Status of FFAGs at KURRI

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Outline

1. Summary of the original FFAG complex in KURRI

2. Beam intensity upgrade by using H^- beam injection

3. Results of H- beam injection

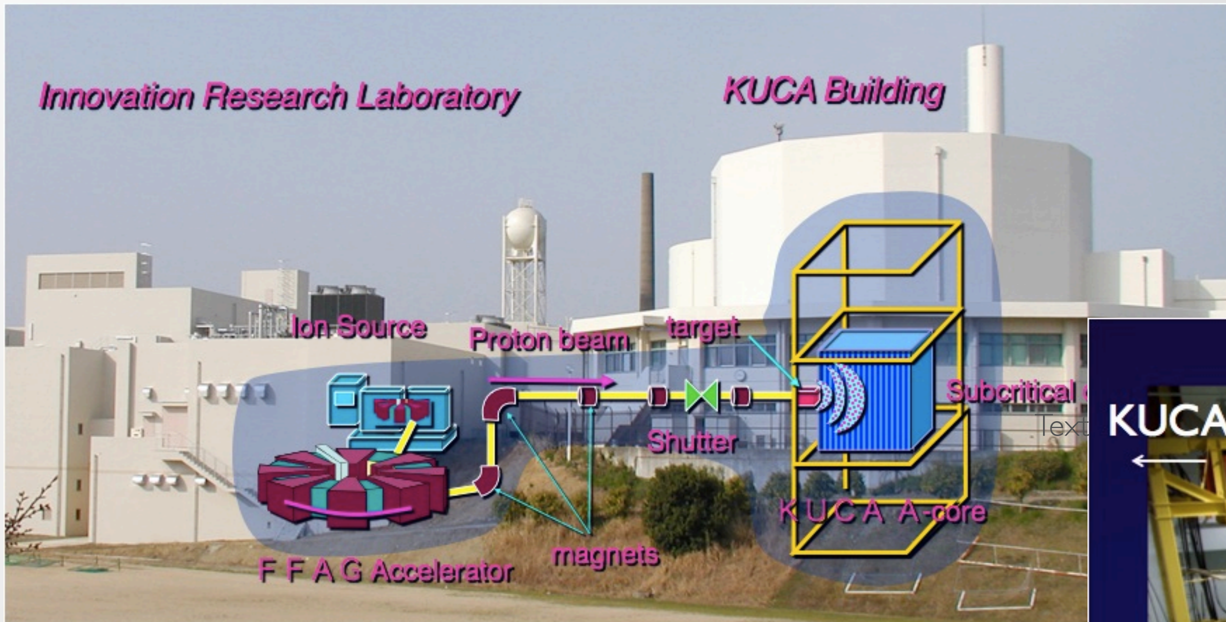
4. Road map of beam intensity and energy upgrade

5. Future of FFAGs at KURRI

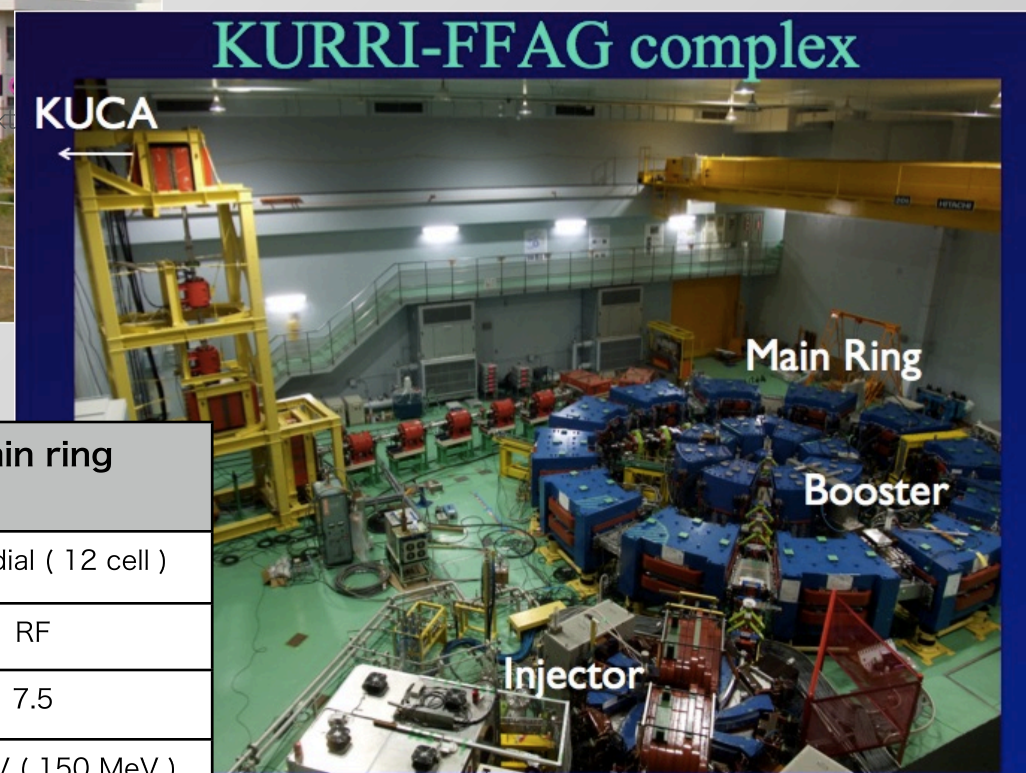
6. Summary

Summary of the original FFAG complex in KURRI

A five-year program "Research and Development for an Accelerator-Driven Sub- critical System Using an FFAG Accelerator" was approved by MEXT in FY2002.



World first experiments of ADSR
FY2008 : Uranium core
FY2009 : Thorium core



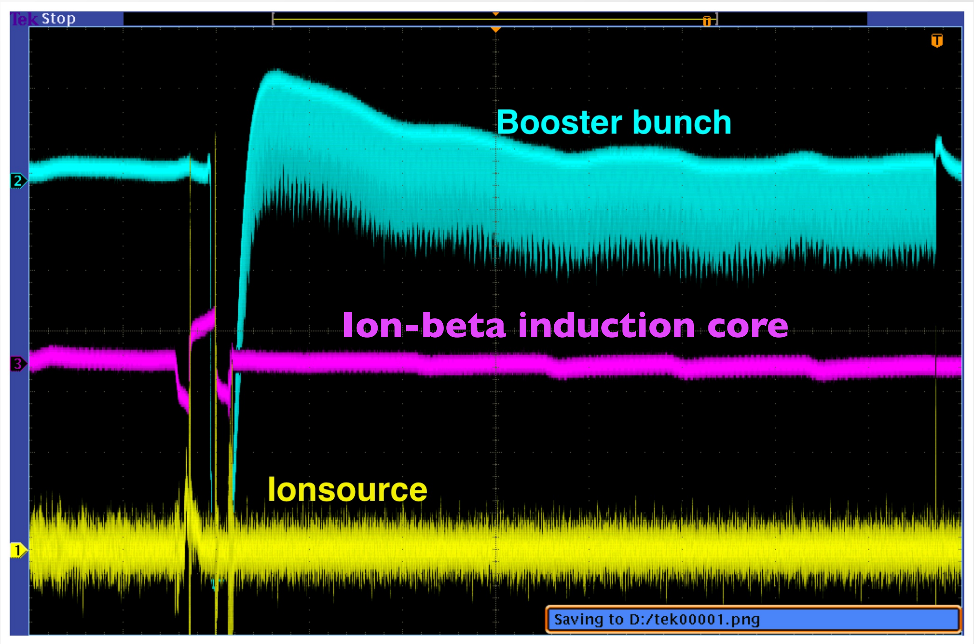
	Injector (Ion-beta)	Booster	Main ring
Lattice	spiral (8 cell)	DFD radial (8 cell)	DFD radial (12 cell)
Acceleration	Induction	RF	RF
k-value	2.5 (variable)	2.5	7.5
Energy	1.5 MeV (2.5 MeV)	11 MeV (20 MeV)	100 MeV (150 MeV)
average radius	0.60 - 0.99 m	1.42 - 1.71 m	4.54 - 5.12 m

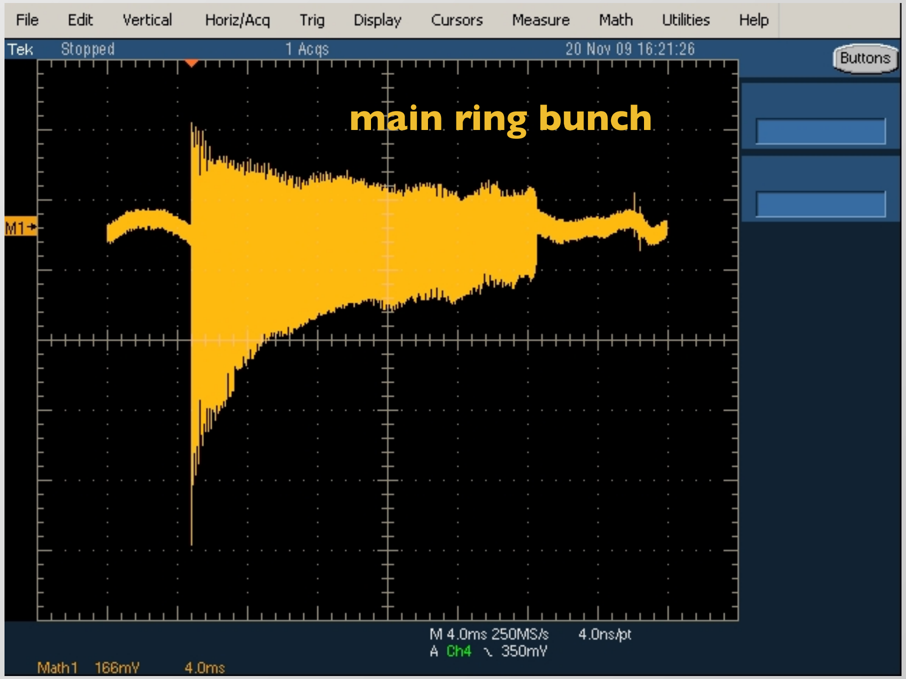
Beam characteristics of FFAGs at the end of FY2009

Ion beta peak current 25 μA

spiral sector, induction acceleration, variable energy by using multi coil ：first trail for the proton FFAG

induction scheme：energy fluctuation is large → poor stability of the injection to the booster





Booster average current 1.5nA (duration 7 μs i.e. 14-turn injection)

Highly completed machine：It took only a few hours to reach final energy once we got rf capture.

It realized designed characteristics → no beam loss

needs optimization of injection angle by adjusting the injection septum magnet

Main ring average current 0.1nA

Return-yoke free magnets make beam injection/extraction possible even in arc section, but they make leakage field larger.

Beam intensity can be improved by cure of beam loss. → but at most a few nA → change the injection scheme

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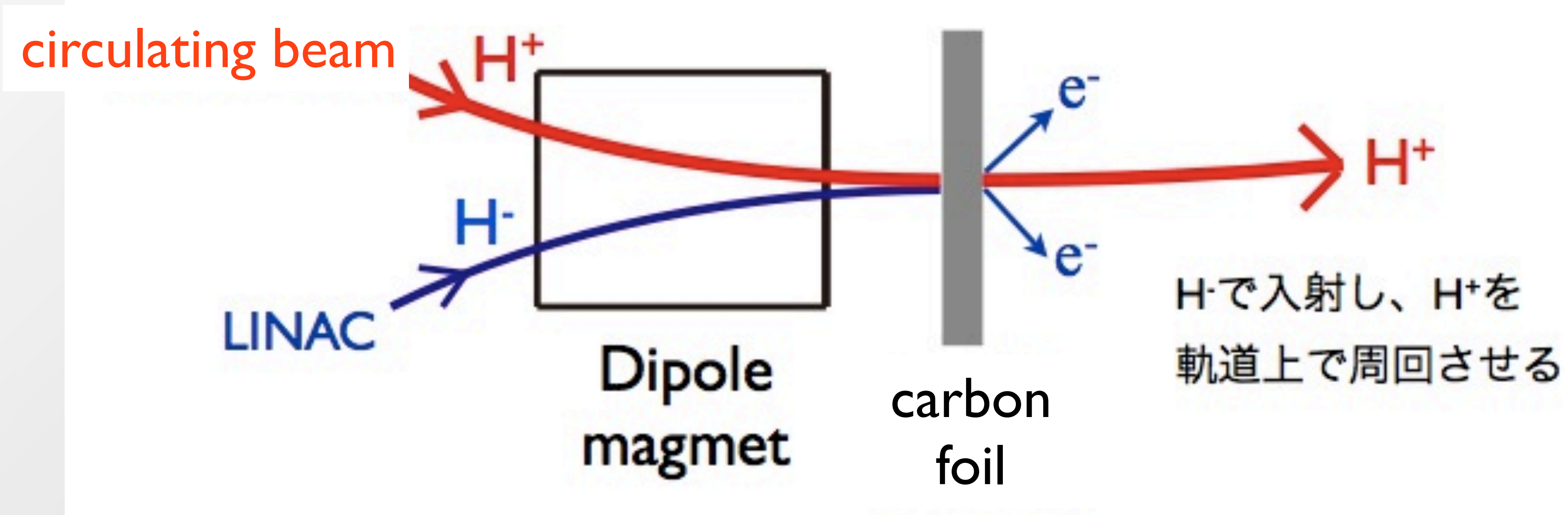
Charge exchange injection system in FFAG main ring

target beam current extracted from the main ring ~1μA

- charge exchange by using carbon foil 10/20 μg/cm^2
- FFAG-ERIT H^- Linac(11MeV) can be used !
- space charge limit

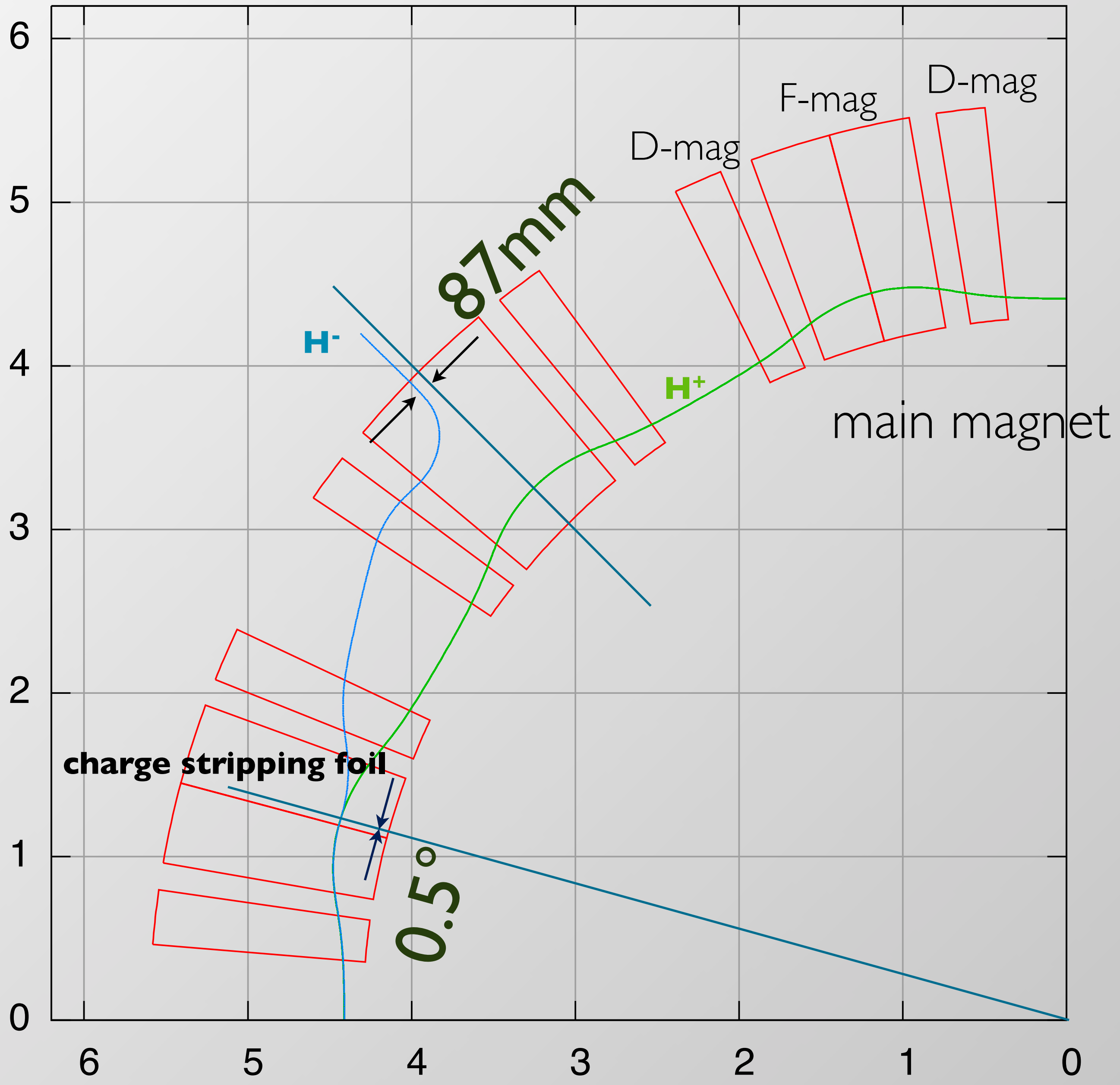
~1×10^{12}ppp (6.3μA@30Hz)

charge exchange beam injection

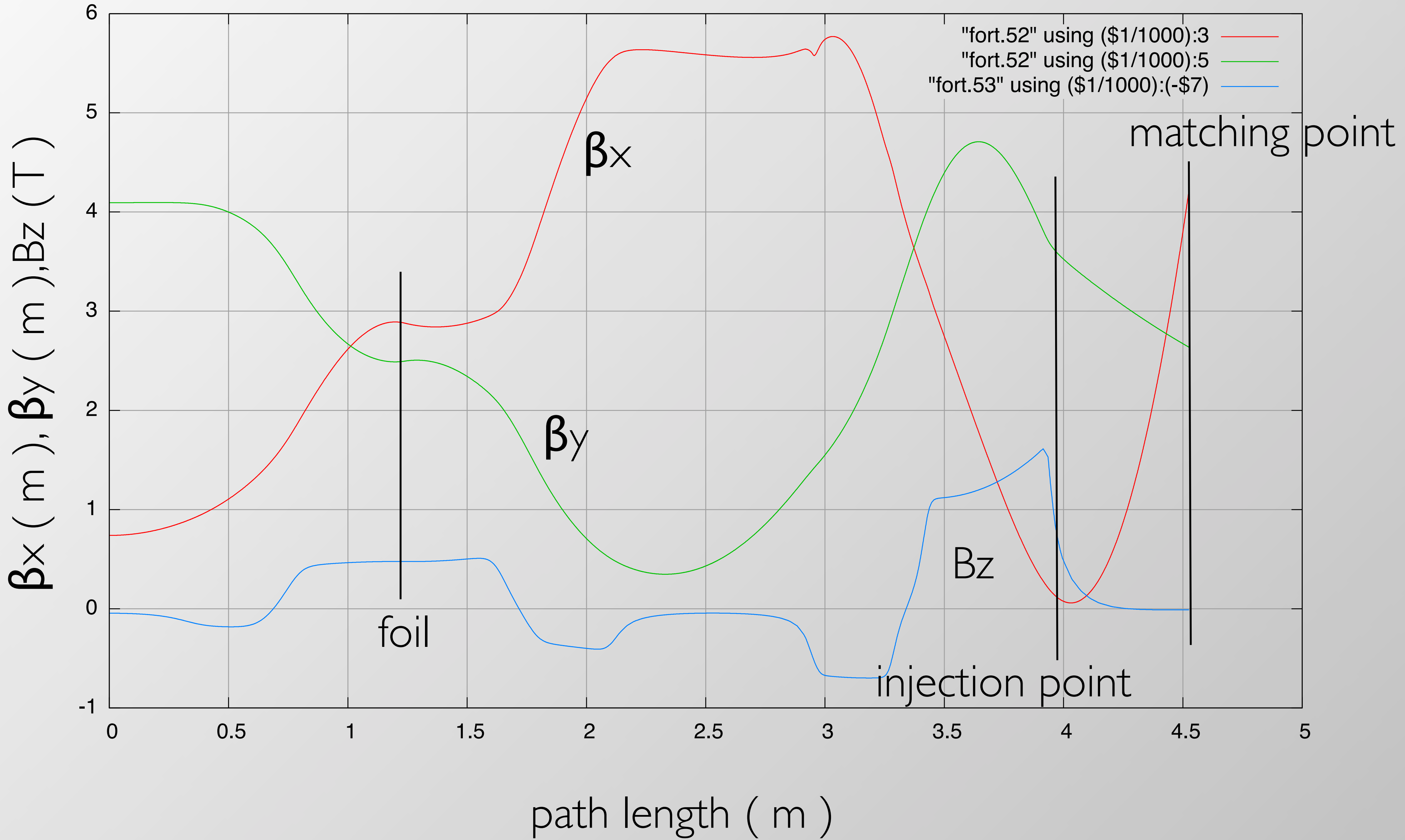


・LINACからH-を入射
・カーボンフォイルでH-をH+に荷電変換させる
・MAIN RINGでH+を加速させる

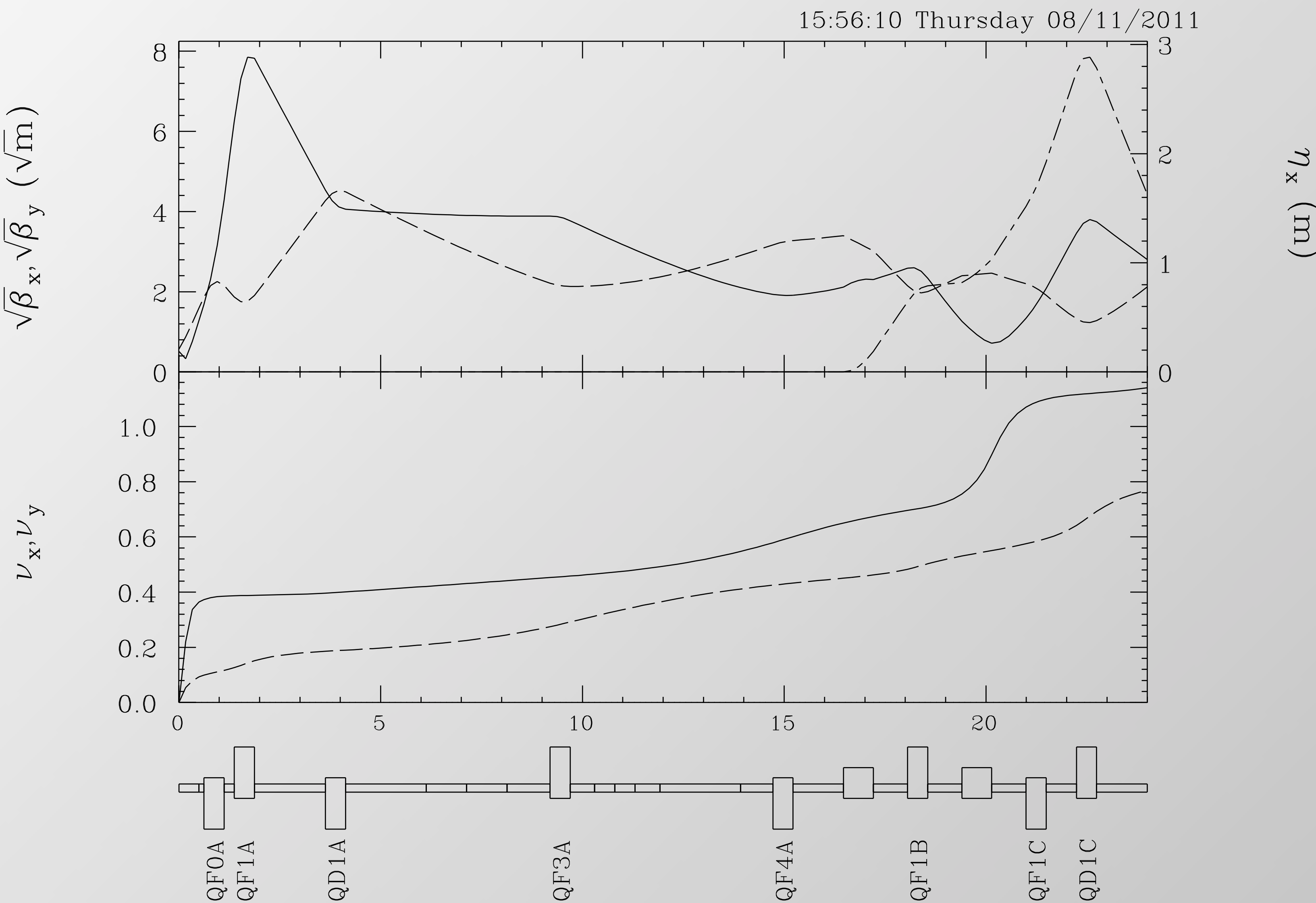
Beam injection to the main ring



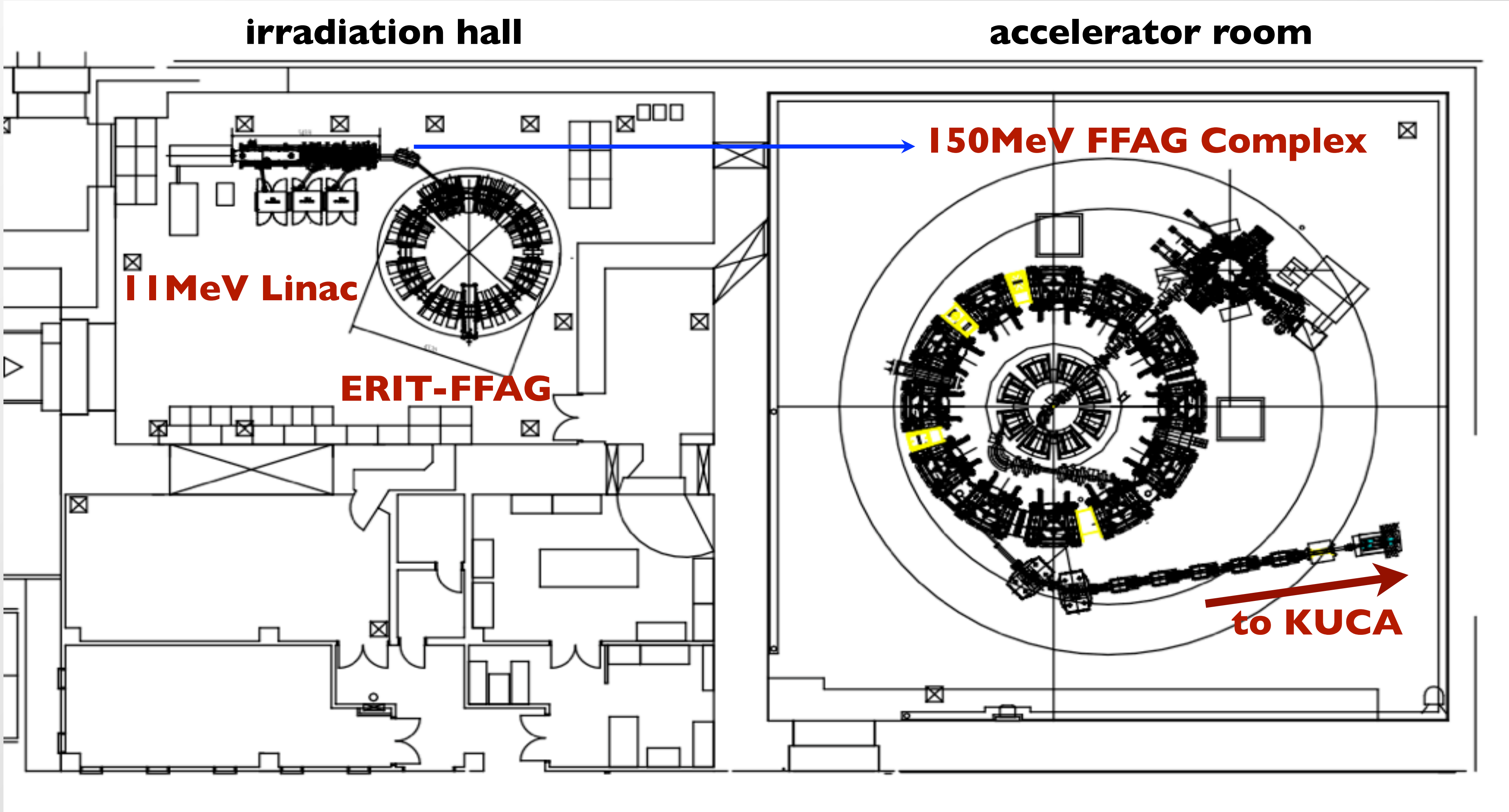
Beta functions calculated from backward tracking in the main ring



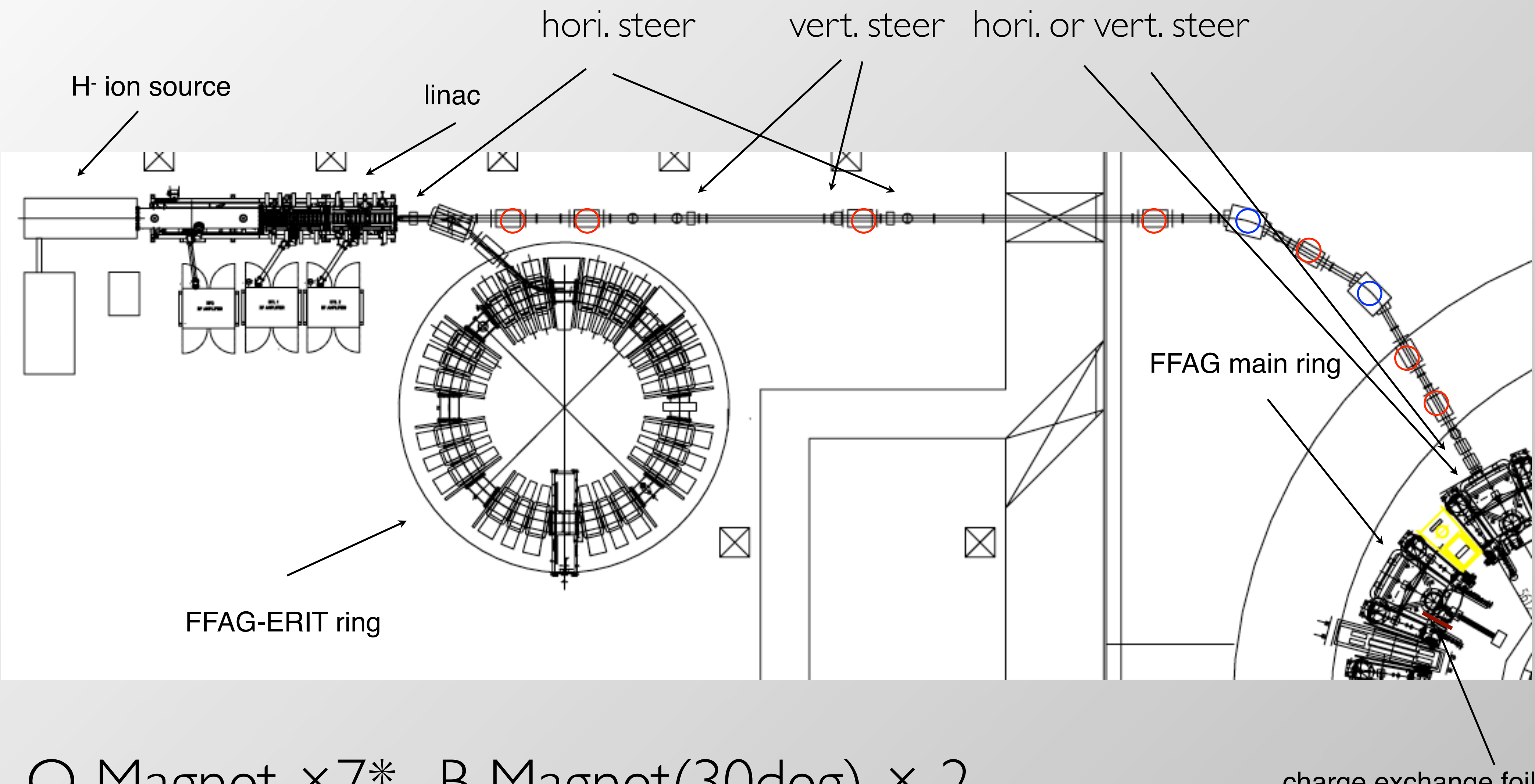
H- beam line beta functions calculated using SAD



Layout of accelerator complex in the Innovation Research Lab.



New beam-line

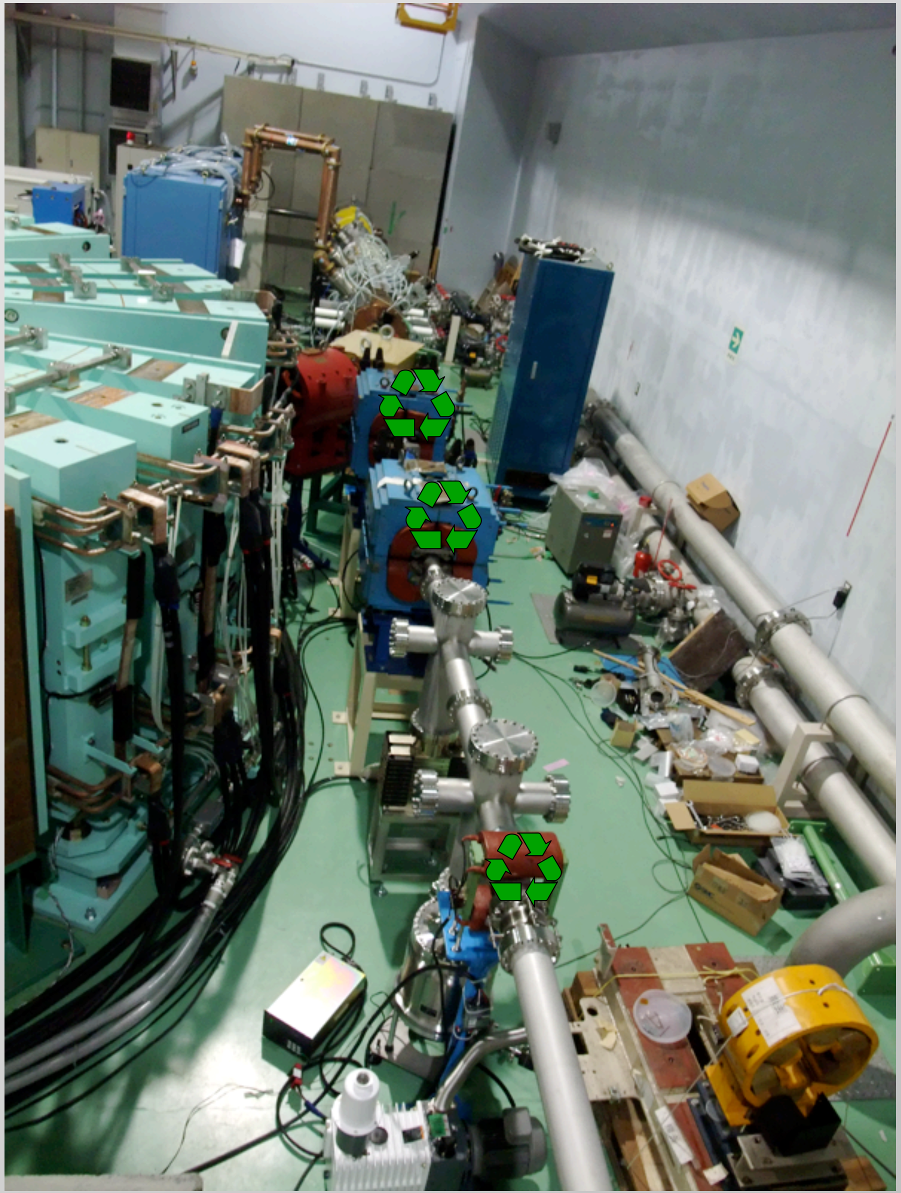


Q Magnet ×7*, B Magnet(30deg) × 2

* added one QM inMay 2011

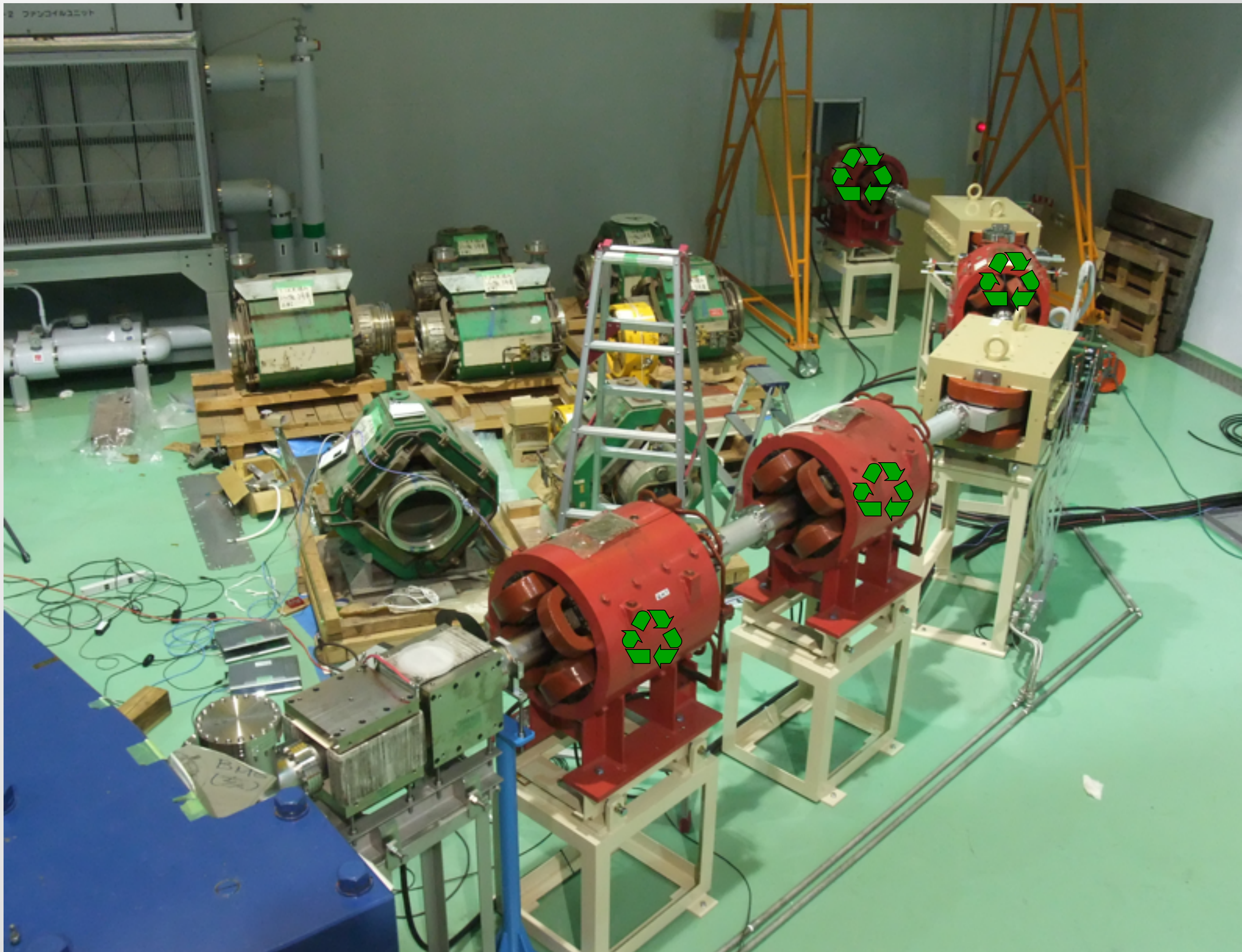
Construction of new beam line

irradiation hall

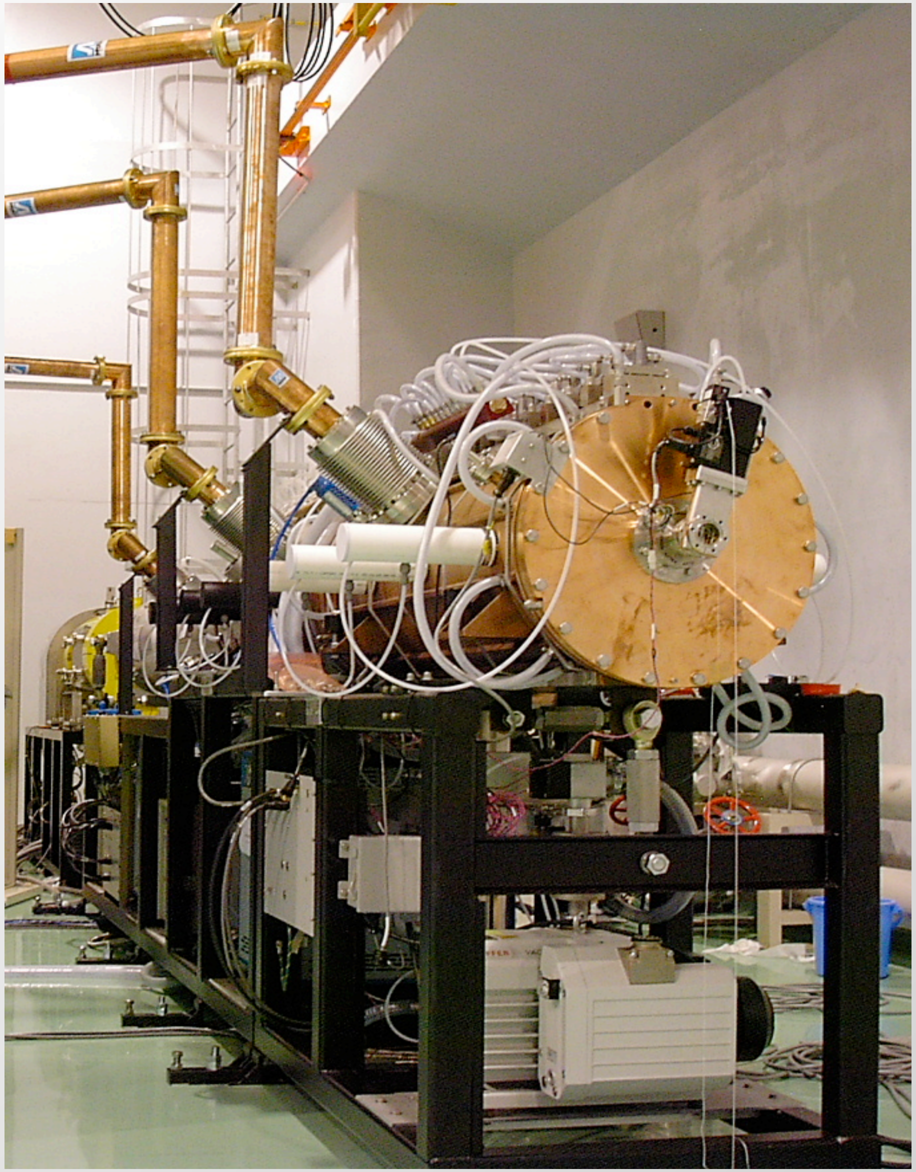


Construction of new beam line

accelerator room



New injector
Linac and H^- Ion Source



Linac beam parameter

Ion : H^-

E_{ext} : 11MeV

Beam Pulse width(MAX) : 100 μsec

Peak Curr.(MAX) : ~5 mA

: ~$3.12*10^{12}$[ppp]

(Present injector) : ~$6.00*10^{8}$[ppp]

rep. rate : 1Hz~200Hz

Horizontal

norm. emittance (90%) : 0.680 mm•mrad

Vertical

norm. emittance (90%) : 0.630 mm mrad

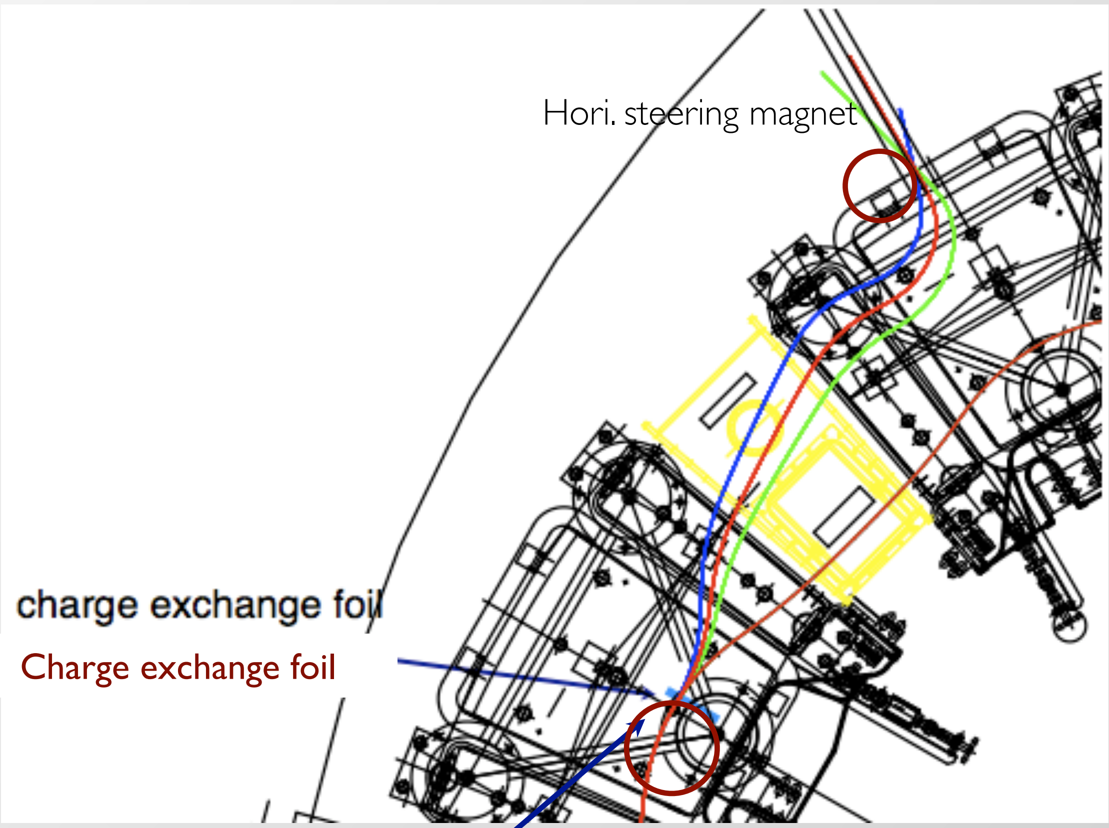
Ene. 90% : ΔE ~ 45KeV

Problems and solutions for the charge stripping injection

- Low injection energy 11MeV → Large energy loss
  Large emittance growth
- Energy loss:
  compensation by rf cavity → put rf voltage and frequency sweep during beam injection
- Emittance growth:
  Off center beam injection makes hitting probability low.
  Orbit shift due to the acceleration can be used in FFAG.

Injection orbit and charge stripping foil

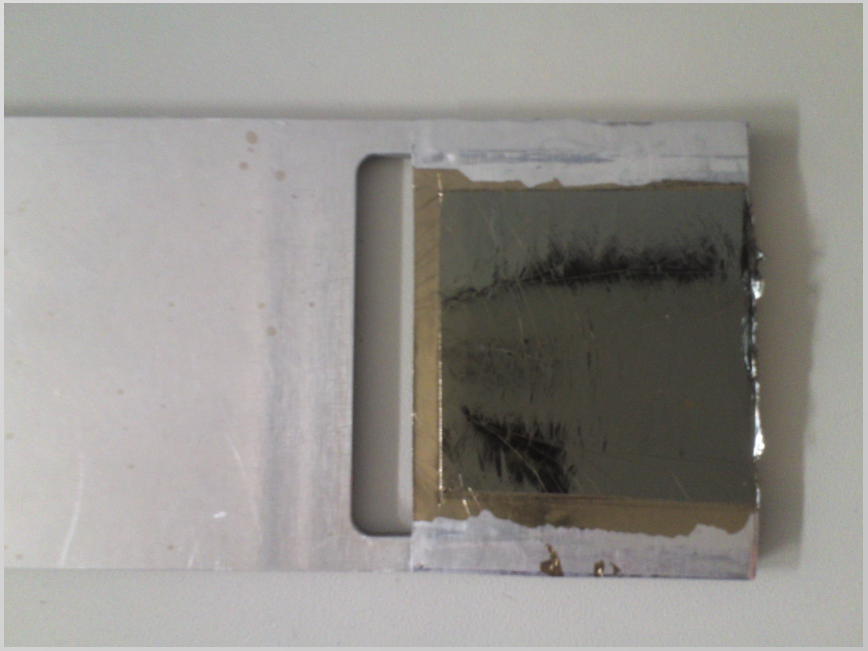
- Injected H- beam is merged into the circulating beam by using only main magnets with no ordinary injection devices such as septum magnets, bumps....
- According to the beam tracking using 3-d B-field map, charge stripping foils are designed to set around the center of the F magnet.



foil: 0.5deg upstream from the center of F magnet(red line)

Charge exchange foil

- Carbon foil (10 - 20μg/cm^2)
- Stripping efficiency ~ 98% - 100%



10μg/cm^2 two layer= 20μg/cm^2

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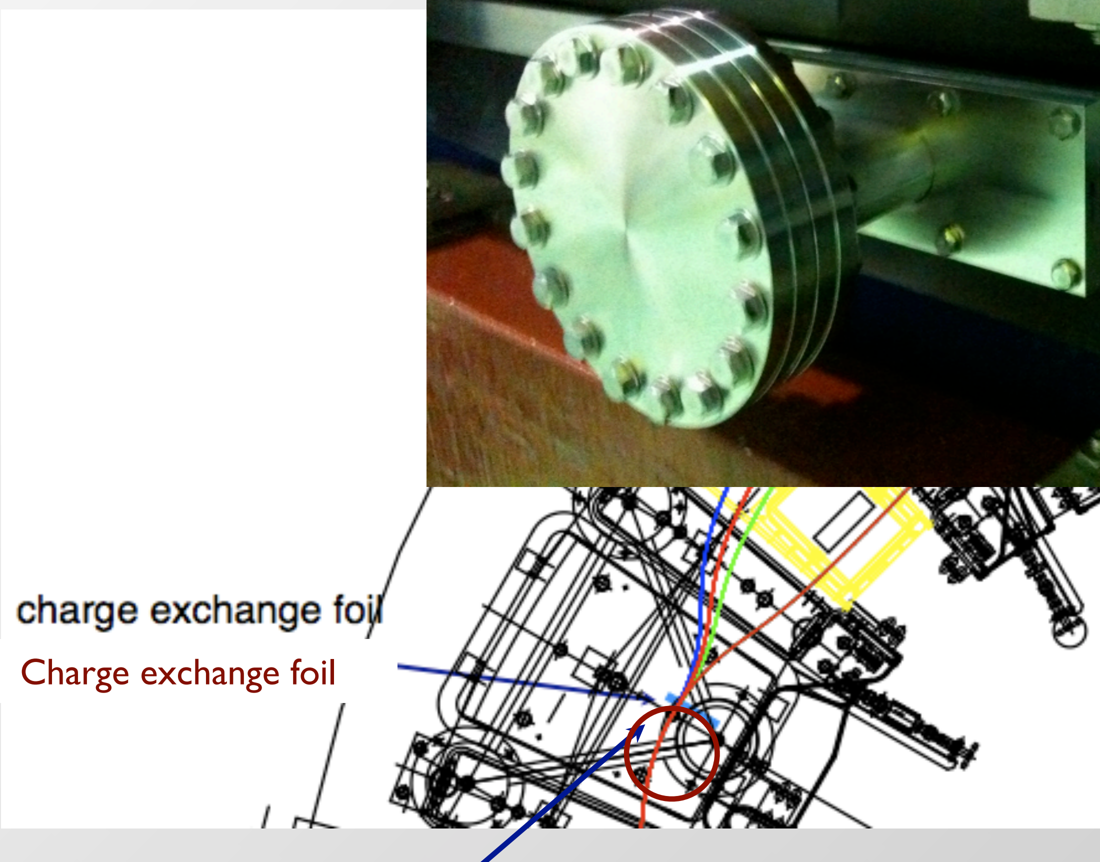

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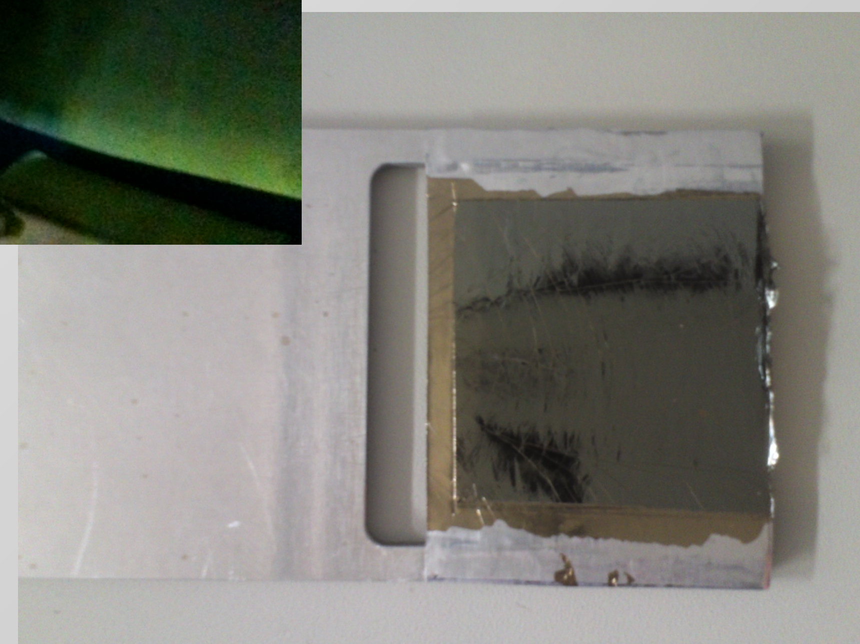

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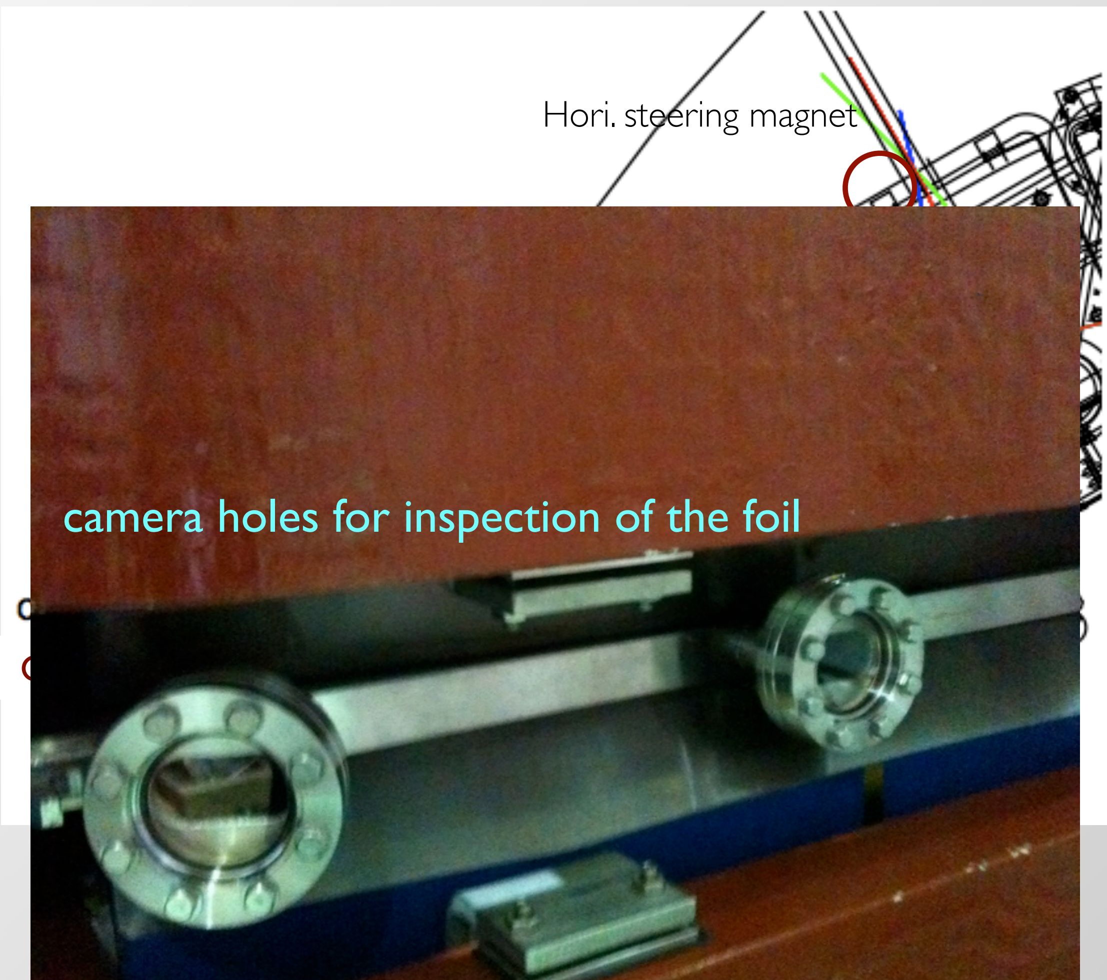

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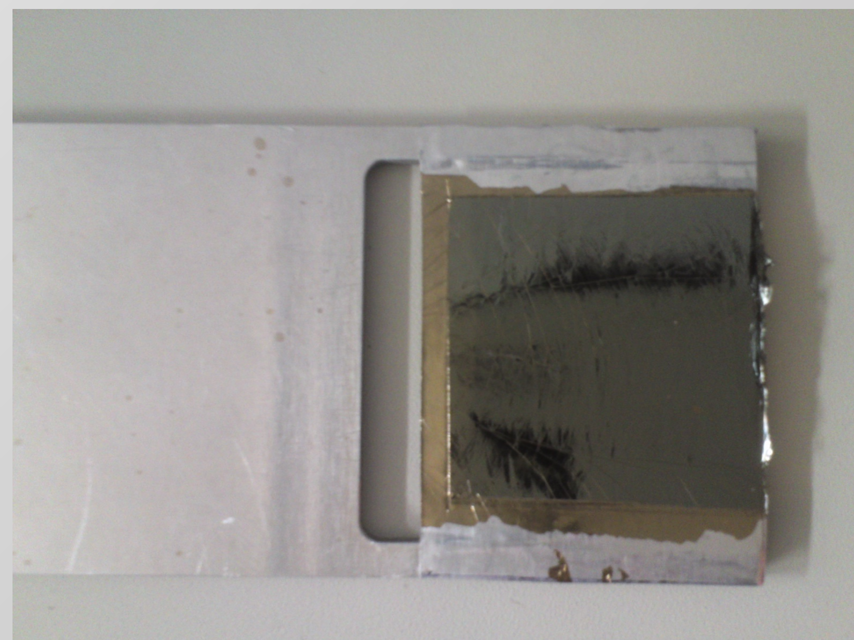

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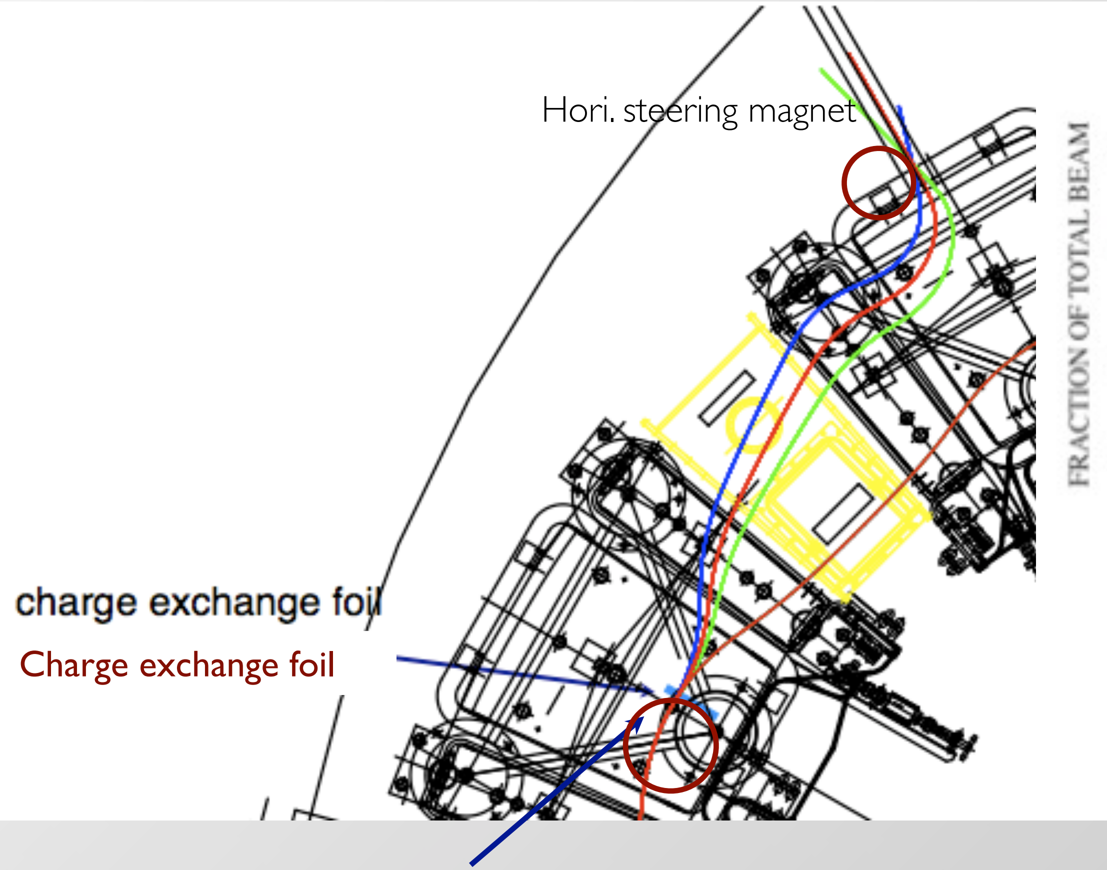
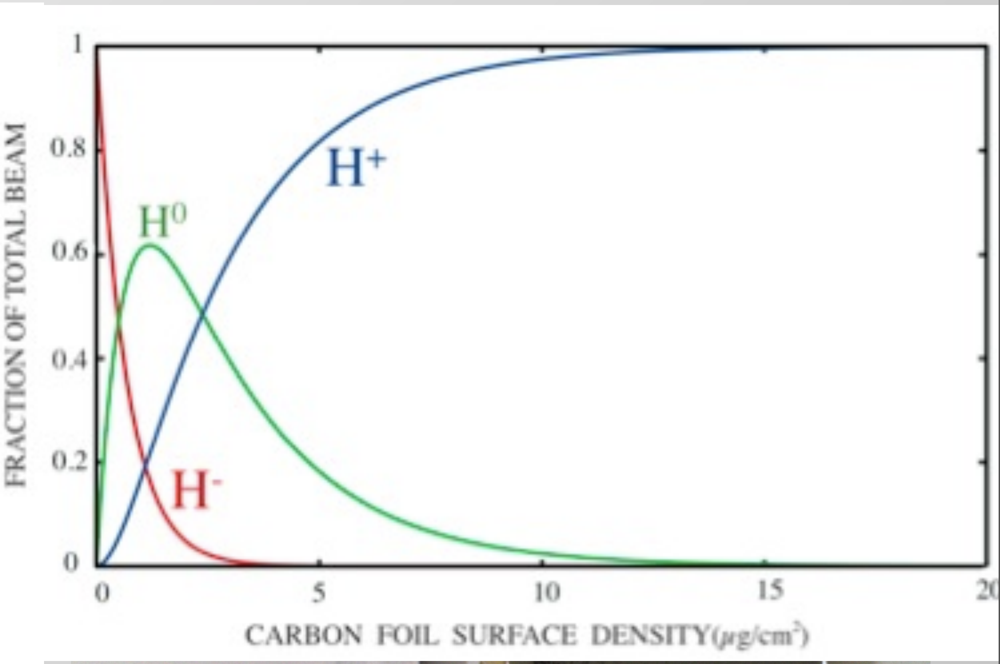


foil: 0.5deg upstream from the center of F magnet(red line)



10μg/cm² two layer= 20μg/cm²

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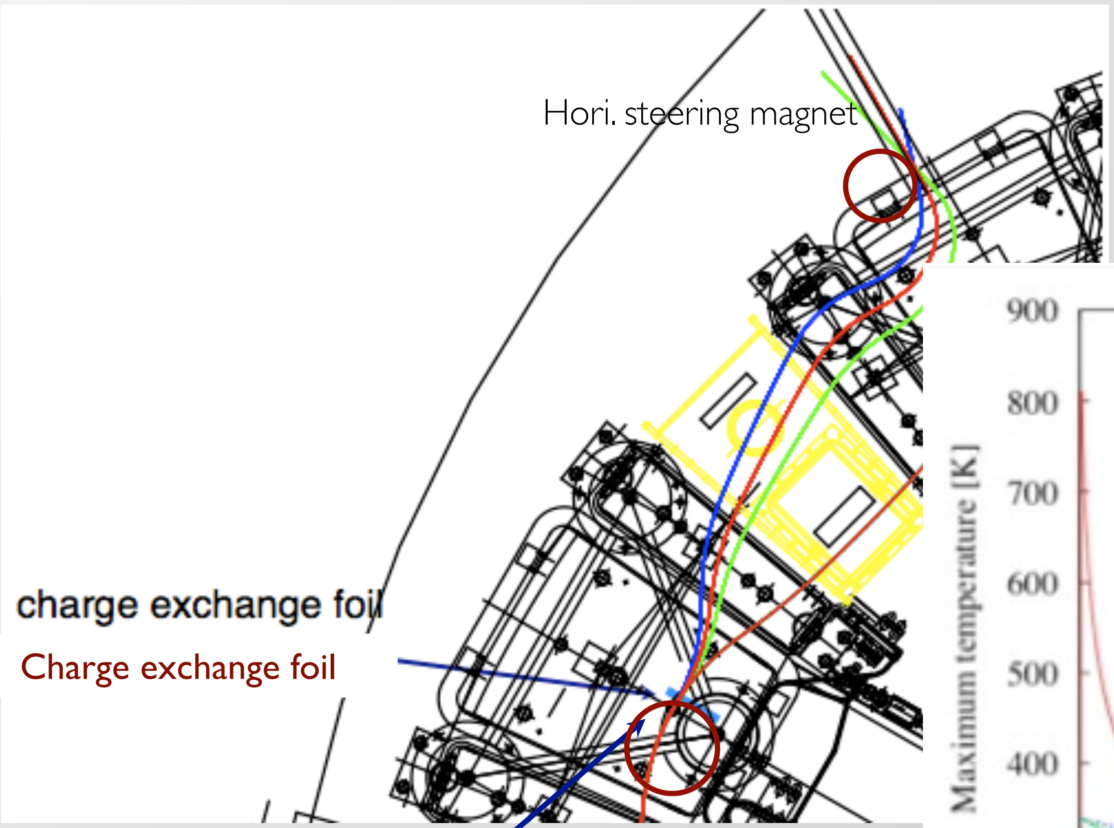

foil: 0.5deg upstream from the center magnet(red line)

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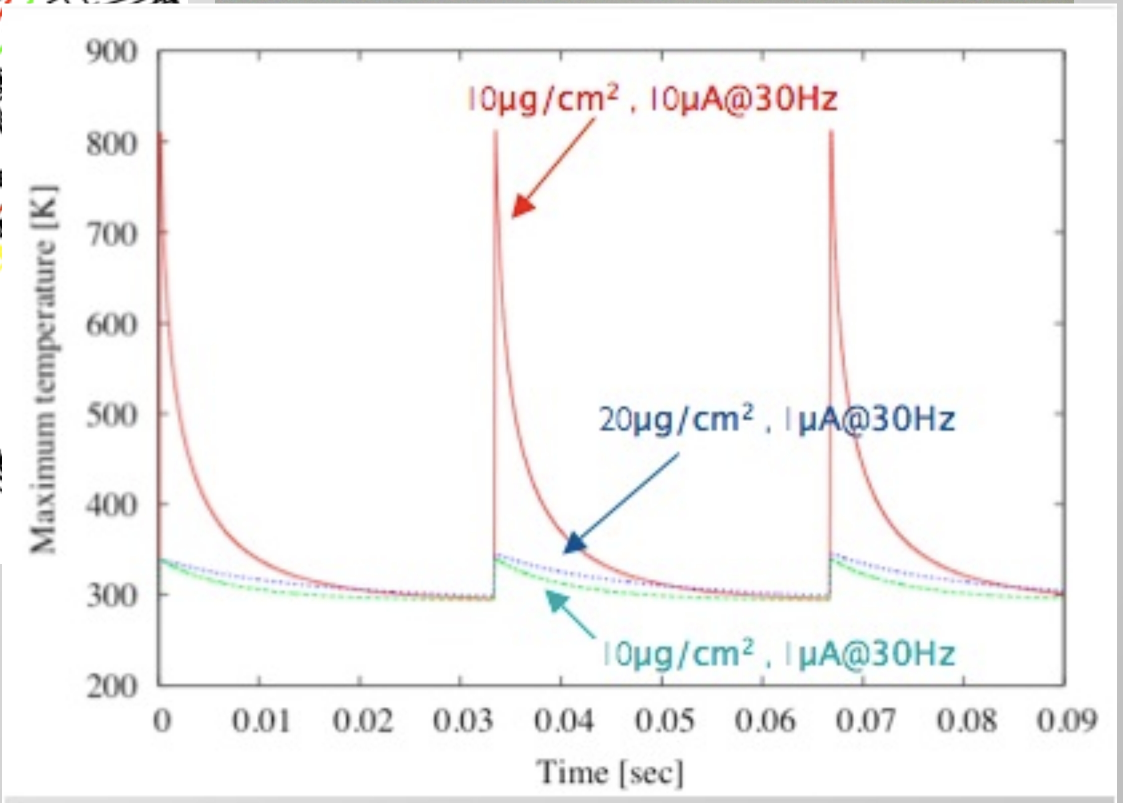
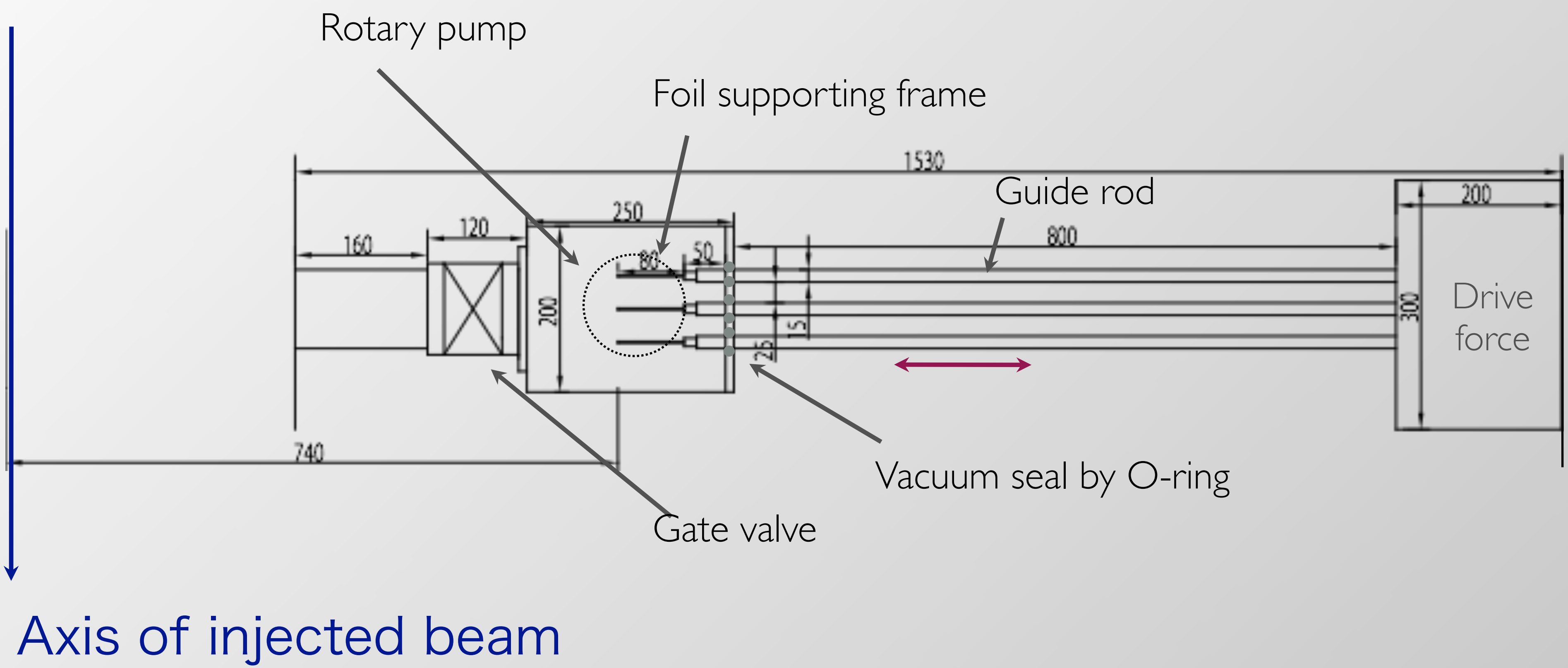


Mechanism for Foil Change



- Three foils will be exchangeable without vacuum breaking.
- Observing method for foil condition will be required.

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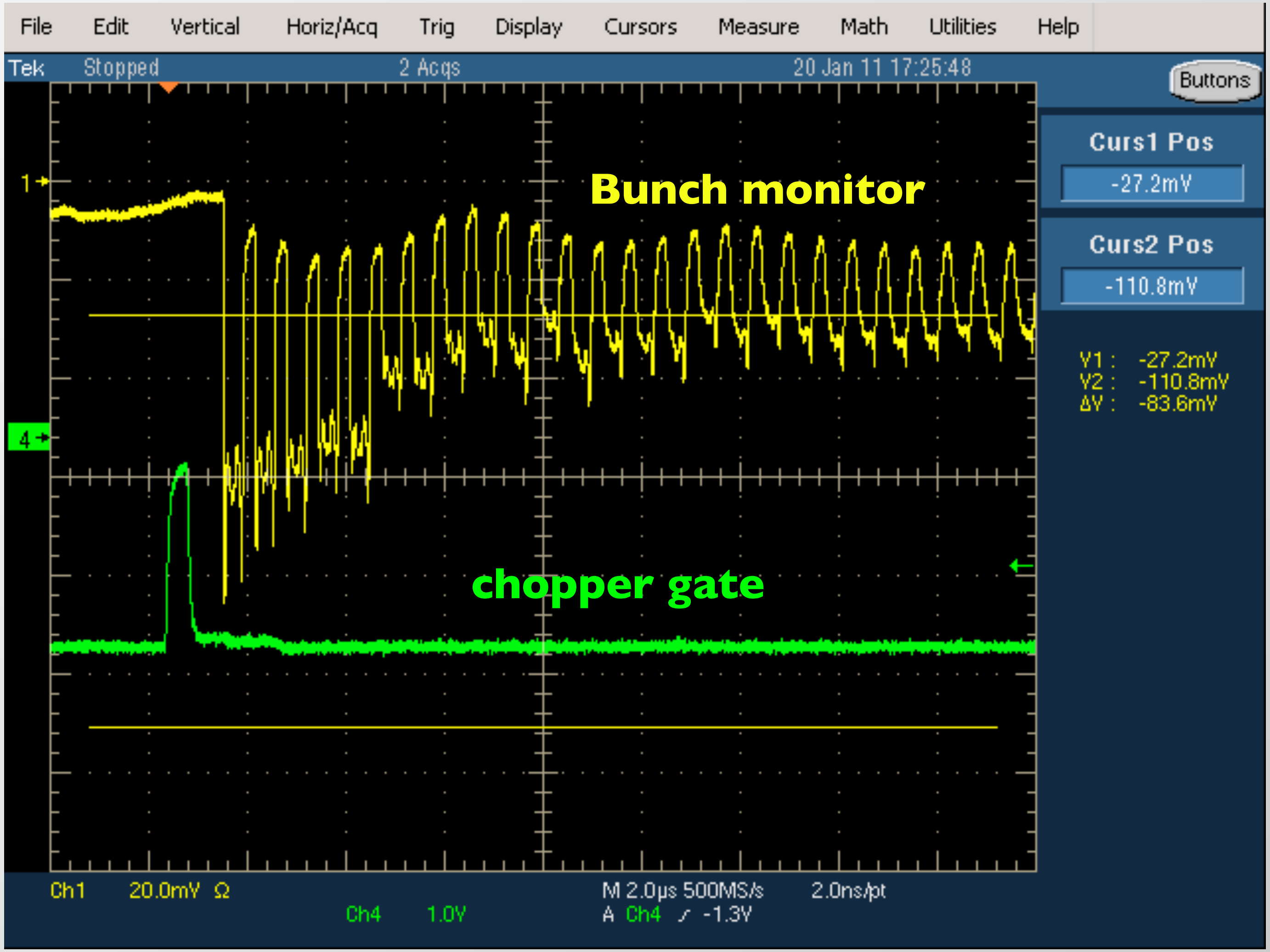
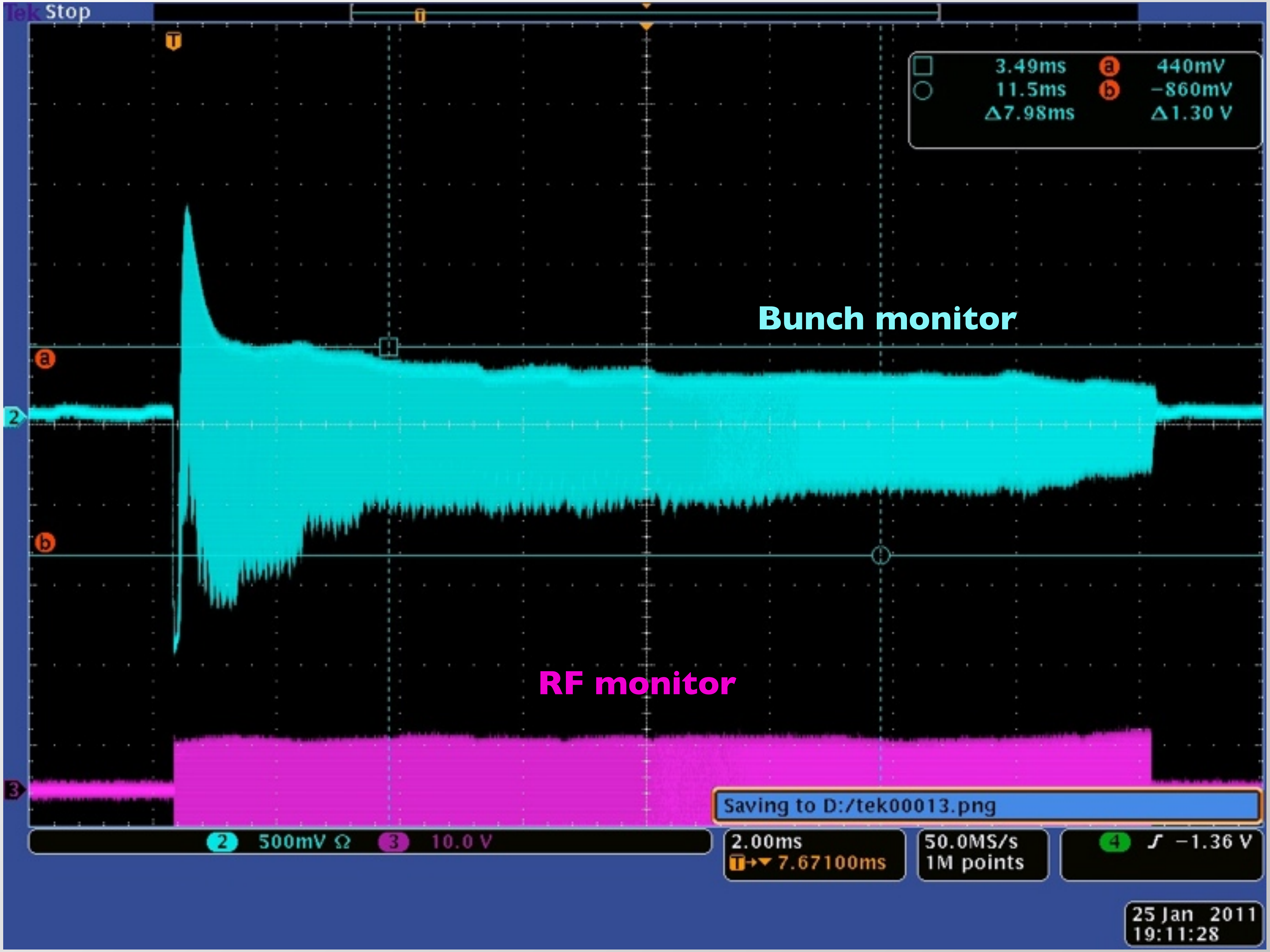
Bunch monitor signal at the injection



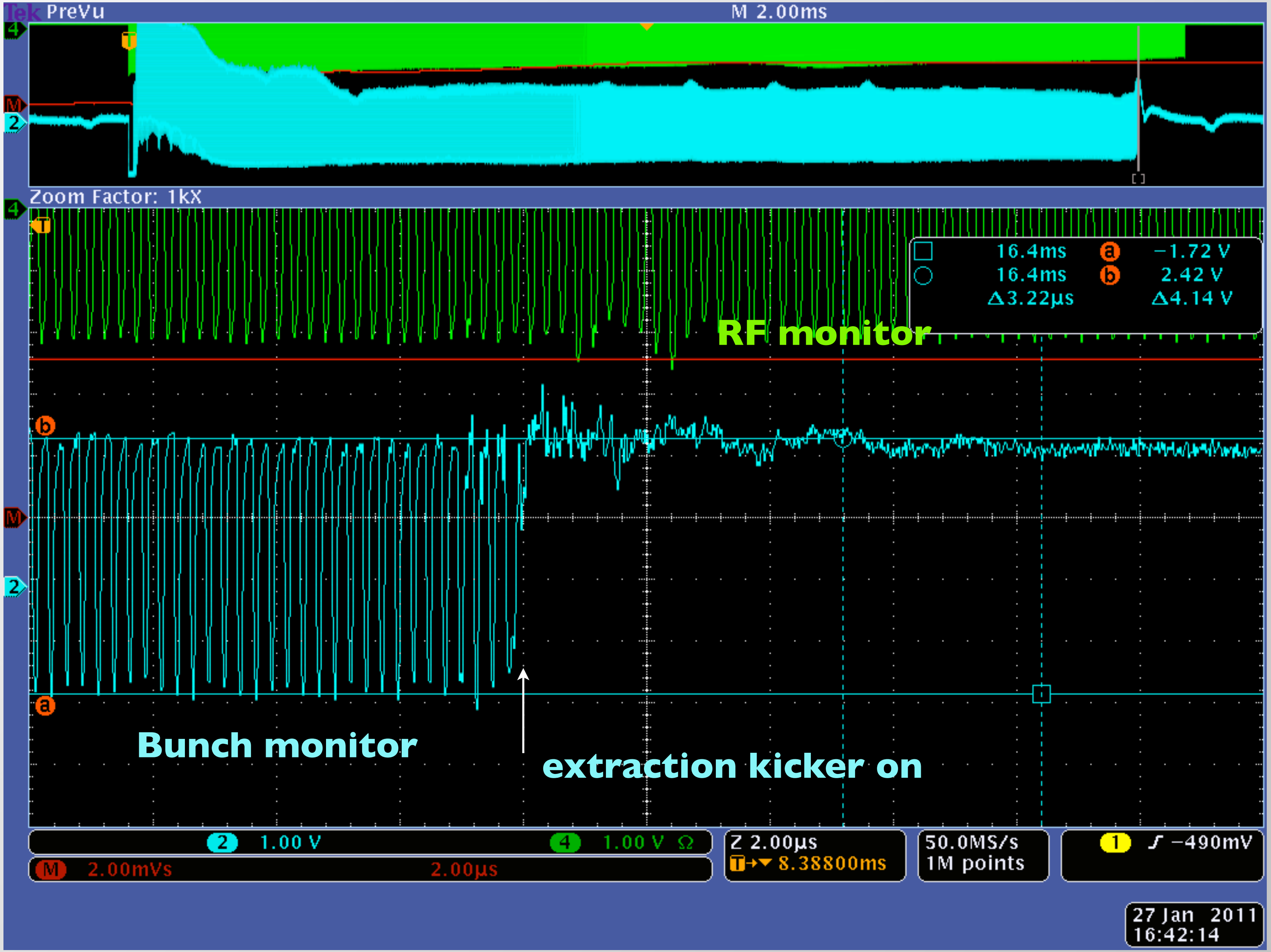
200 ns pulse shaped by the beam chopper
no rf voltage
injected beam is decreased under 30 % within first 10 turns after the injection

File Edit Vertical Horiz/Acq Trig Display Cursors Measure Math Utilities Help
Tek Stopped 10 Acqs 20 Jan 11 18:45:02
Buttons
Curs1 Pos
-410.0mV
Curs2 Pos
400.0mV
V1 : -410.0mV
V2 : 400.0mV
Bunch monitor
RF monitor
Ch1 200mV
Ch3 500mV Ω Ch4 1.0V
File Edit Vertical Horiz/Acq Trig Display Cursors Measure Math Utilities Help
Tek Stopped 10 Acqs 20 Jan 11 18:35:38
Buttons
Curs1 Pos
-340.0mV
Curs2 Pos
350.0mV
V1 : -340.0mV
V2 : 350.0mV
ΔV : 690.0mV
Bunch monitor
RF monitor
Ch1 200mV 5.0μs Ch3 500mV 5.0μs Ch4 1.0V 5.0μs



Tek Stop
3.49ms
11.5ms
Δ7.98ms
440mV
−860mV
Δ1.30 V
Bunch monitor
RF monitor
Saving to D:/tek00013.png
500mV Ω
10.0 V
2.00ms
7.67100ms
50.0MS/s
1M points
−1.36 V
25 Jan 2011
19:11:28

BUNCH MONITOR SIGNAL DURING THE ACCELERATION AND EXTRACTION



Commissioning log

- Oct - Nov '10 Construction of the H- beam line
- Dec '10 Beam characteristics measurement from the linac
- 13 Jan '11 Beam profile observation using fluorescence plate at the foil
- 15 Jan Observation of the circulating beam
- 19 Jan RF capture
- 25 Jan Acceleration up to 100MeV
- 26 Jan Beam extraction
- 3 Feb Start delivering the beam to KUCA
- 14 Feb Radiation safety inspection
- 3-25 Feb ADSR experiments at KUCA

ADSR experiments

- Uranium loaded core was used.
- Beam intensity from the main ring was increased by factor of 10.
- However, the beam intensity was fluctuated 20 - 100 % at ~0.5Hz.
- KUCA was not able to obtain stable operation.
- The fluctuation due to charge up of the foil support made of ceramic has been found.
- A metal support has been installed; the fluctuation disappeared.
- We are preparing stable beam for the next ADSR experiments (Nov 2011).

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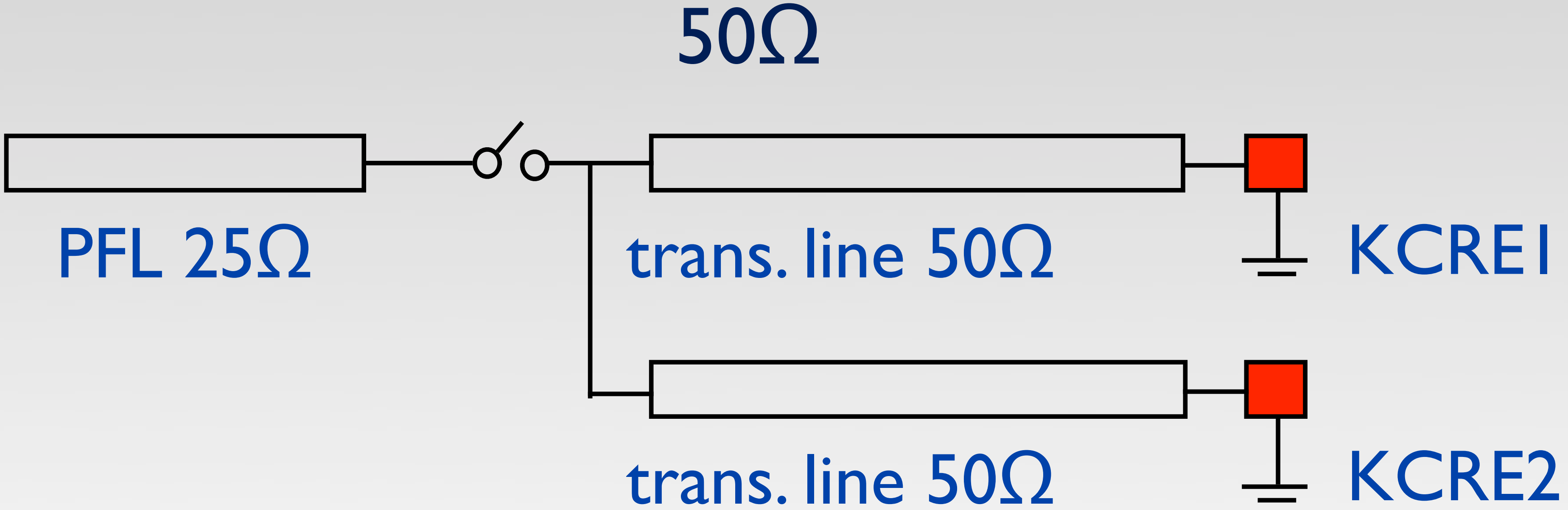
items to do for intensity improvement

- improvement of the injection efficiency
- improvement of the acceleration efficiency
- improvement of the extraction efficiency
- improvement of the transparency in the beam transport system
- moderation of space charge effect
- cure of the betatron resonances
- correction/reduction of COD(remove the injection septum magnet)

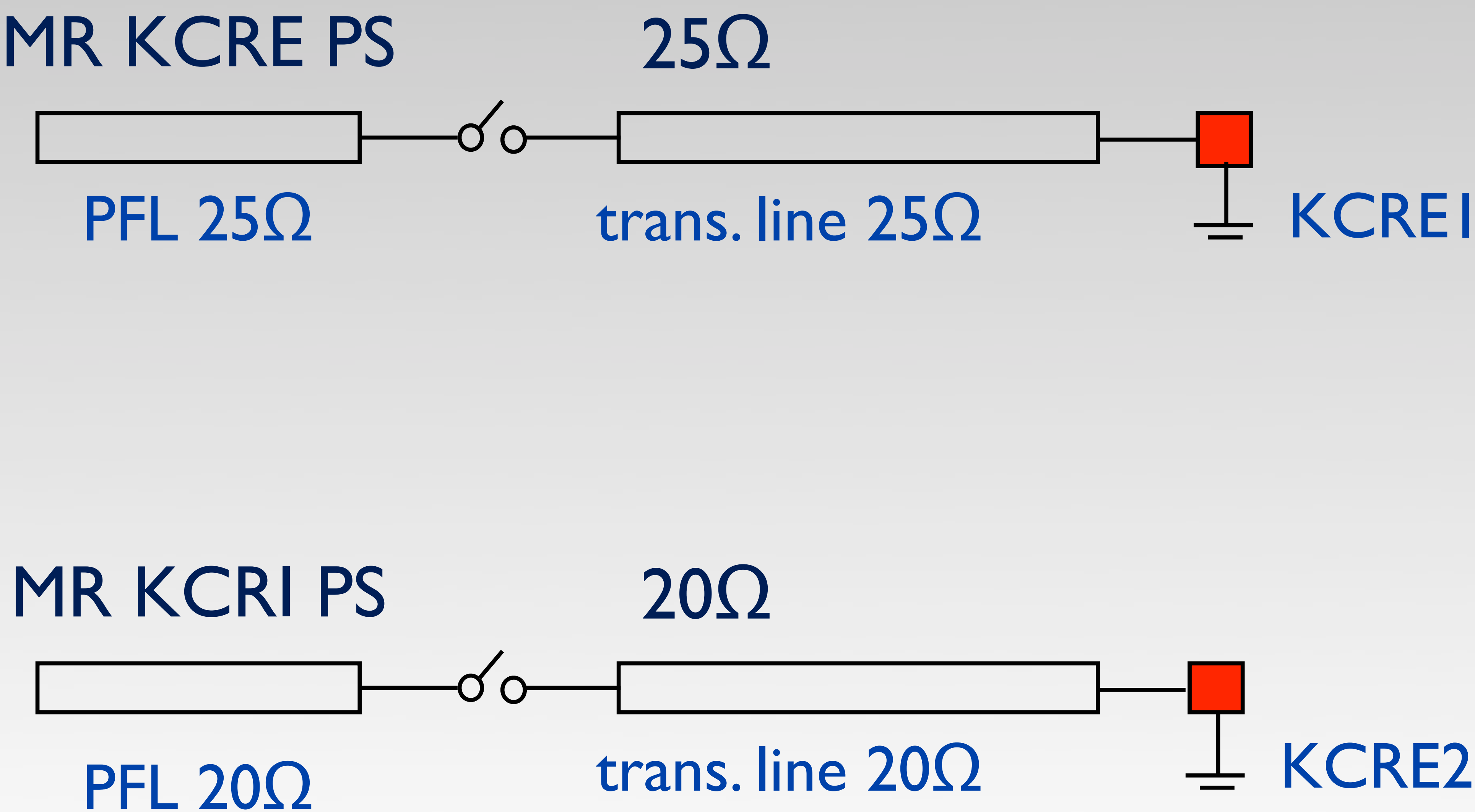
Road map of beam upgrade

FY	Energy	Current	items	method
2010	100MeV	1nA	-	-
2011	150MeV	10nA	improvement of injection efficiency	adjustment of the injection parameters
			improvement of acceleration efficiency	study of acceleration pattern
			improvement of extraction efficiency	kicker system upgrade
			transparency improvement in beam transport	add monitors, steerers and a QM
2012	150MeV	0.1 - 1 μA	moderation of space charge effects	raise the rep. rate to 100 - 200 Hz (add another cavity)
			cure of the betatron resonances	add correction poles and power supplies; remove SMI

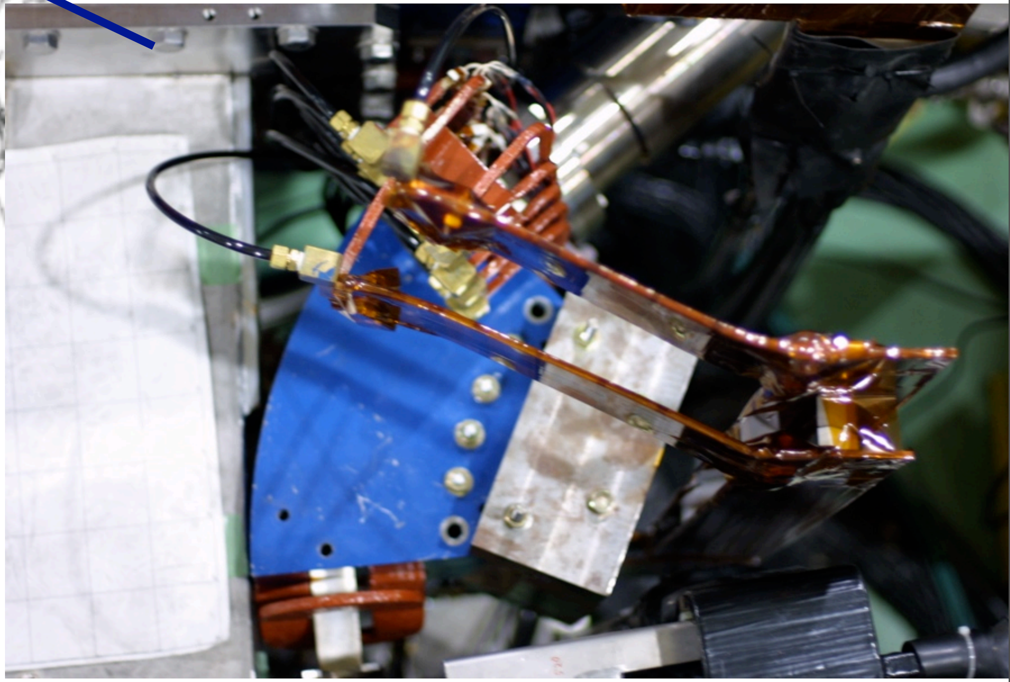
Current System



Upgraded System

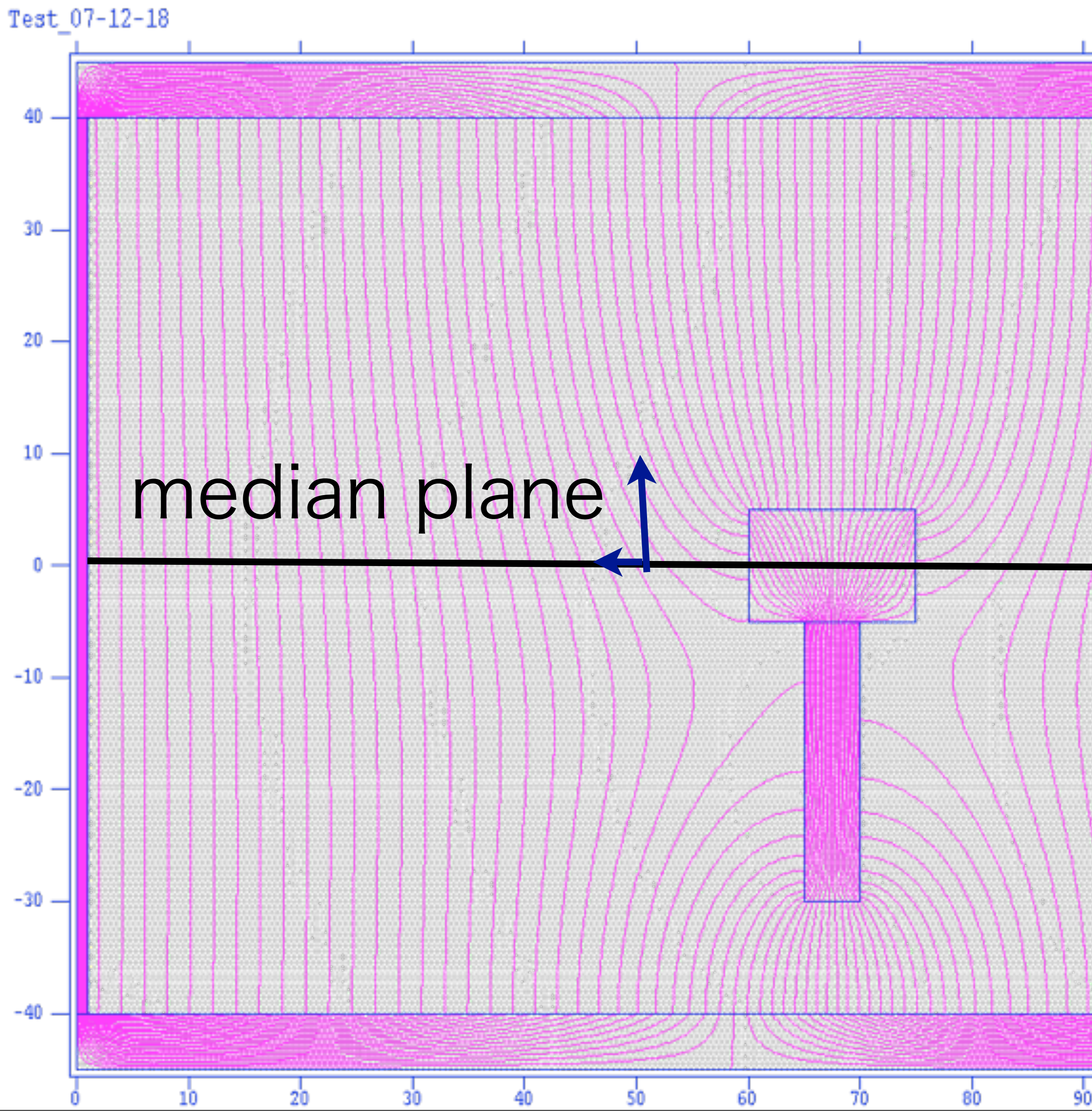


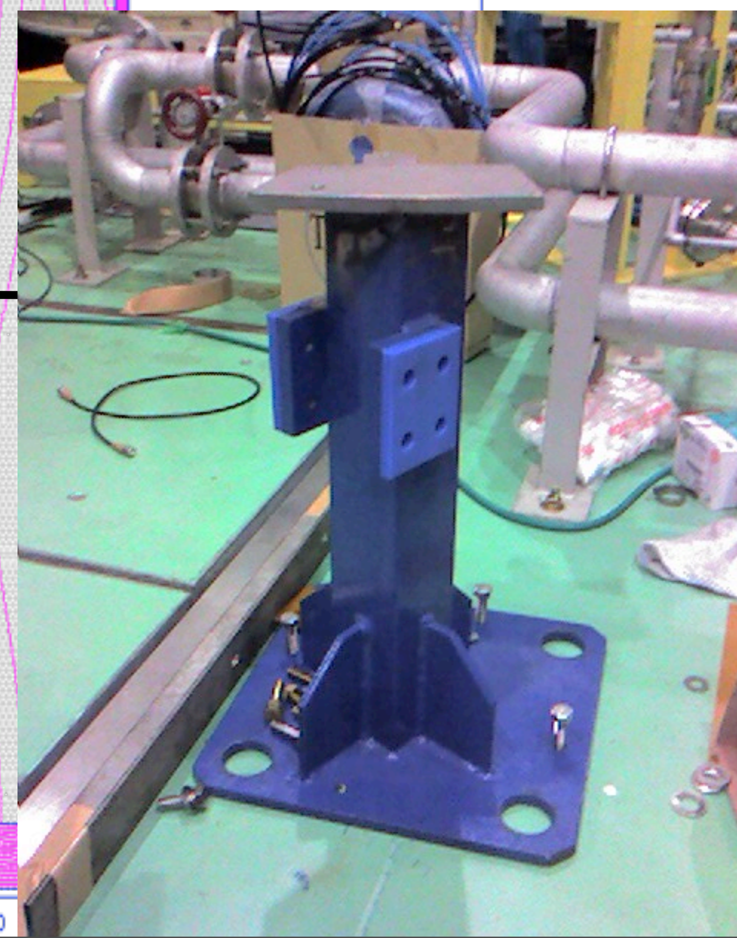
BMBT



injection septum magnet

Do not use magnetic stuff even for a base





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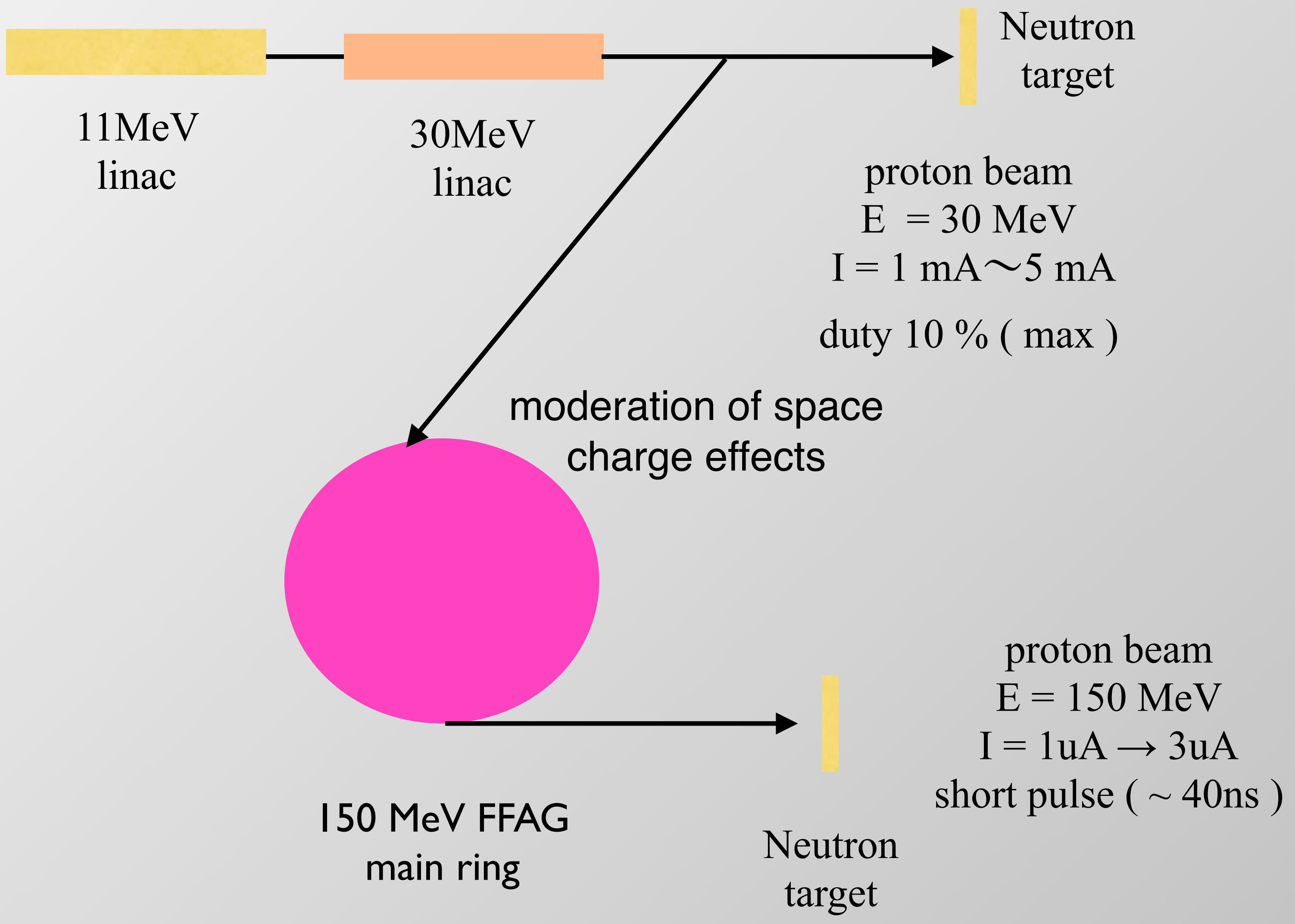
FFAG users in KURRI

- Now
  - ADSR experiment (100MeV / 1nA)
  - Irradiation experiment for material engineering (higher the better : 150MeV / 10nA in FY2011)
- Future
  - proton users (irradiation, cancer therapy : BNCT complemental)
  - neutron users
    - pulsed neutron : essential for TOF measurement
    - ADSR : MW beam power -> 700MeV FFAG

A plan of pulsed neutron source based on linacs and FFAG in KURRI



Summary

- H- beam injection has been successfully done.
- The beam intensity has been increased from 0.1nA to 1nA.
- With the improved proton beam, ADSR experiments in KUCA has been done. Beam stability is critical issue for the ADSR.
- As a future plan of KURRI, a pulsed neutron source using FFAG main ring is now under consideration. The target beam energy/intensity are 150MeV/1μA for the pulsed neutron source.