KEK Digital Accelerator and Its Beam Commissioning

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on behalf of

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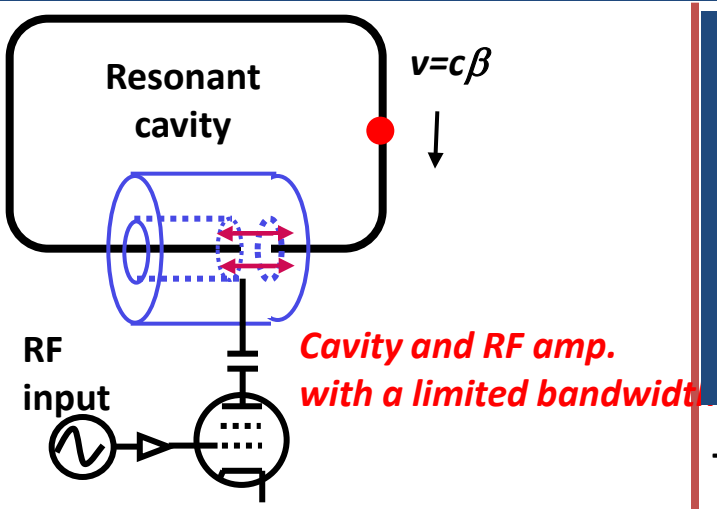
IPAC 2011

Outline of Talk

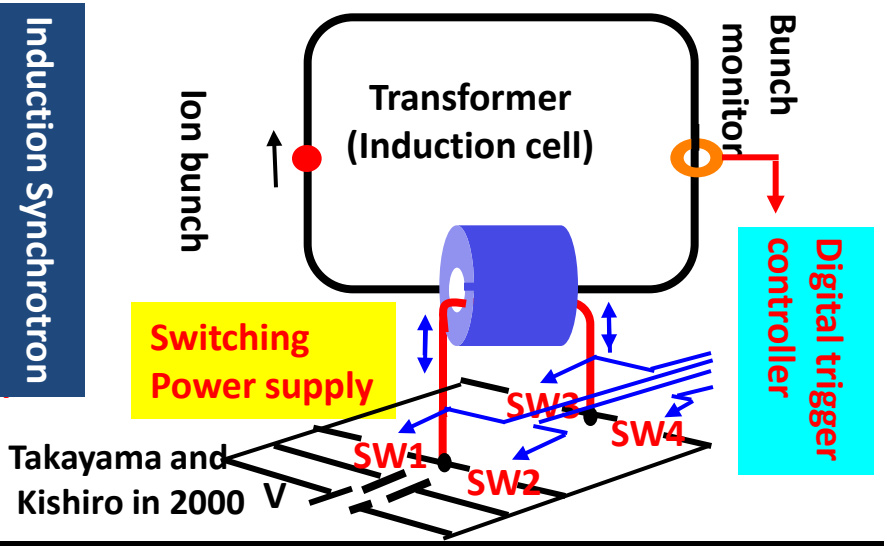
1. Principle of induction Synchrotron
2. Outline of KEK Digital Accelerator
   - 2-1 ECRIS
   - 2-2 Longitudinal chopper
   - 2-3 LEBT and Electrostatic injection kicker
   - 2-4 Ring lattice
   - 2-5 Induction acceleration system
3. Beam Commissioning
   - 3-1 Injection optics
   - 3-2 Barrier bucket capture
   - 3-3 Bunch squeezing experiment
   - 3-4 Acceleration scenario
4. Expected Applications and Summary

Characteristics of Induction Synchrotron

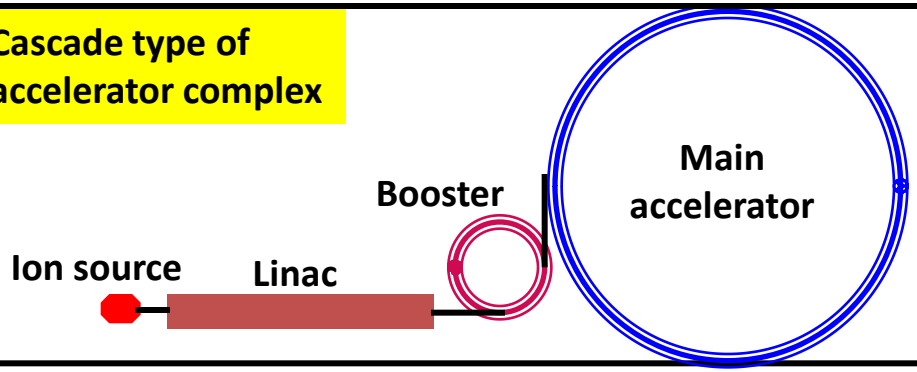
RF Synchrotron



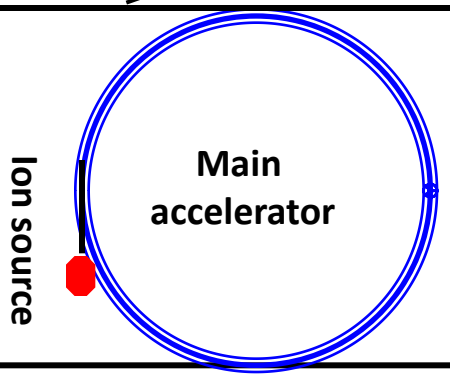
Induction Synchrotron



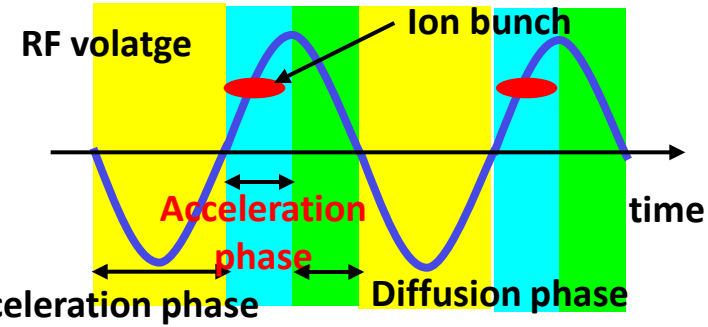
Cascade type of accelerator complex



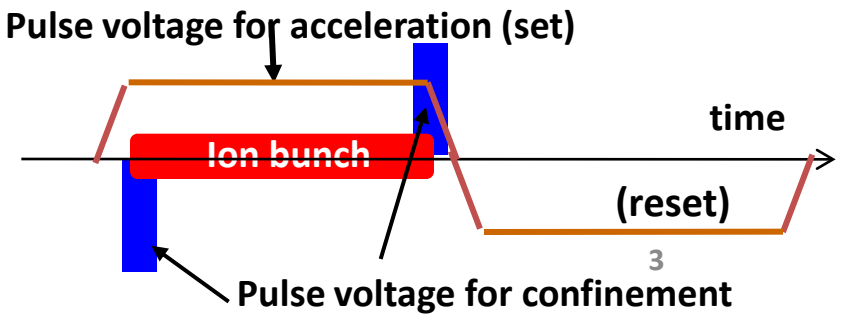
Single stage accelerator



Functionally combined acceleration/confinement -> increase in the local density -> limit on a beam current

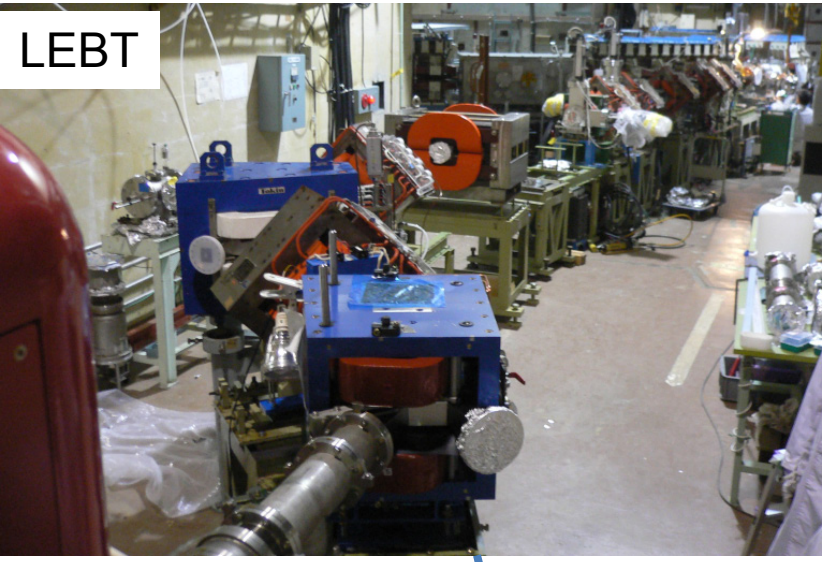


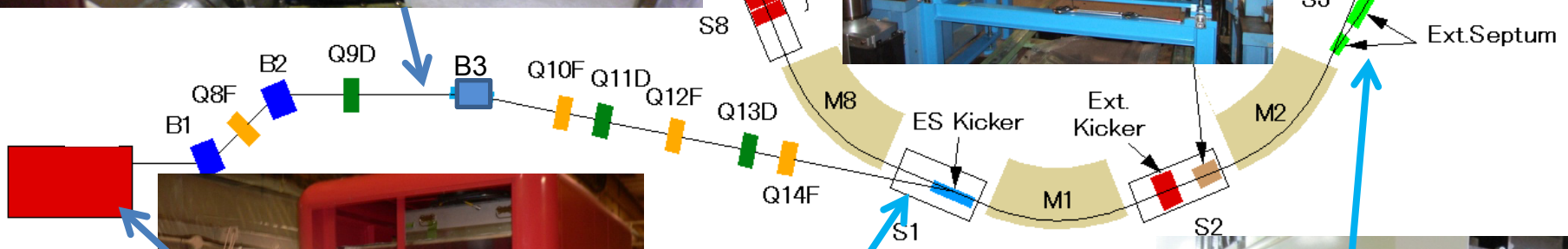
Functionally separated acceleration/confinement -> increasing a freedom of beam handling

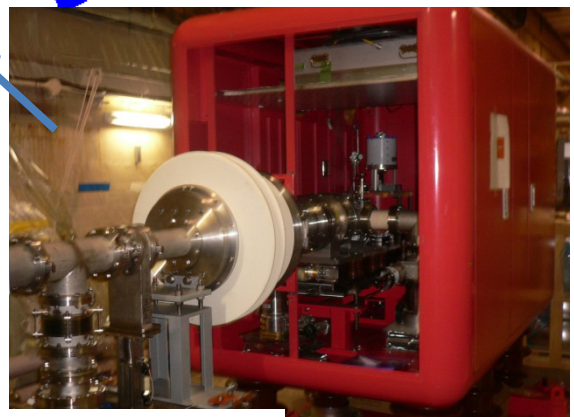


KEK Digital Accelerator

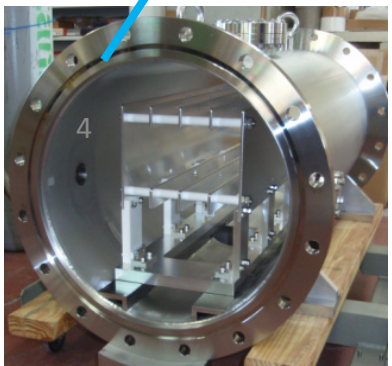
T. Iwashita *et al.*, *"KEK Digital Accelerator"*
Phys. Rev. ST-AB 14, 071301 (2011).

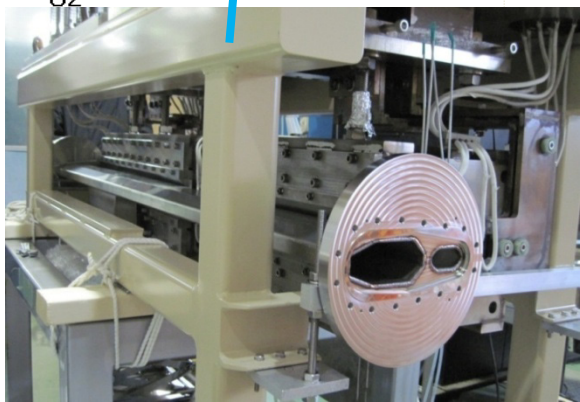




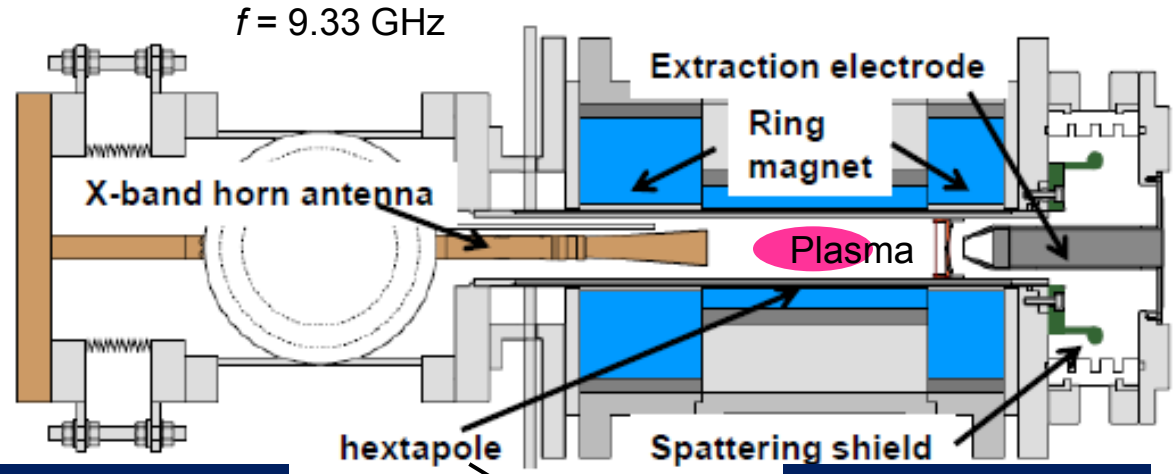


ECRIS & HVT



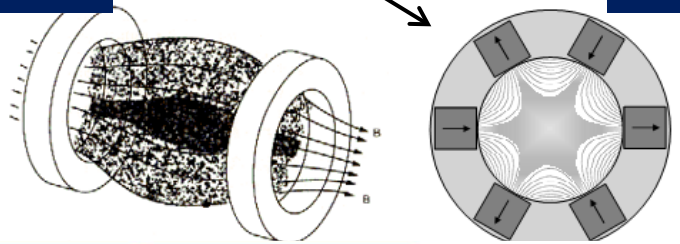


ECR Ion Source : Schematic and Output



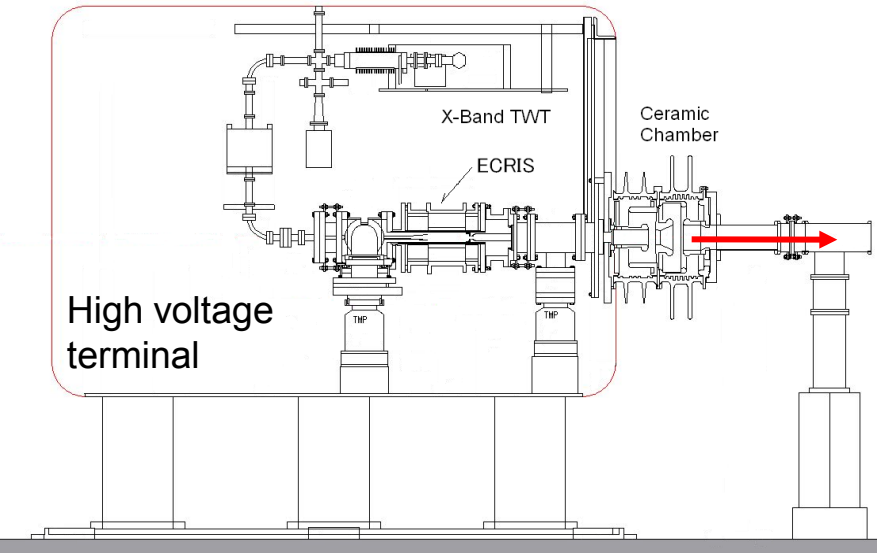
Mirror fields

Hexapole fields



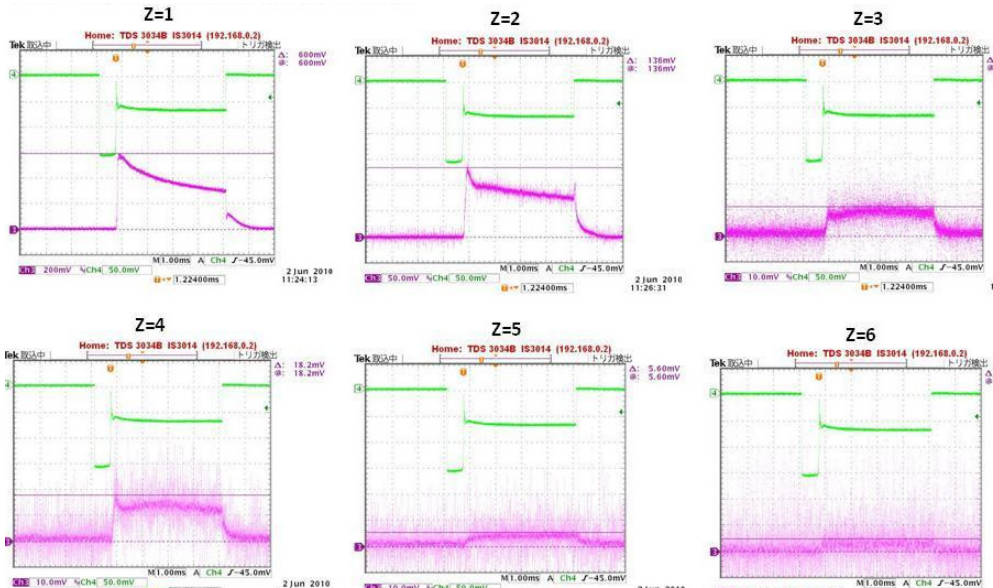
Properties:
Permanent magnets
10 Hz pulse mode operation

No power for guiding magnets
No cooling water



He^{2+}, N^{x+}, O^{5+}, Ne^{5+}, Ar^{5+} at early stage

Ne Ion Pulse



Einzel Lens Longitudinal Chopper (1): Idea and Device

Why we need a Chopper?

1 turn injection < 10 μsec

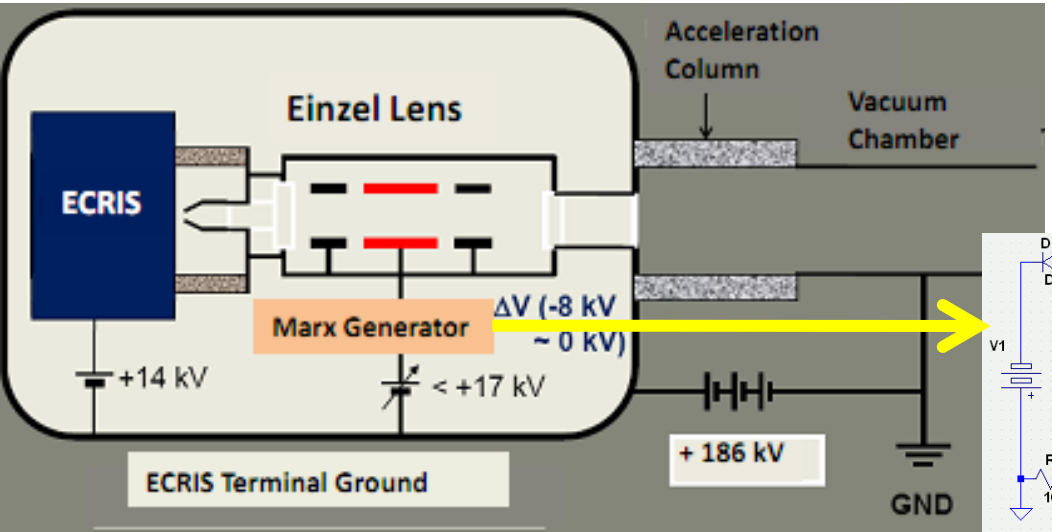
A long pulse from ECRIS ~ 2 - 5 msec

What type is desired?

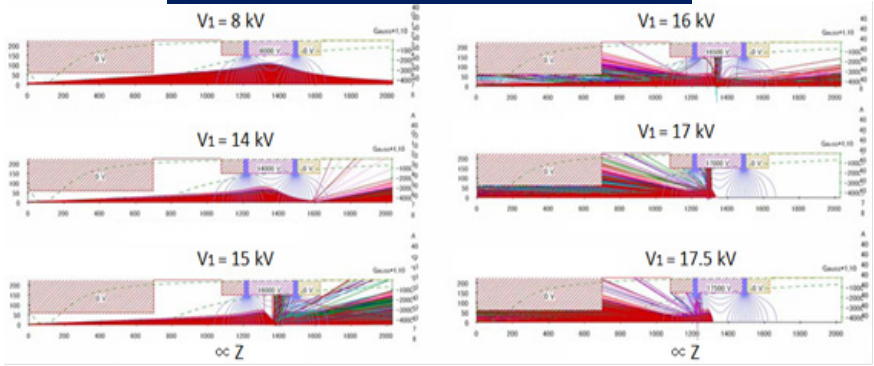
Low energy operation
Low cost

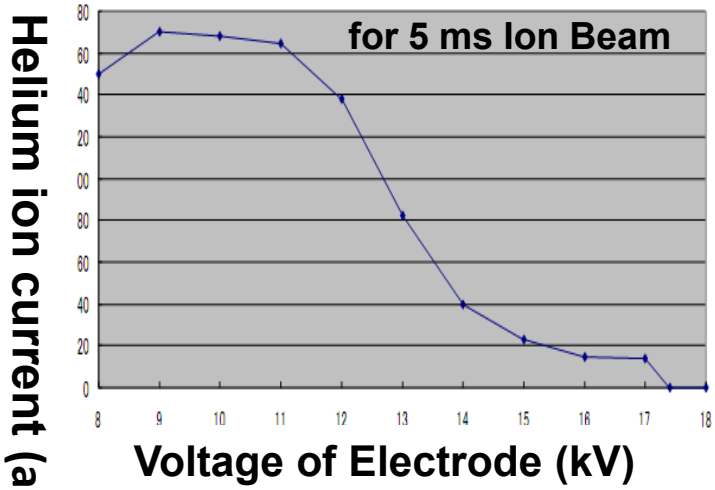
→ Low energy x-ray
Reduced out-gassing
Reduced secondary e⁻

Einzel lens longitudinal chopper

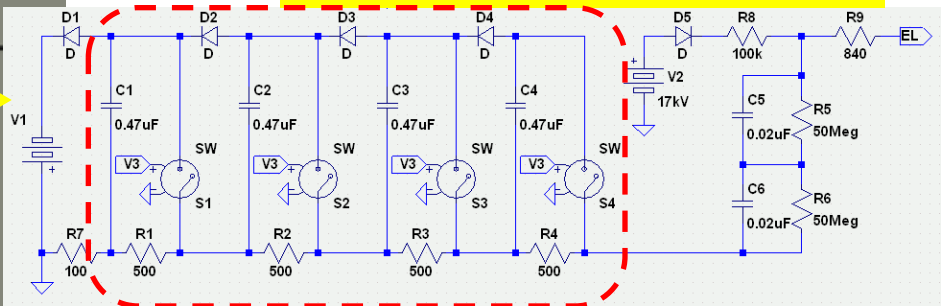


Longitudinal gate study



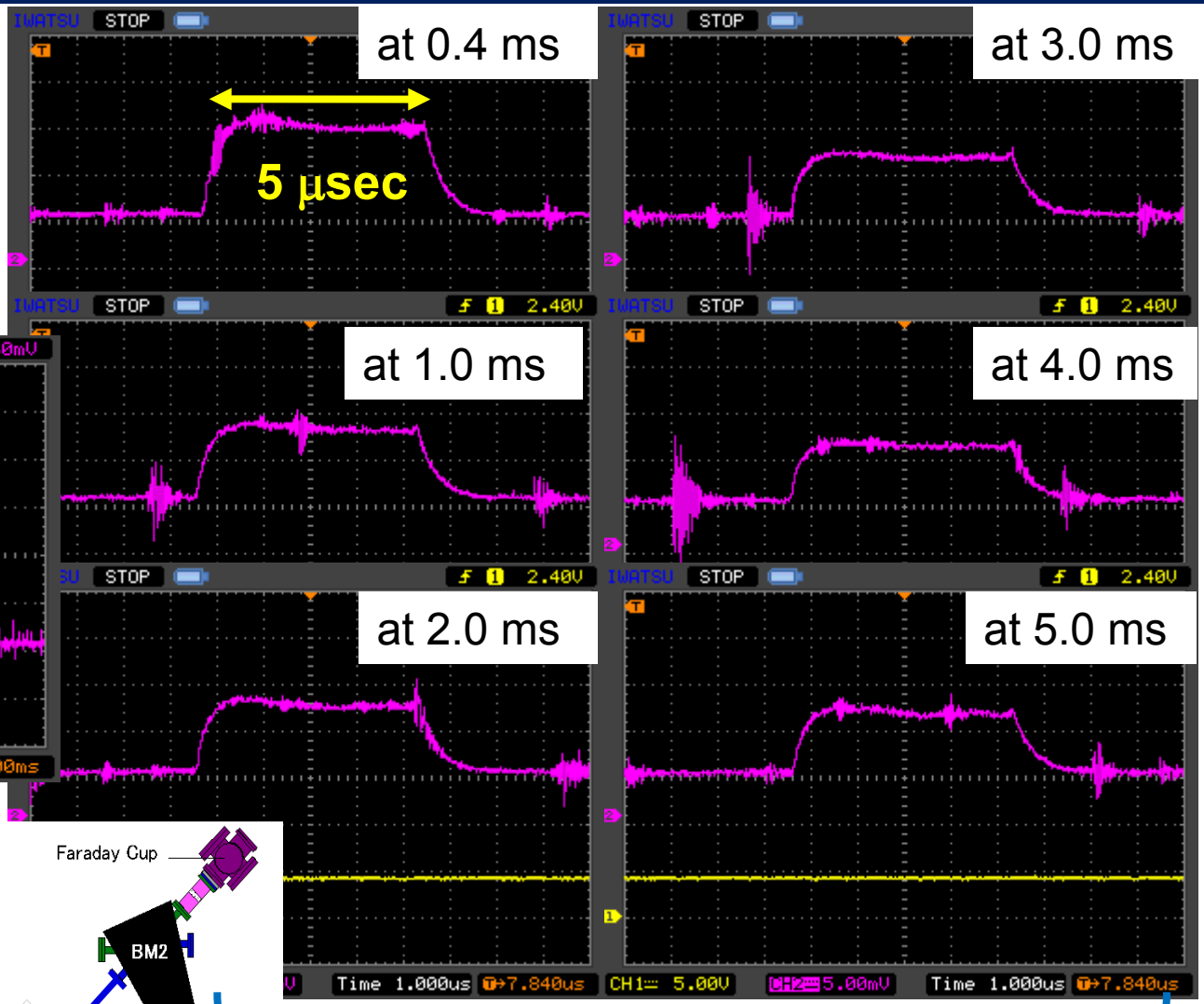


FET switch driven 4 stages Marx generator

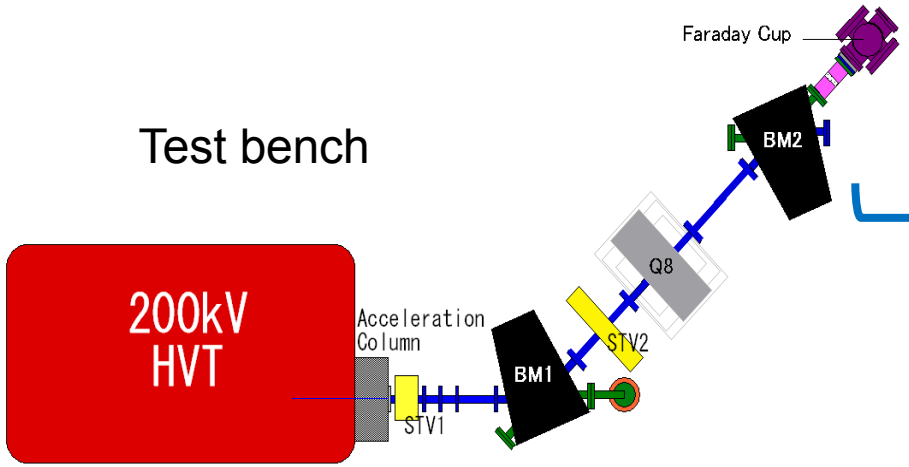


Einzel Lens Longitudinal Chopper (2): Chopping experiment

He1+ beam from ECRIS



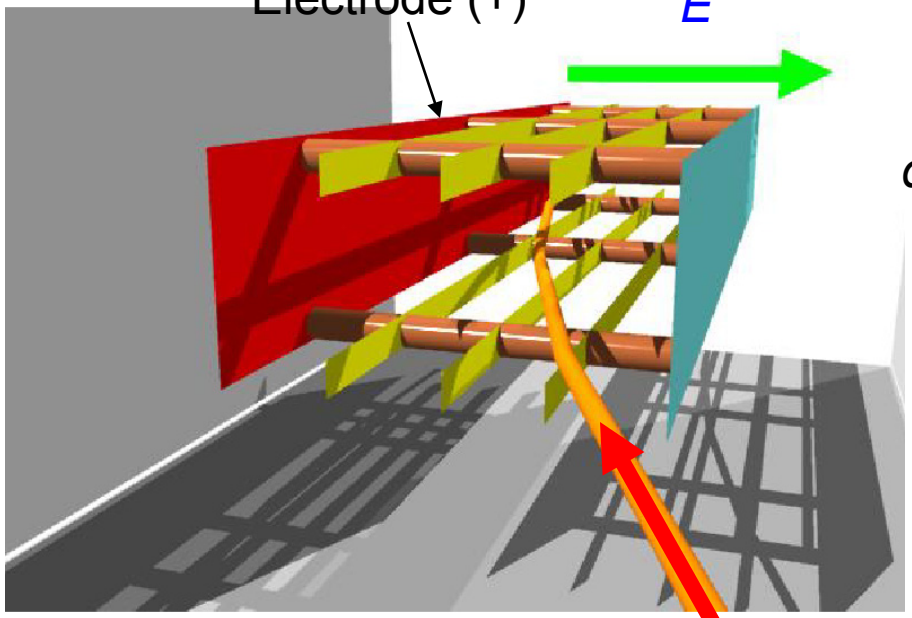
Test bench

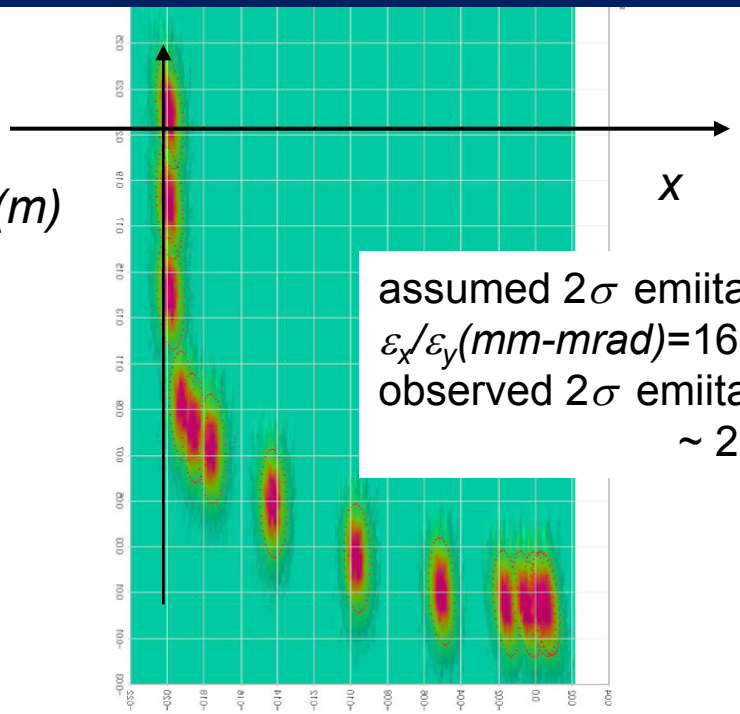


He1+ pulses chopped at different timing

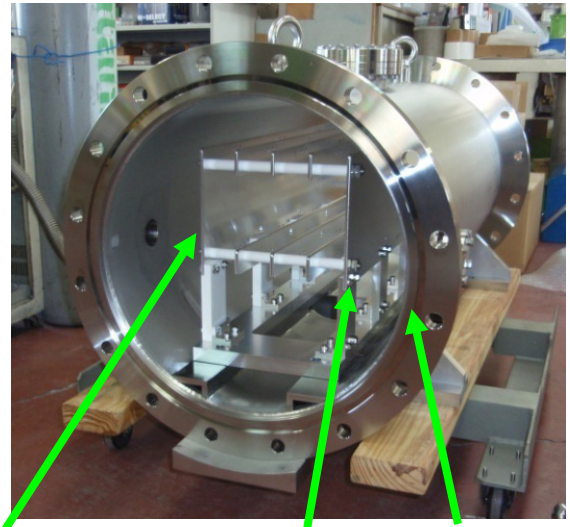
T.Adachi *et al.*, *Rev. Sci. Inst.* **82**, 083305 (2011)
and in this conference, TUPC096

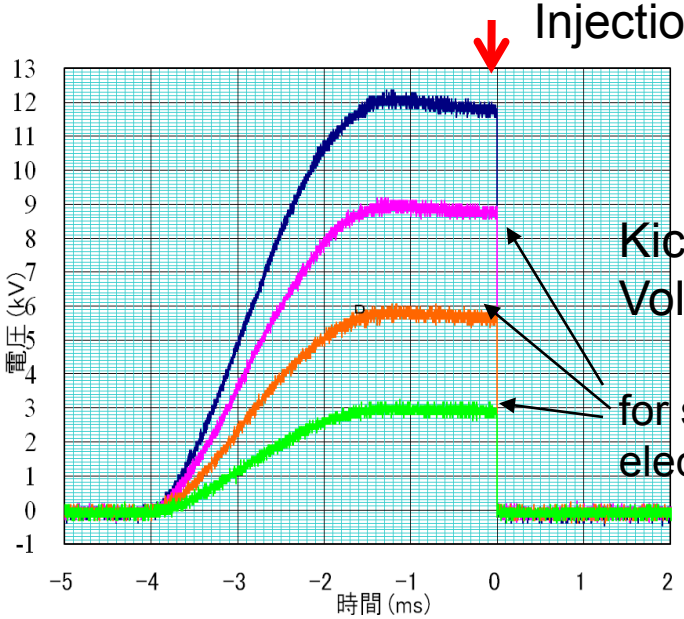
Electrostatic Injection Kicker





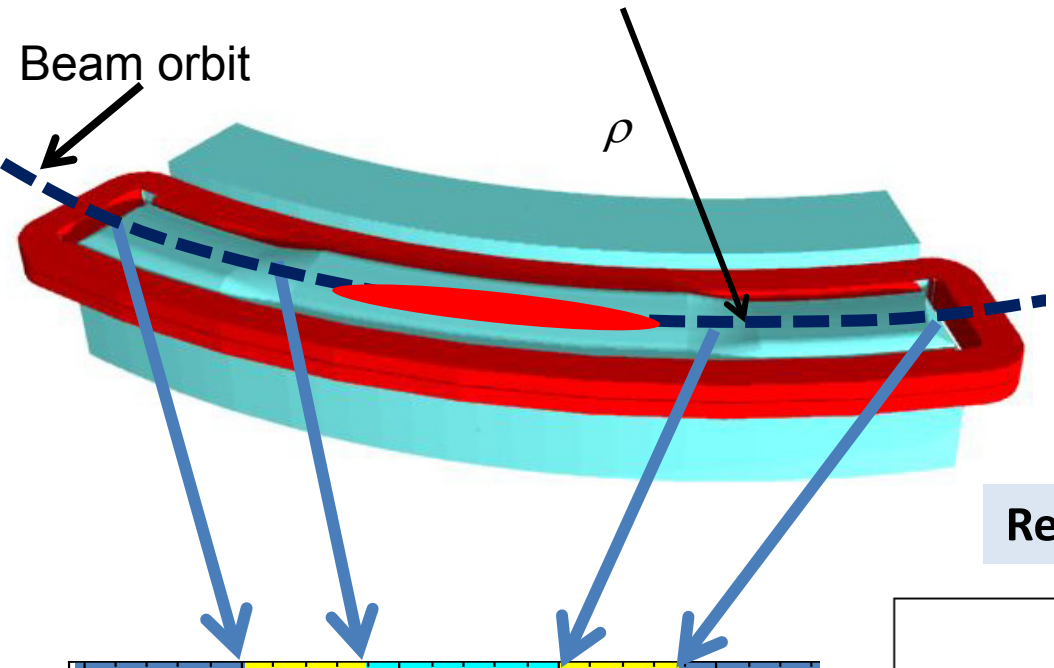
assumed 2σ emiitance:
$\varepsilon_x/\varepsilon_y$(mm-mrad)=165/32
observed 2σ emiitance:
~ 25

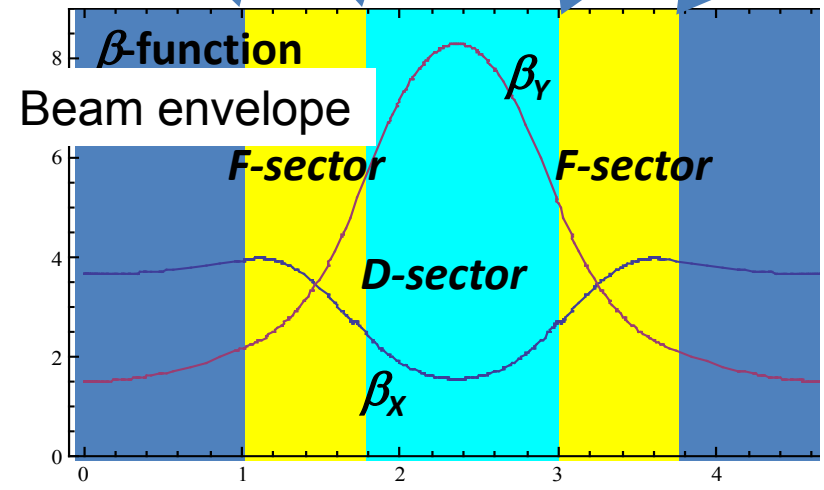




DA Ring Machine & Beam Parameters

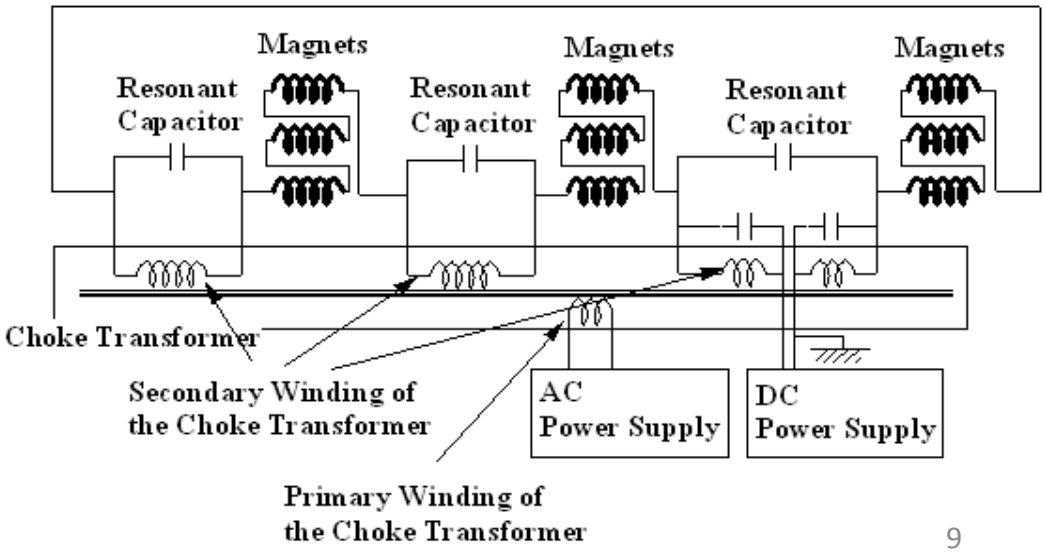
Combined-function type magnet (lower half)



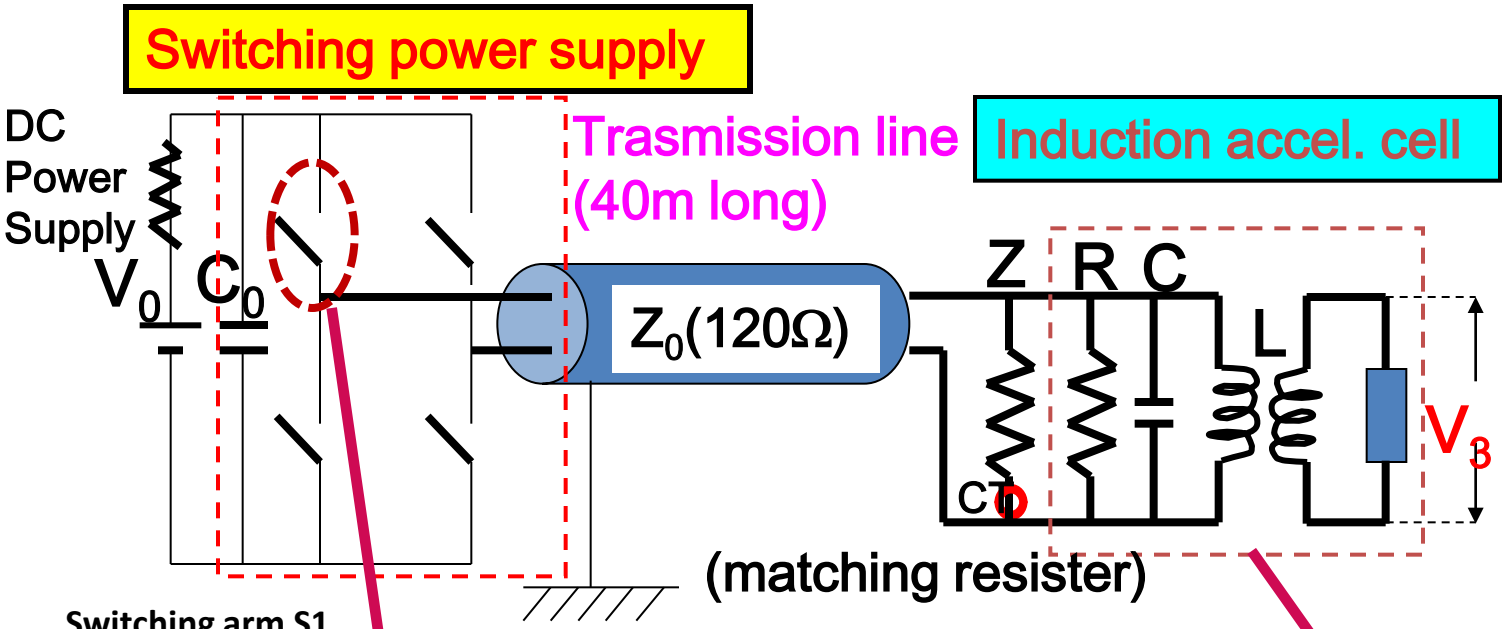


Bending radius	ρ	**3.3 m**
Ring circumference	C_0	**37.7 m**
Maximum flux density	B_{max}	**0.84 T (1.1 T)**
Accele. voltage/turn	V	**3.24 kV**
Repetition rate	f	**10 Hz**
Betatron tune	ν_x/ν_y	**2.1/2.3**

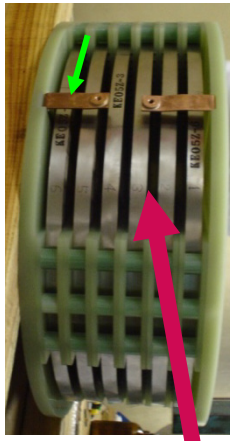
Resonant LCR Circuit Power Supply



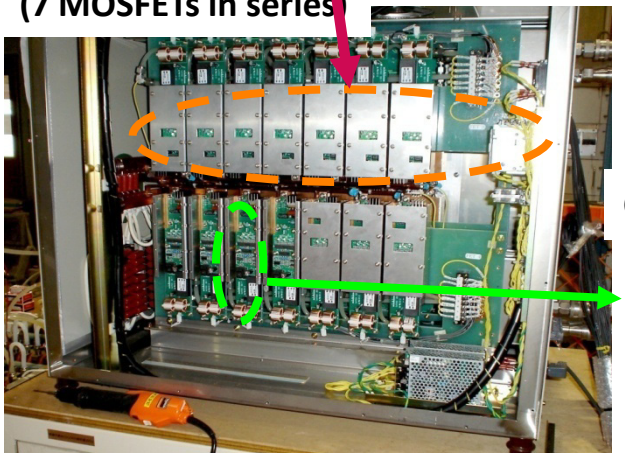
Equivalent Circuit of Induction Acceleration System and Individual Instruments



Primary loop



Switching arm S1
(7 MOSFETs in series)

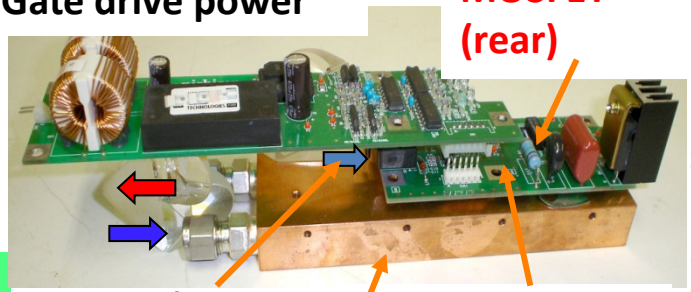


2.5kV, 20A, 1MHz, 500nsec

Development by KEK・Nichicon

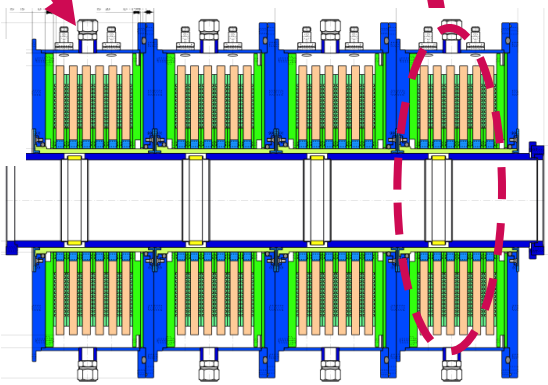
MOSFET board

Gate drive power



Cupper heat sink

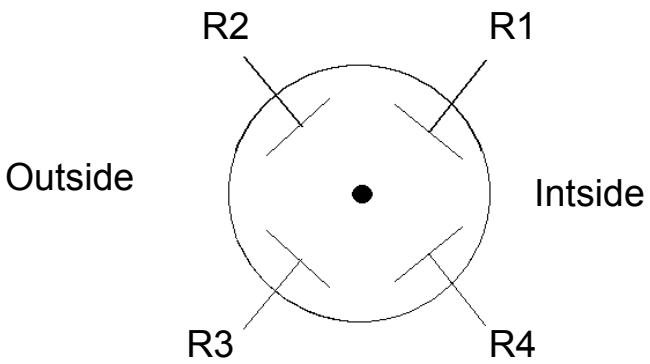
Finemet (nano-structure crystalline, Hitachi Metal)



Stacked induction cells
(output : 2 kV/cell)

Beam Commissioning (1): Injection Optics

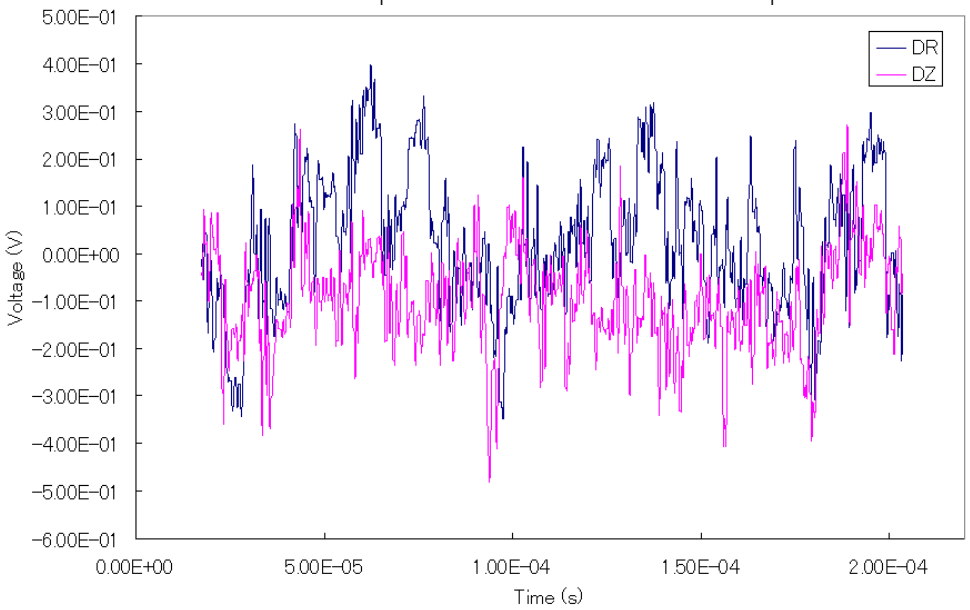
ES Position Monitor



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

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

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



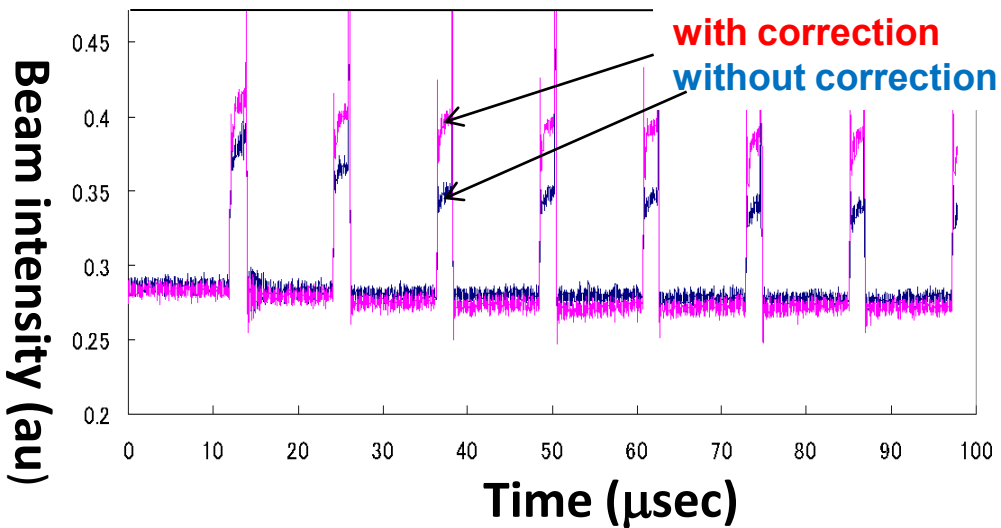
FFT analysis

Betatron tunes

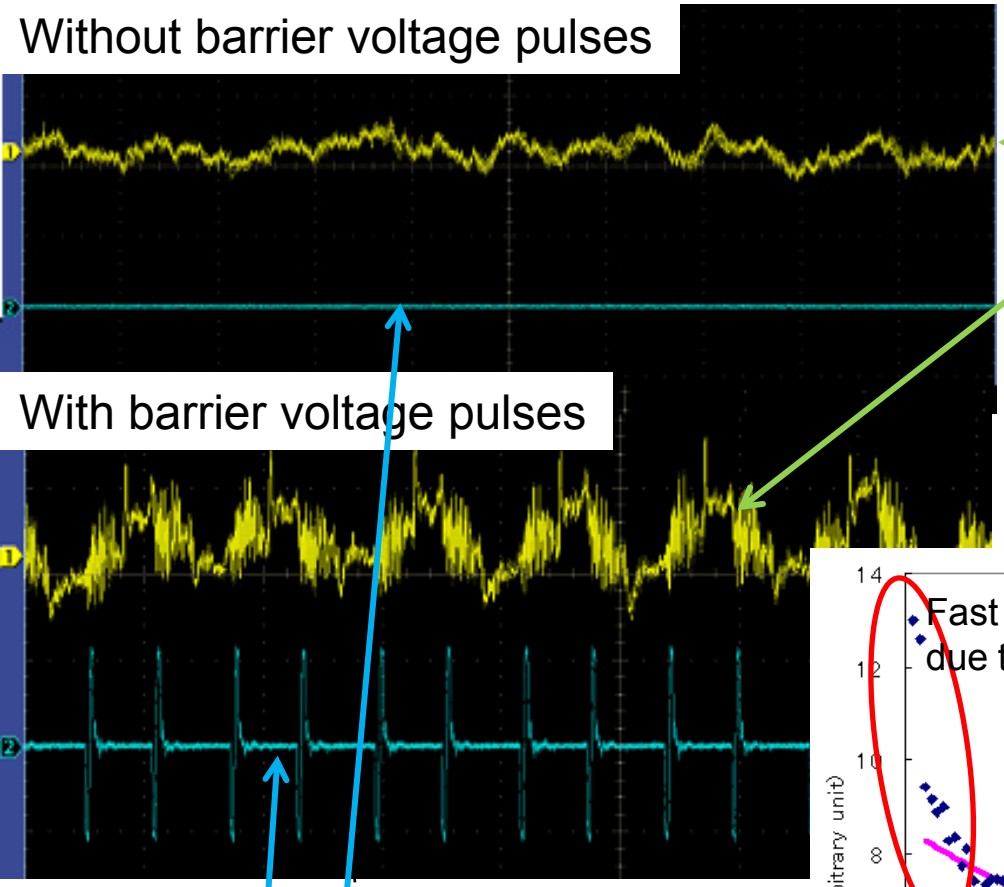
Q_x=2.19 (design 2.17)

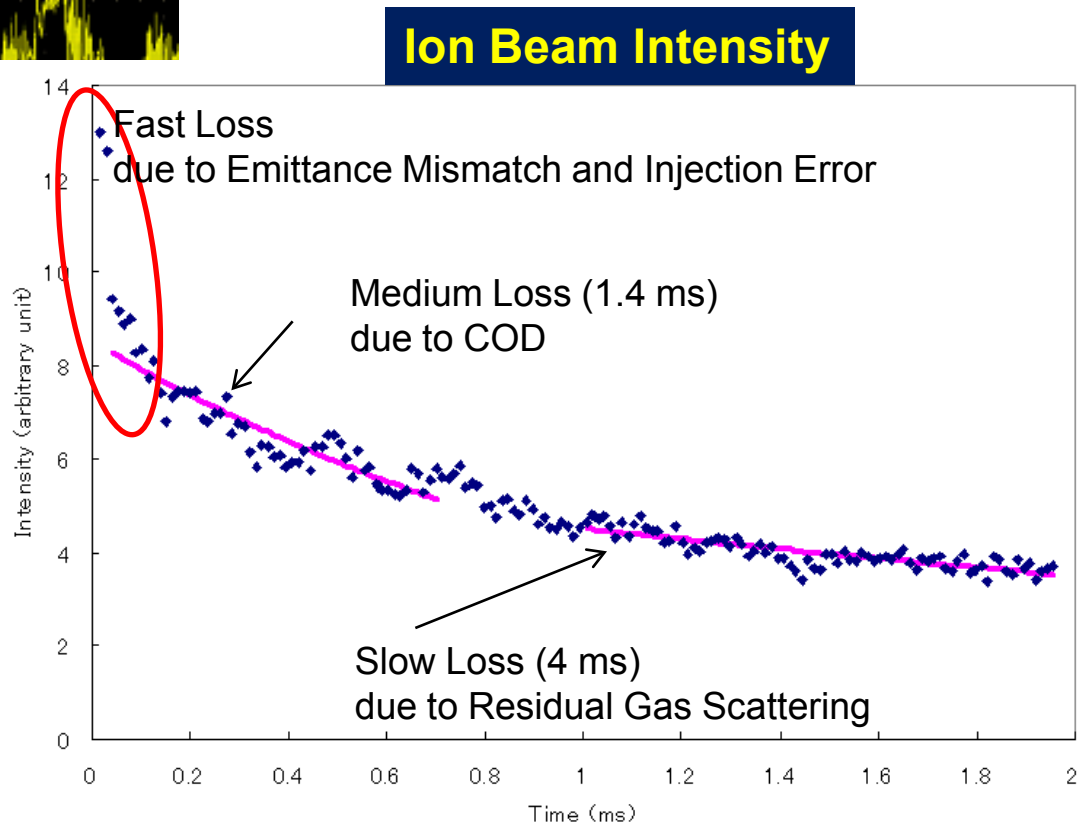
Q_y=2.30 (design 2.30)

After injection error correction

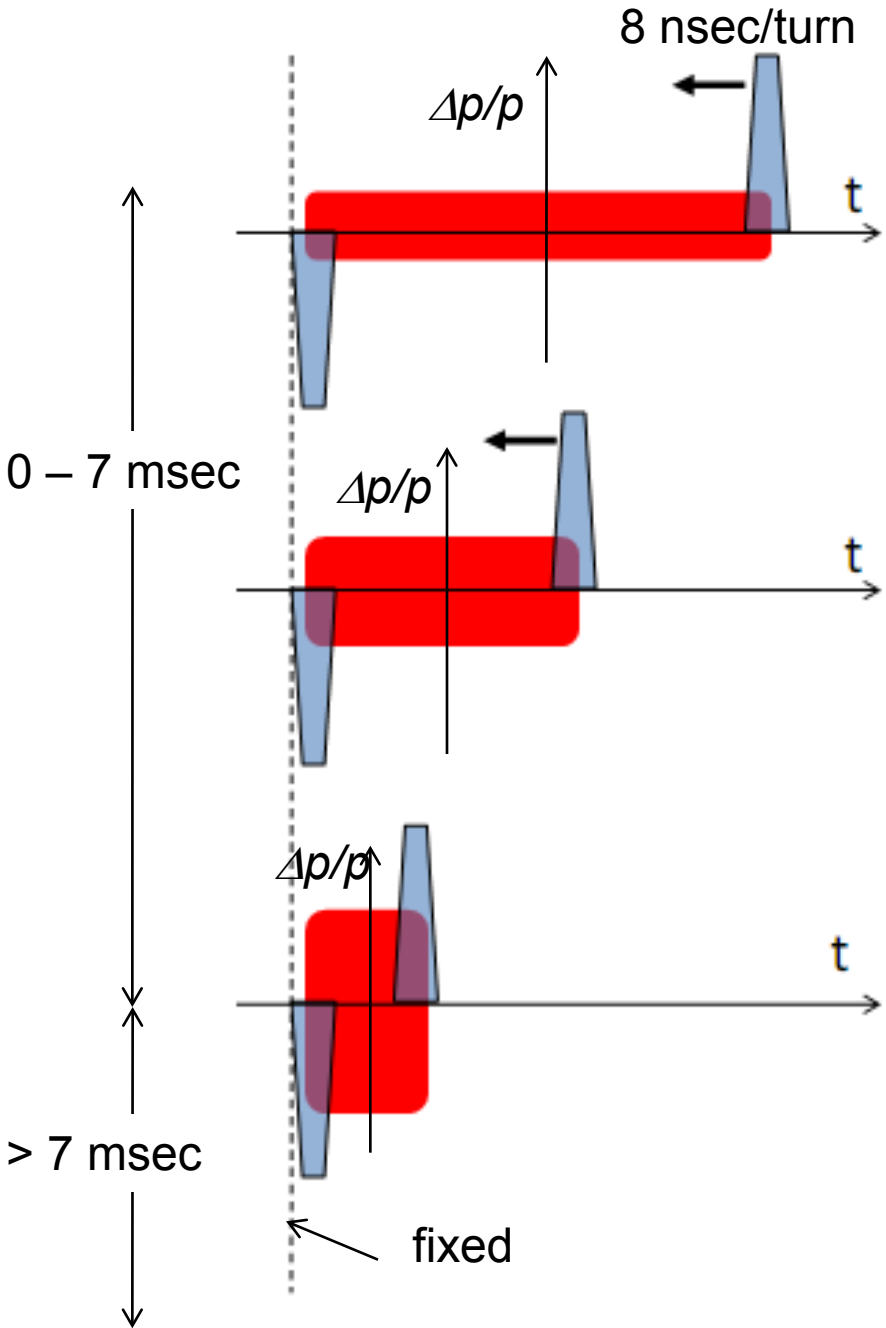


Beam Commissioning (2): Barrier Bucket Trapping and Life-time

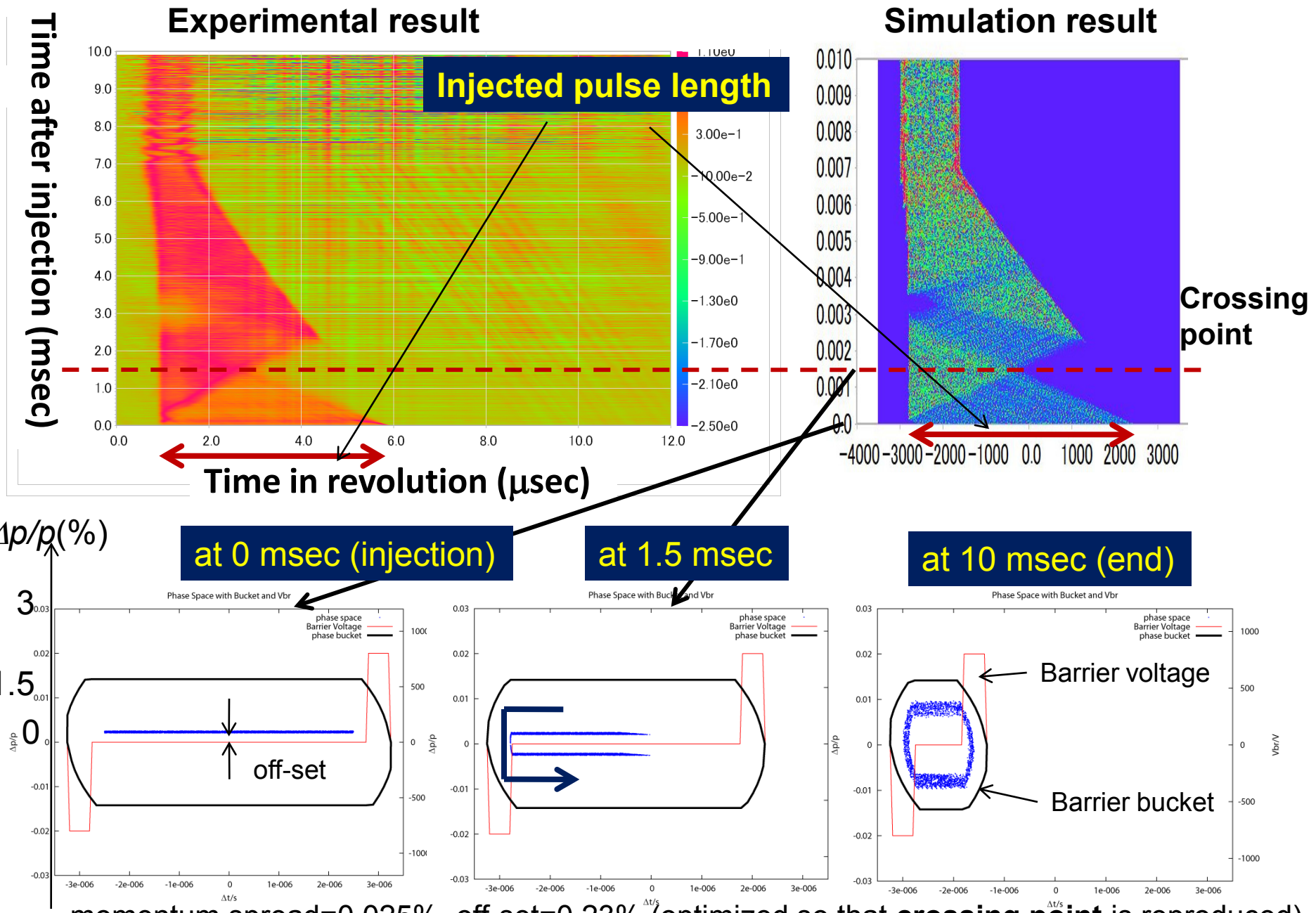




Beam Commissioning (3): Bunch Squeezing Experiment



Beam Commissioning (4): Mountain View of longitudinal distribution



momentum spread=0.025%, off-set=0.23% (optimized so that **crossing point** is reproduced)

Induction Acceleration Scenario

Technical Capability of Induction Acceleration Cell

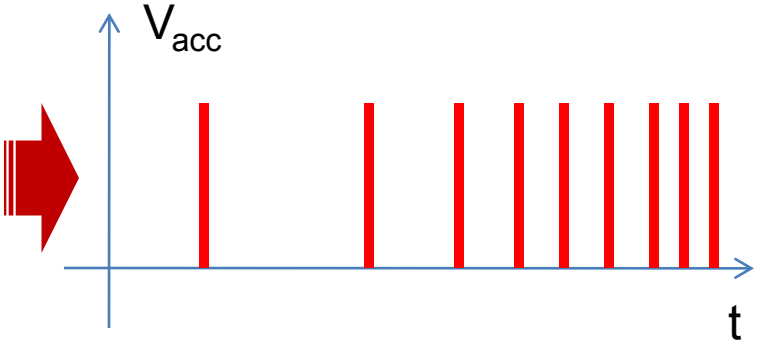
Fixed output voltage ~ 1 - 2 kV/cell

Maximum pulse length ~ 0.5 - 2 μsec/pulse

Maximum rep-rate ~ 1 MHz

(If magnet ramping is slow)

1) Pulse density control



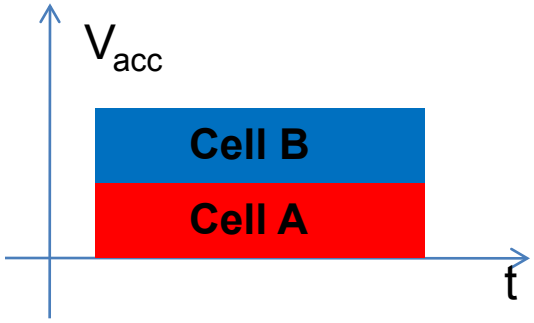
When requirement exceeds its capability,

(If larger acceleration voltage is required)

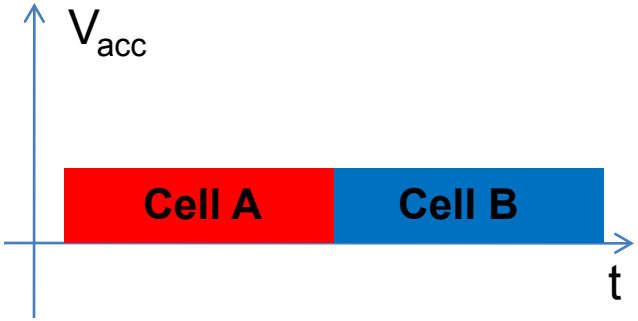
(If longer pulse width is required)

(If higher rep-rate is required)

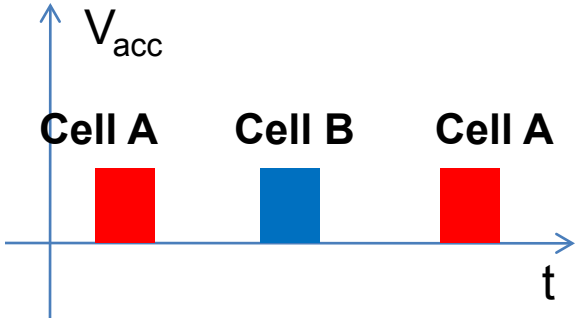
2) Superimpose of pulses in time



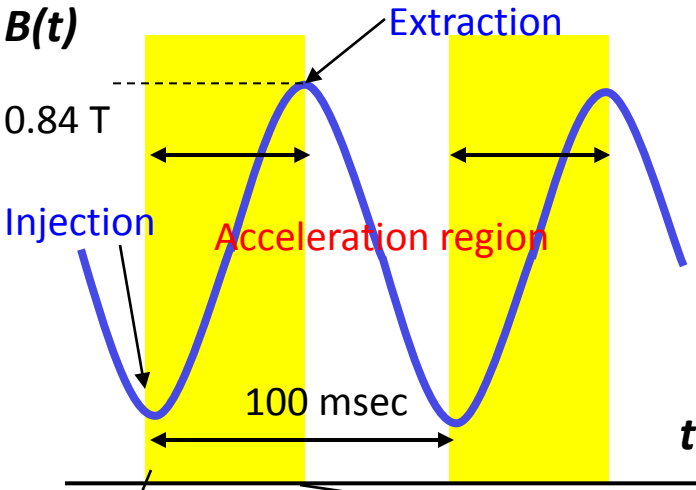
3) Sequential trigger in time

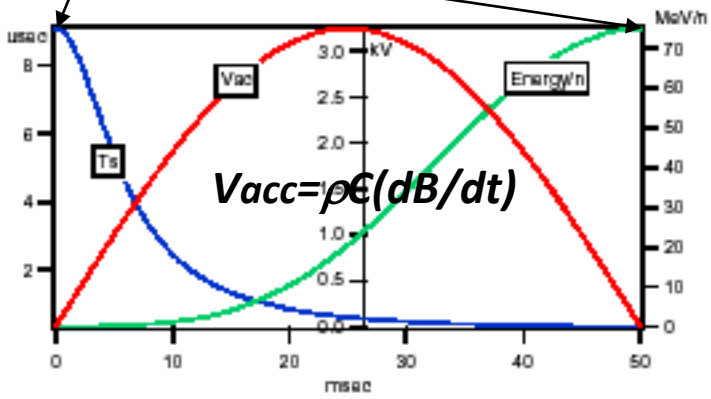


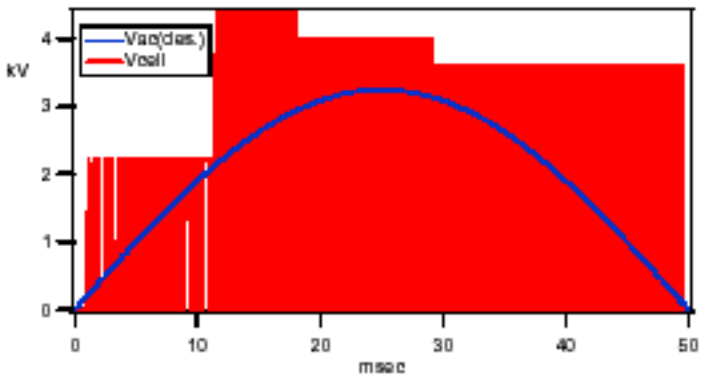
4) Intermittent operation



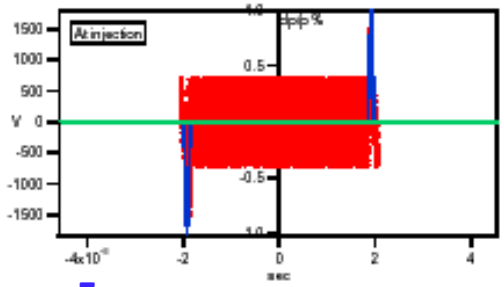
Scenario of induction acceleration/capture of He2+ and C6+



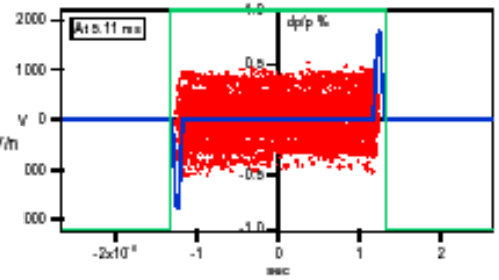




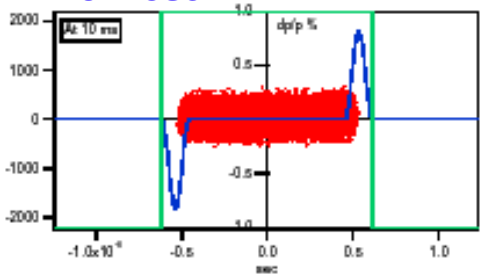
near Injection



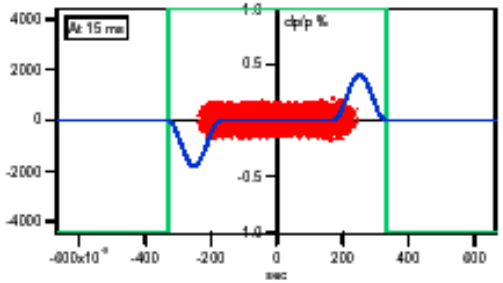
5 msec



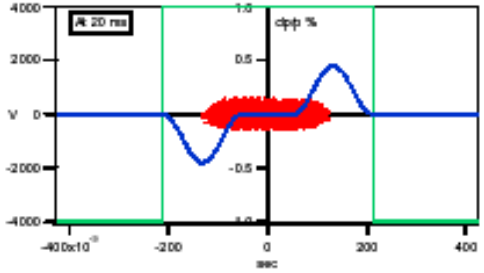
10 msec



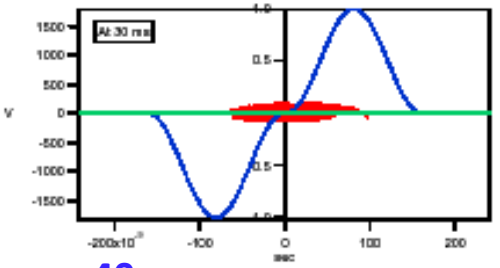
15 msec



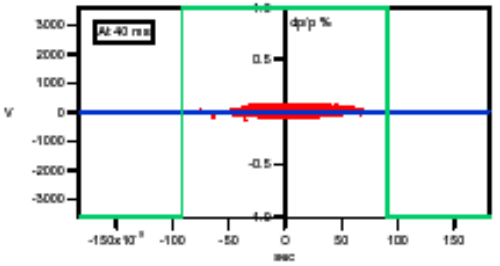
20 msec



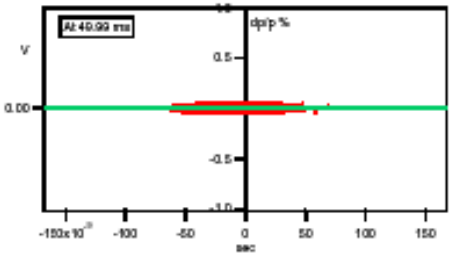
30 msec



40 msec



50 msec



Summary and Next Step

Key devices newly developed for the KEK-DA have been confirmed to work in the desired manner.

- **Permanent magnet ECRIS operated in the pulse mode.**
- **Einzel lens longitudinal chopper was demonstrated for the first time.**
- **Electrostatic injection kicker worked with sufficient performance.**
- **Induction acceleration system operated in the rapid cycle synchrotron mode**

Beam commissioning started in early June.

- **Basic machine properties such as Tune, COD, or Injection errors have been evaluated.**
- **Barrier bucket beam handling has been examined.**
- **Induction acceleration study will be started after summer shutdown.**
  (Test acceleration was officially approved in the mid-July.)

Next step: Heavy ion beams from the KEK-DA will be delivered to Applications "Laboratory Space Science using Virtual Cosmic Rays" from this winter.

■**Astrobiology:** manifest a role of cosmic ray on production of life in space

■**Space Electronics**: study on cosmic ray damages on LSI devices for deep solar-system explore missions

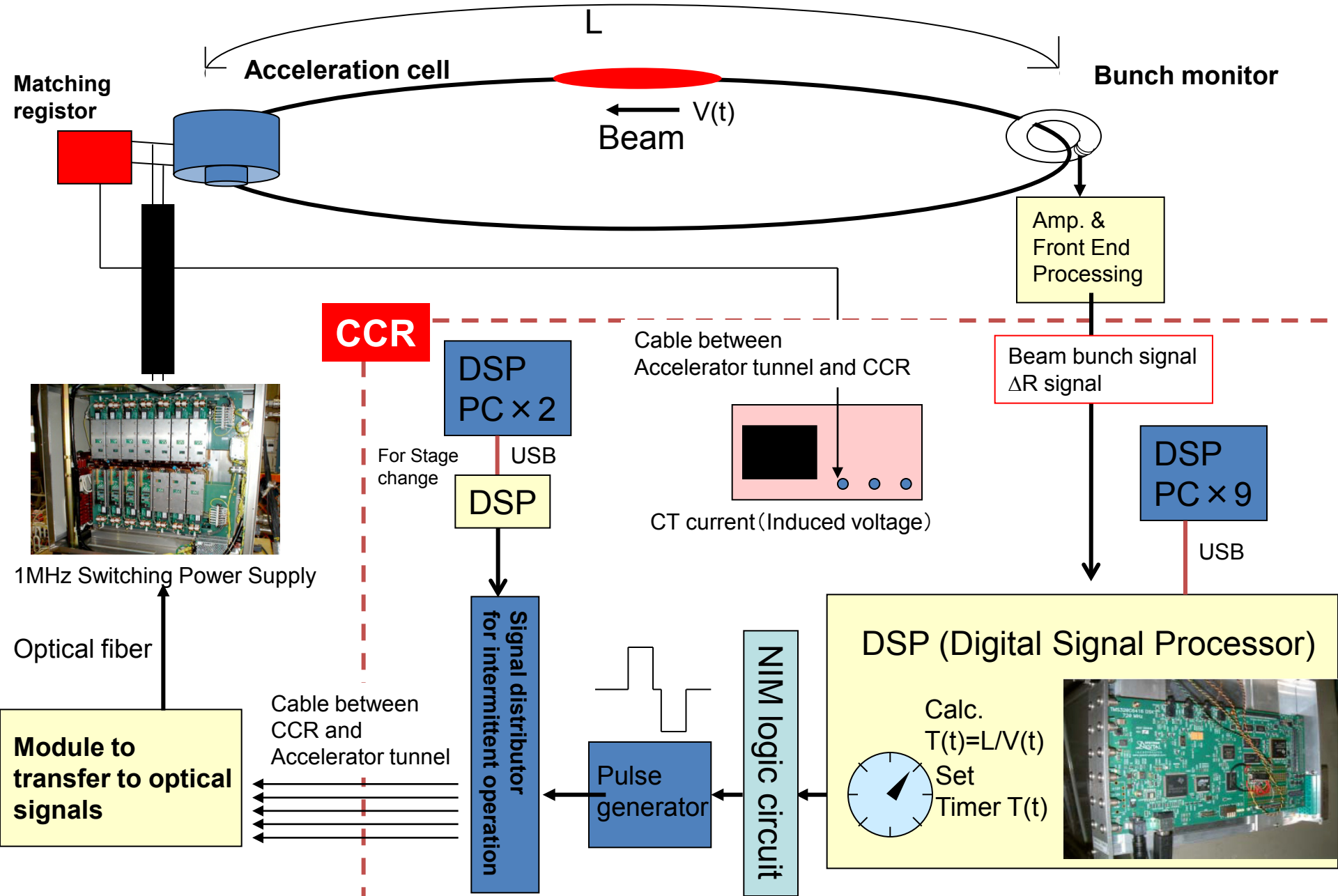
development of cosmic-ray-resist electronics system

Thank you for Your Attentions

Other Papers related to the KEK Digital Accelerator

TUPC096	Solid-state Marx Generator driven Einzel Lens Chopper
WEPS075	Induction Sector Cyclotron for Cluster Ions
THP0027	Novel Switching Power Supply Utilizing SiC-JFET and Its Potential for the Digital Accelerator

Control of Induction Acceleration System



From Betatron to Induction Synchrotron / Cyclotron

Betatron

$$V = \oint E \cdot dl = -\frac{d\Psi}{dt} \quad \left(\Psi \equiv \int B \cdot ds\right)$$

Iron york

Fulx density

Exciitation coil

N

S

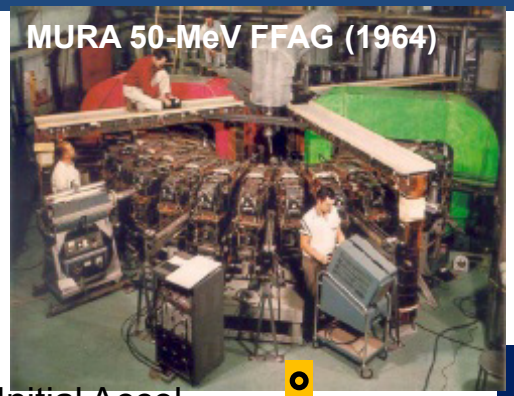
Vacuum chamber

Top view

Orbit

r

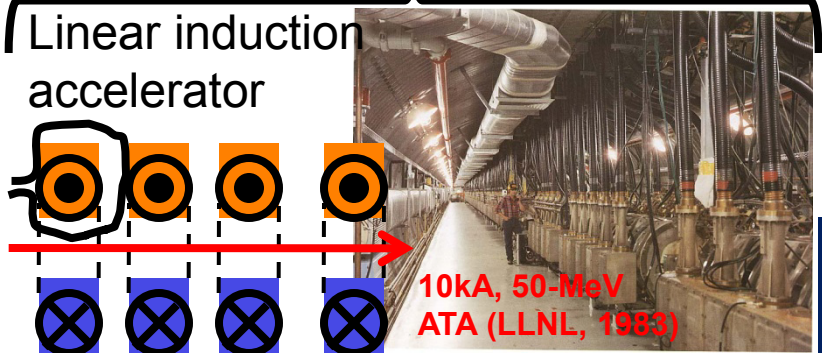
(first Betatron)



Initial Accel. in FFAG

Topological modification

Linear induction accelerator



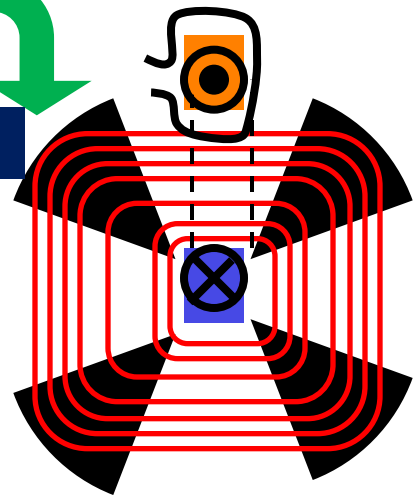
Excitation Coil (primary)

Synchrotron (KEK, 2006)

f < 1 - 3 MHz

Cyclotron

f < 1 Hz (burst ~ 1 kHz)



for more history

K.Takayama and R.Briggs (*Eds.*) "Induction Accelerators" (Springer, 2010 October)