FFAGs for ERIT and ADS Projects at KURRI

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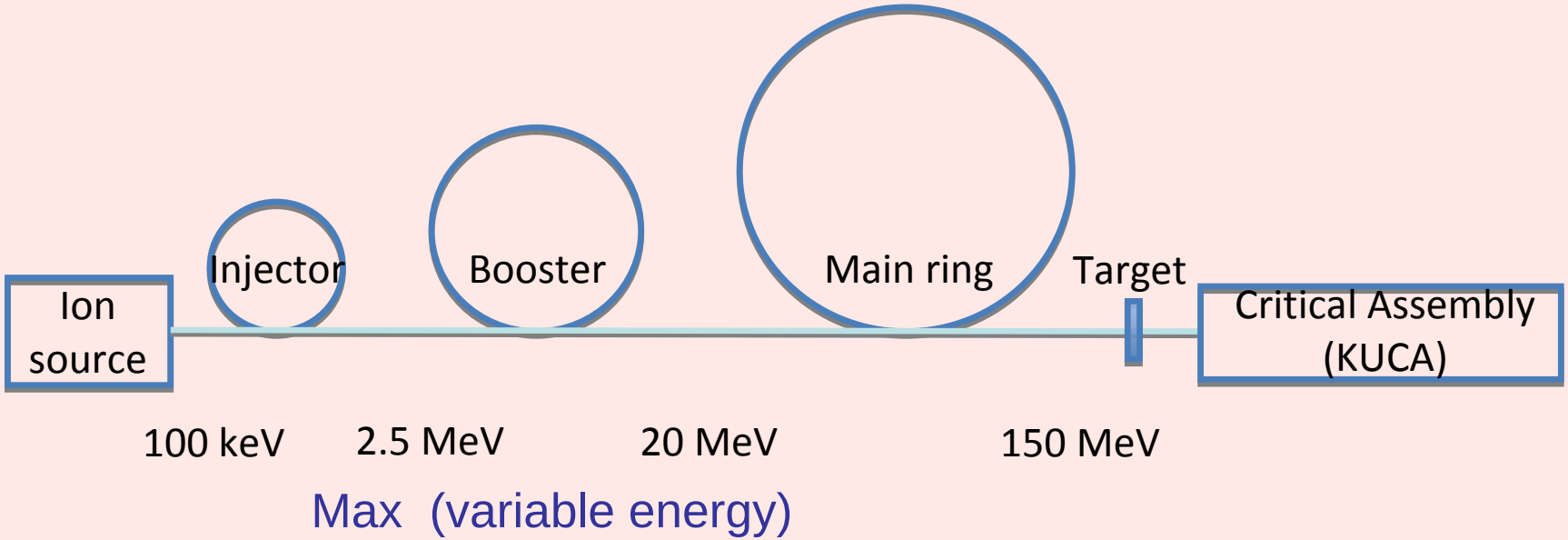
FFAG complex for ADS study

FFAG-ADS Project

To study

Accelerator Driven Sub-critical Reactor (ADS)

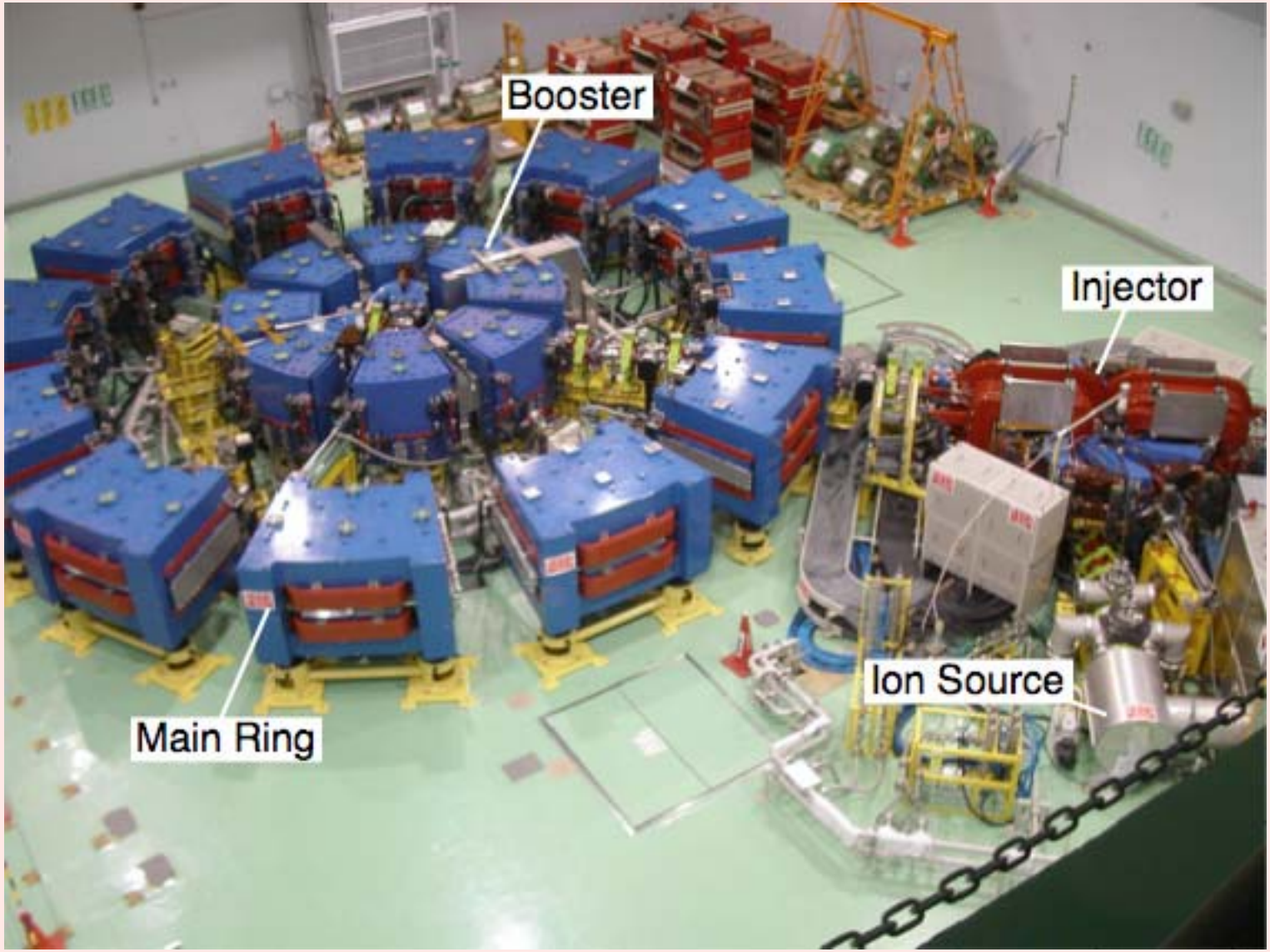
- Narrow energy spectrum of n beam
- Energy and Flux of the n beam
  can be easily controlled.

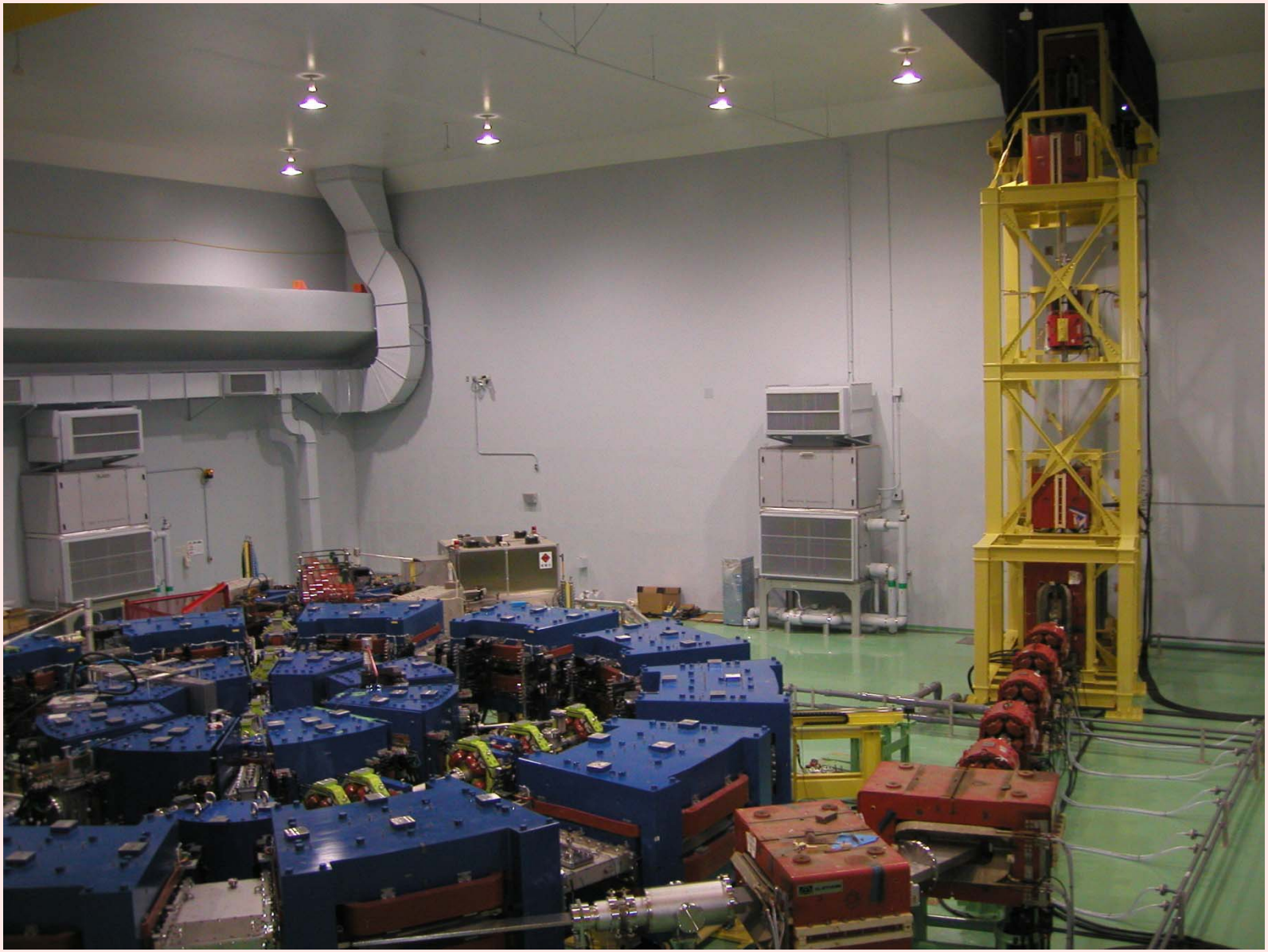


Accelerators for ADS

	Injector	Booster	Main Ring
Focusing	Spiral, 8 cells	Radial, 8 cells	Radial, 12 cells
Acceleration	Induction	RF	RF
Field index, *k*	2.5*	4.5	7.5
Energy (max)	0.1-2.5 MeV*	2.5-20 MeV	20-150 MeV
P_{ext}/P_{inj}	5.00(Max)	2.84	2.83
Average orbit radii	0.60 - 0.99 m	1.42 - 1.71 m	4.54 - 5.12 m

* Output energy of the injector is variable


Booster
Injector
Ion Source
Main Ring



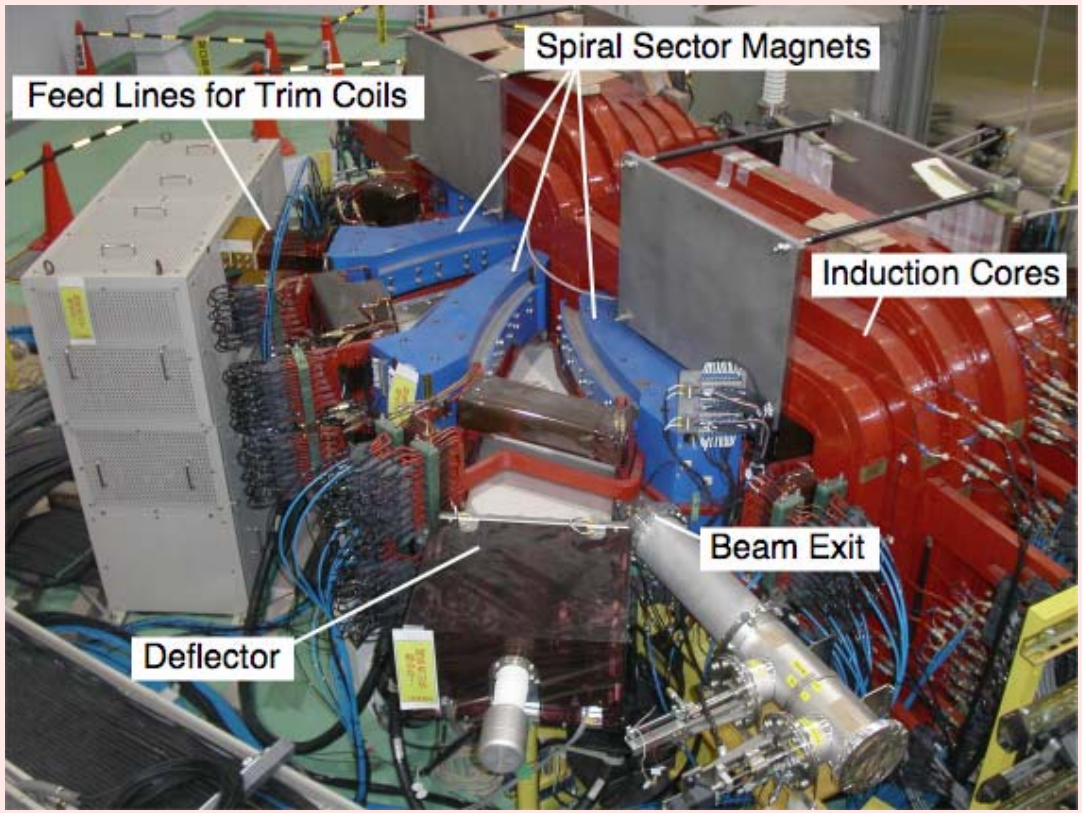
Injector

	Design	Achieved
E_{inj}	0.1MeV	0.12MeV
E_{ext}	2.5MeV	1.5MeV
Curr.	10nA(lim)	10nA
Rep.	120 Hz	118 Hz

Spiral sector magnets
spiral angle = 42 deg

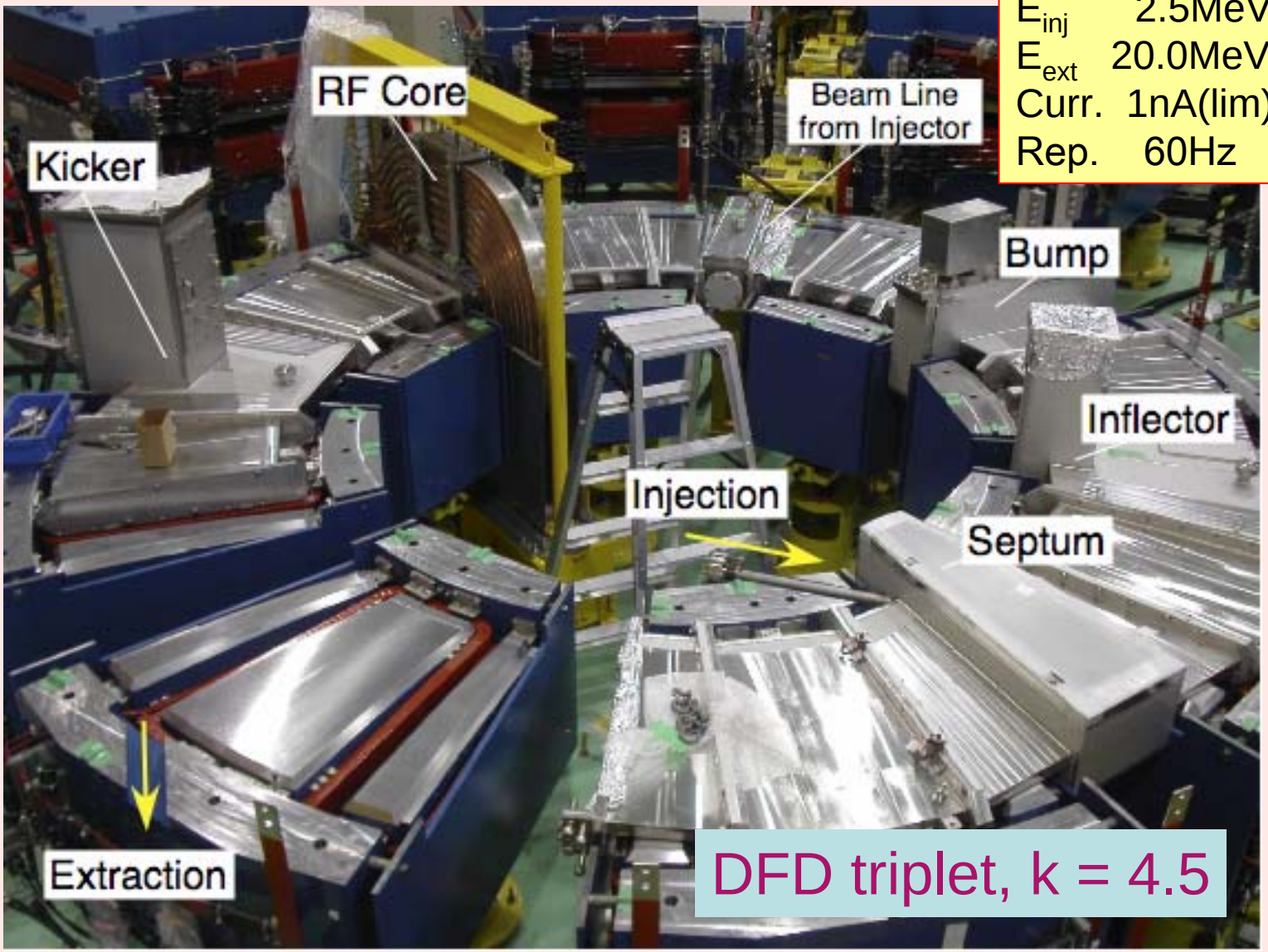
Induction acceleration
500 V/turn

Variable field-index k,
by means of trim-coils

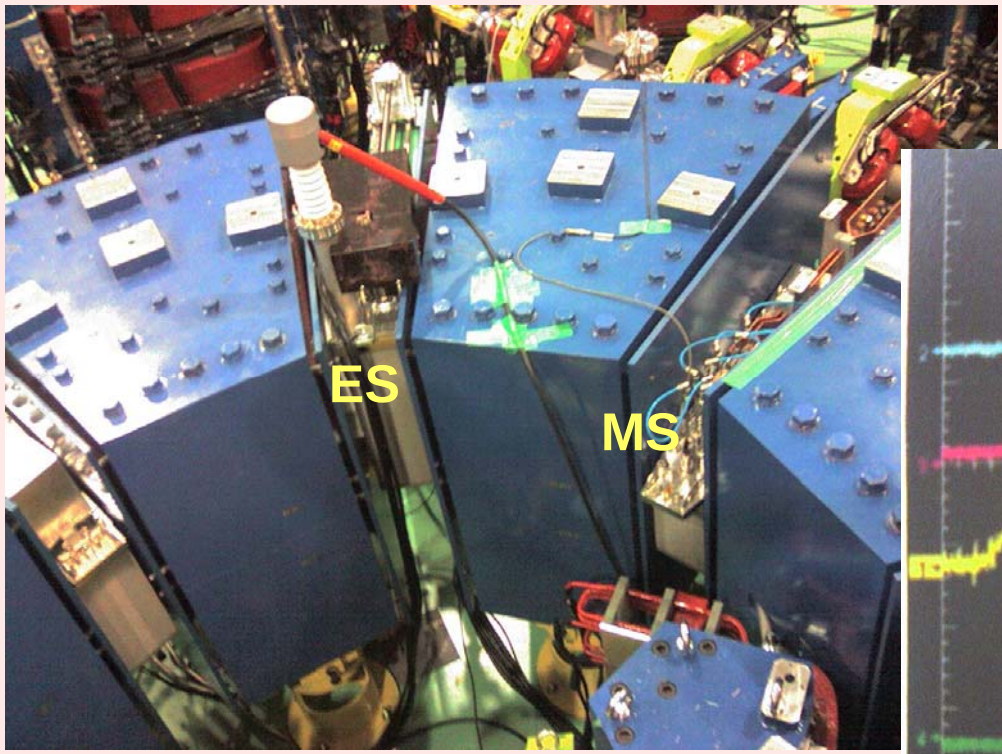


Booster

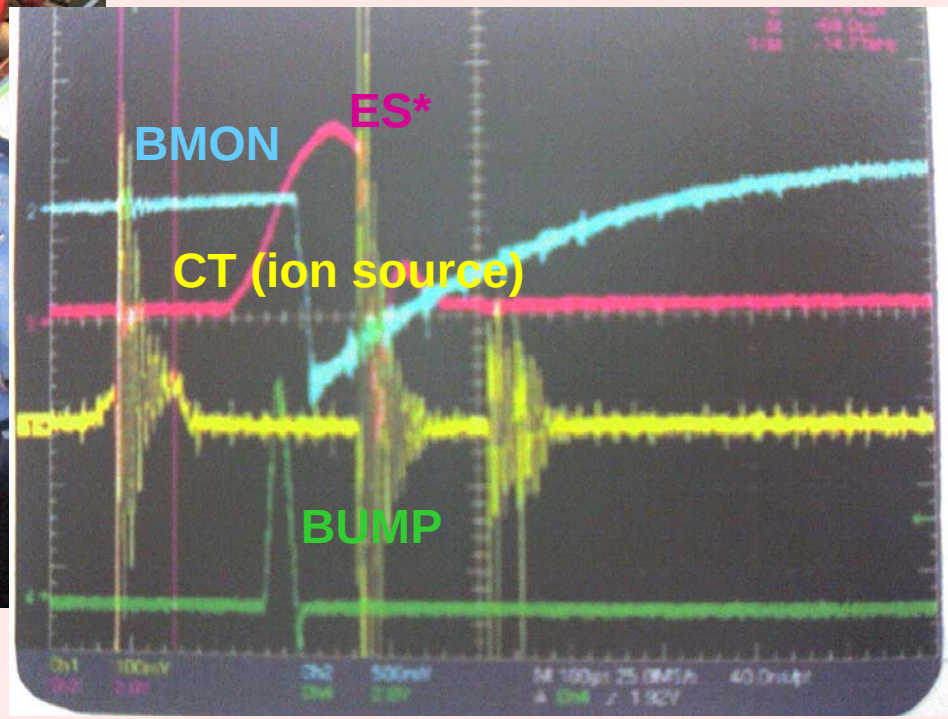
	Design	Achieved
E_{inj}	2.5MeV	1.5MeV
E_{ext}	20.0MeV	11.6MeV
Curr.	1nA(lim)	1nA
Rep.	60Hz	59 Hz



Booster Injection



100us/div



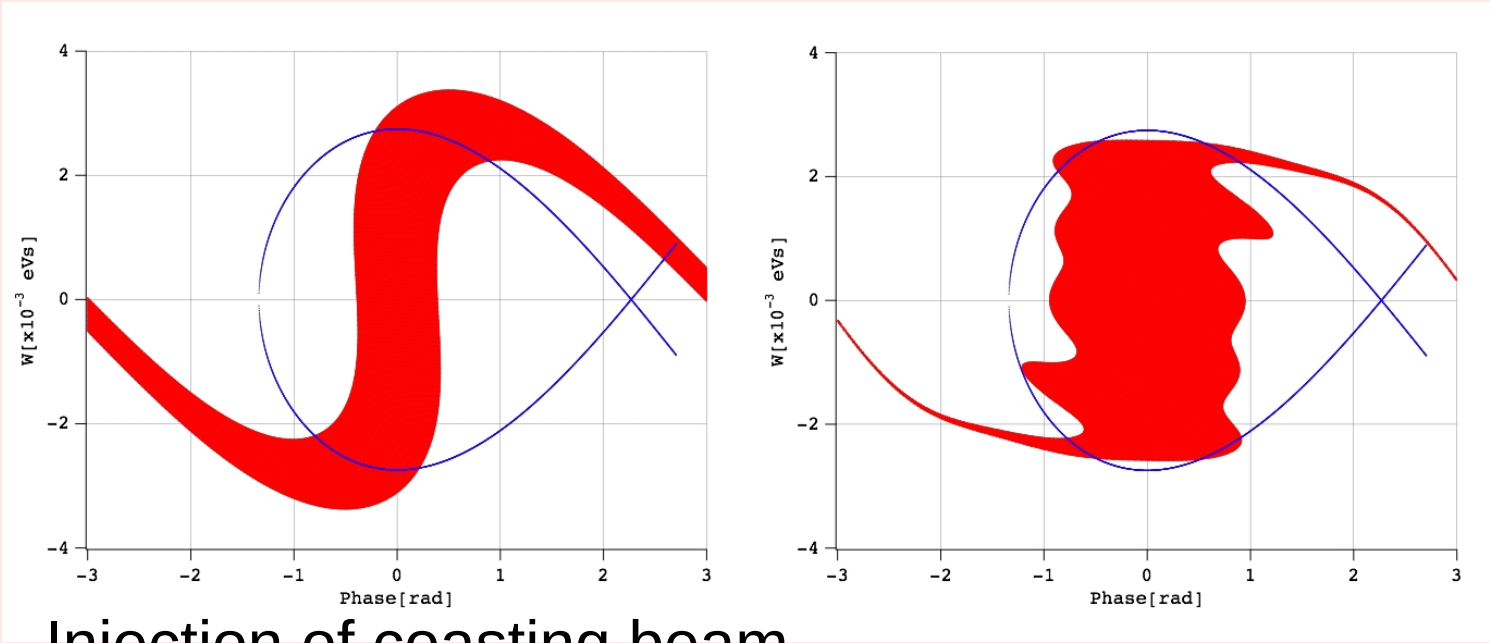
*** Monitor delay of ES =40us**

RF cavity

Magnetic alloy
Max : 1kV

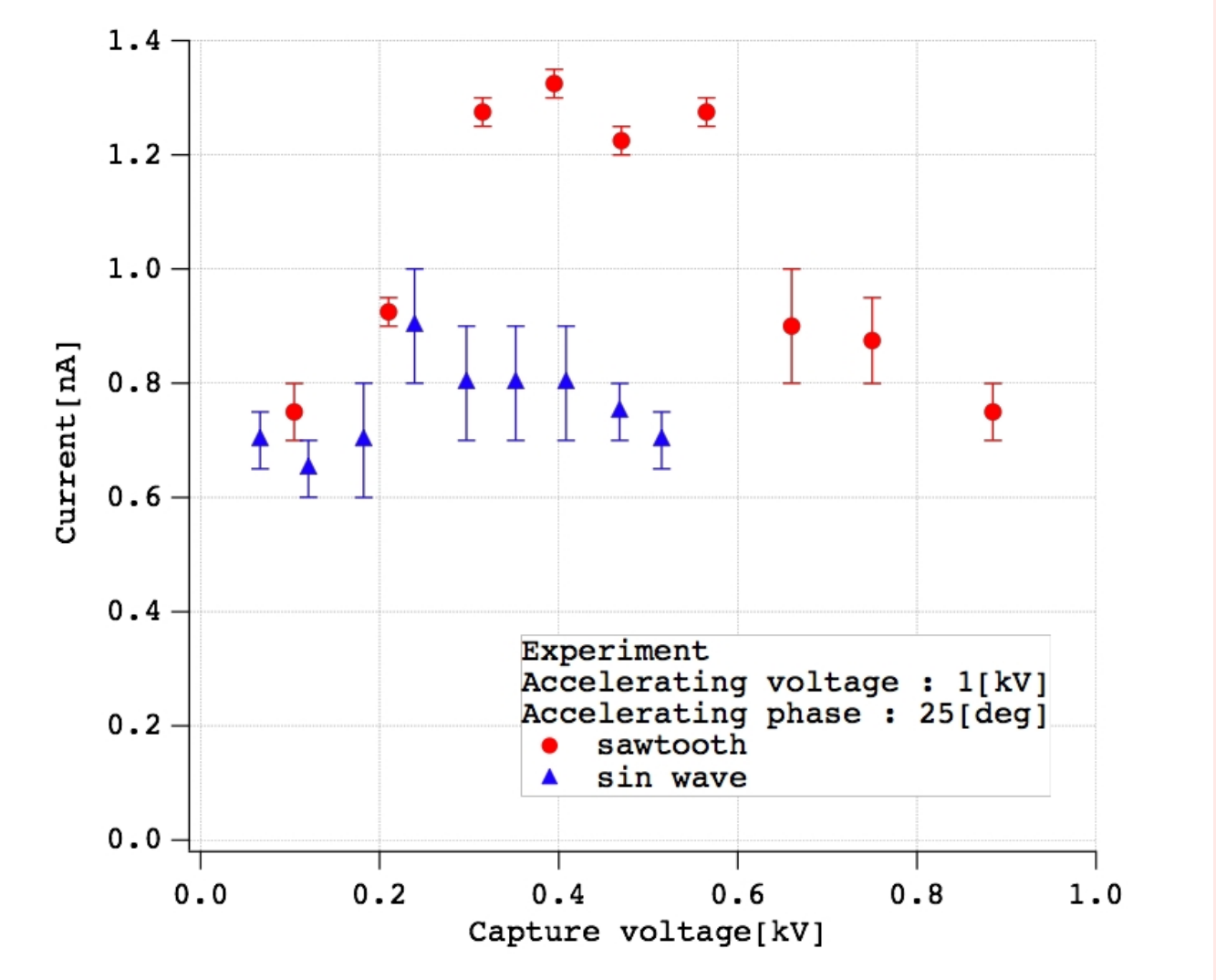
Longitudinal Matching

Fast longitudinal matching by bunch rotation
(proposed by M. Aiba), H. Horii et al.



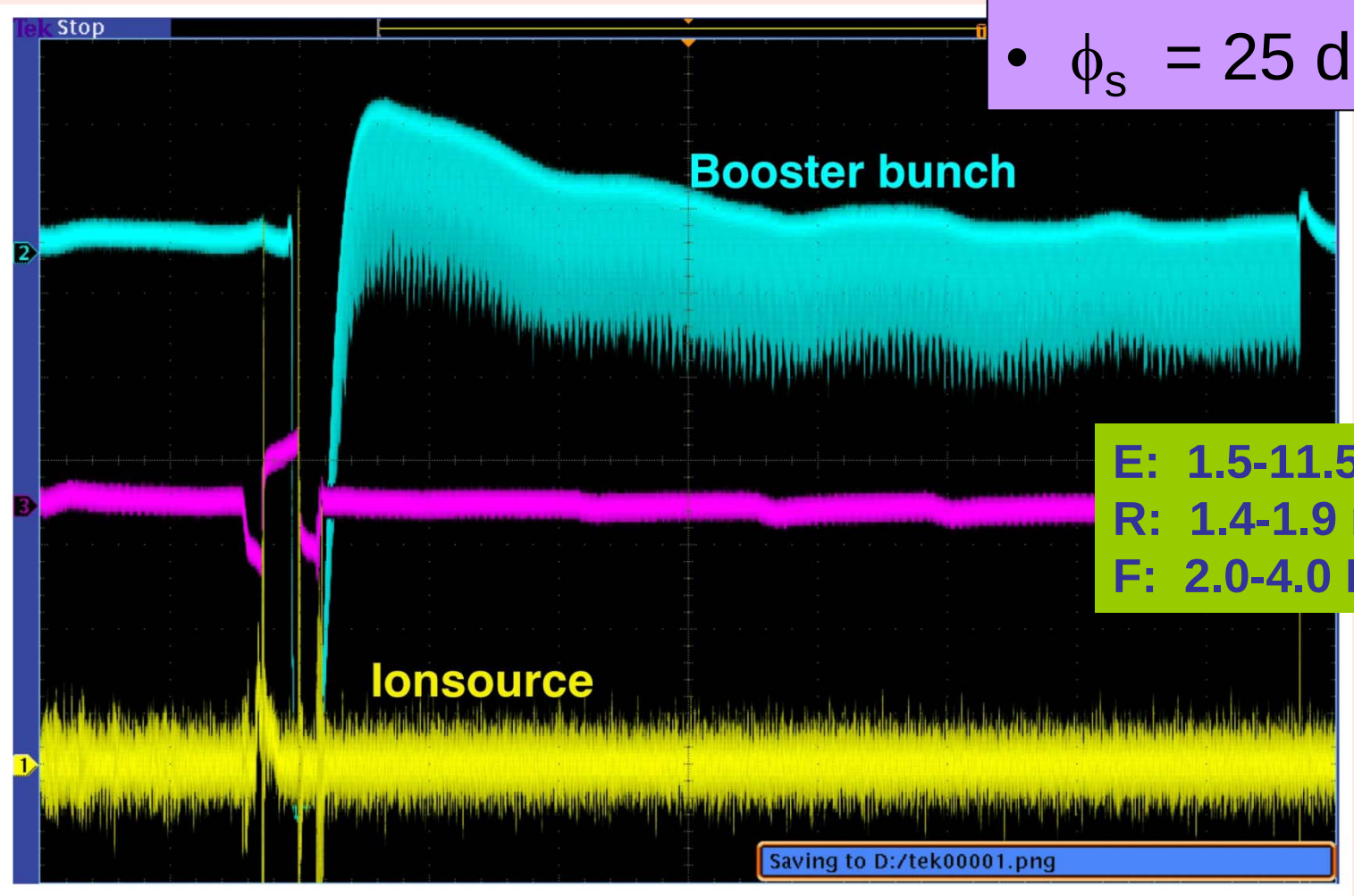
1. Injection of coasting beam
2. Bunch rotation in a waiting bucket
3. Matching with acceleration bucket within ~(T_{syn}/4)
4. Acceleration

Dependence on capture voltage



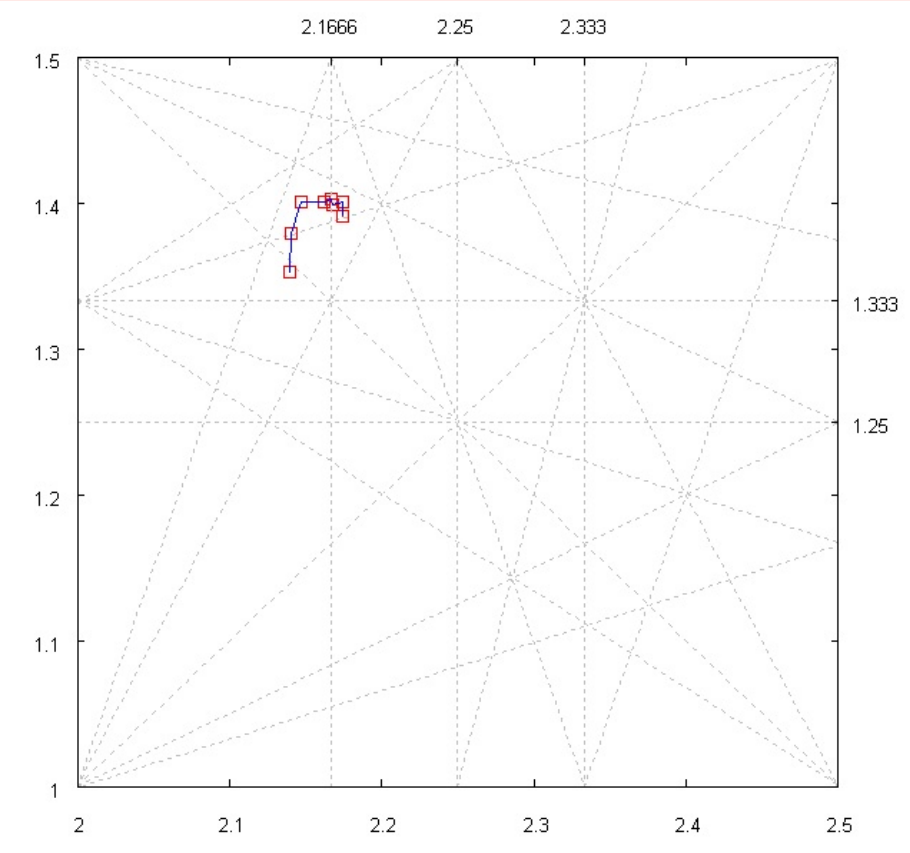
Acceleration

- V = 1 kV
- ϕ_s = 25 deg



Full-span 10ms

Tune measurement



Coherent oscillations were excited by ..

Horizontal; RF knockout
Vertical ; Vertical exciter

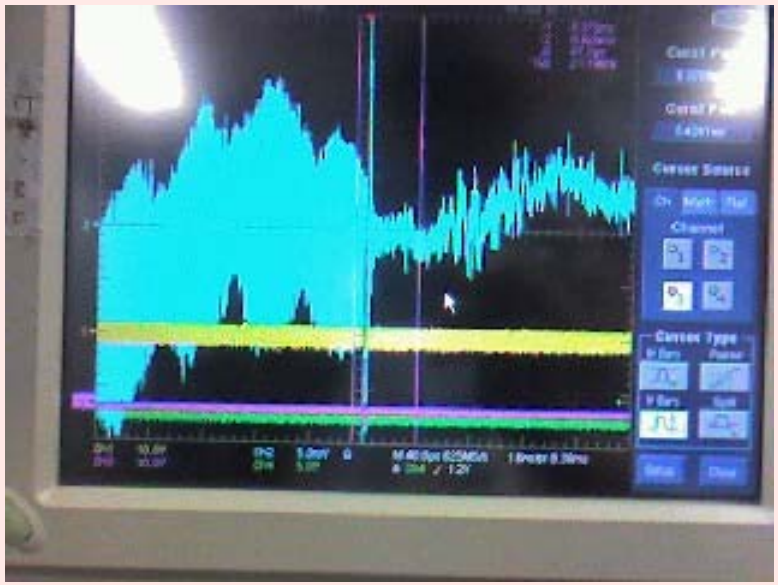
Measured tunes agreed with the designed values

Extraction

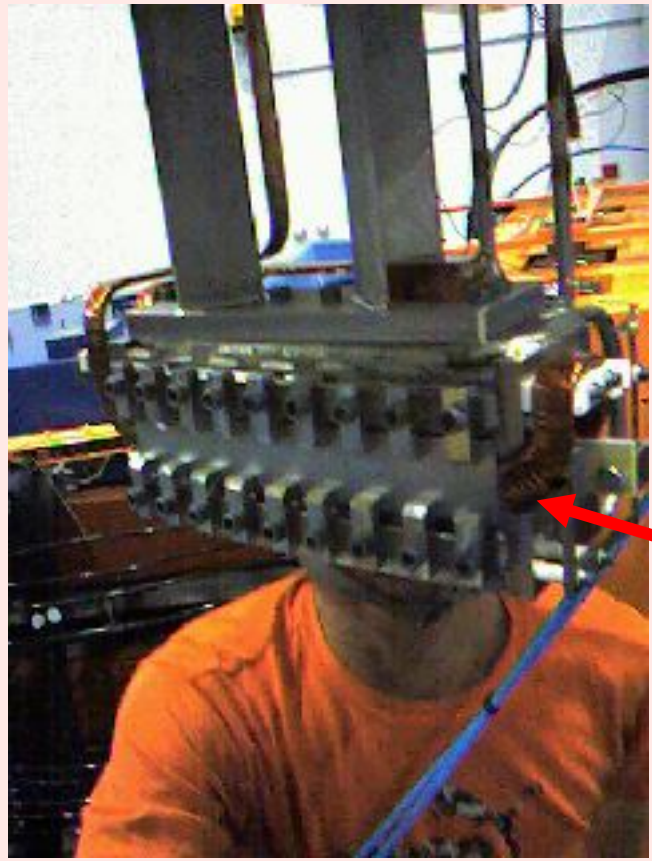
By Kicker and Magnetic septum

Typical efficiency;

circulating … 1.0nA
extracted … 0.7nA

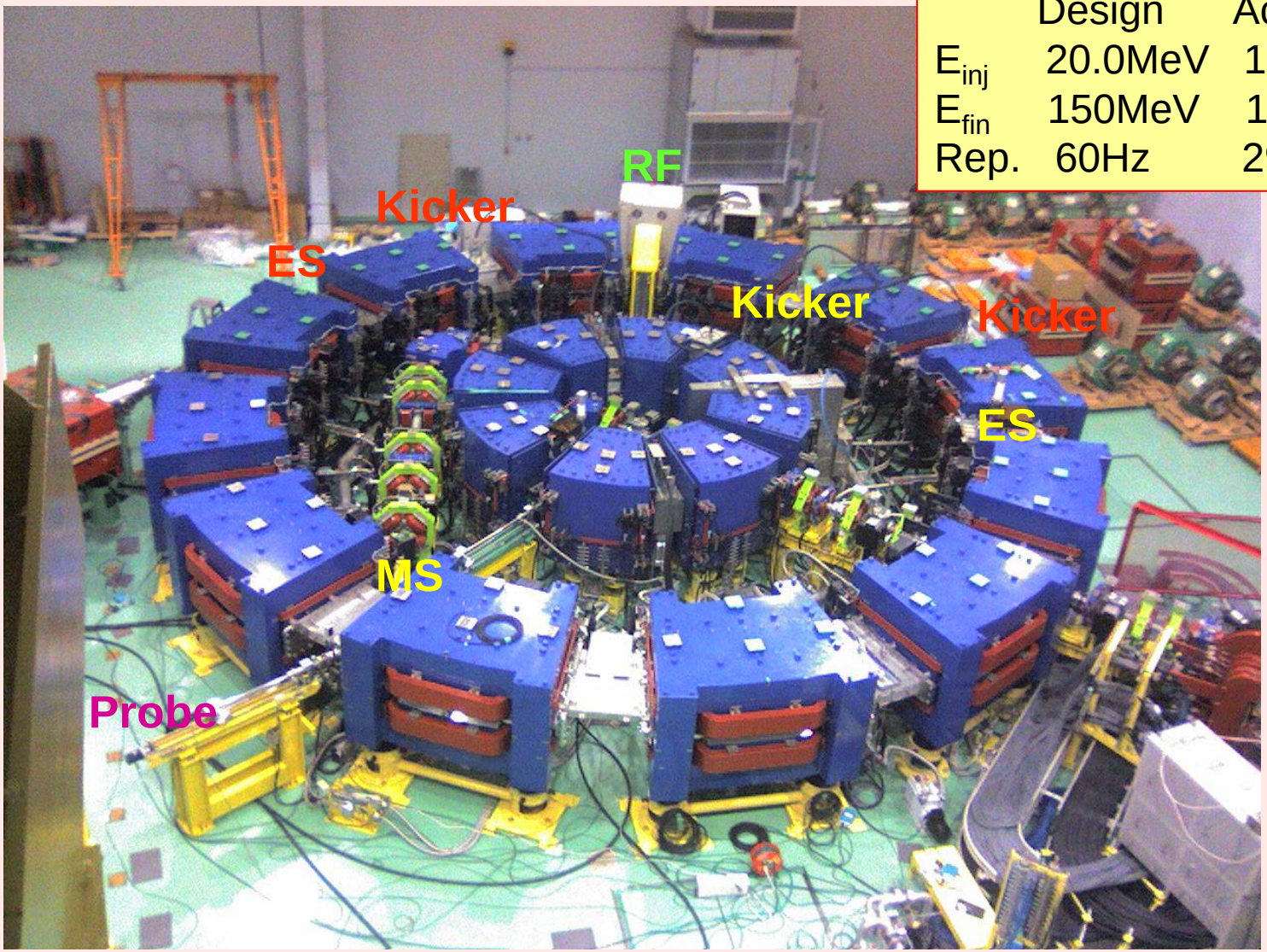


MS



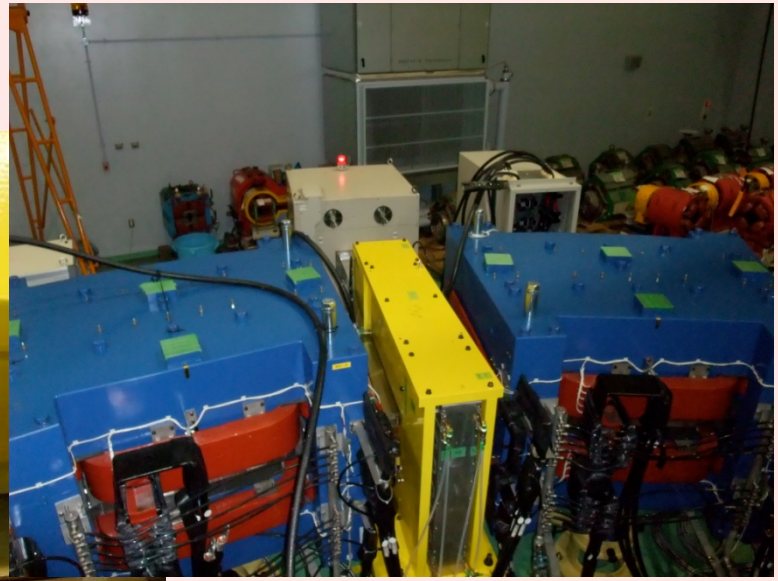
Main Ring

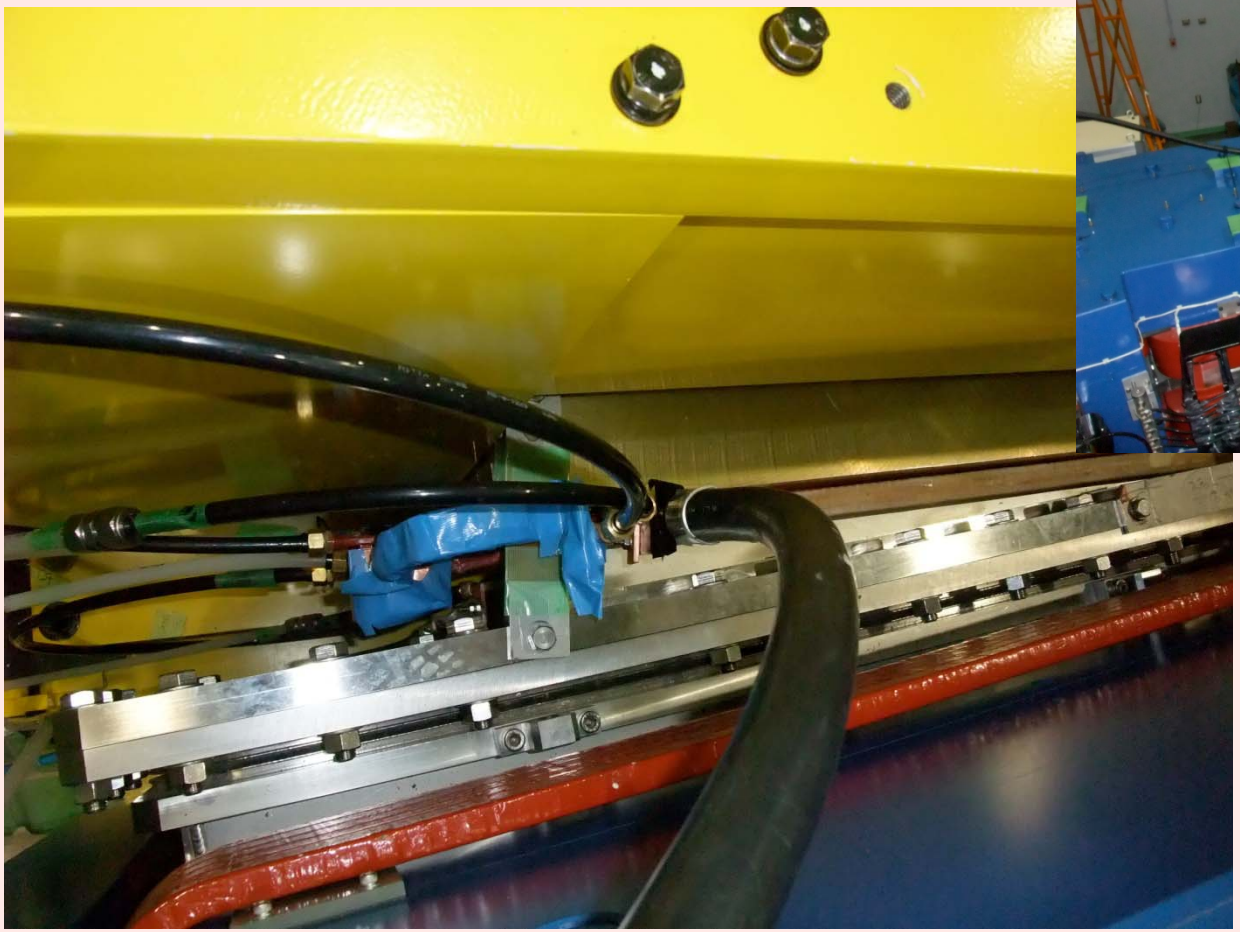
	Design	Achieved
E_{inj}	20.0MeV	11.6MeV
E_{fin}	150MeV	100MeV
Rep.	60Hz	29.5Hz



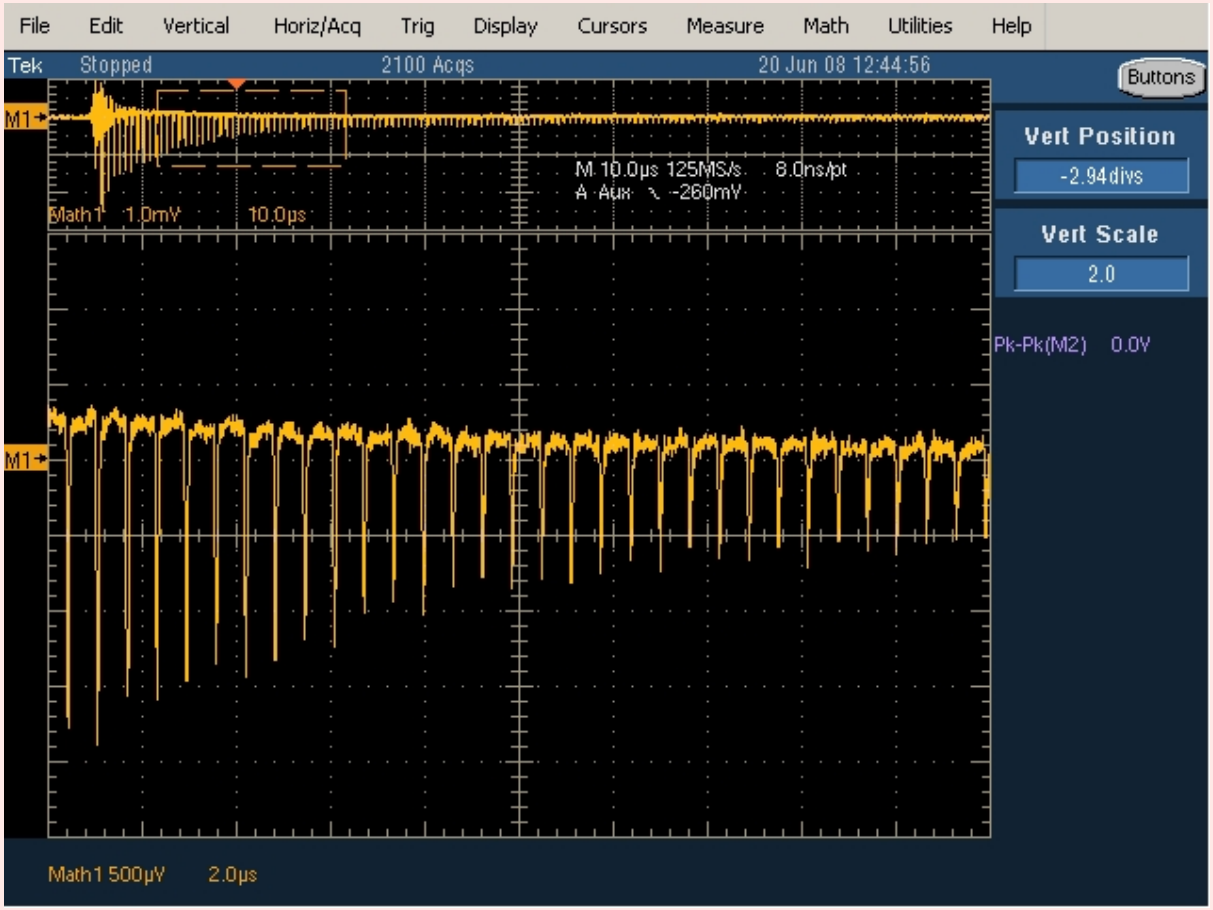
COD correction

Main source of Closed Orbit Distortion is RF cavity.



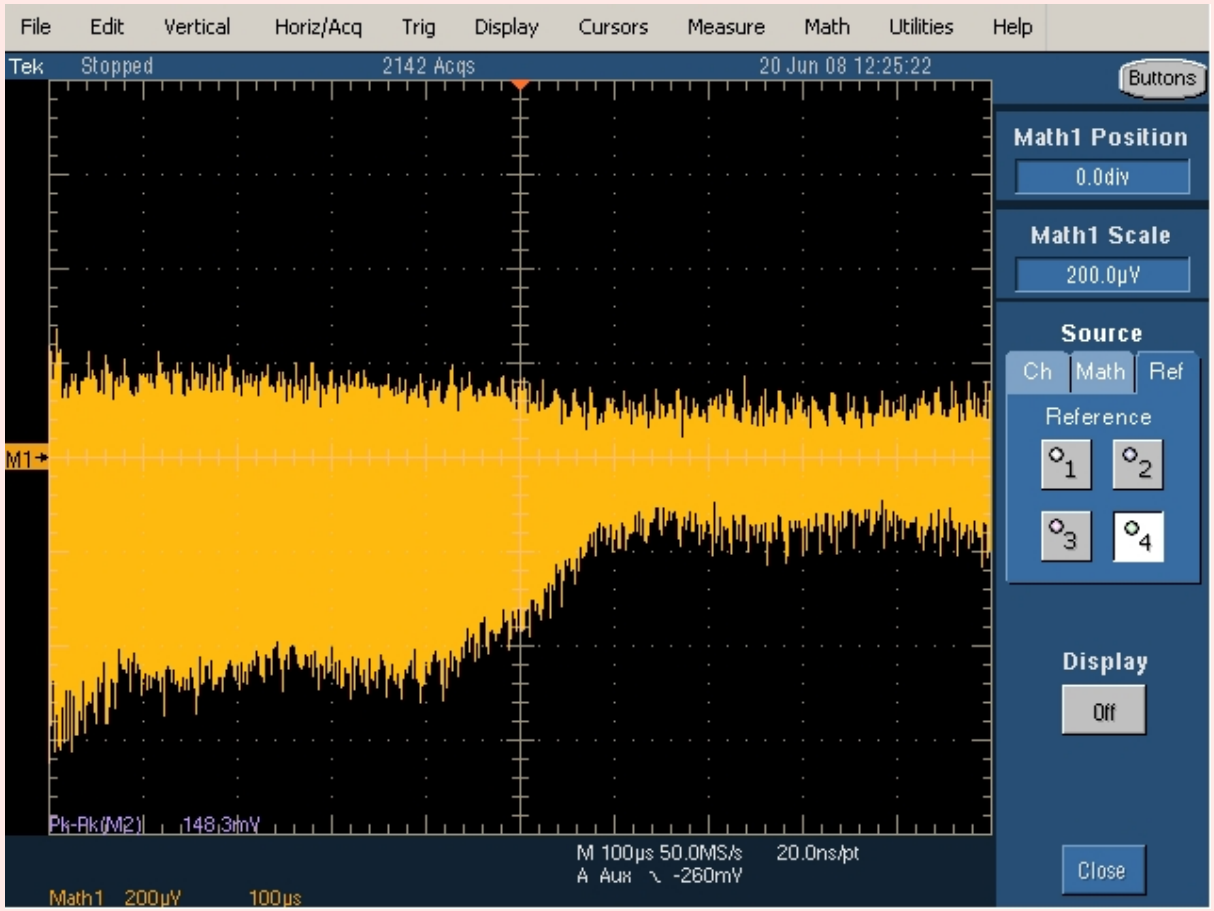


Injection



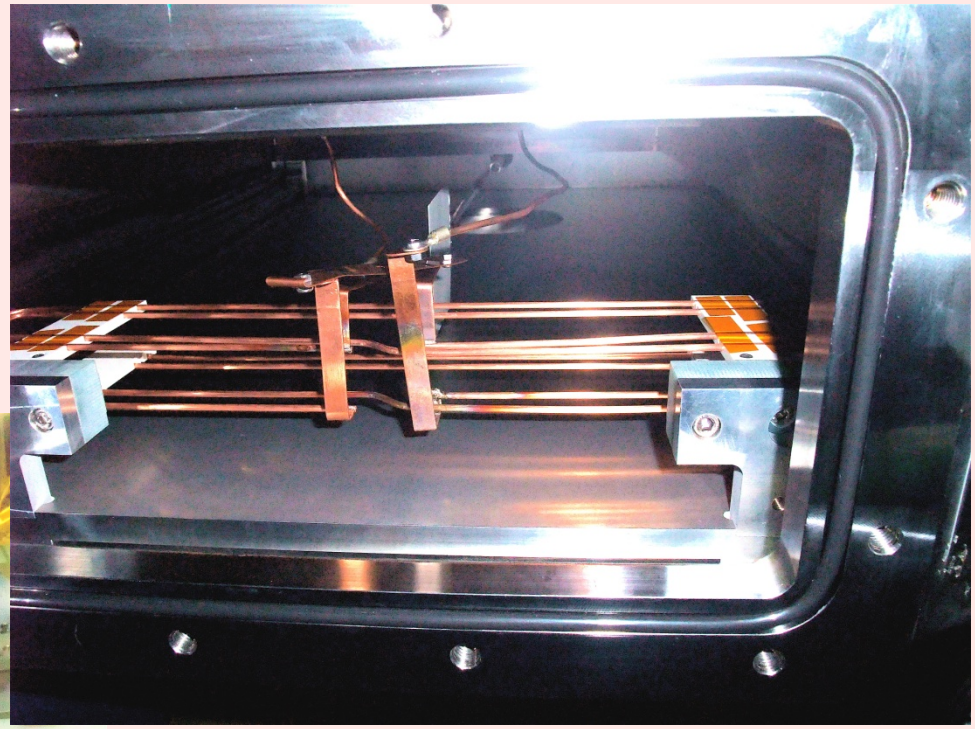
Measured revolution frequency : f_0 = 1591.84 kHz

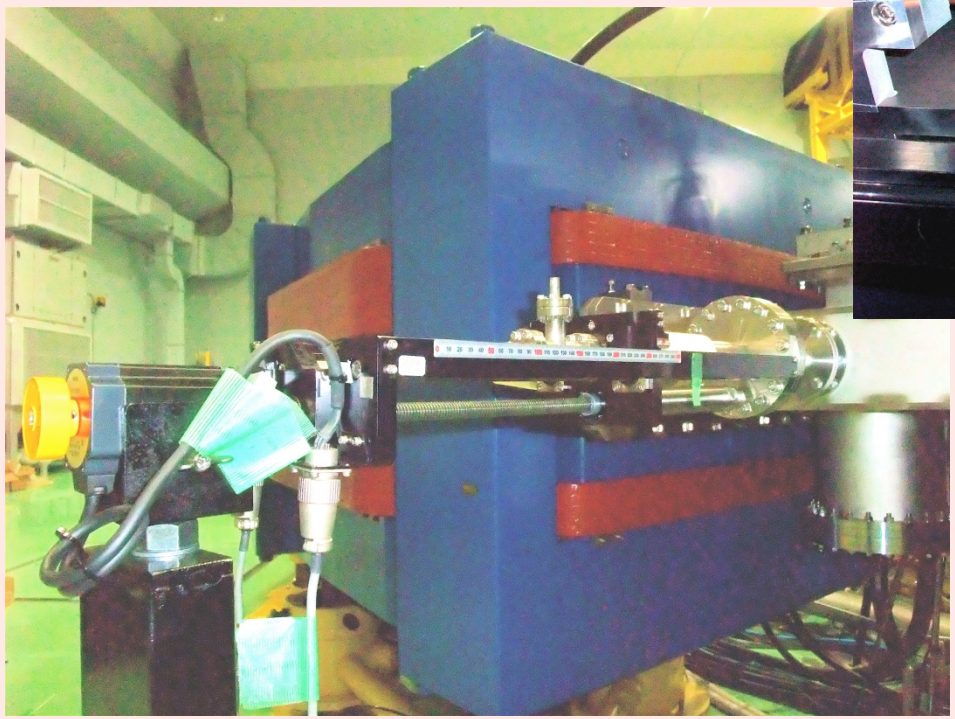
Resonant beam loss at ~25MeV



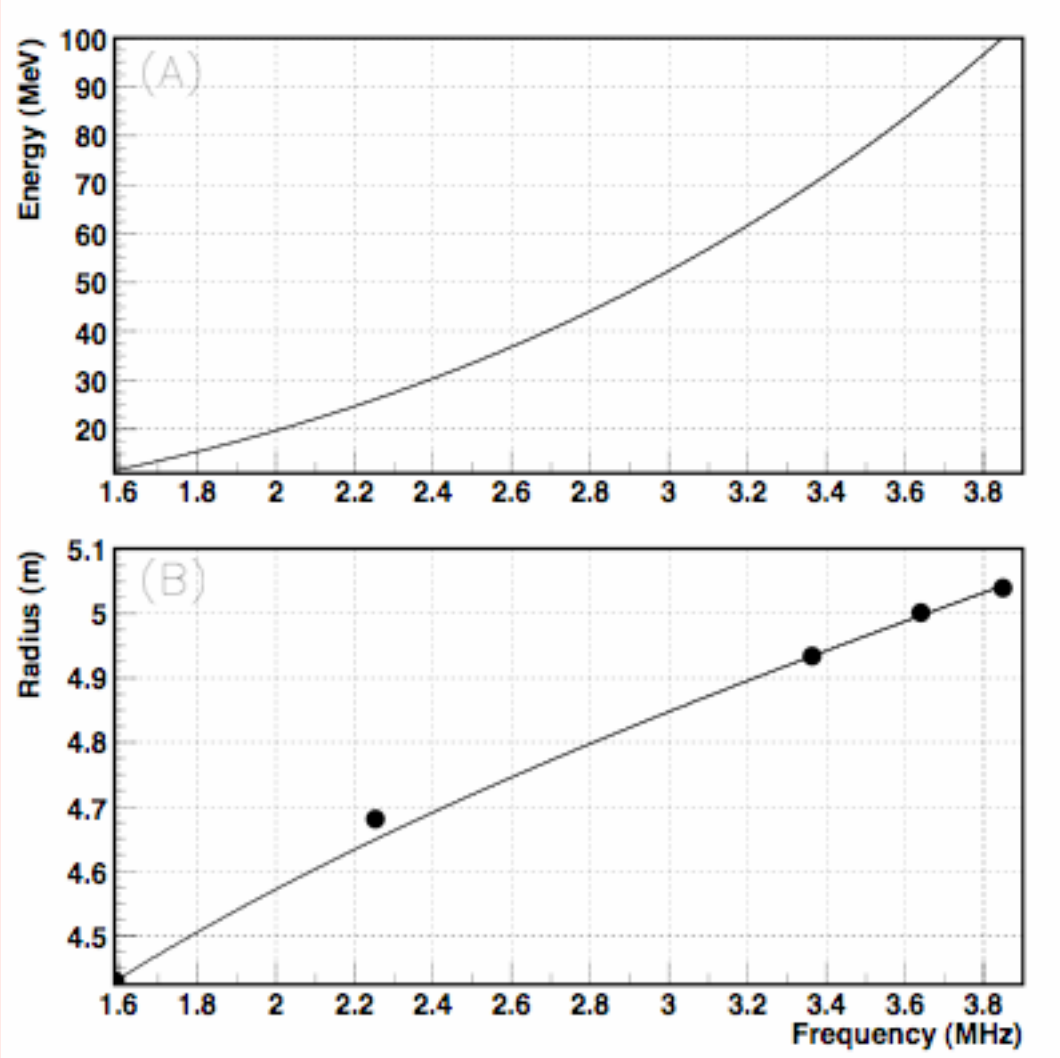
Detecting accelerated beams

Radial probe with fluorescent screen
can detects a beam at an arbitrary position.





Scaling rule



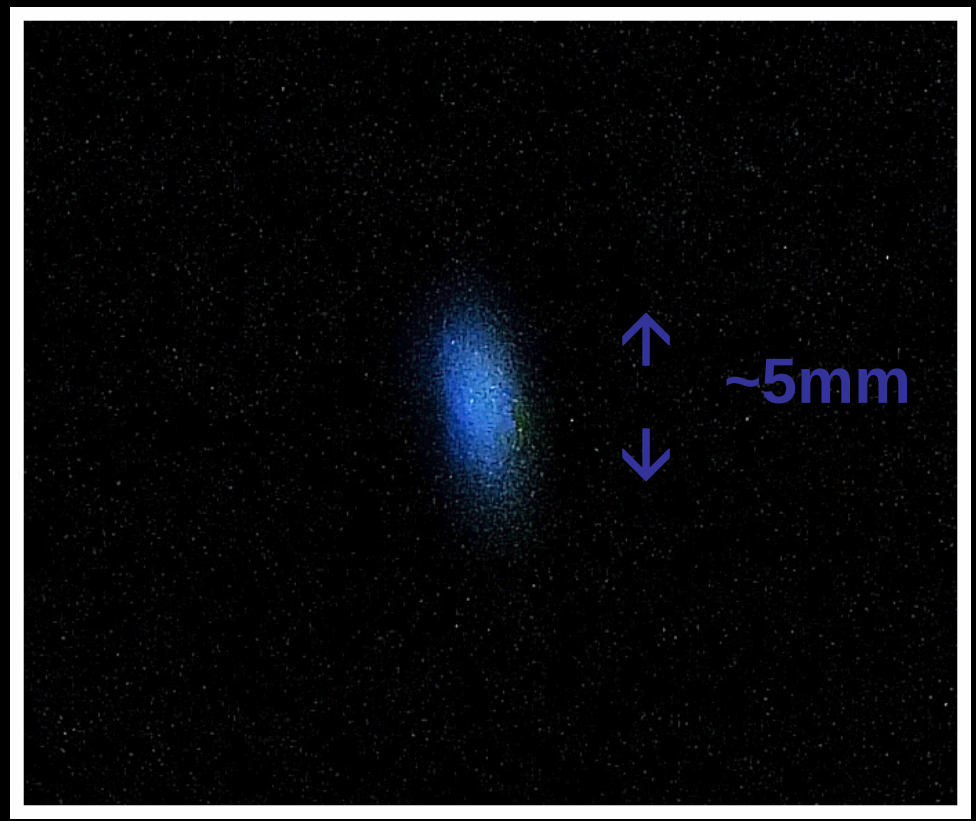
$$(B/B_0)=(R/R_0)^k$$

$$k=7.5$$

Reference values;

R_0= 4430 mm
f_0 = 1591.84 kHz
E_0= 11.6 MeV

100 MeV beam



Fluorescence of a beam
at R=5039mm (~100MeV)


100MeV
2008. 6. 3

To increase beam-intensity

We have two plans;

(1) **Additional iron-plate at D-pole**
to push locally the betatron tune
away from a resonance

(2) **Replace electrostatic-septum by another kicker**,
to improve the injection efficiency.

SUMMARY

- Booster

  is very stable under operation with

  1.5 MeV => 11.6 MeV, 59 Hz

  Extracted beam intensity is ~1.0 nA

- Main ring

  successfully accelerated proton beams up to 100 MeV,

  with repetition rate of 29.5 Hz.

  100 MeV is a present energy limit restricted by the radiation safety regulations.

- Next task

  to increase beam intensity,

  and extract 100 MeV beams.

FFAG-ERIT

THPP067

Purpose of Project
(NEDO 3-year project: 2005-2007)

- Development of a prototype of compact accelerator-based thermal/epithermal neutron source for Boron Neutron Capture Therapy(BNCT)

- Performance

  - Neutron flux enough for 1 hour treatment
  - Thermal/epithermal neutron flux: $\phi \sim 1 \times 10^9$ n/cm^2/s

- FFAG-ERIT(Energy-emittance Recovery Internal Target) method

ERIT Emittance Recovery Internal Target

for neutron production with FFAG accelerator

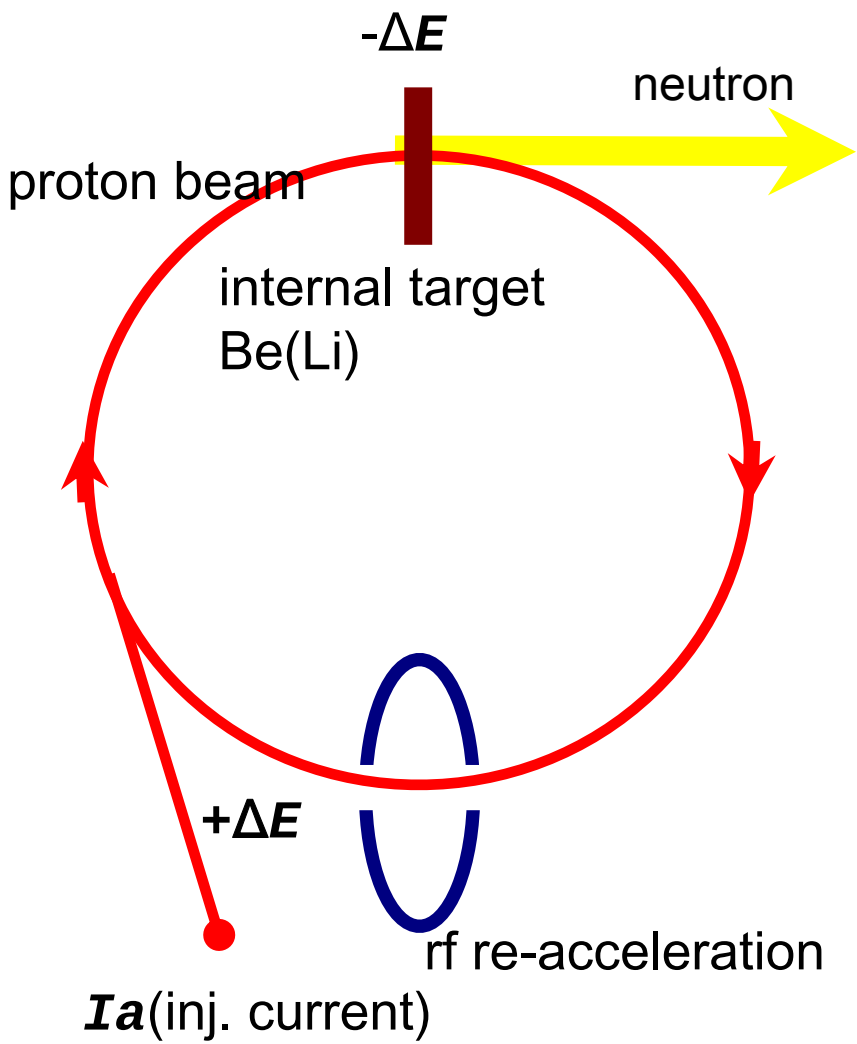
- Beam current
  - reduced by storaging the beam in the ring

$$I_s = I_a N_t$$

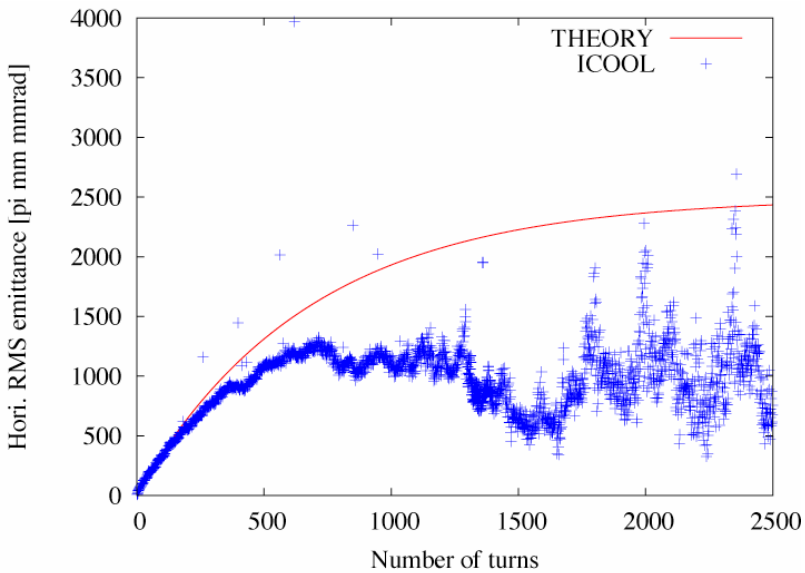
- Energy loss
- Emittance growth
  - recovered by rf re-acceleration and Ionization Cooling

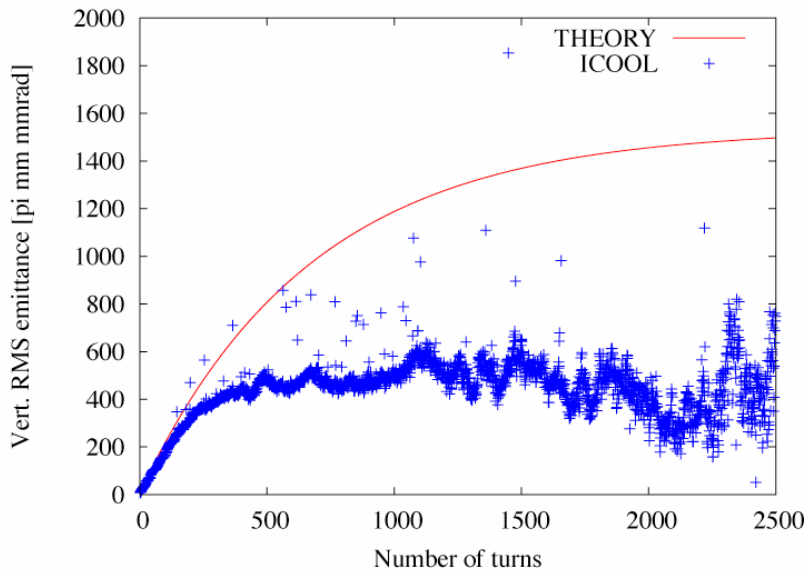
Need large momentum acceptance! -> FFAG

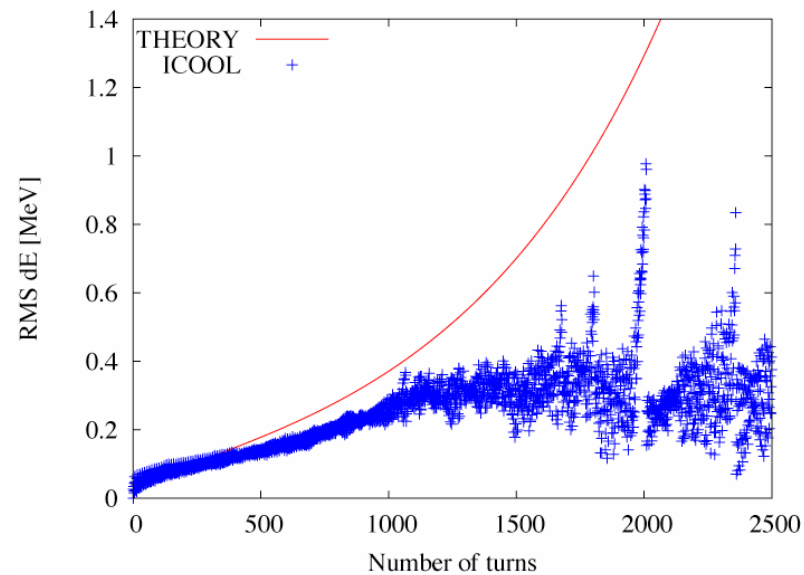
Zero-chromaticity



ICOOL simulation for ERIT scheme







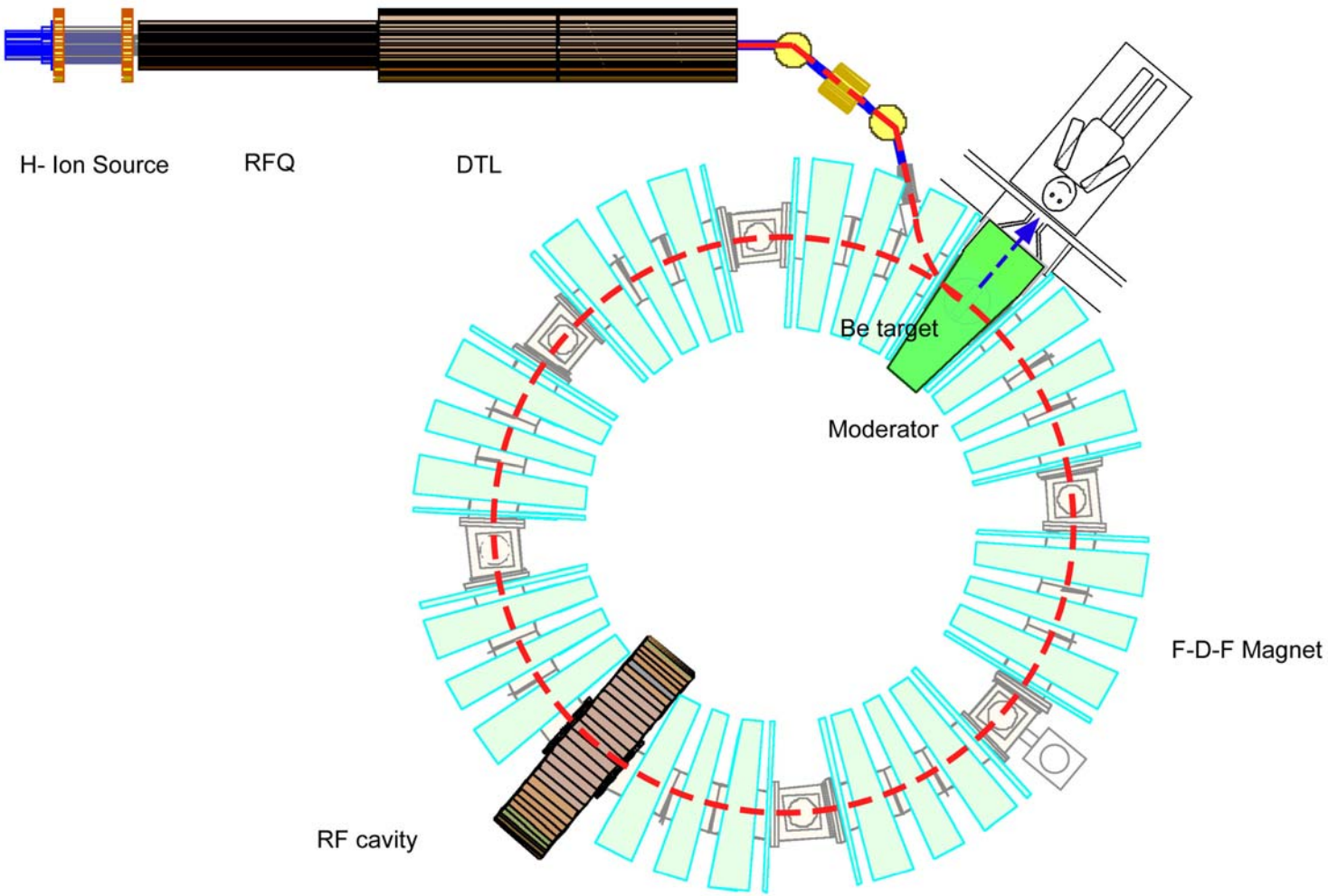
FDF radial sector FFAG

Be thickness = 5 um

Energy = 11MeV

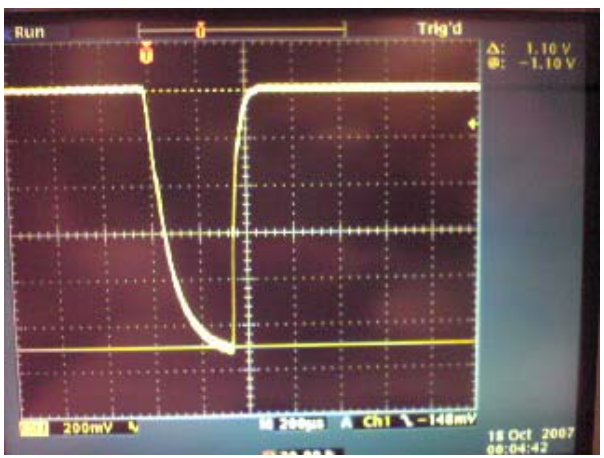
RF voltage = 200kV

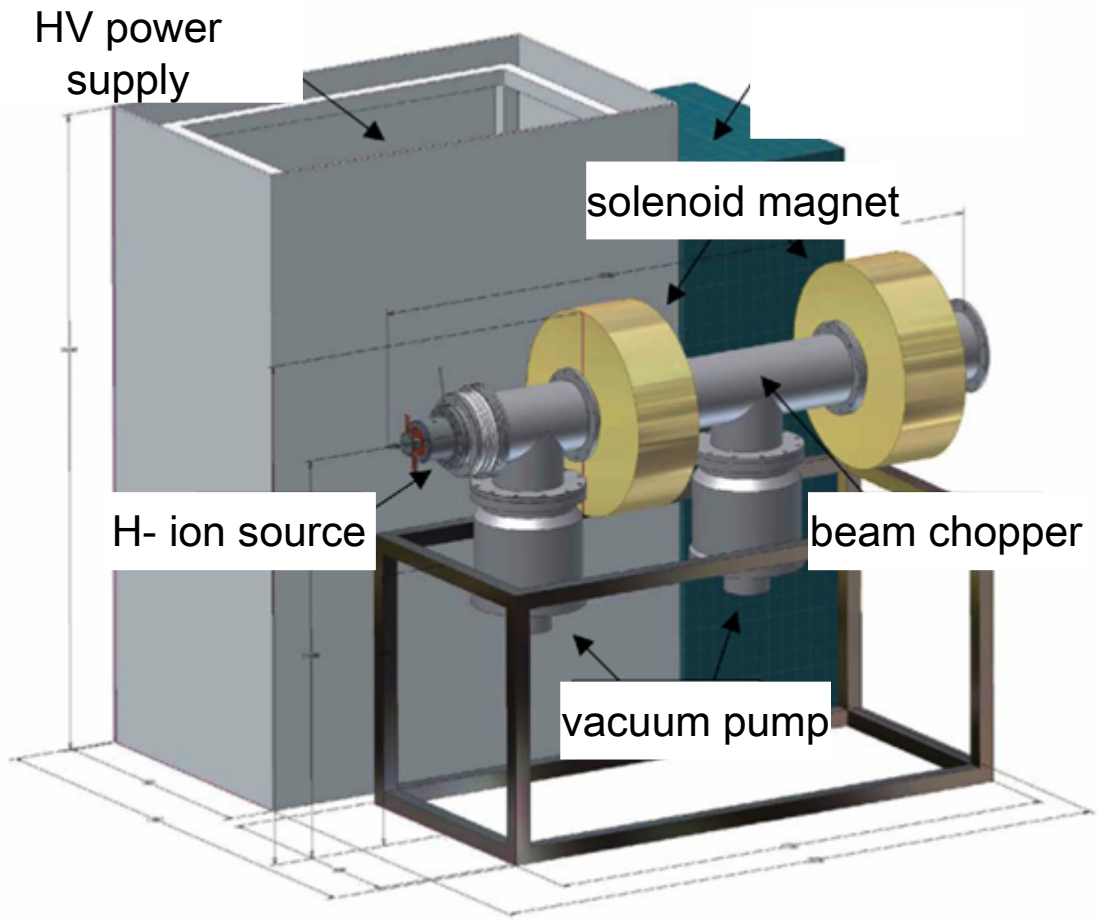
Schematic layout of FFAG-ERIT



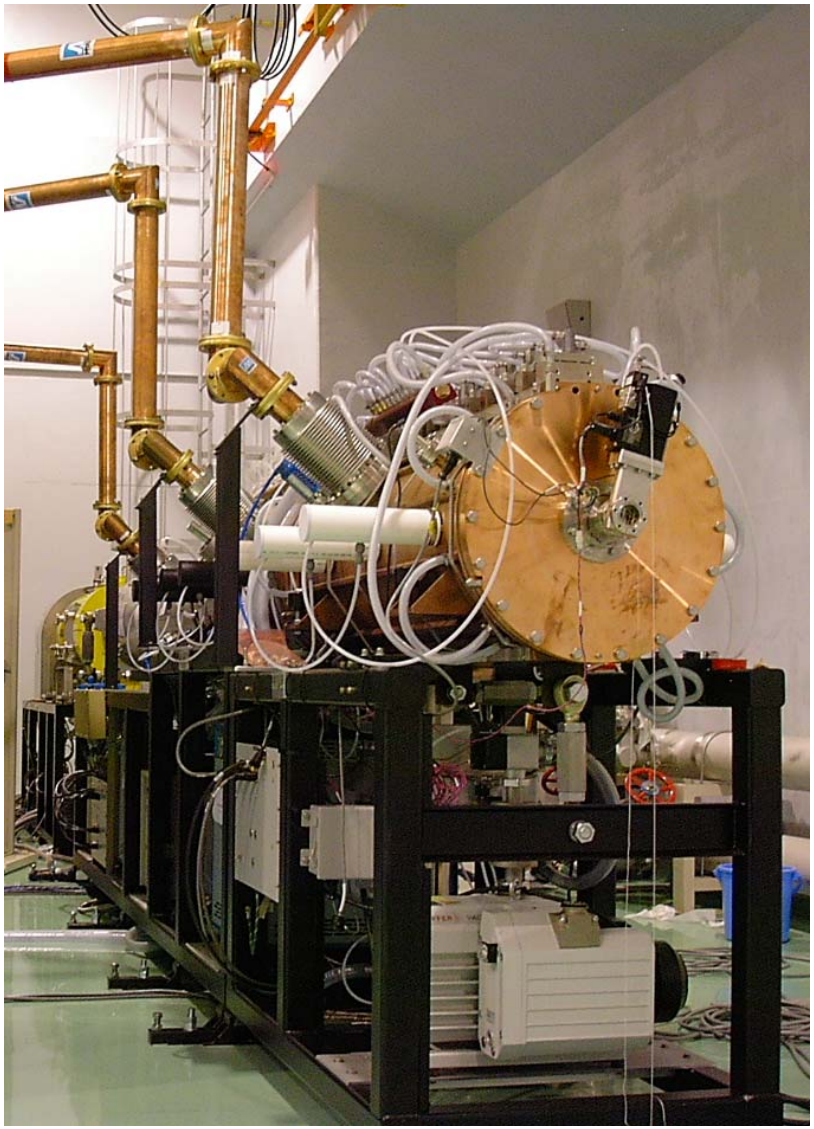
Ion source

- particle: negative hydrogen
- extraction energy： 30 keV
- rep. rate：200Hz (goal：500Hz)
- beam duration：2%, maximum
- beam current：
  - 100μA (ave.)
  - 1-5mA (peak)
- nor. emittance：<1πmm-mrad



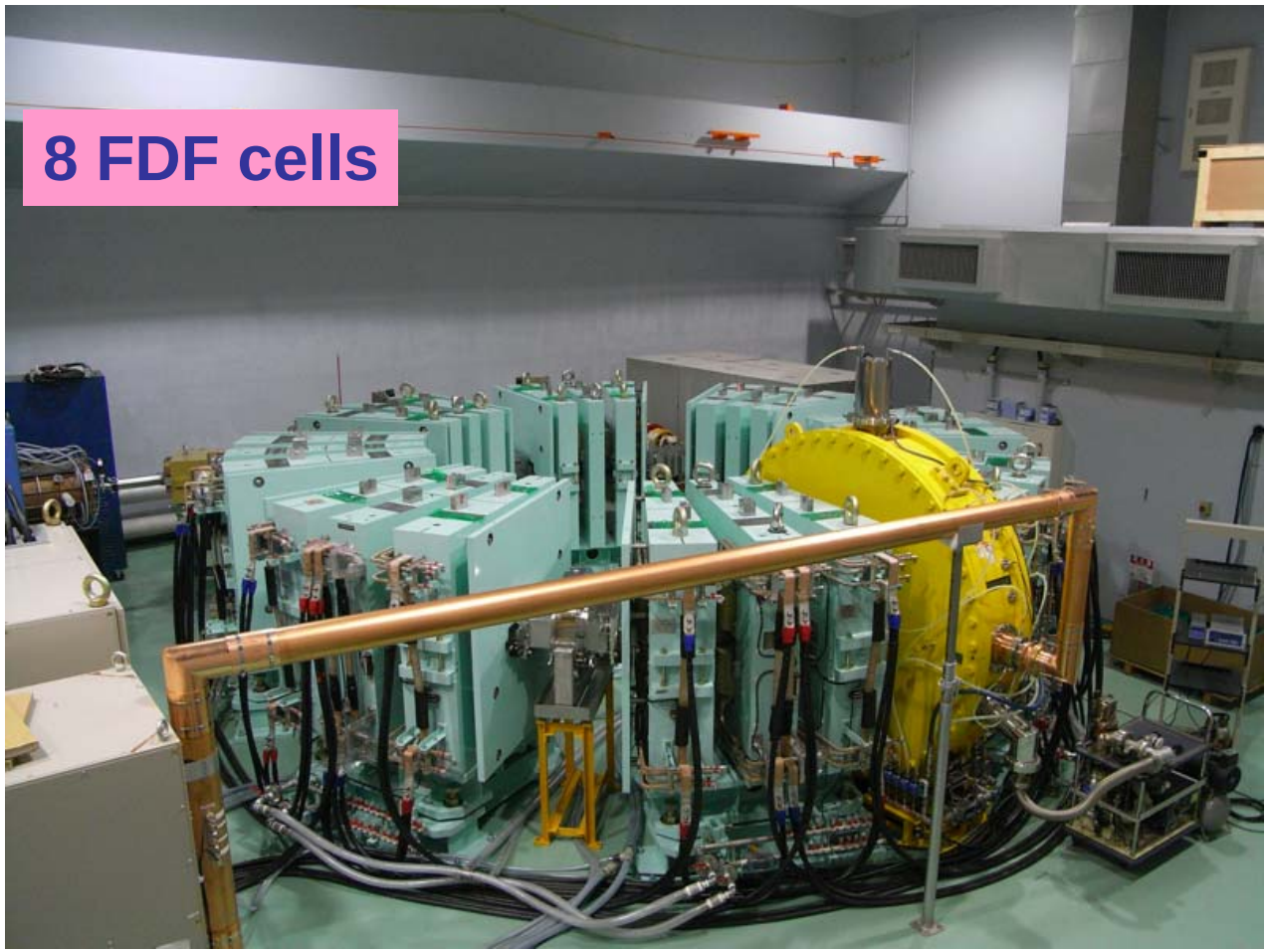


LINAC (RFQ/DTL)



- Ion speces	H^-
- Injection energy	30keV
- Extruction energy	11MeV
-beam current	>100μA
-rf duty(tube)	~ 2%
-Rep. rate	20-200Hz

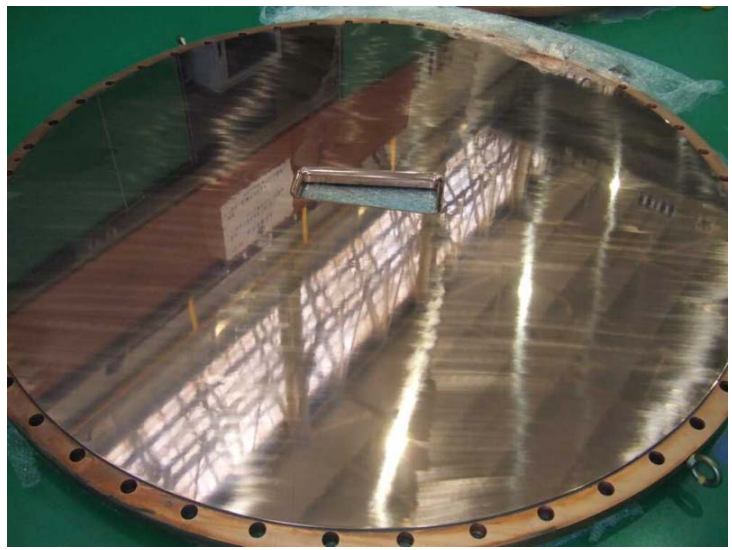
FFAG-ERIT RING



-beam energy	11MeV	-acceptance	Av>3000mm.mrad,
-circ. beam current	70mA		dp/p>+-5%(full)
-beam life(# of turns)	500-1000turns	-ν_x, ν_y	1.77, 2.27

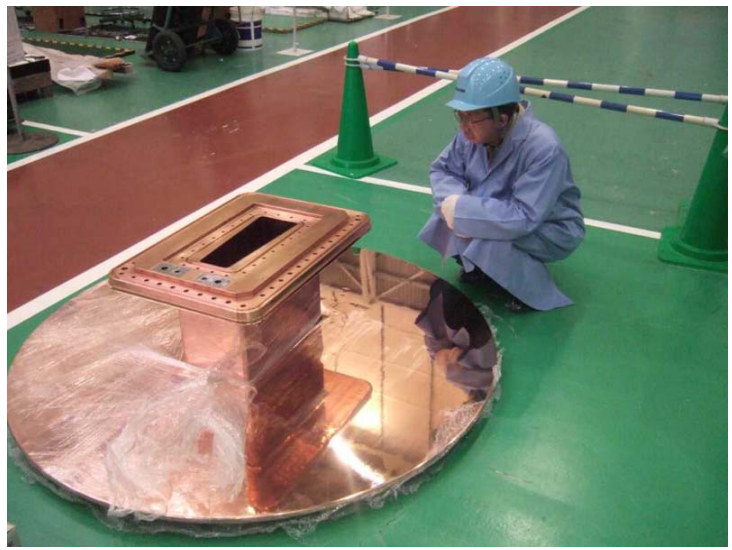
rf cavity

End plate



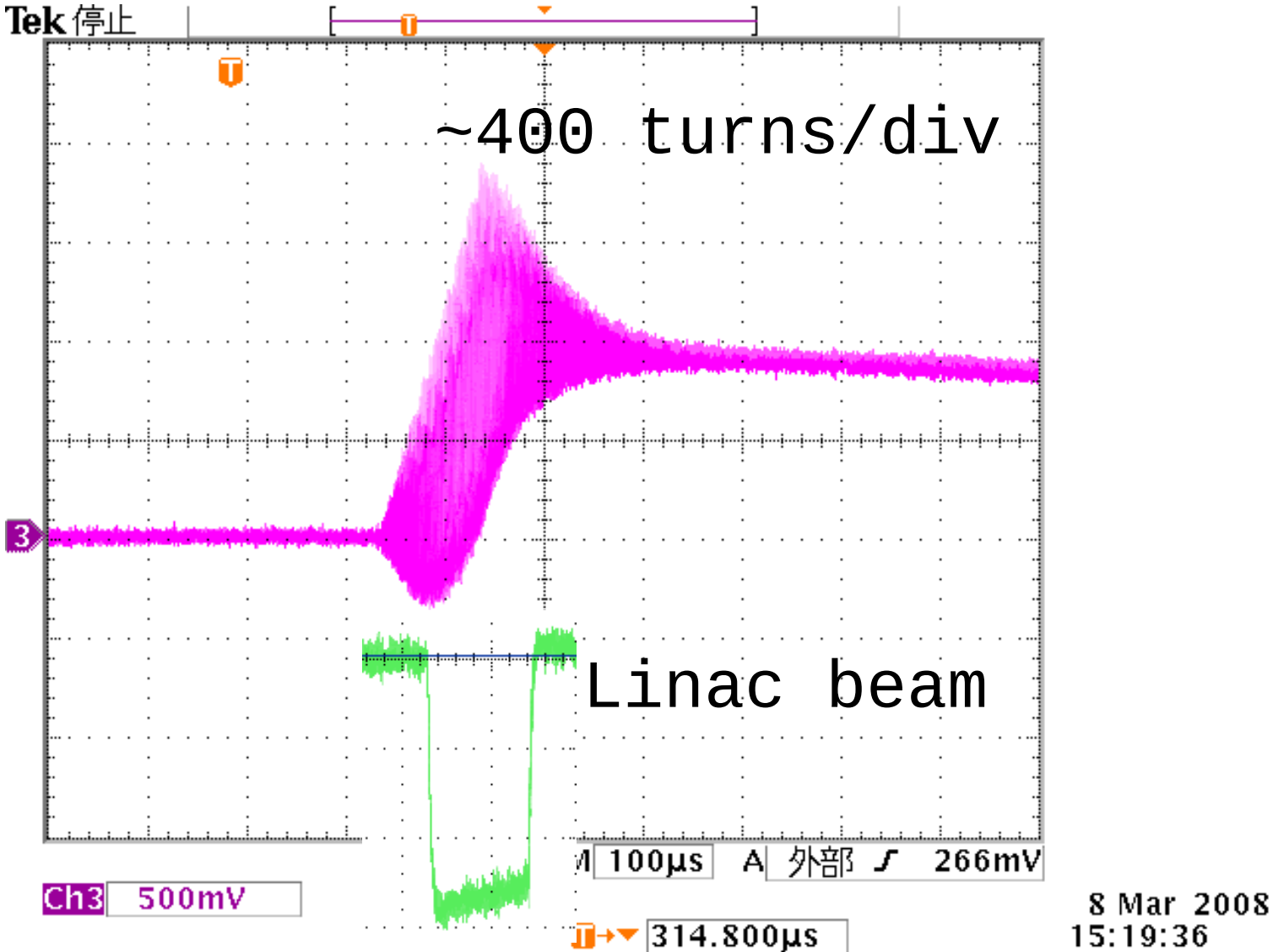
frequency
18.1MHz

rf voltage
>200kV

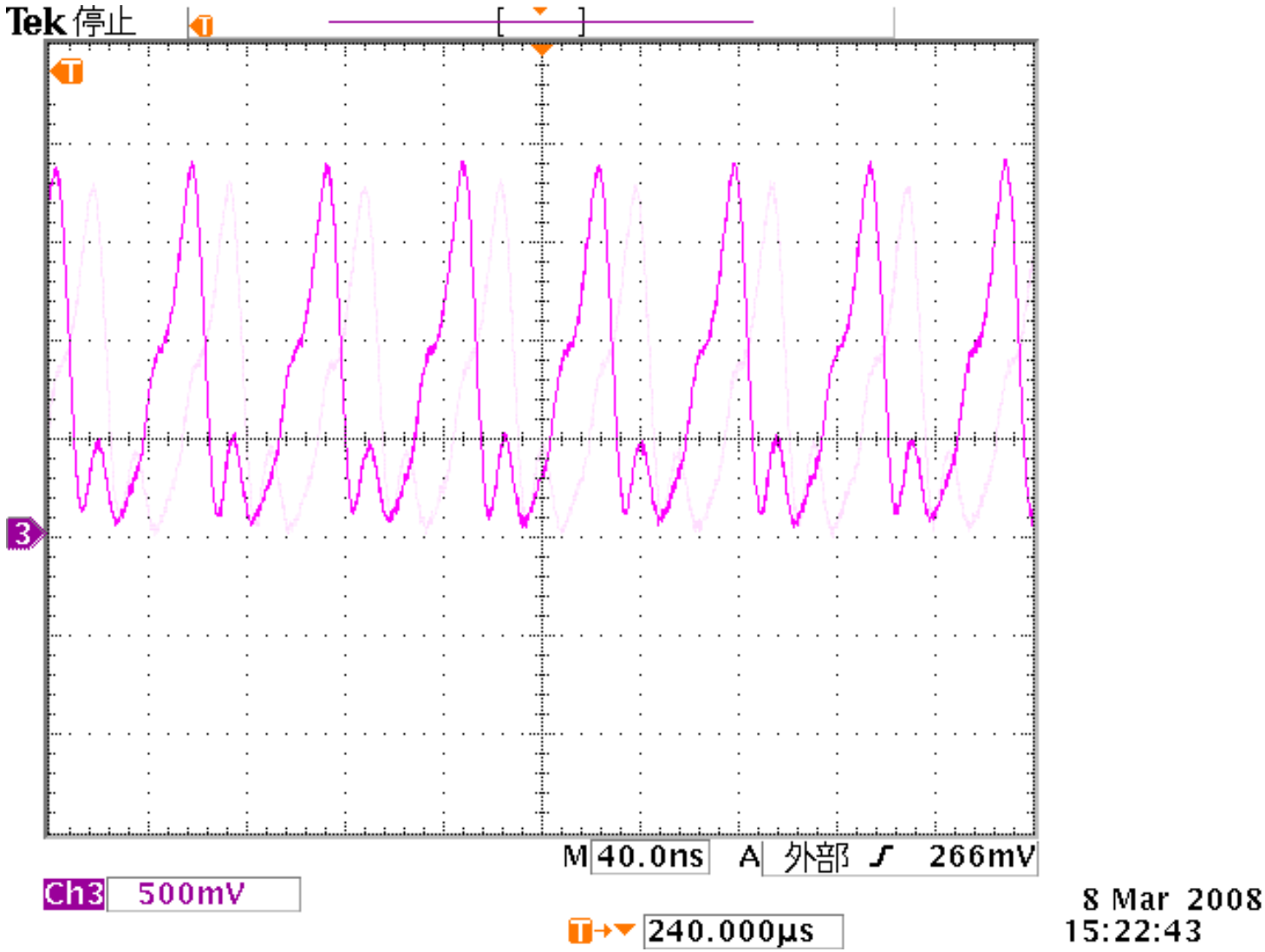


Gap capacitive plate

Beam storage



Bunch signal



First stored beam!

march 6,2008

Summary

- The accelerator –based neutron source for BNCT using ERIT has been developed and the first beam test was successfully completed.

- The beam accumulation and survival in the FFAG storage ring were increased by ERIT scheme with RF reacceleration as expected.
This is the world-first ionization cooling experiment.

- Yield and spectrum of moderated neutrons are under optimization