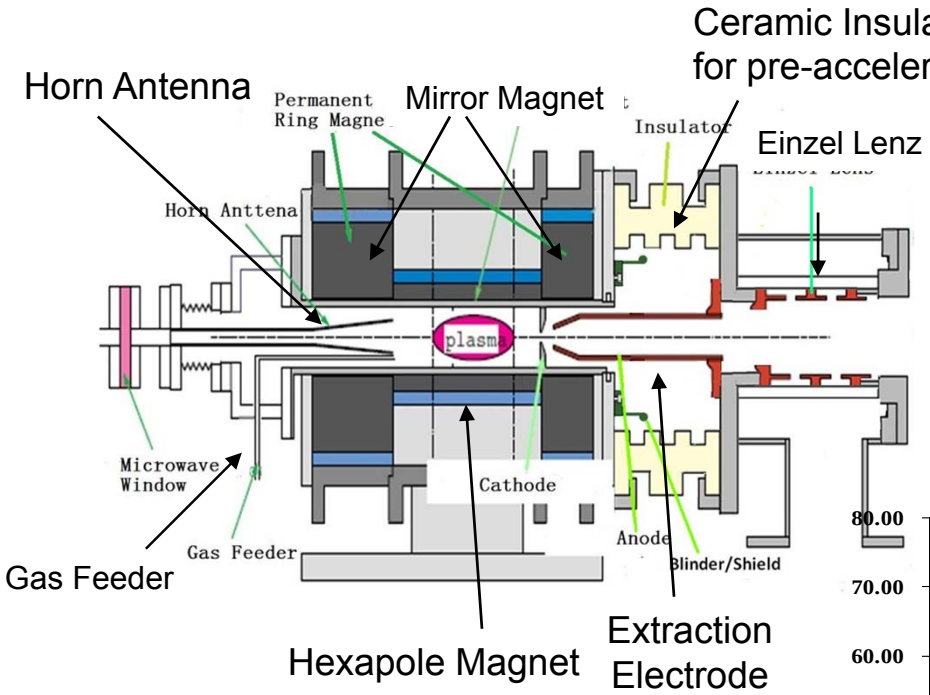




Induction Acceleration Hardware Overview

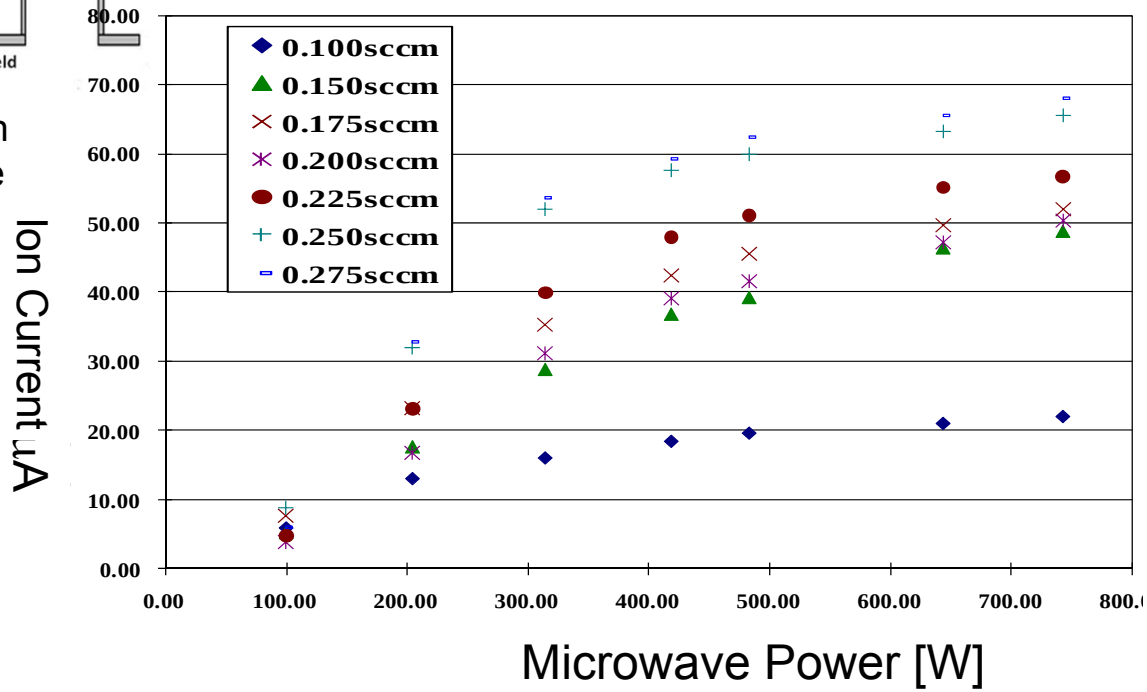


ECR Ion Source and High Voltage Terminal

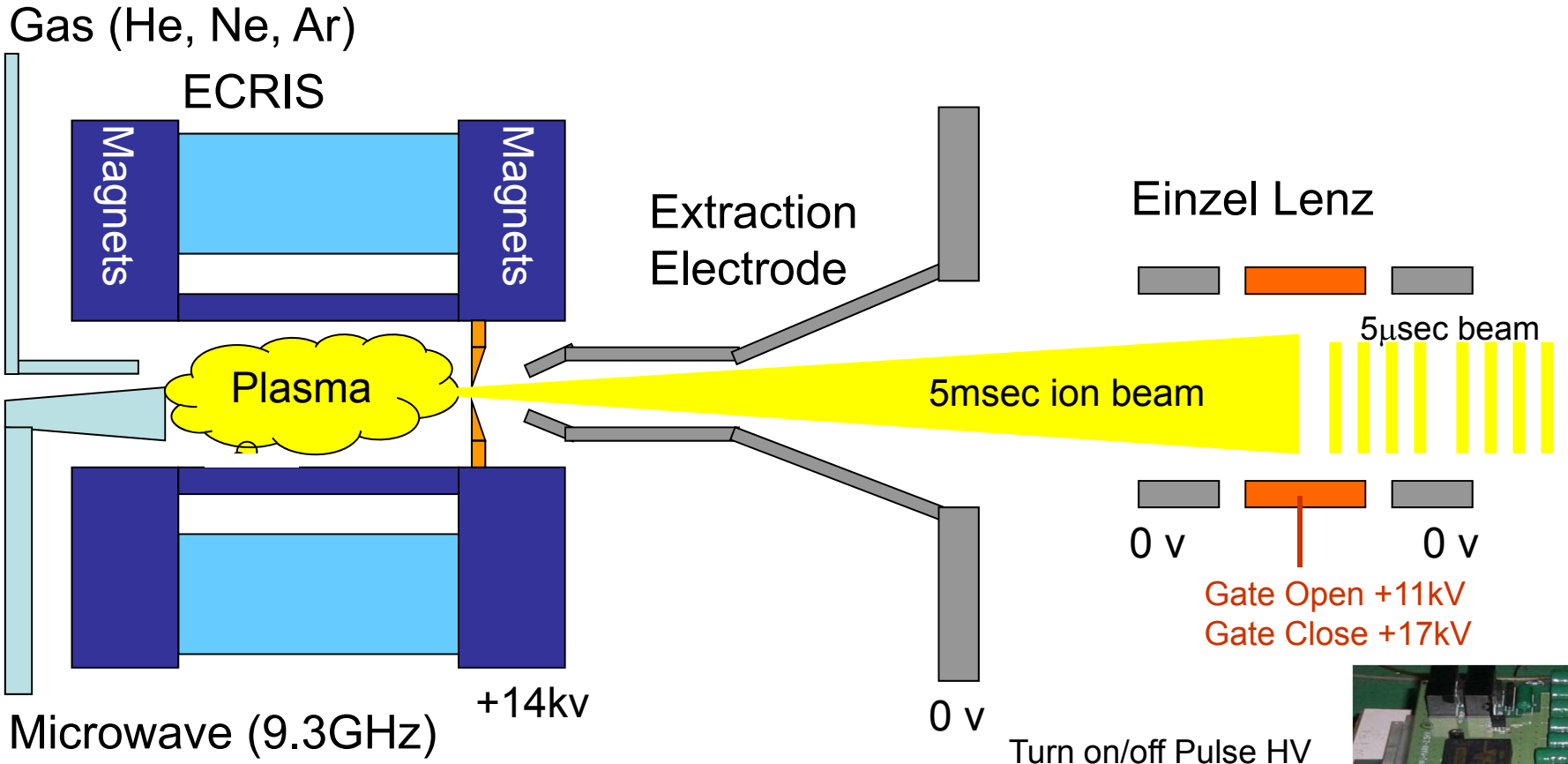


- Permanent Magnet ECRIS installed inside 200kV High Voltage Terminal
- He^{1+} is provided for acceleration experiment
- C, N, O, etc can be available by changing gas

200kV High Voltage Terminal



Einzel Lenz Chopper



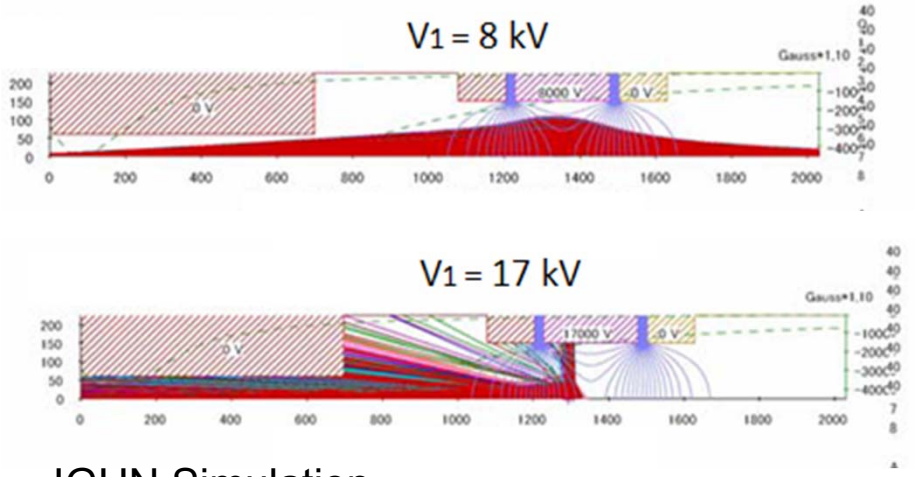
Control beam width by changing voltage of center electrode of Einzel Lenz

- Chop 5msec width beam from ECRIS
  make 5μsec beam requested by acceleration scheme

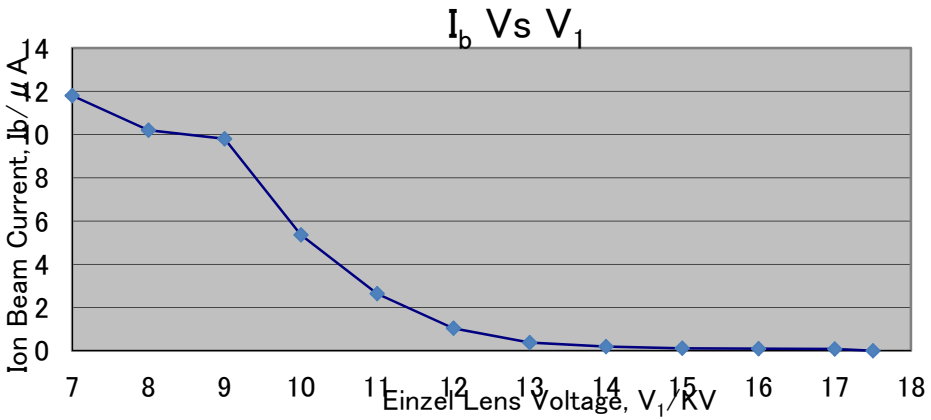
Turn on/off Pulse HV by **Solid State Marx Generator** with High power MOS-FET

T.Adachi et. al,. "A Solid-state Marx Generator driven Einzel lens Chopper", Review of Scientific Instruments 82, 083305 (2011)

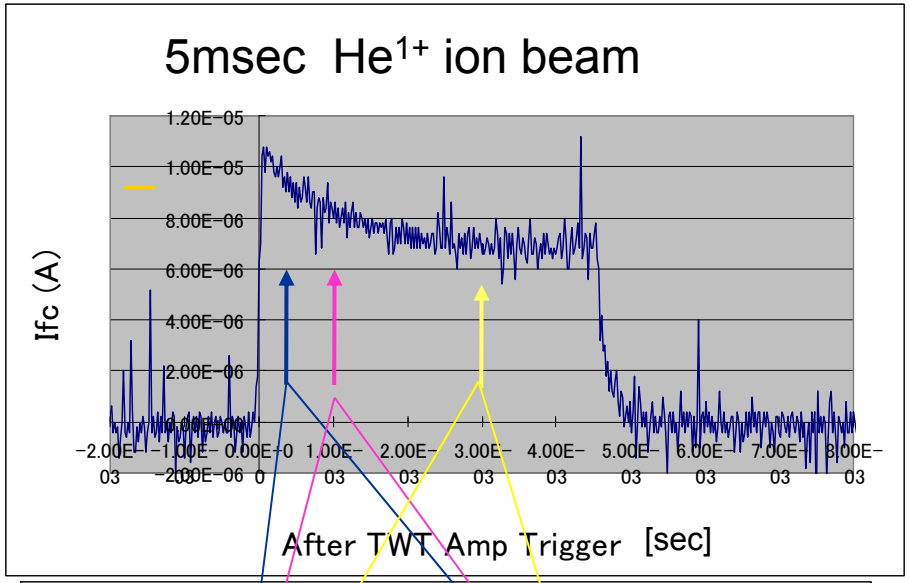
EL chopper: Simulation / Experiments

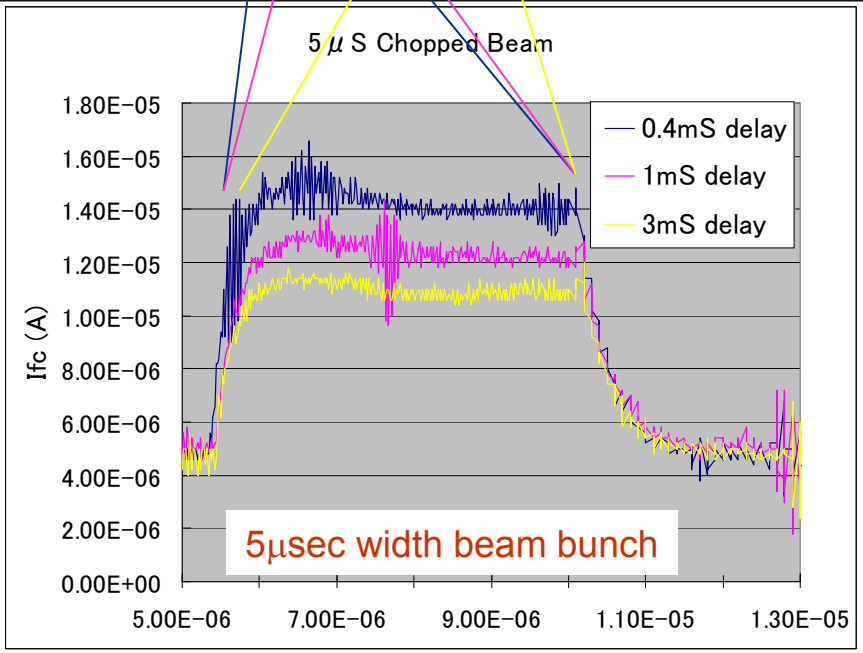


IGUN Simulation:
17kV of center electrode can stop 14keV beam

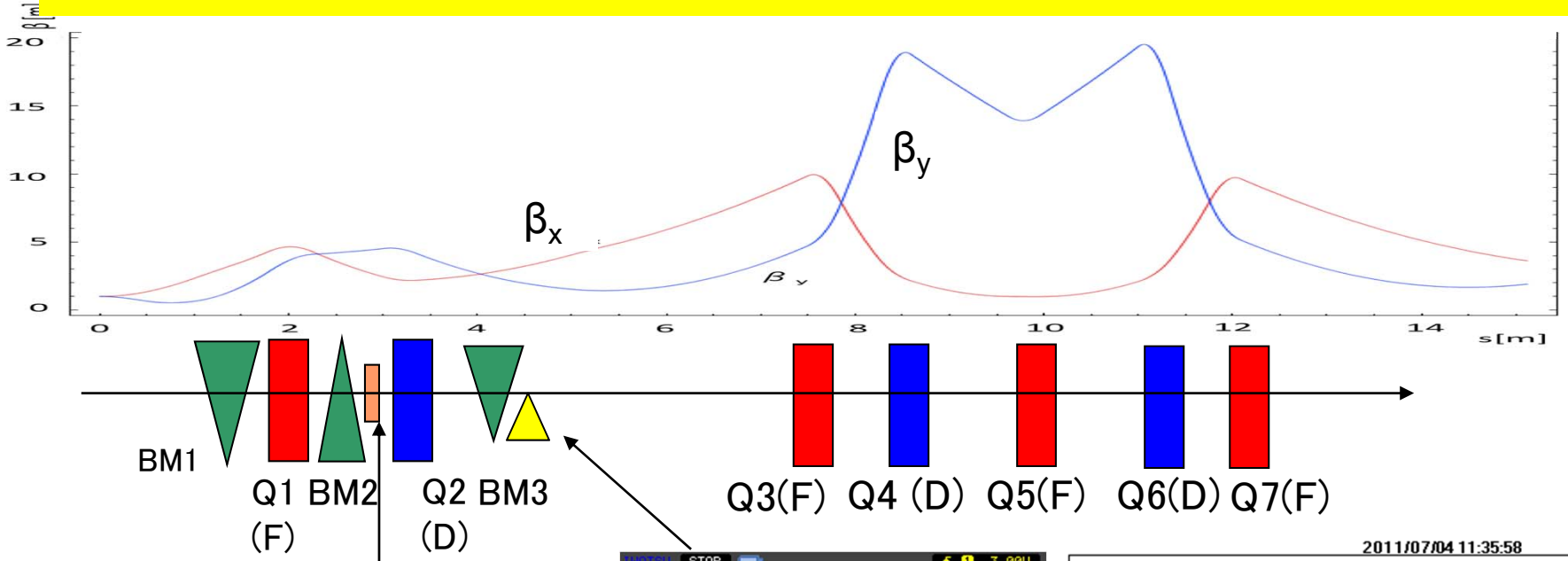


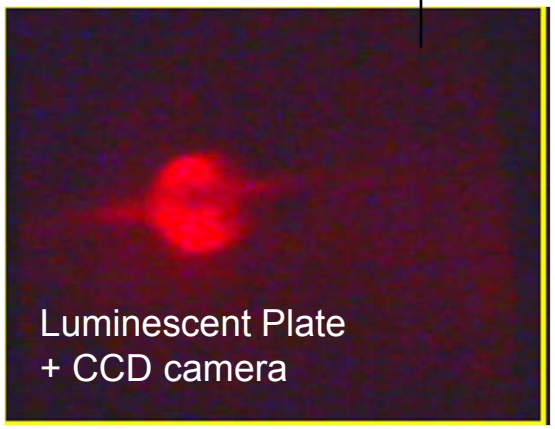
Test bench results

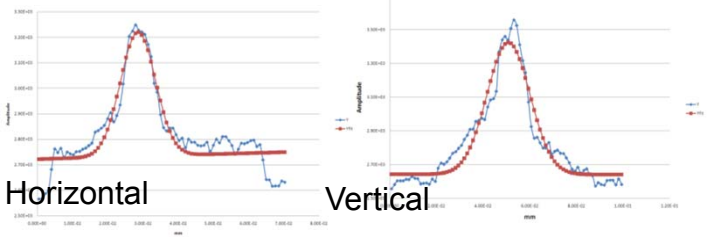


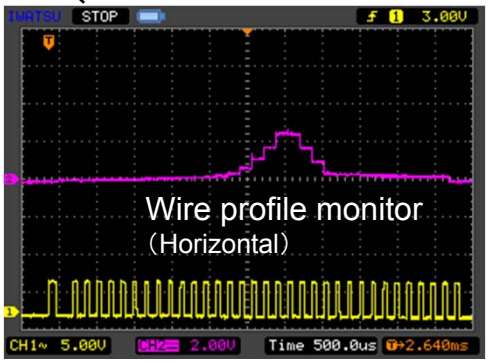


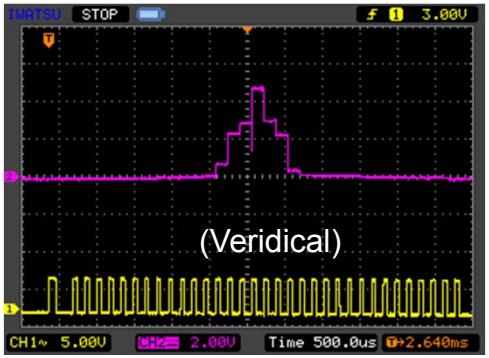
Beam Profile measurement at beam transport line

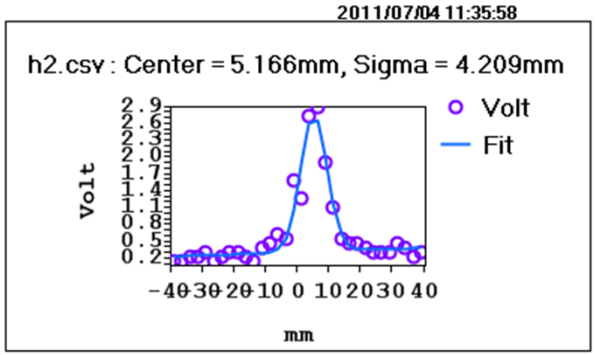


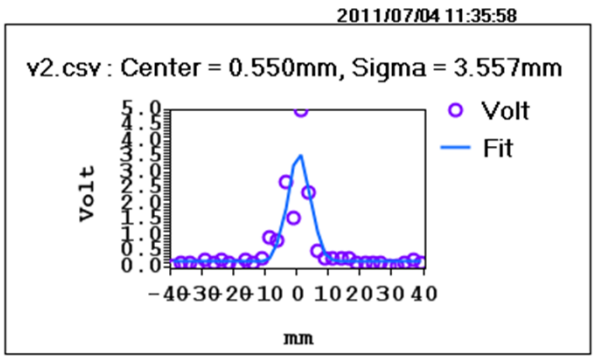




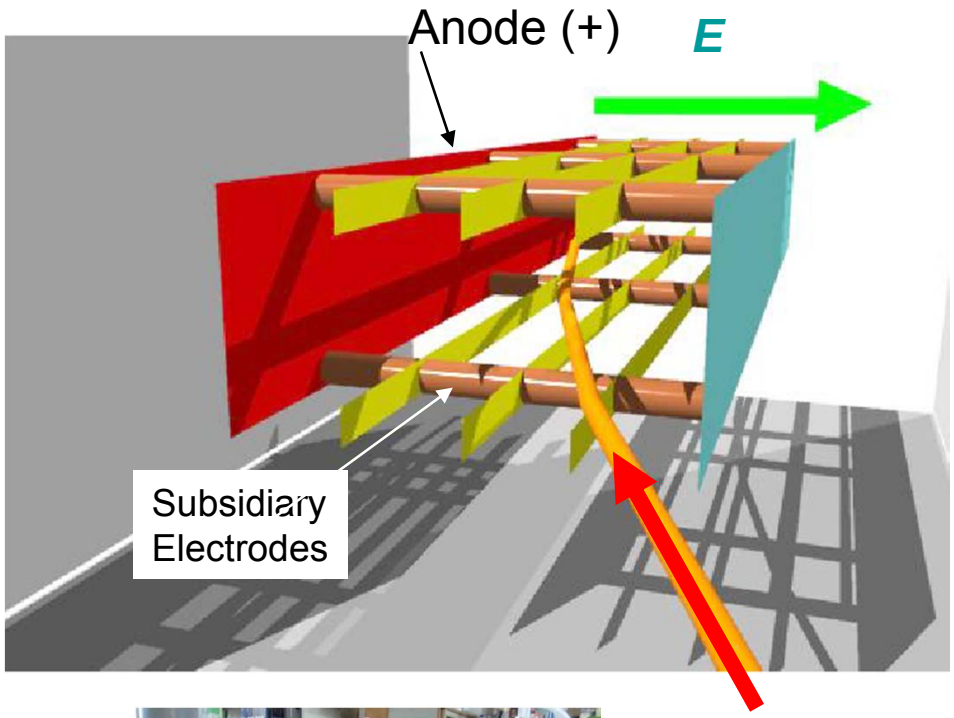


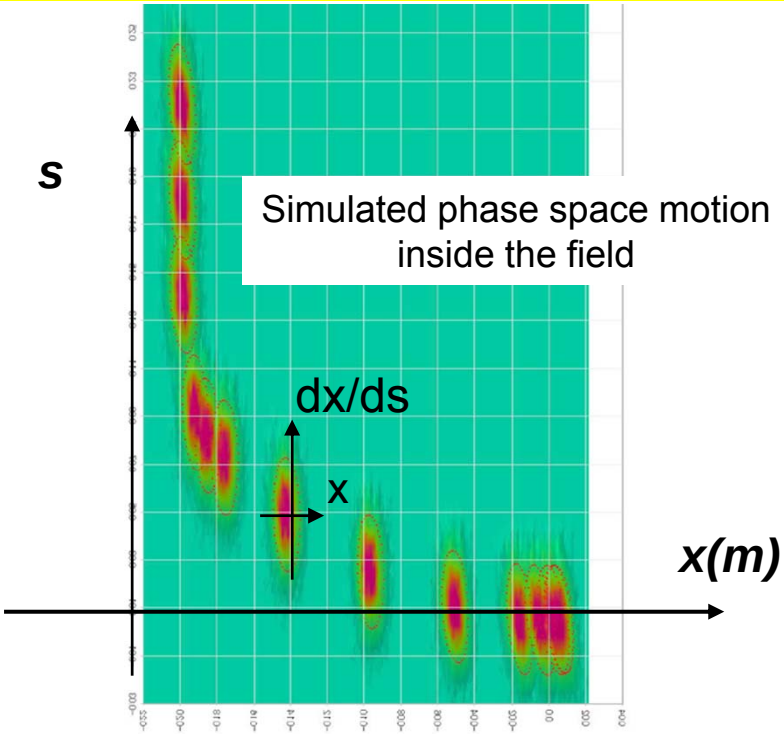


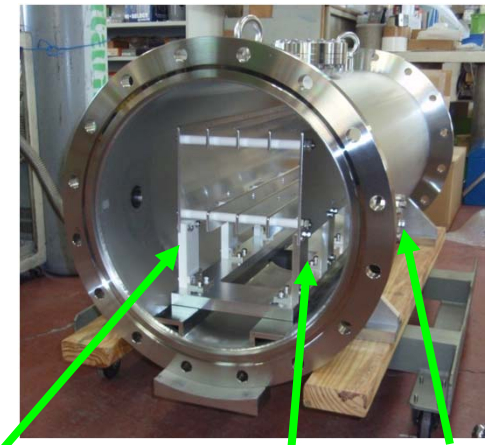


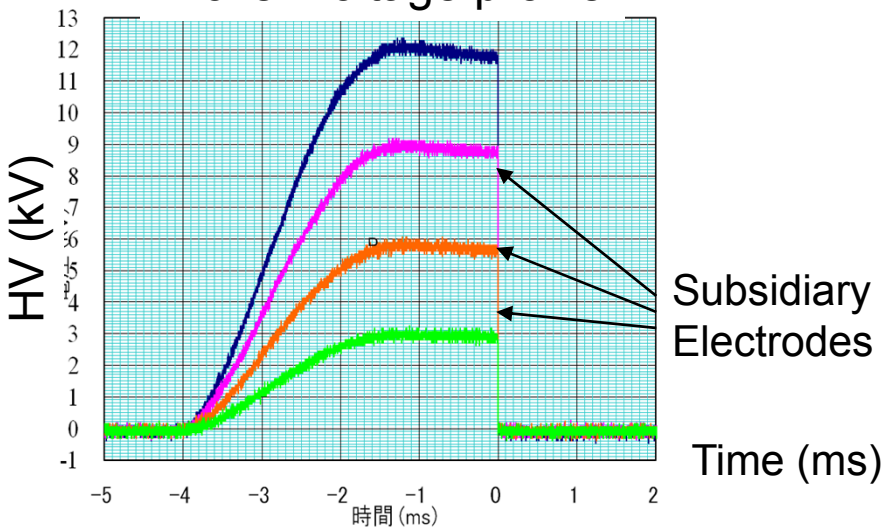


Electrostatic Injection Kicker

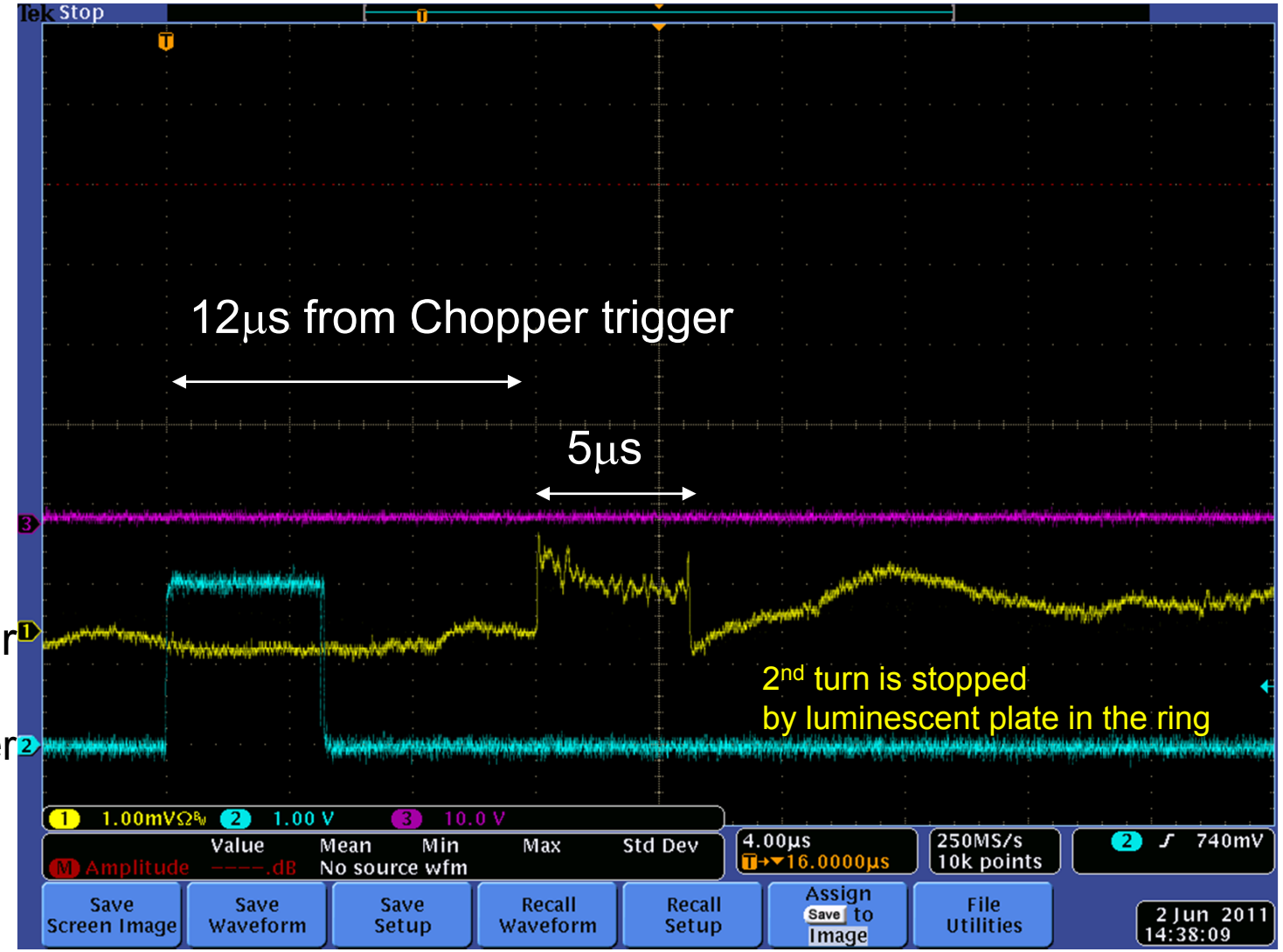




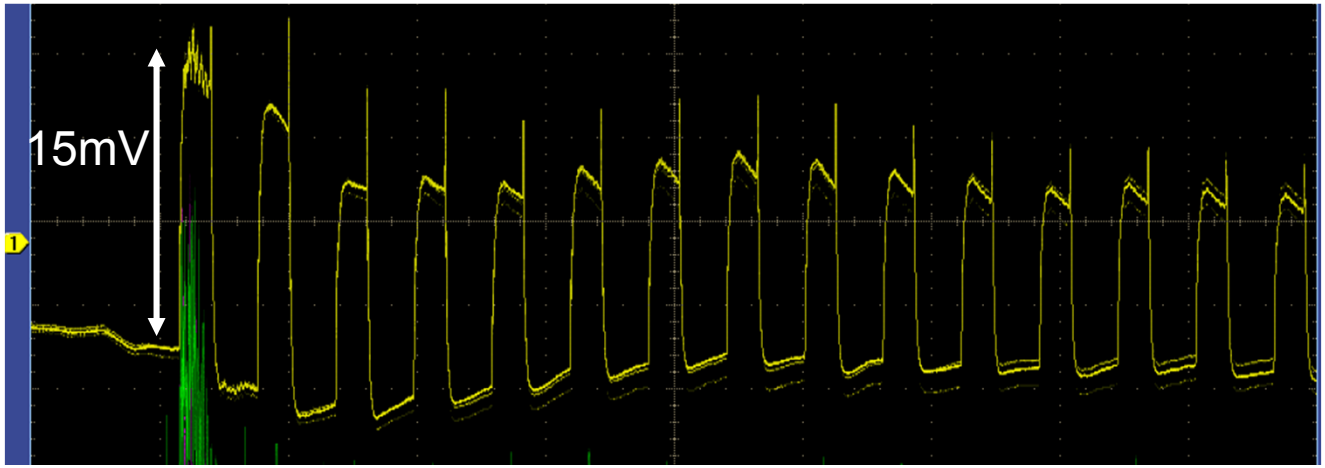


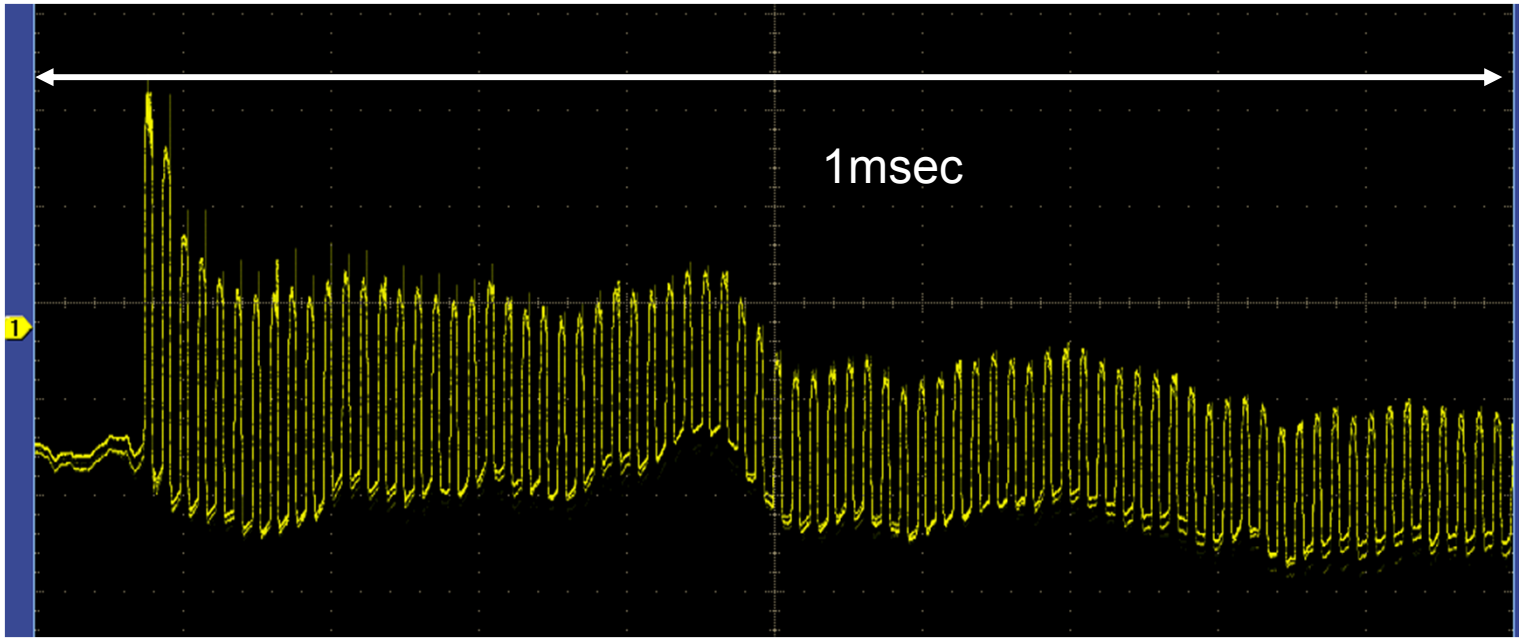


First Beam of KEK-DA



Circulating Beam

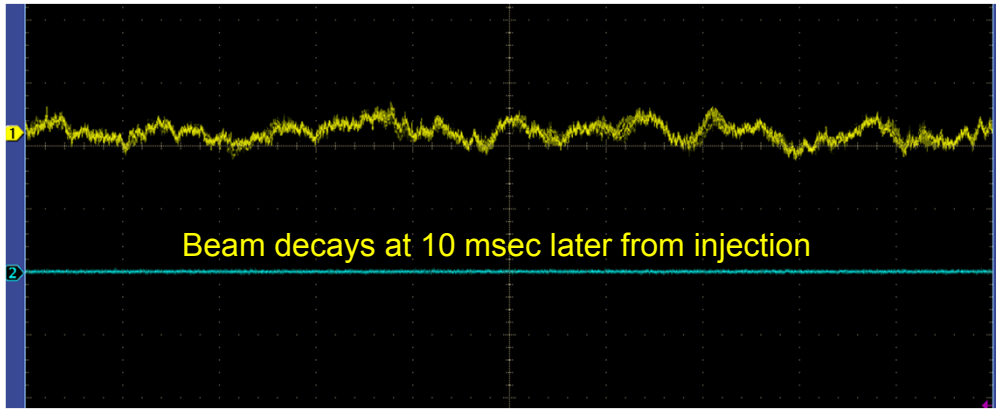




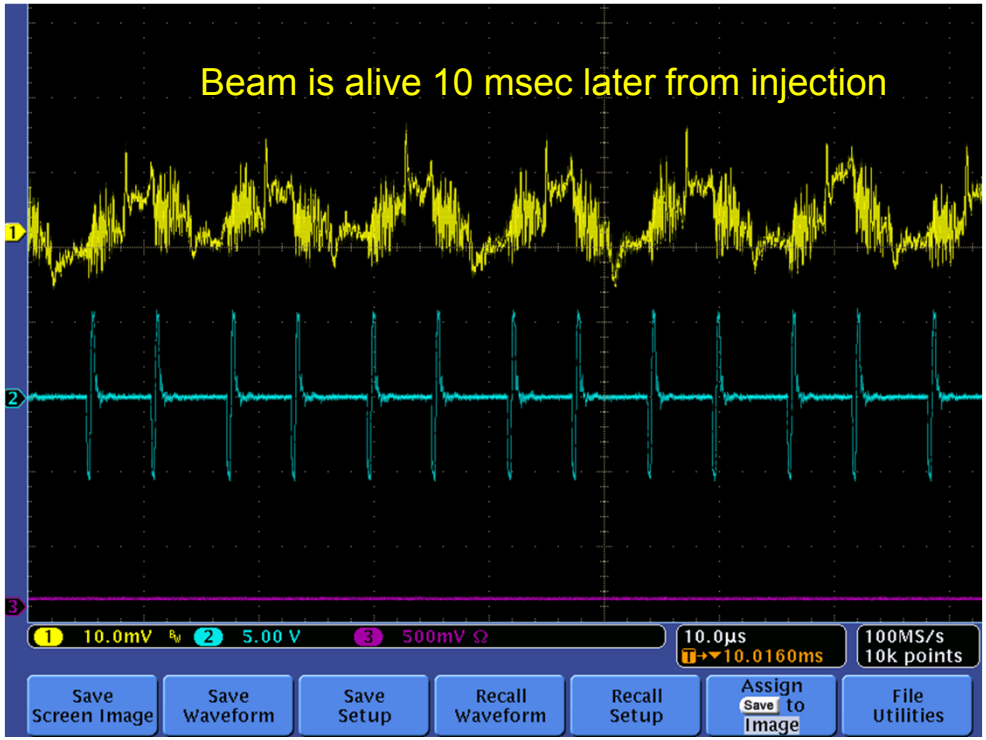
Beam Confinement with Barrier Bucket

(without acceleration)

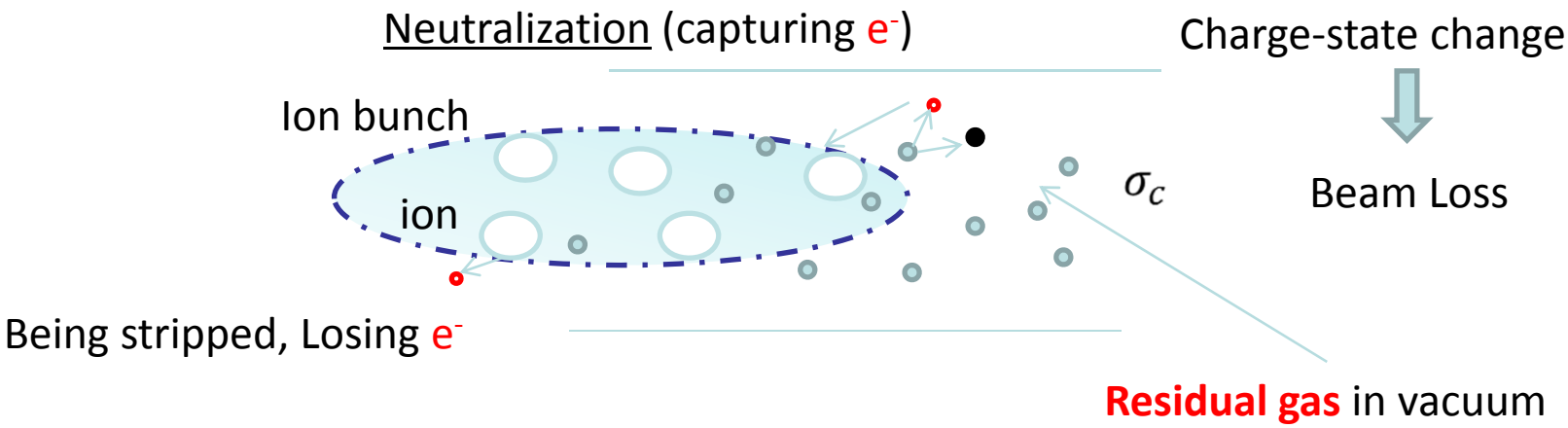
V_{bb} off

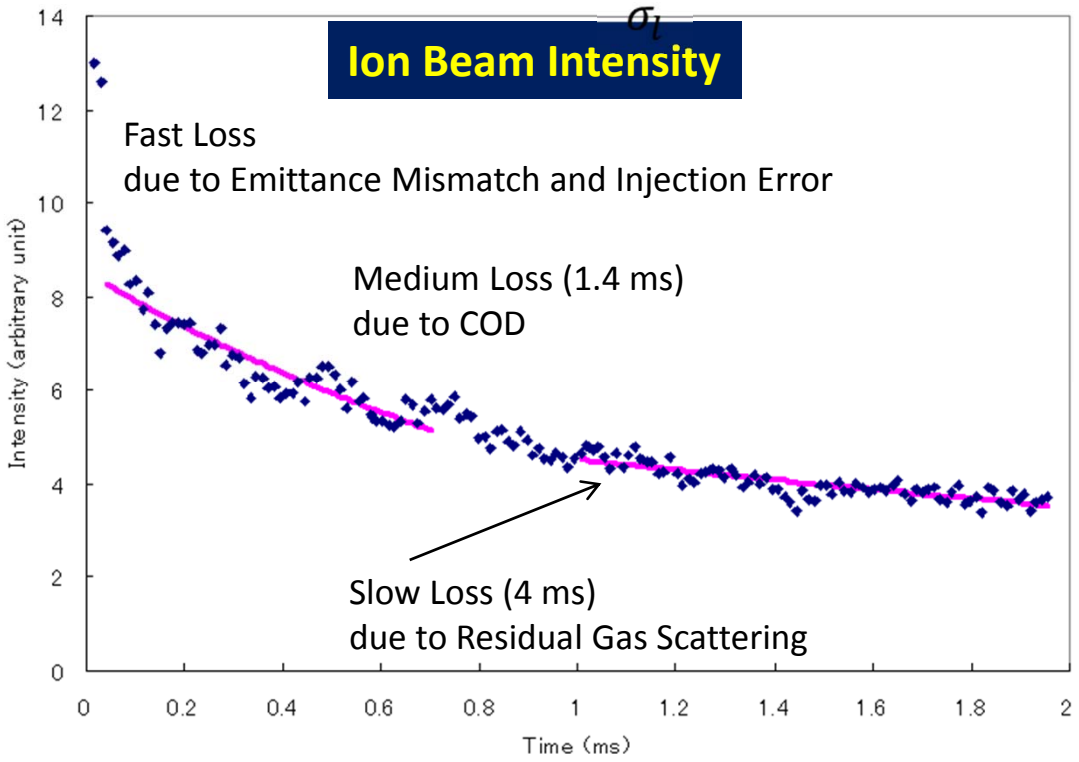


V_{bb} on



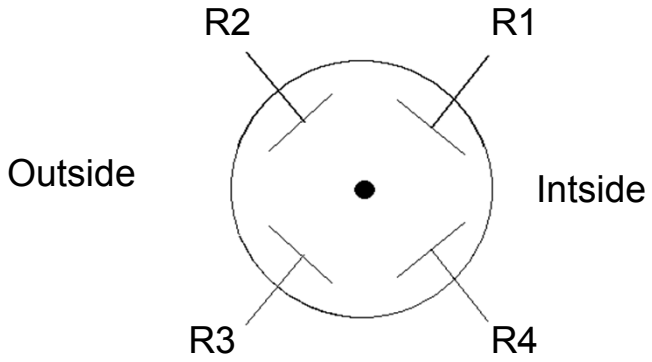
Loss by Residual Gas: neutralized &stripped & scattering





Injection Optics

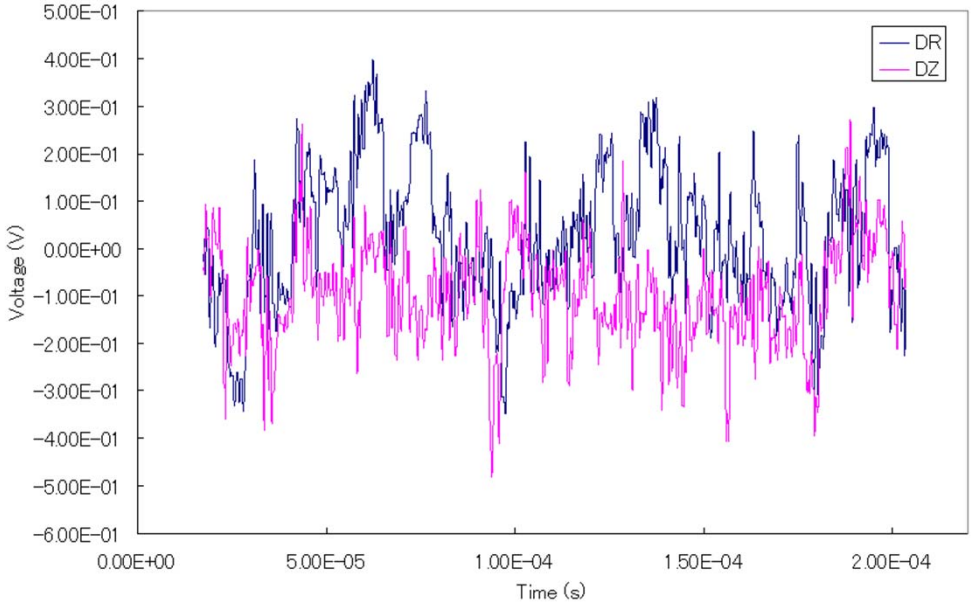
ES Position Monitor



R_+ = R2+R3, R_- = R1+R4

Z_+ = R1+R2, Z_- = R3+R4

$$\Delta R = \frac{R_+ - R_-}{R_+ + R_-} \quad , \quad \Delta Z = \frac{Z_+ - Z_-}{Z_+ + Z_-}$$



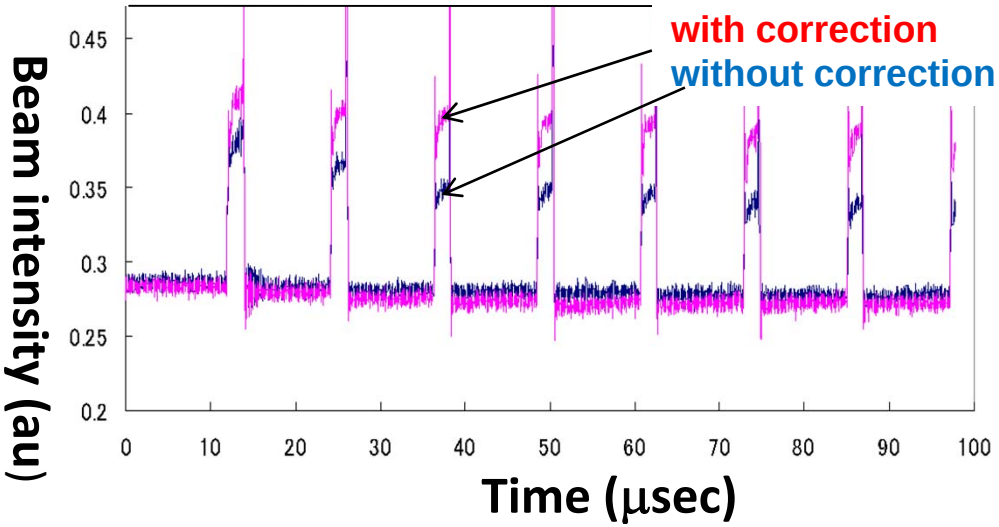
FFT analysis

Betatron tunes

Q_x=2.19 (design 2.17)

Q_y=2.30 (design 2.30)

After injection error correction



Control System of induction Acceleration in KEK-DA

Induction Acceleration Cell

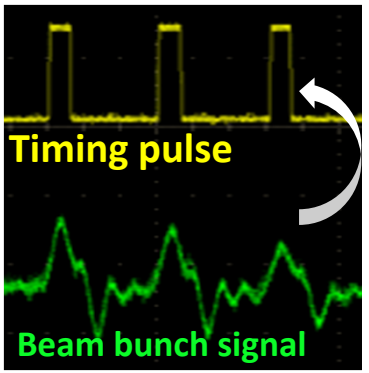
Matching resistance

V(t)

Beam

L

Beam monitor



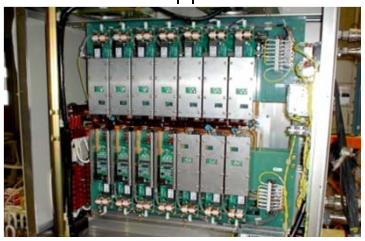
ECRIS

Pulse chopper timing signal

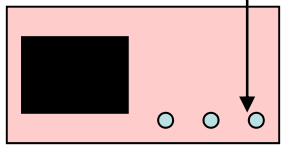
ΔR monitor

Amp. & Front End Processing

CCR(Central Control Room)



1MHz switching power supply



Oscilloscope for monitoring induction output voltage

ΔR signal

Beam timing pulse

PC for DSP control

USB

Optical fiber

Optical Converter module

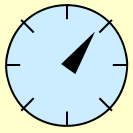
Signal divider (for alternative Operation)

Wave shaping

NIM Logic circuit

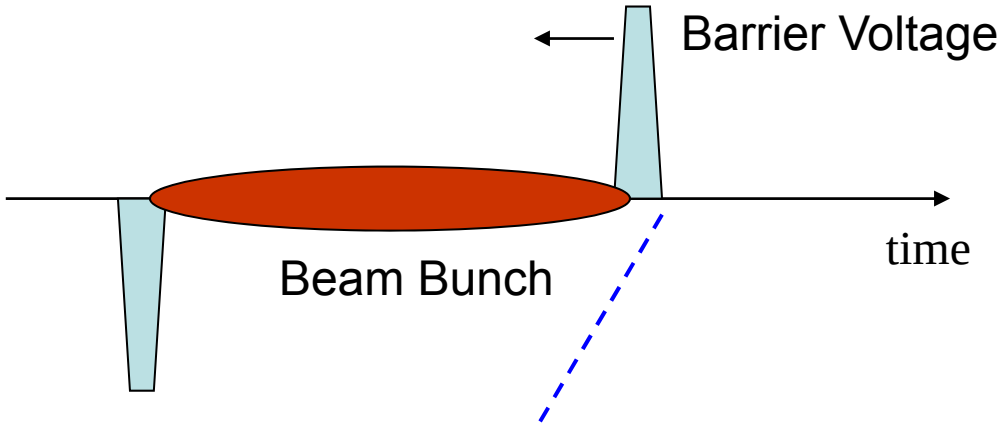
DSP (Digital Signal Processor)

TOF calculation
T(t)=*L*/V(t)

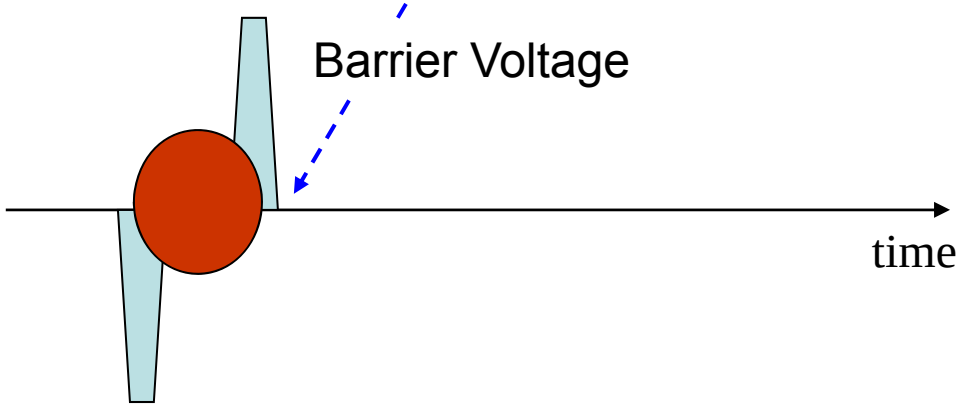


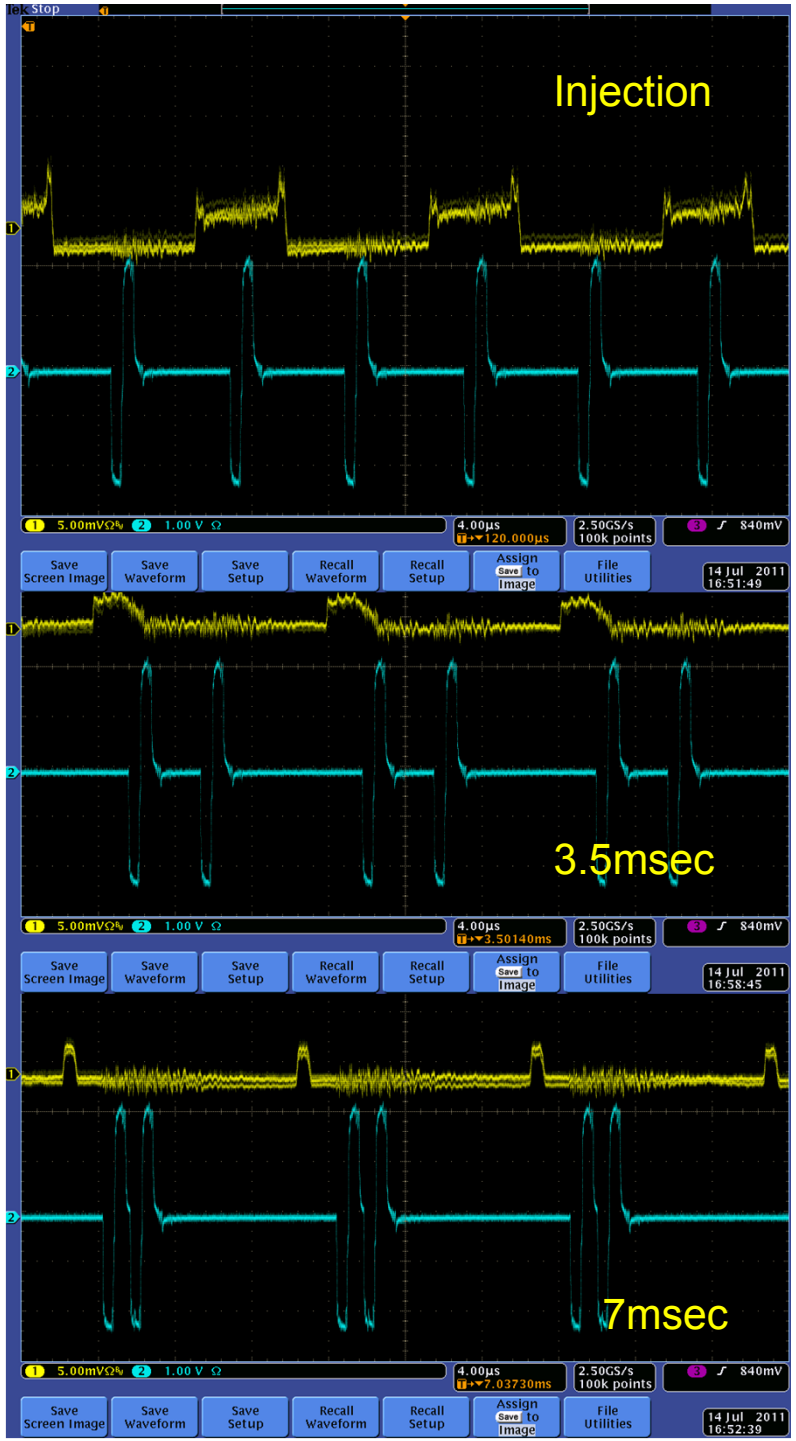
Set Timer T(t)

Bunch Squeeze Experiment

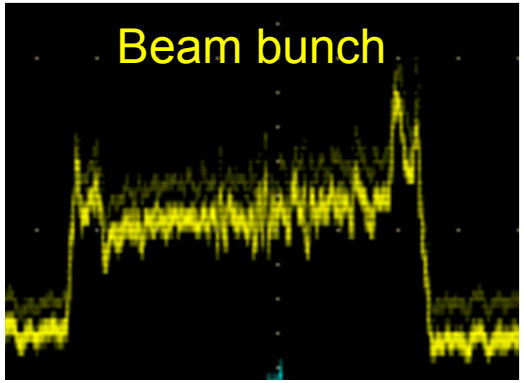


DSP (Digital Signal Processor) changes timing of Barrier Voltage by 8nsec/turn

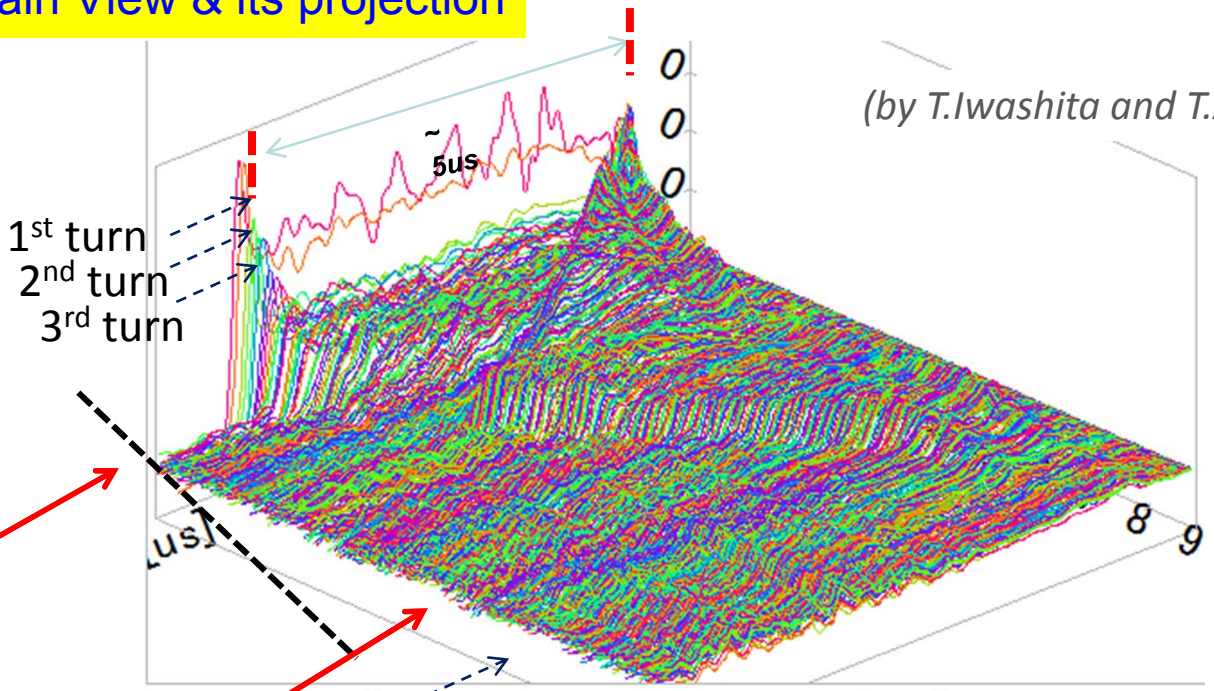




Squeezing in Mountain View & its projection



(by T.Iwashita and T.Adachi)

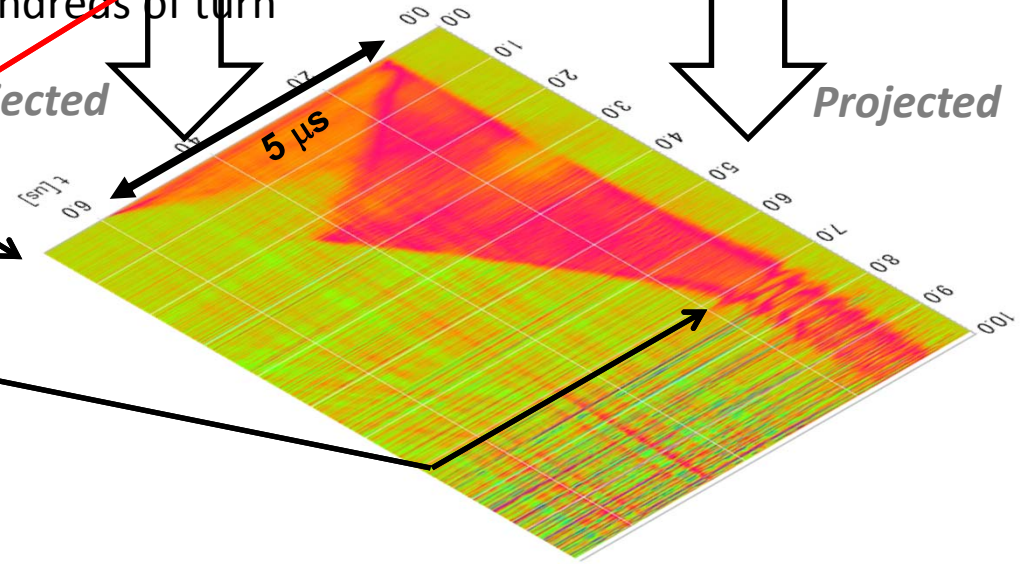


At injection

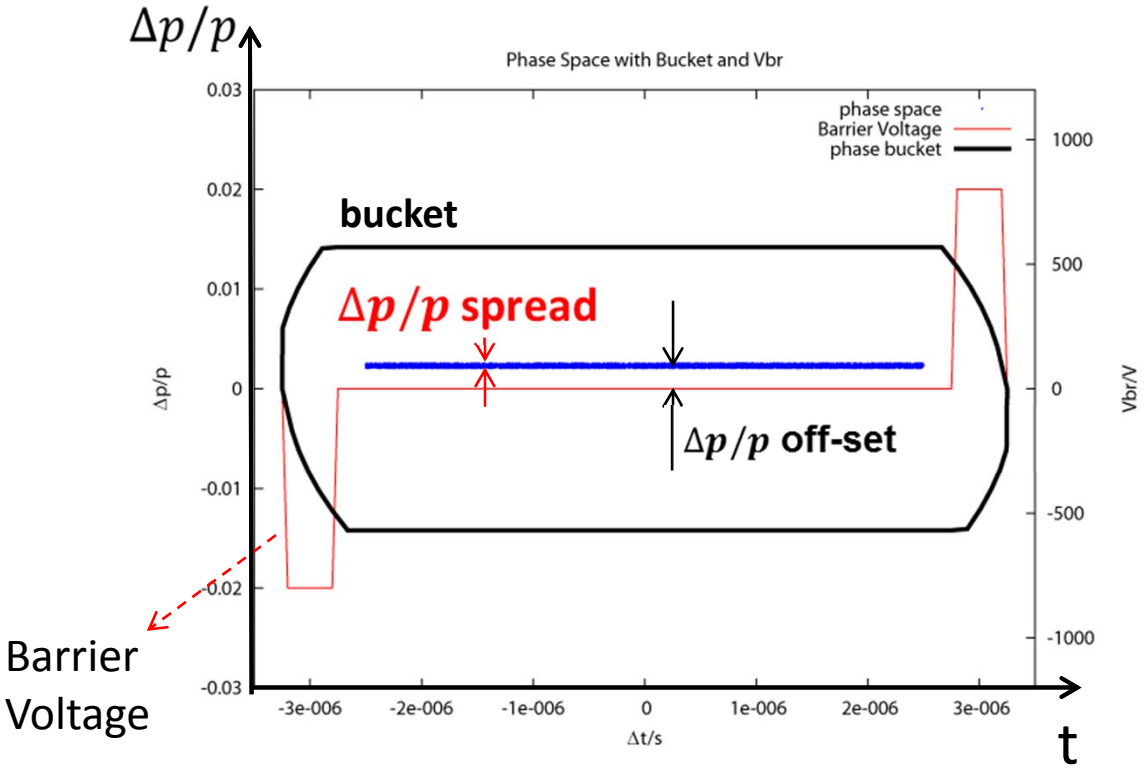
Stop squeezing at 7ms

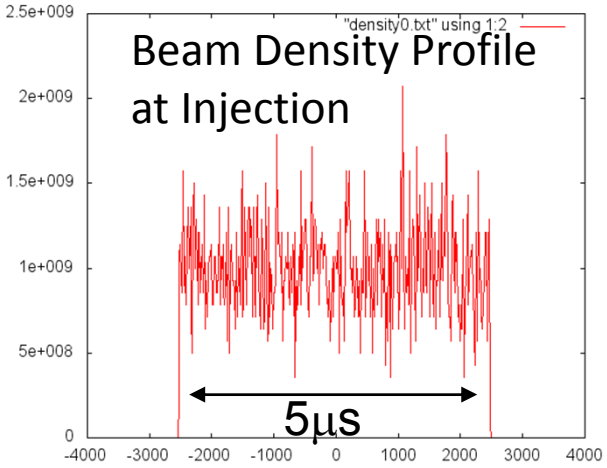
Projected

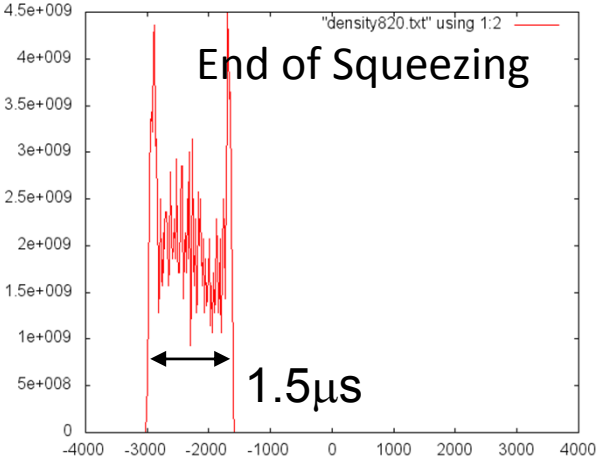
Projected



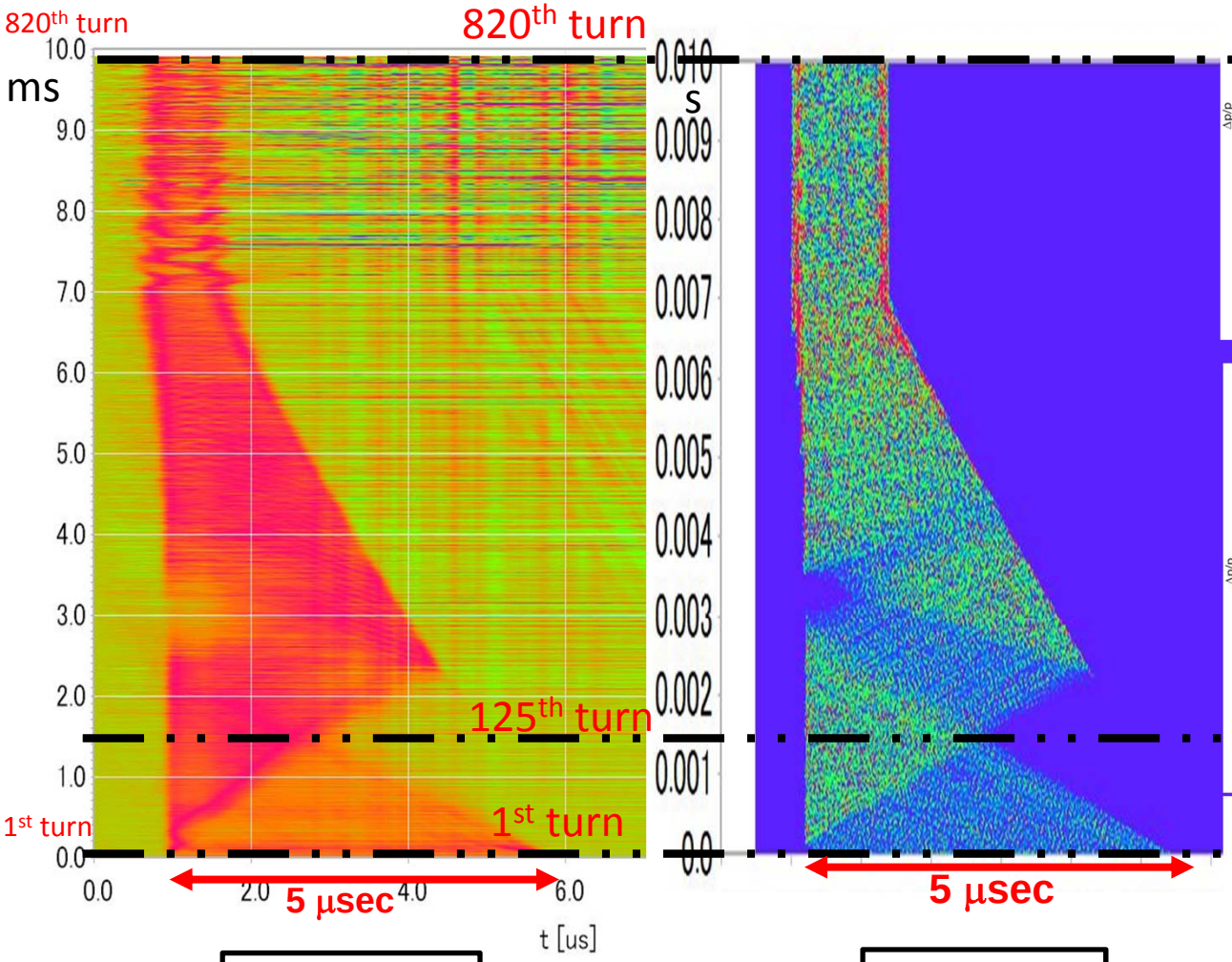
Simulated Phase Space Motion of Squeezing Experiment



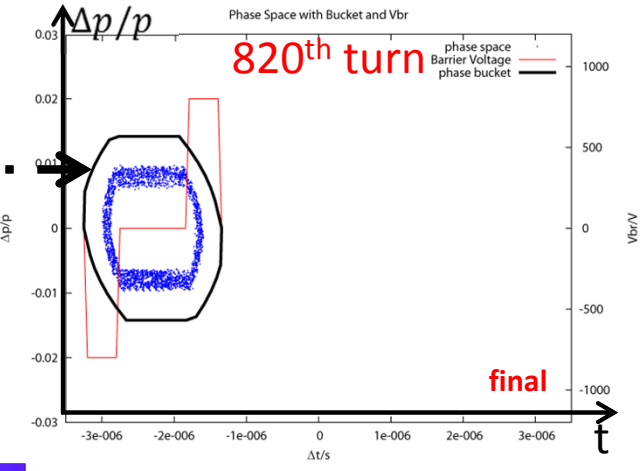


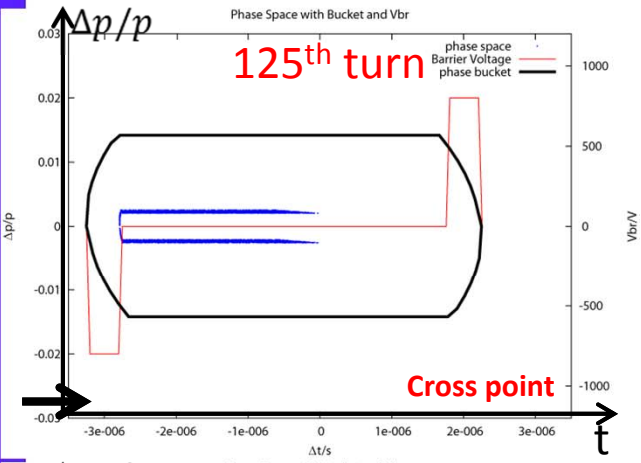


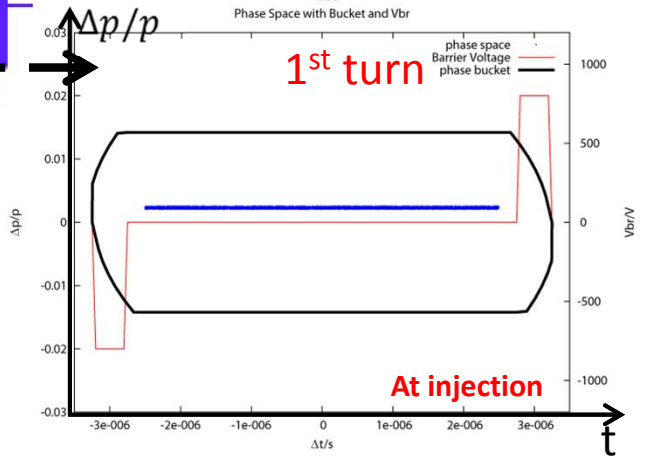
Comparison: Experiment VS. Simulation



Experiment **Simulation**







- momentum spread=0.025%
- off-set=0.23%

} estimated from Experiment

Replace DSP by FPGA (Next Generation)

L

Induction Acceleration Cell

Beam monitor

V(t)

Beam

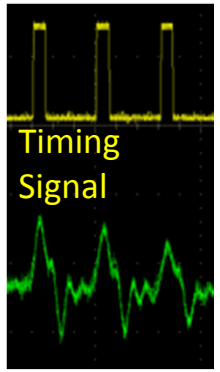
Matching resistance

ECRIS

ΔR monitor

Chop timing signal

Amp. & Front End Processing

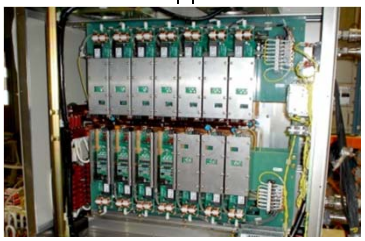


Beam bunch signal

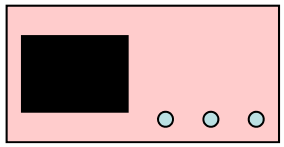
CCR(Central Control Room)

ΔR signal

Beam timing Signal



1MHz switching power supply



Oscilloscope for Monitoring induction output voltage

PC for FPGA control

JTAG

Optical fiber

Optical Converter module

Signal divider (for intermittent Operation)

FPGA

Less overhead, much compact than present DSP system

Xilinx Vertex5

300MHz

ADC

Analog Devices

400MHz

Induction Acceleration In minimum B fields

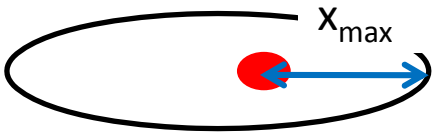
Sweep distance in the horizontal direction:

$$x = D(s)\cdot\frac{\Delta p}{p} \qquad (1)$$

where

$D(s)_{\max} = 1.4$ m

$x_{\max} = 4$ cm



Allowed maximum momentum spread:

$$\left(\frac{\Delta p}{p}\right)_{\max} = \frac{4}{140} = 2.8\times10^{-2}$$

Preliminary

Meanwhile,

$$\frac{\Delta p}{p} \equiv \frac{1}{\beta^2}\cdot\frac{\Delta E}{E} \qquad (2)$$

where

$$\frac{1}{2}A\cdot m\cdot(c\beta)^2 = Q\cdot e\cdot V_0$$

$$\beta^2 = \frac{2\cdot Q\cdot eV_0}{A\cdot mc^2} = \frac{2\times1\times200[\text{keV}]}{4\times931\times10^3[\text{keV}]} = 1.07\times10^{-4}$$

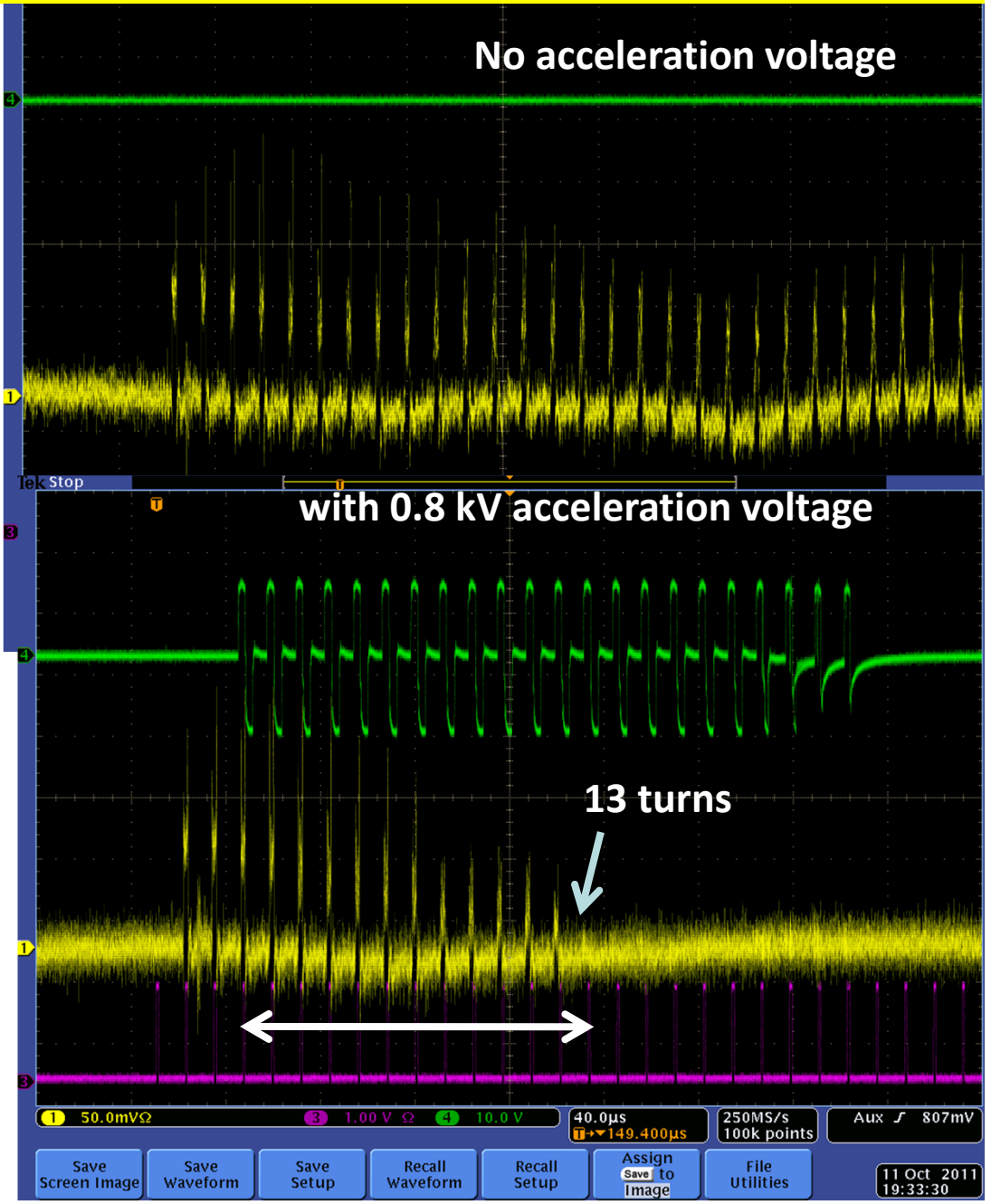
$$E = A\cdot mc^2 + Q\cdot eV_0 = (4\times931+0.2)\times10^3[\text{keV}]$$

$$= 3.724\times10^6[\text{keV}]$$

$$\Delta E = Q\cdot eV_{acc}\cdot N(turn) = 1\times0.8N[\text{keV}]$$

$$\frac{\Delta p}{p} = \frac{0.8N}{1.07\times10^{-4}\times3.724\times10^6} = 2\times10^{-3}N \quad (3)$$

$$N = \frac{2.8\times10^{-2}}{2\times10^{-3}} = 14 \text{ turn}$$



Ion Beam expected at KEK-DA

2010-2012 B_{max}=0.84T, 10Hz operation、200kV injection

Species	Z	Q	Energy MeV/u	PPP	PPS (10Hz)
He	4	2+	88.0	2.1×10^{10}	2.1×10^{11}
O	16	6+	50.4	7.0×10^{10}	7.0×10^{11}
Ne	20	6+	32.6	7.0×10^{10}	7.0×10^{11}
Ar	40	8+	14.6	5.3×10^{9}	5.3×10^{10}

2012-（Magnet upgrade, install Laser Ablation Ion Source）

B_{max}= 1.1T, 10Hz operation、200kV injection

Species	Z	Q	Energy MeV/u	PPP	PPS (10Hz)
He	4	2+	146.8	1.8×10^{10}	1.8×10^{11}
^{3}He	3	2+	248.5	1.75×10^{10}	1.75×10^{11}
C	12	6+	146.8	5.8×10^{9}	5.8×10^{11}
Ar	40	8+	120.5	1.9×10^{9}	1.9×10^{10}
Fe	56	26+	127.8	1.3×10^{9}	1.3×10^{10}
Au	197	79+	96.8	4.4×10^{8}	4.4×10^{9}

Summary

- KEK-DA started beam commissioning from June 2011
- Fortunately damage from earthquake was very limited
- 10～20μA of He^{1+}beam is provided from ECRIS
- Barrier trapping, bunch squeezing, acceleration experiments are going on

Next Plan

- Accelerate & Extract Helium beam including He^{2+}
- Accelerate N, O, Ne, Ar, etc.
- Build a new application line

T. Iwashita et. al, "KEK digital accelerator"
Physical Review Special Topics - Accelerators and Beams, July 2011 Vol.14, Issue 7

T.Adachi et. al,. ‘‘A Solid-state Marx Generator driven Einzel lens Chopper’’,
Review of Scientific Instruments 82, 083305 (2011)