Induction Sector Cyclotron for Cluster Ions

K. Takayama, *KEK and Tokyo Institute of Technology*
T. Adachi, *KEK and Grad. Univ. of Advanced Studies*
H. Tsutsui, *Sumitomo Heavy Industries, Ltd.*
W. Jiang, *Nagaoka University of Technology*
Y. Oguri, *Tokyo Institute of Technology*

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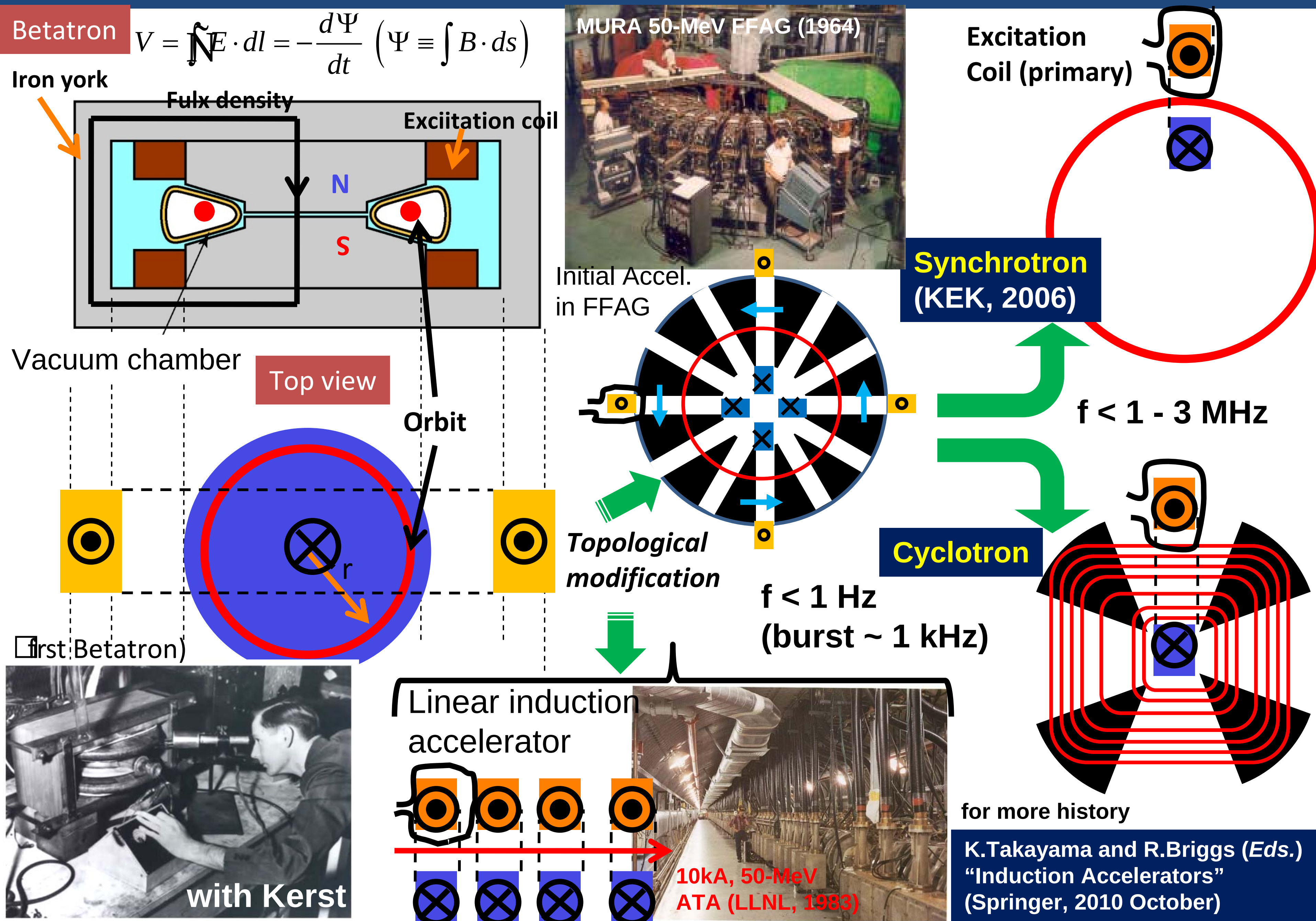
Cyclotrons 2010

Outline of Talk

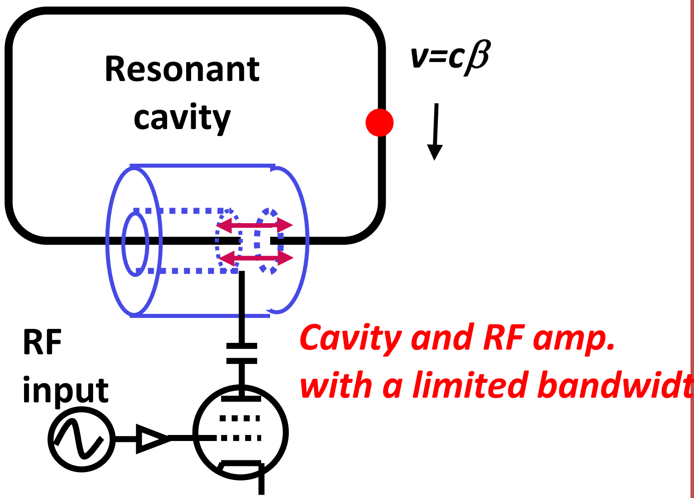
1. A brief history of induction acceleration in circular rings
2. Example of Induction acceleration
   KEK Induction Synchrotron
      Schematic features
      Key hardwares
3. Outline of Induction Sector Cyclotron (ISC)
4. Acceleration and confinement in the longitudinal direction
5. Induction cell
6. Capability of ISC
7. Parameters of a typical ISC for C-60 ions
8. Summary

From Betatron to Induction Synchrotron / Cyclotron

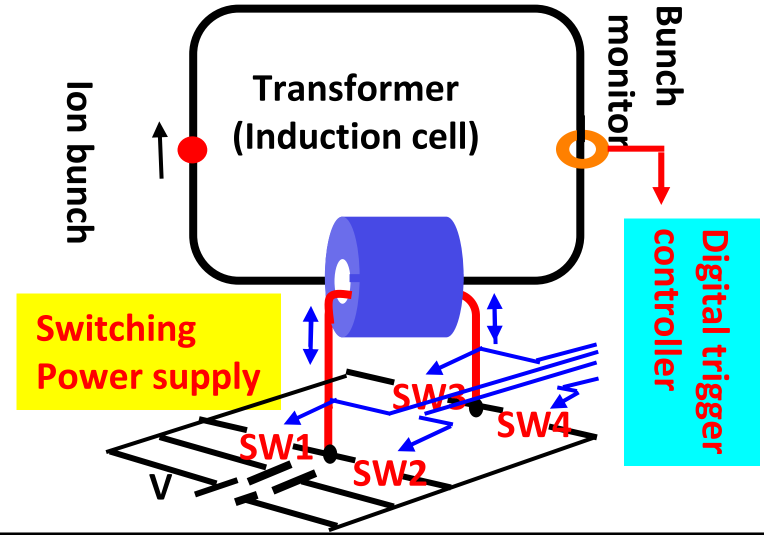


Characteristics of Circular Induction Accelerator (Synchrotron)

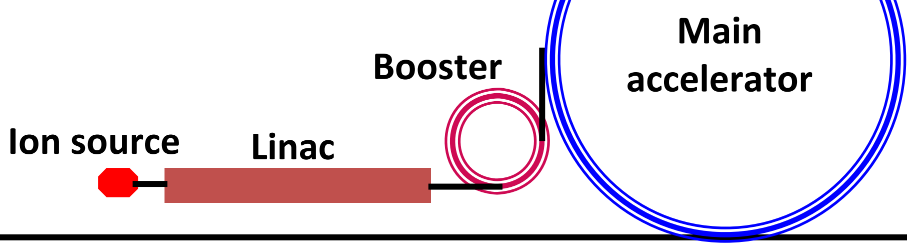
RF Synchrotron



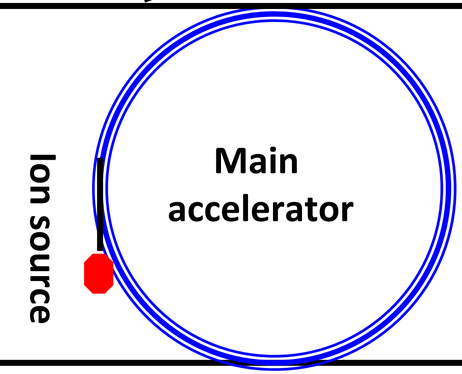
Induction Synchrotron



Cascade type of accelerator complex

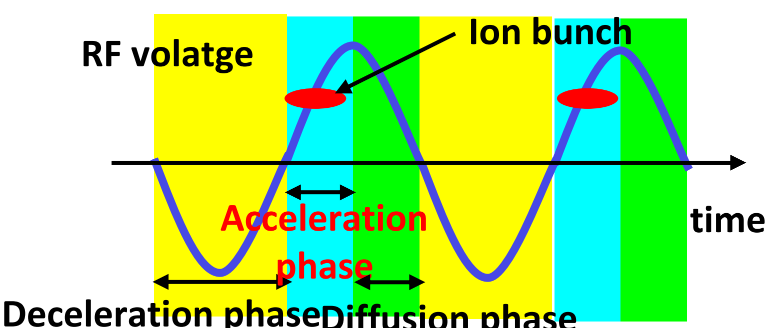


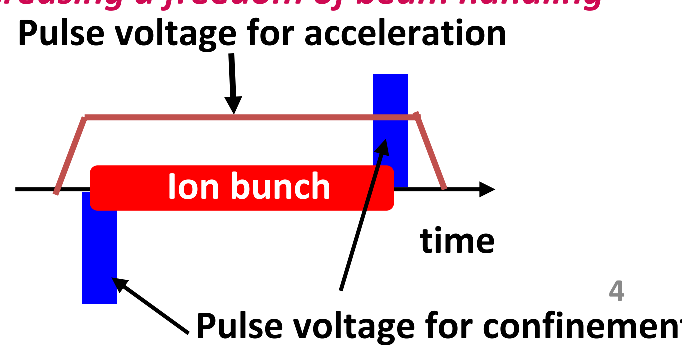
Single stage accelerator



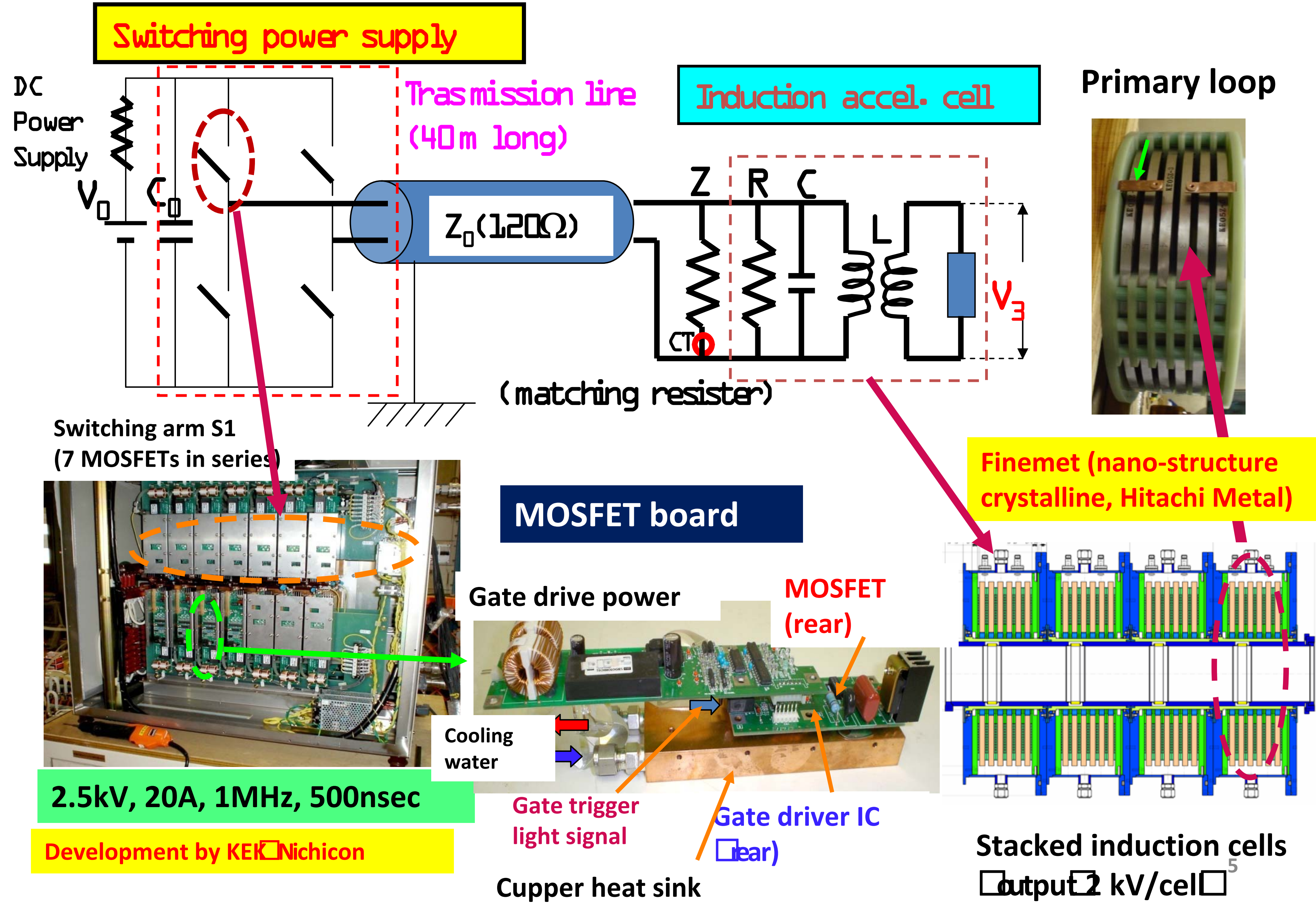
Functionally combined acceleration/confinement -> increase in the local density -> limit on a beam current

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





Equivalent Circuit of Induction Acceleration System and Individual Instruments



Demonstration of the Induction Synchrotron Concept (2006, March)

ion□H^+
500 MeV -> 6 GeV
$N=2.5 \times 10^{11}$

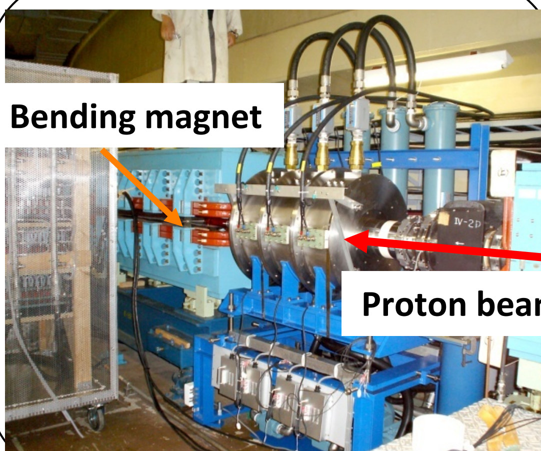
Switching Power Supply
□40kW□Max f_{rep}=1MHz□

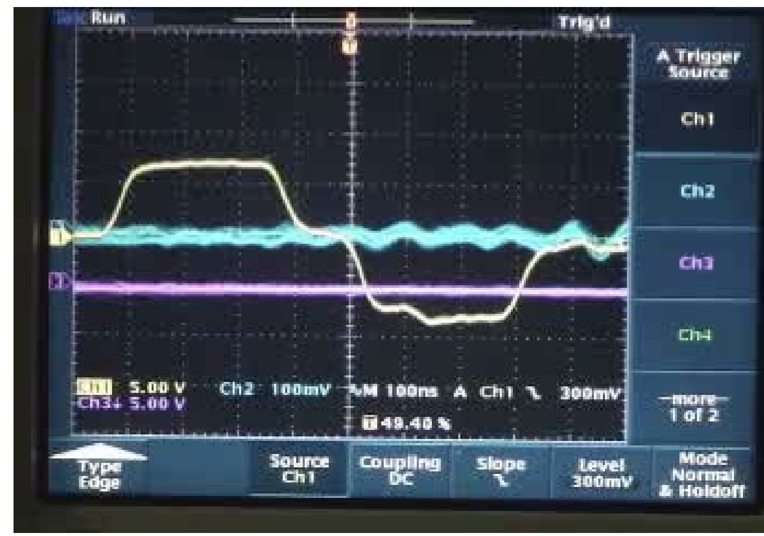
Pulse voltage for confinement

Pulse voltage for acceleration

Proton bunch signal

500 MeV → 6 GeV





Induction cell
10 cells
V_{out}= 2kV/cell

KEK 12GeV
Proton Synchrotron
C_0=340m

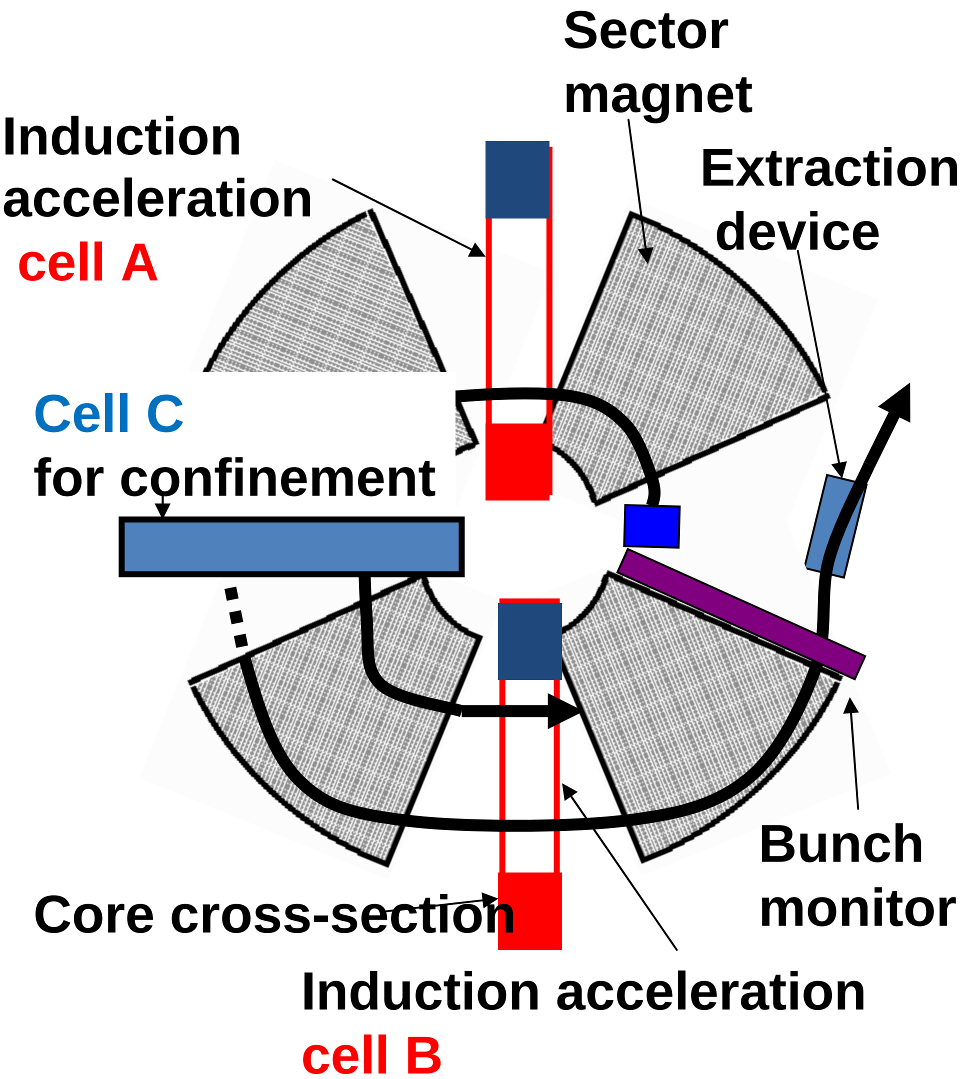
40MeV H-Linac

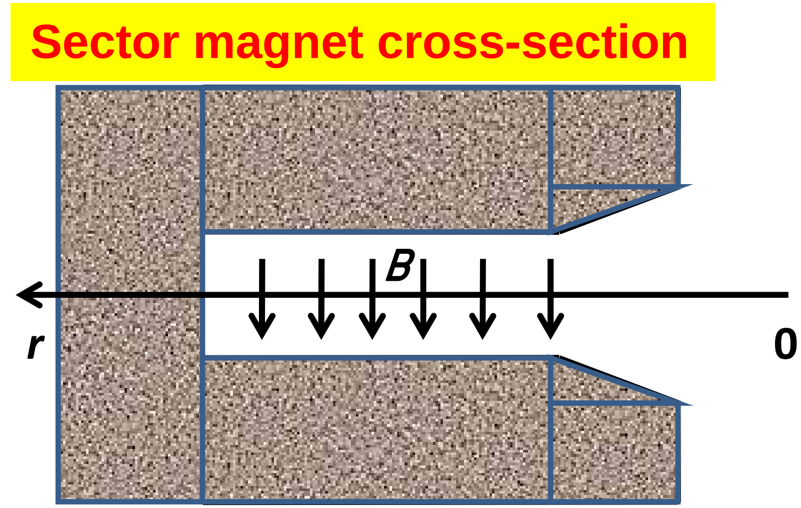
750keV
Cockloft

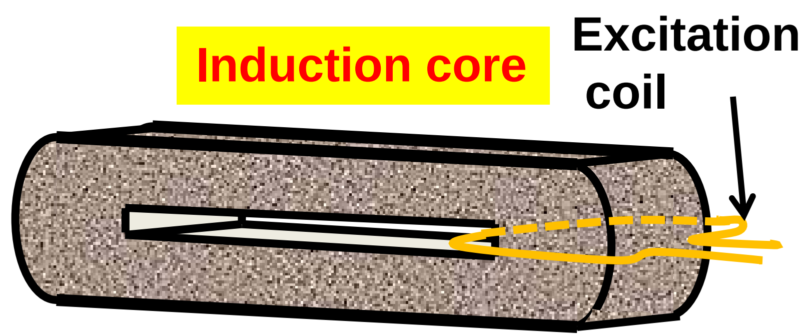
500MeV Booster
C_0=37m

K.Takayama *et al.*, *Phys. Rev. Lett.* 98, 054801(2007)

Layout of Induction Sector Cyclotron

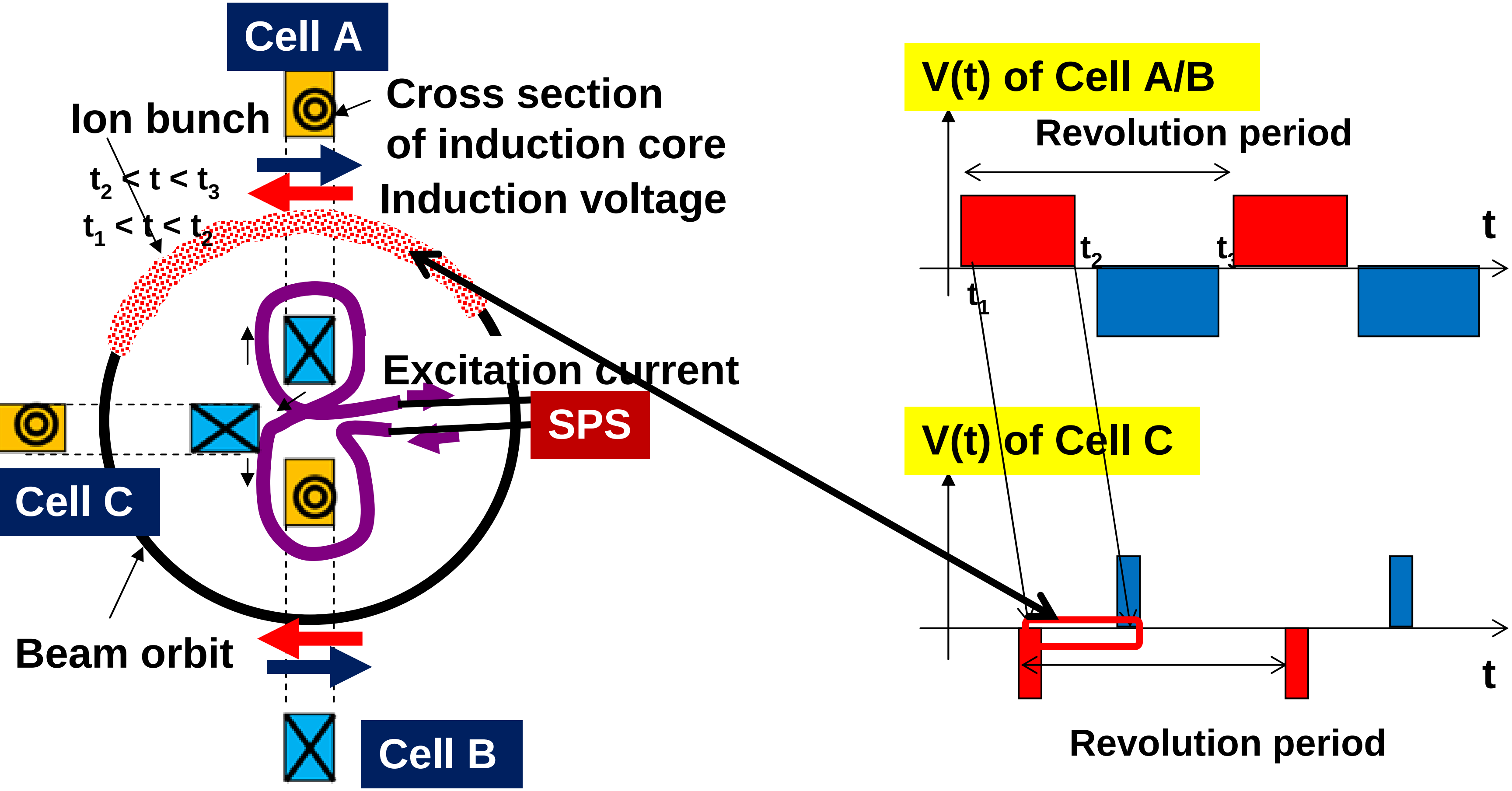






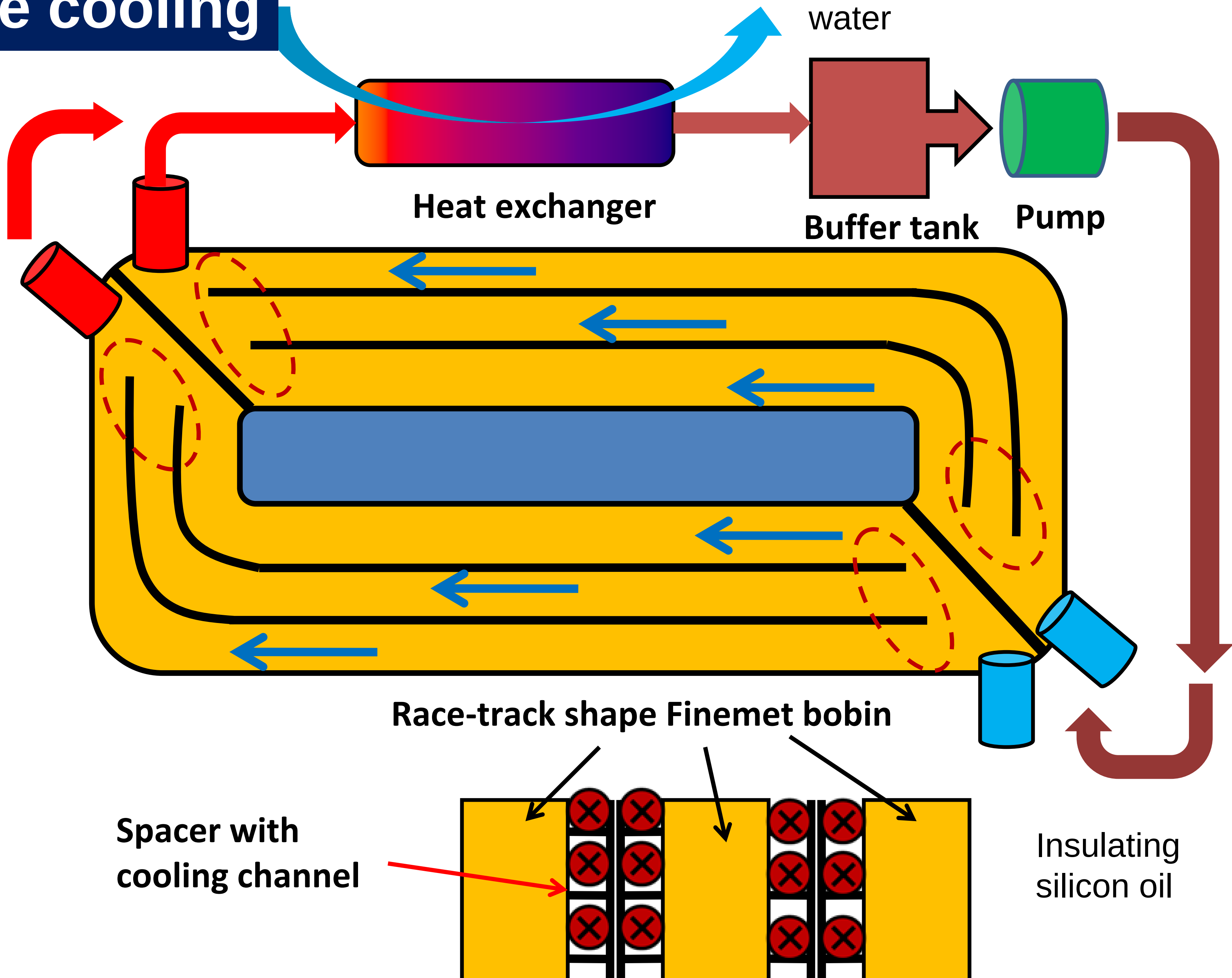
- Induction cells are located between adjacent sector magnets.
  Two type cells will be used.
  Cell A/B for acceleration
  Cell C for confinement
- Horizontally wide aperture induction cells are required.
  In order to realize this shape, a nanocrystalline thin tape as a magnetic material will be wound in a race-track shape.

Acceleration Principle and Pulse Profiles

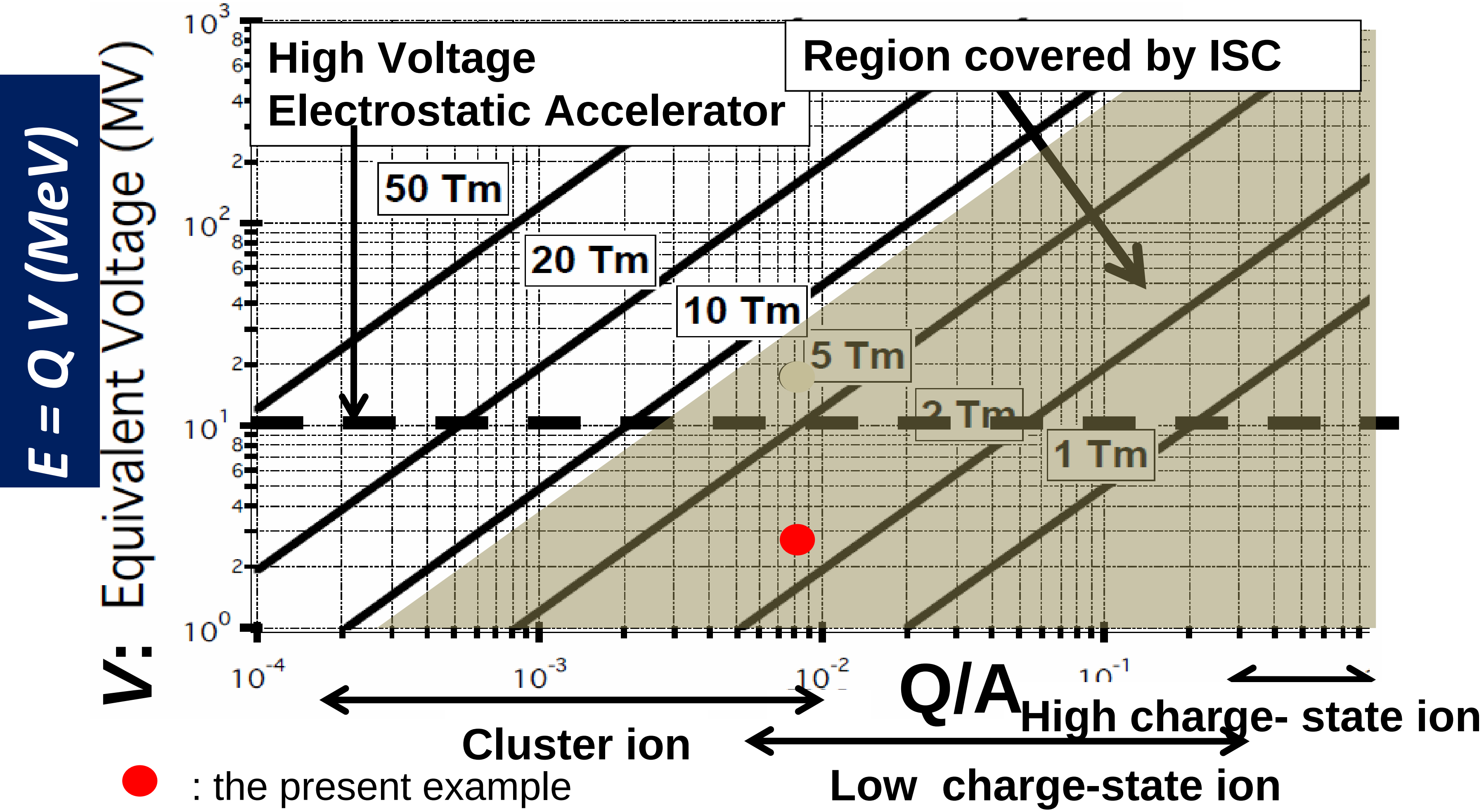


- An ion beam is bunched by barrier voltages generated in Cell C. The beam pulse occupies less than half of the orbit length.
- Cell A/B are set and reset every turn of the ion bunch to avoid saturation of the core material.
- The primary coil of Cell A/B is connected in series with 8-figure, being driven by a common PS. Set-voltage in Cell A and reset voltage in Cell B contribute to the induction acceleration.
- This series connection is helpful to duplicate the core inductance, resulting in mitigation of the droop voltage.

Core cooling



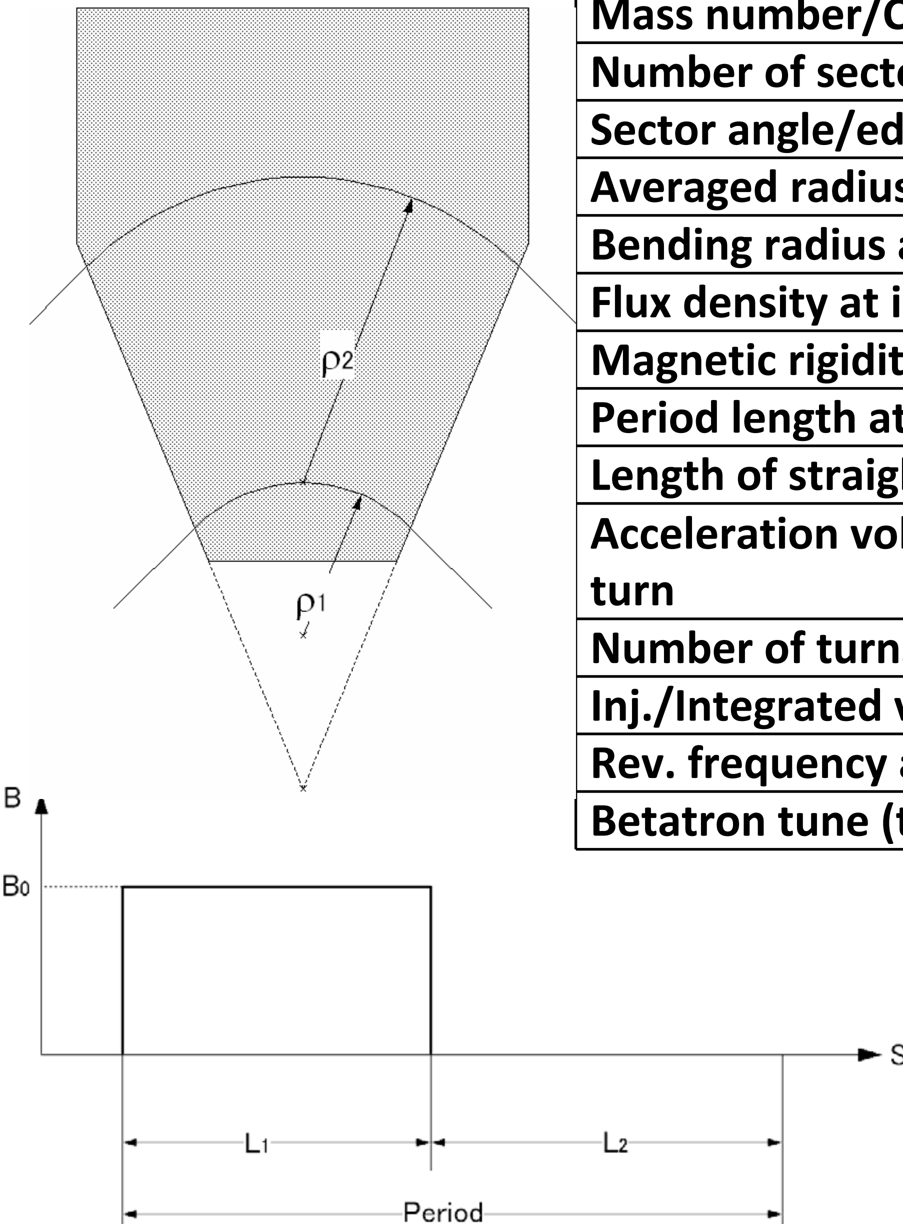
Achievable Energy vs. Magnetic Rigidity of ISC



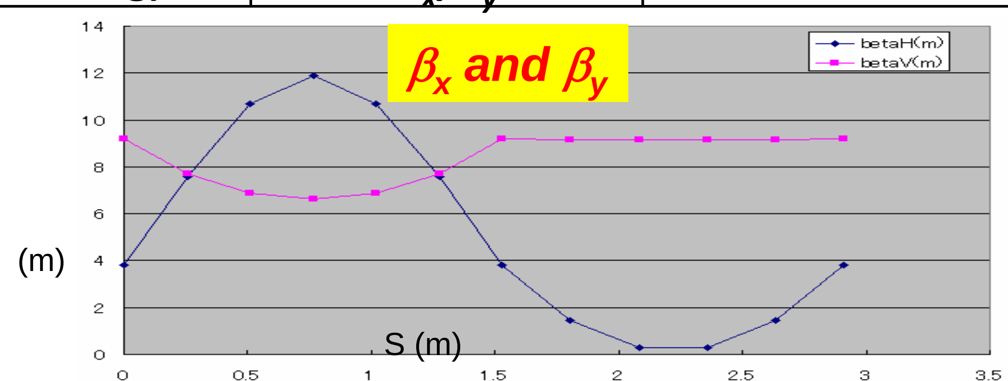
- **Achievable energy is simply dependent of the magnetic rigidity of sector magnet as well as in other cyclotrons.**
- **Equivalent voltage, which can be easily compared with the acceleration voltage of electro-static accelerator, is shown as a function of the ratio of charge state "Q" to mass number "A".**

Machine Parameters of a Typical ISC for C-60

Hard edge model



Item	Symbol	Numerical value
Mass number/Charge state	A/Q	720/7
Number of sector magnets	N	4
Sector angle/edge angle	η_0/κ	$(\pi/4)/(\pi/8)$
Averaged radius at inj/ext	r_1/r_2	1.85/3.7 m
Bending radius at inj/ext	ρ_1/ρ_2	0.974/1.948m
Flux density at inj/ext	$B(r_1)/B(r_2)$	0.67/1.34 Tesla
Magnetic rigidity	$B\rho$	0.653/2.61 Tm
Period length at inj/ext	L_1+L_2	2.9/5.8 m
Length of straight section		1.38/2.75 m
Acceleration voltage per turn	V_{acc}	30 kV (2 × 15 kV)
Number of turns	N_{turn}	100
Inj./Integrated voltage	$V_1/V_2\,(V_{acc} \times N_{turn})$	200 kV/3.0 MV
Rev. frequency at inj/ext	f_1/f_2	52.8/105 kHz
Betatron tune (tracking)	ν_x/ν_y	1.889/0.229



Remained Issues and Summary

- 3D design of a full sector magnet and full tracking assuming 3D mag. fields
- Interference between the sector magnet and induction core
- Injection/extraction system
- Wide aperture monitor system
- High charge-state cluster ion source
- Survival rate of cluster ions or required vacuum pressure

■ An induction circular accelerator with fixed guiding fields, Induction Sector Cyclotron, has been proposed.

■ Its properties of
turn-by-turn induction acceleration
barrier bucket confinement
have been presented.

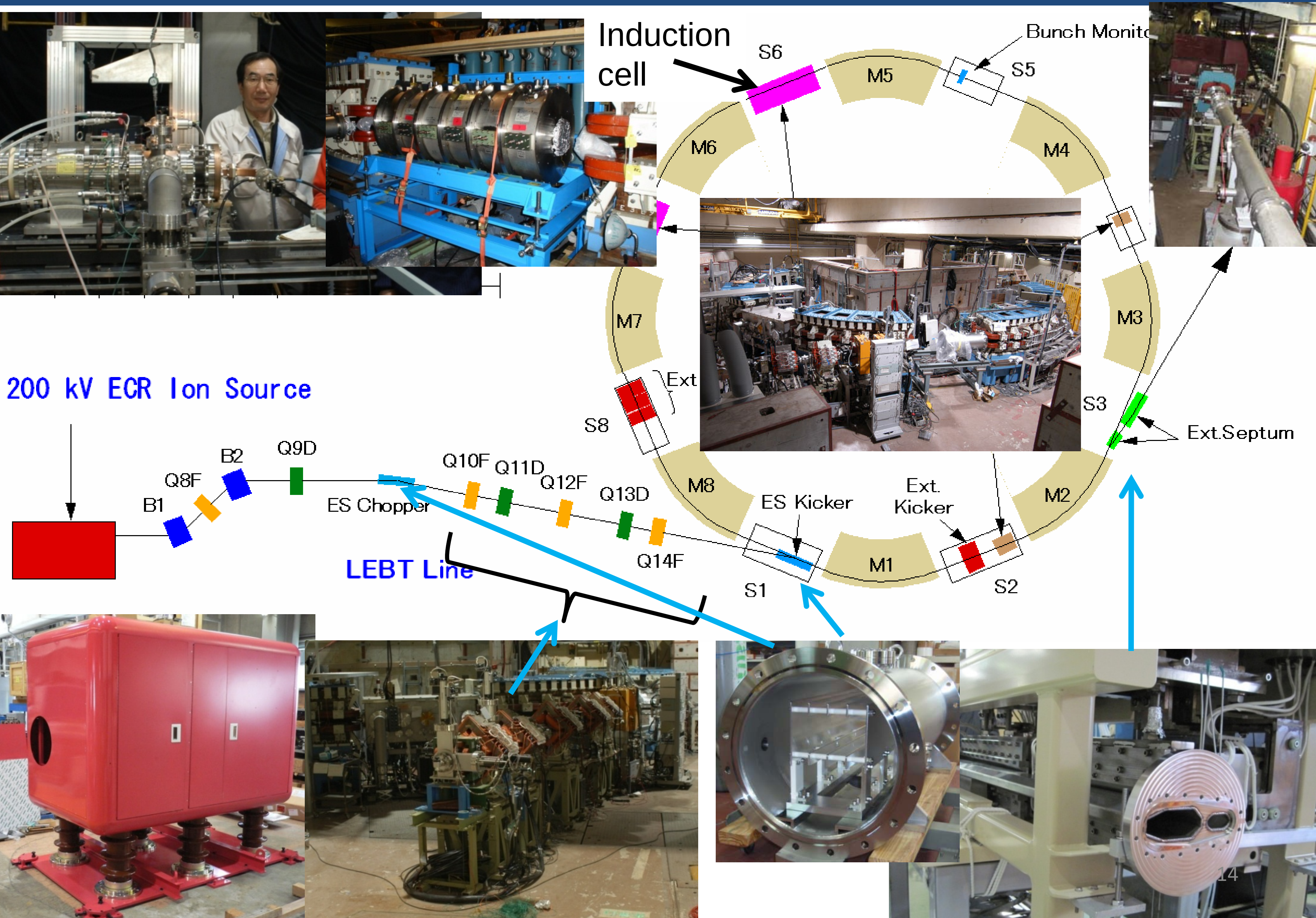
■ Machine parameters of a typical ISC, which could be useful for acceleration of cluster-ions, such as C-60, has been given.

We are planning to construct a prototype.

Your comment, suggestion, criticism, and advice are really welcome through this conference.

β_x and β_y

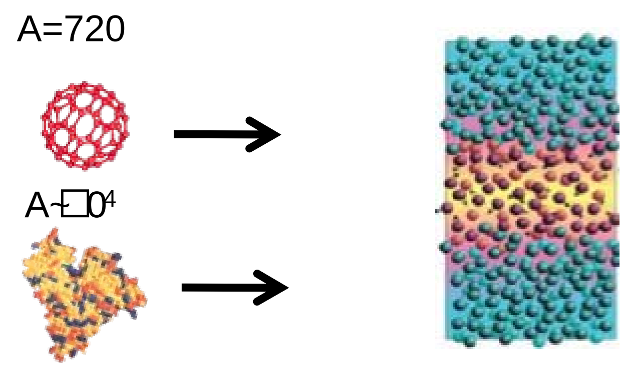
KEK Digital Accelerator



Motivation

Acceleration of cluster ions, Q/A of which is extremely small (< 1/10-100).
Its acceleration frequency falls out of that of RF.
So far a unique solution has been an electrostatic accelerator.
A single-end electrostatic accelerator has a limitation of achievable charge-state.

Why



Energy density of swift cluster ions is extremely high in space.

⬇

Deep damage on a target material is unpredictable because of nonlinear effects.

⬇

- ■ **Unique driver for development of functionally noble materials**
- ■ **Unique driver for studying Material Science or Warm Dense Matter Science**

by Y. Oguri, in Proceedings of RPIA 2006