Status report on KURRI FFAG Facility

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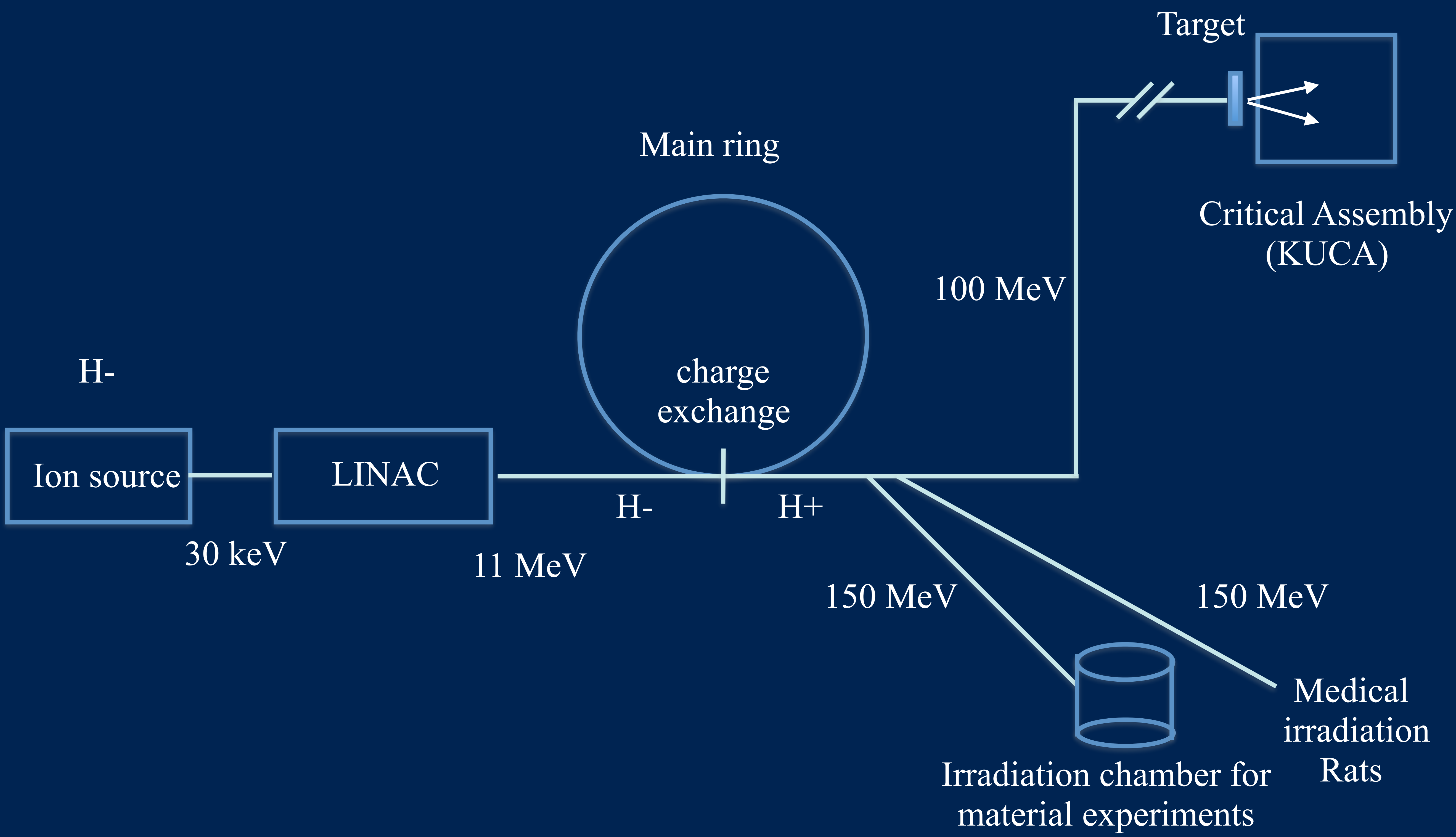
FFAG 17 at Cornell University, Ithaca Sep. 8 2017

OUTLINE

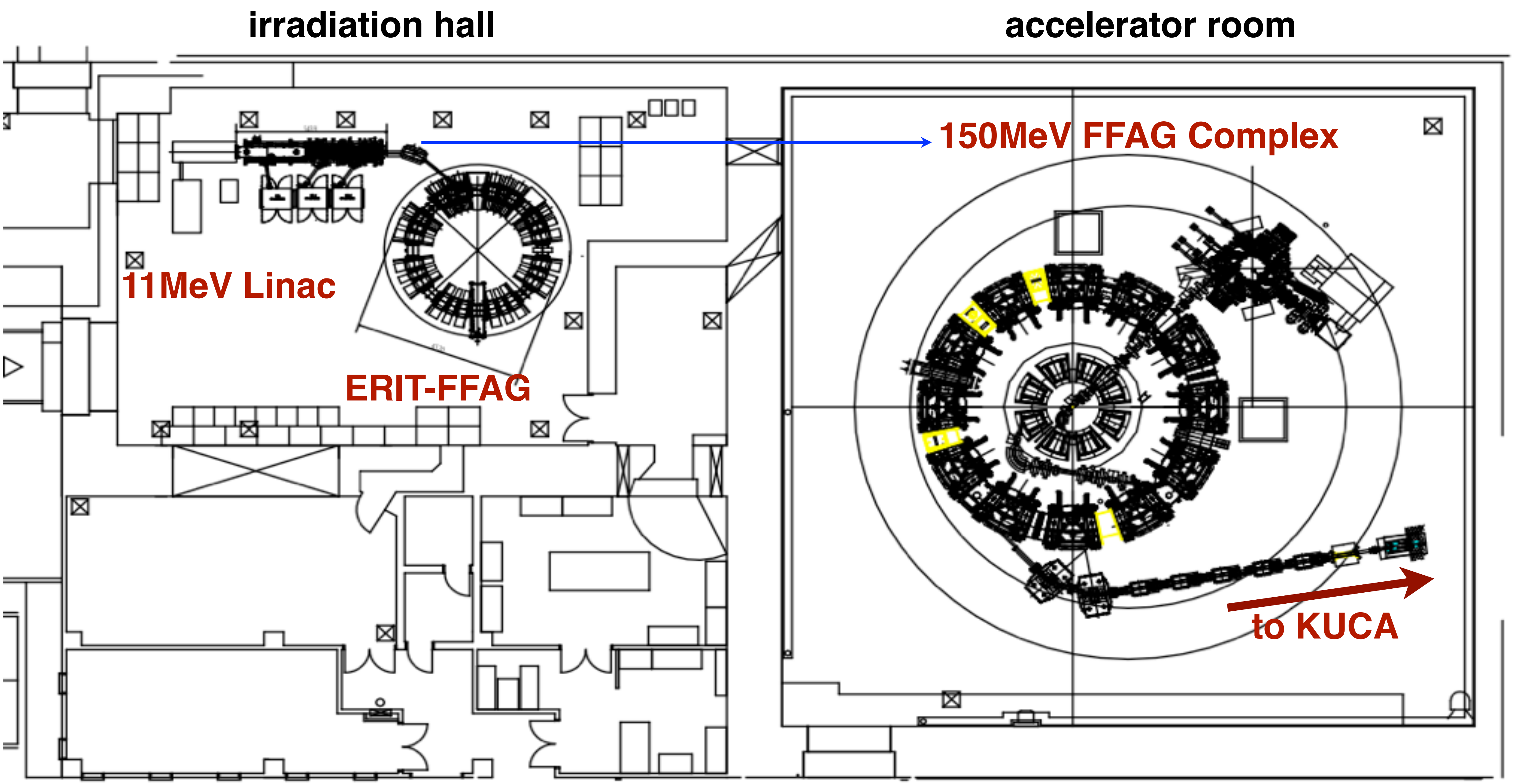
1. Present status of the KURRI FFAG facility
    1. Overview of the Complex
    2. Recommissioning of the LINAC
2. Scenario for the Recommissioning of the Main Ring (Tom)
3. Upgrade plans of the Facility
    1. Modification of ERIT to MERIT
    2. Energy upgrade with an additional ring
4. Summary

Overview of the Complex

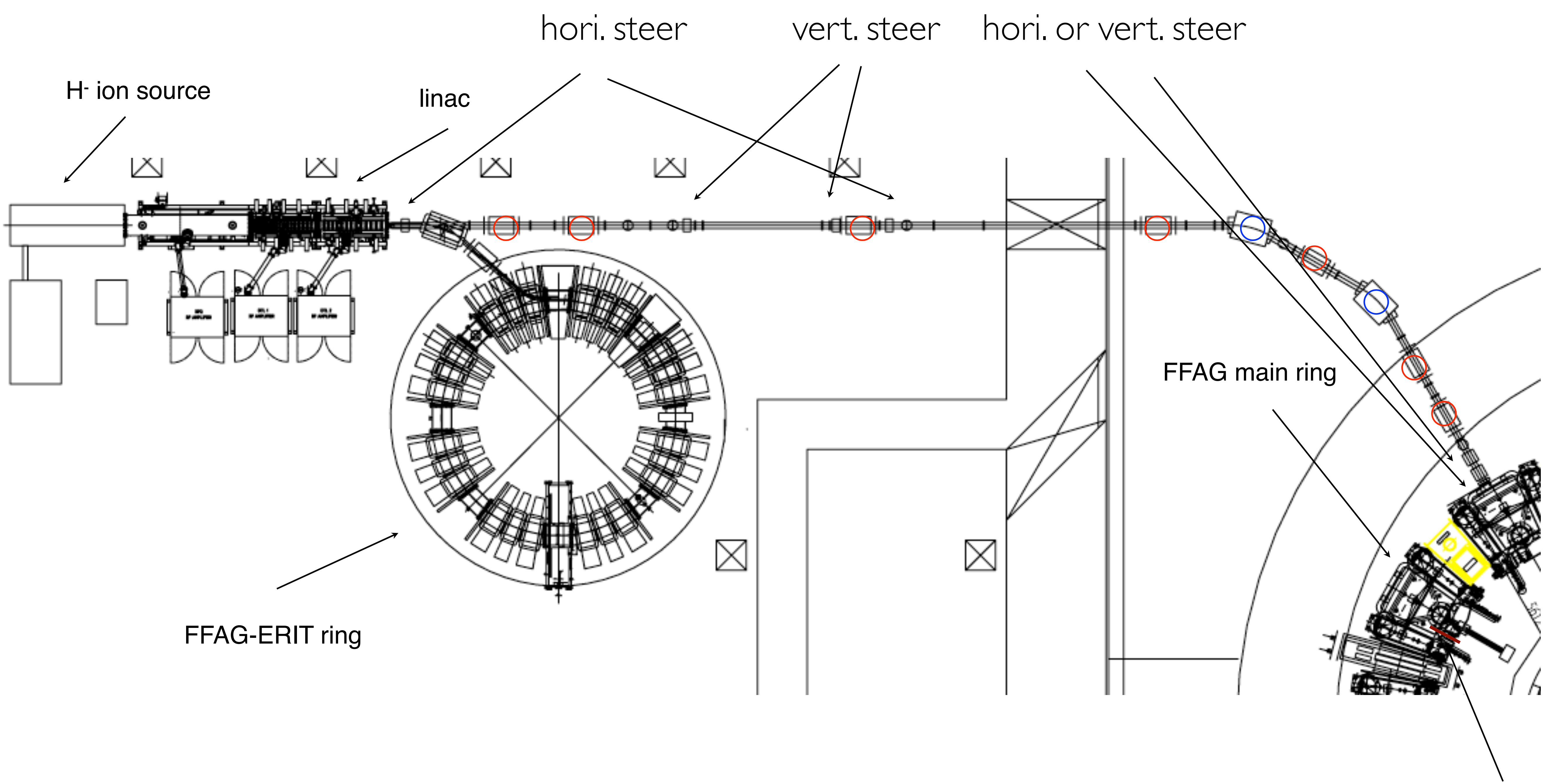
Schematic Diagram of the KURRI FFAG Complex



Layout of accelerator complex in the Innovation Research Lab.



Beam Line from Linac to MR

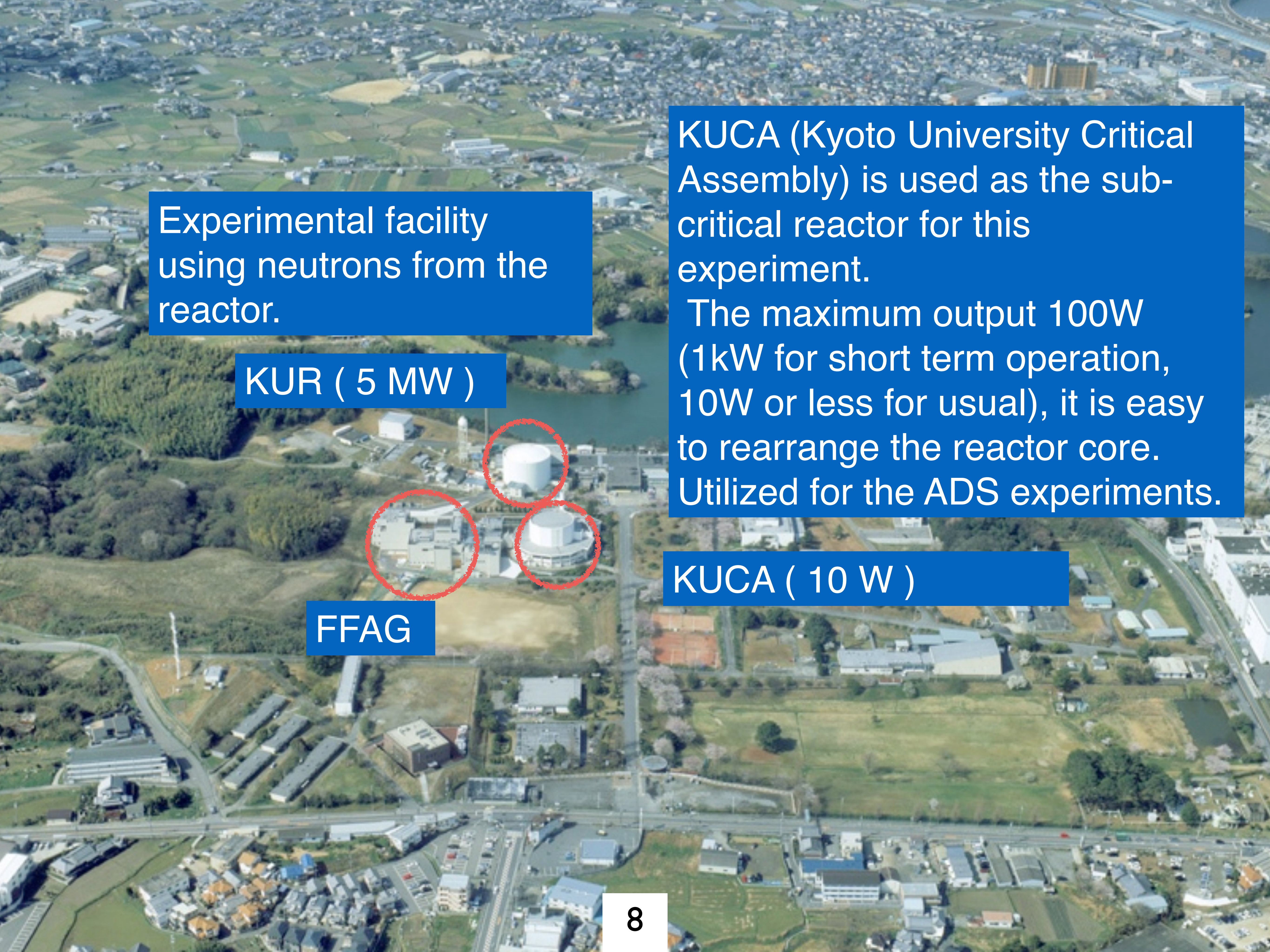


Q Magnet ×8*, B Magnet(30deg) × 2

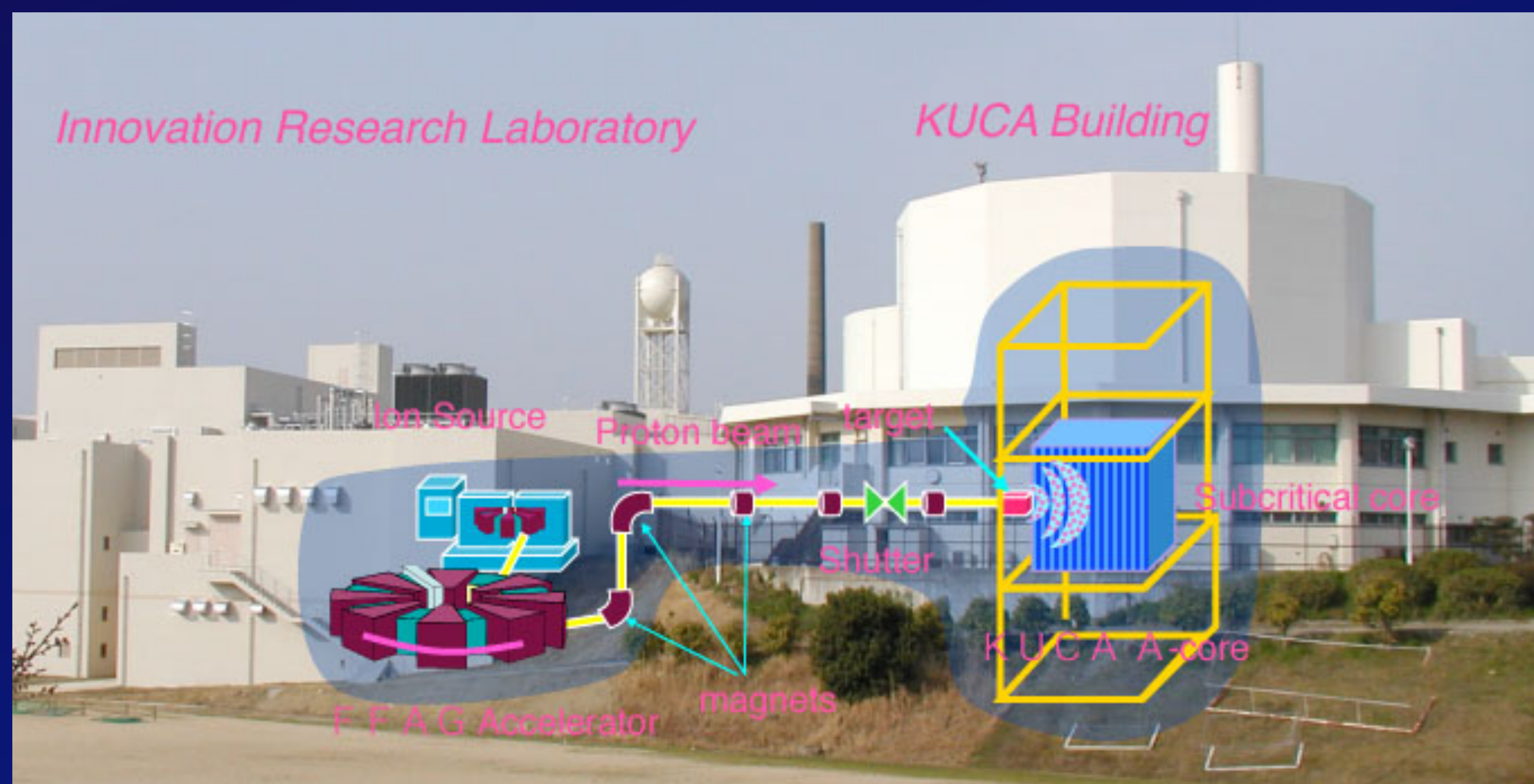
* added one QM inMay 2011

Beam Users

- ADS experiment
- Irradiation for materials
- Medical experiment (irradiation to living rats)

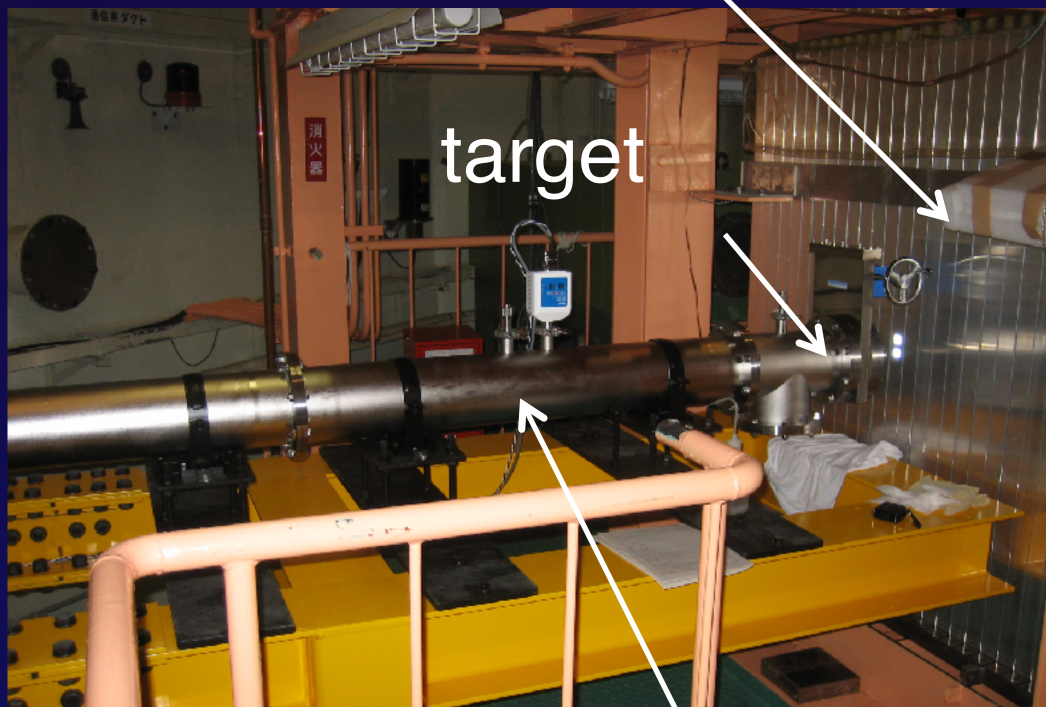

Experimental facility using neutrons from the reactor.
KUR (5 MW)
FFAG
KUCA (Kyoto University Critical Assembly) is used as the sub-critical reactor for this experiment.
The maximum output 100W (1kW for short term operation, 10W or less for usual), it is easy to rearrange the reactor core.
Utilized for the ADS experiments.
KUCA (10 W)

The KURRI-FFAG accelerator complex has been constructed in the innovation research lab. ; connected to KUCA to deliver the high energy proton beam.



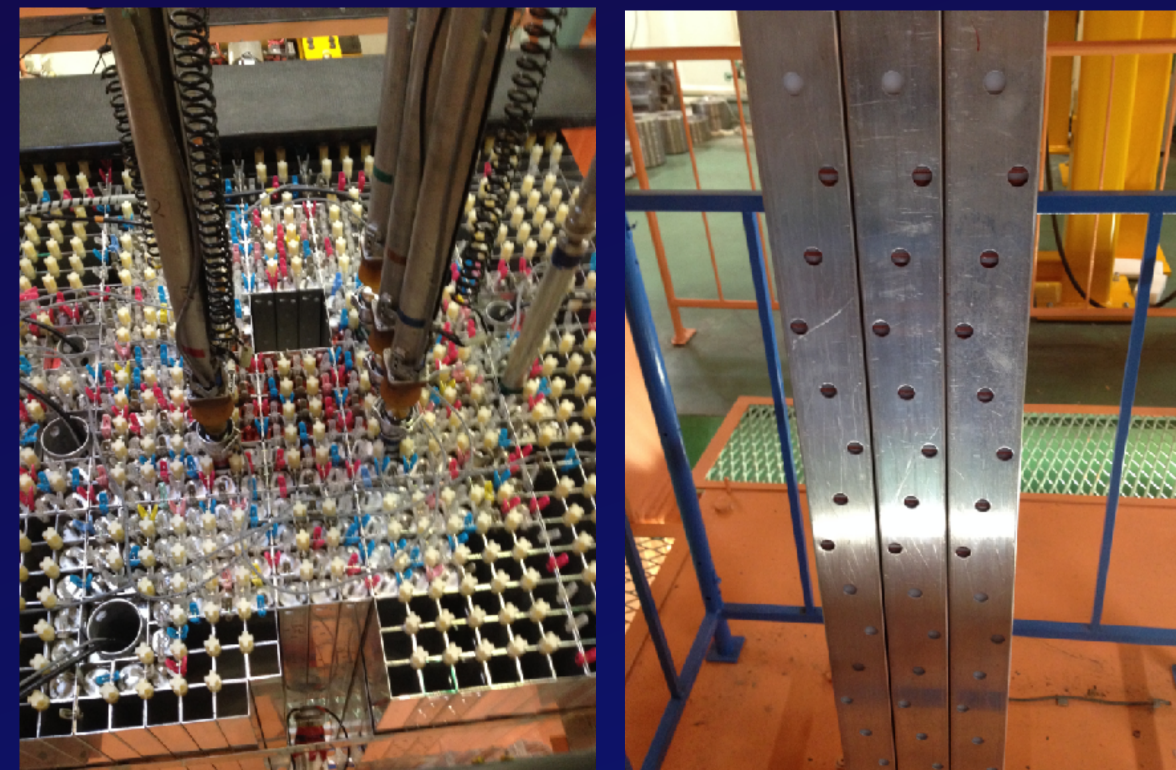
ADS Experiment Setup

Reactor core

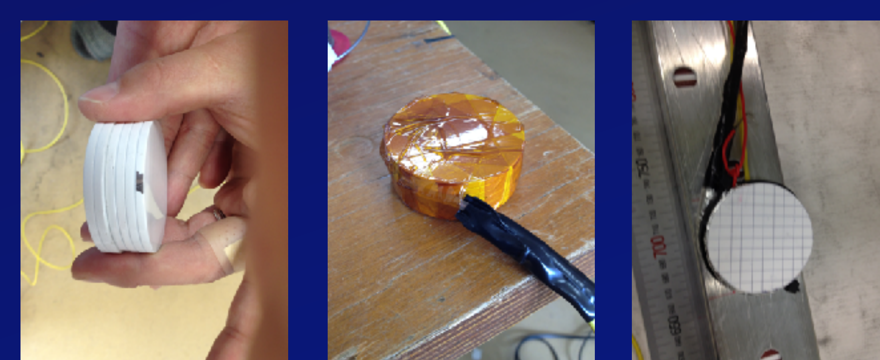


Beam transport line

- FFAG Accelerator :
  - 100 MeV Protons
  - 20 Hz repetition rate
  - 1nA intensity
  - W and Pb-Bi target
- KUCA A-Core :

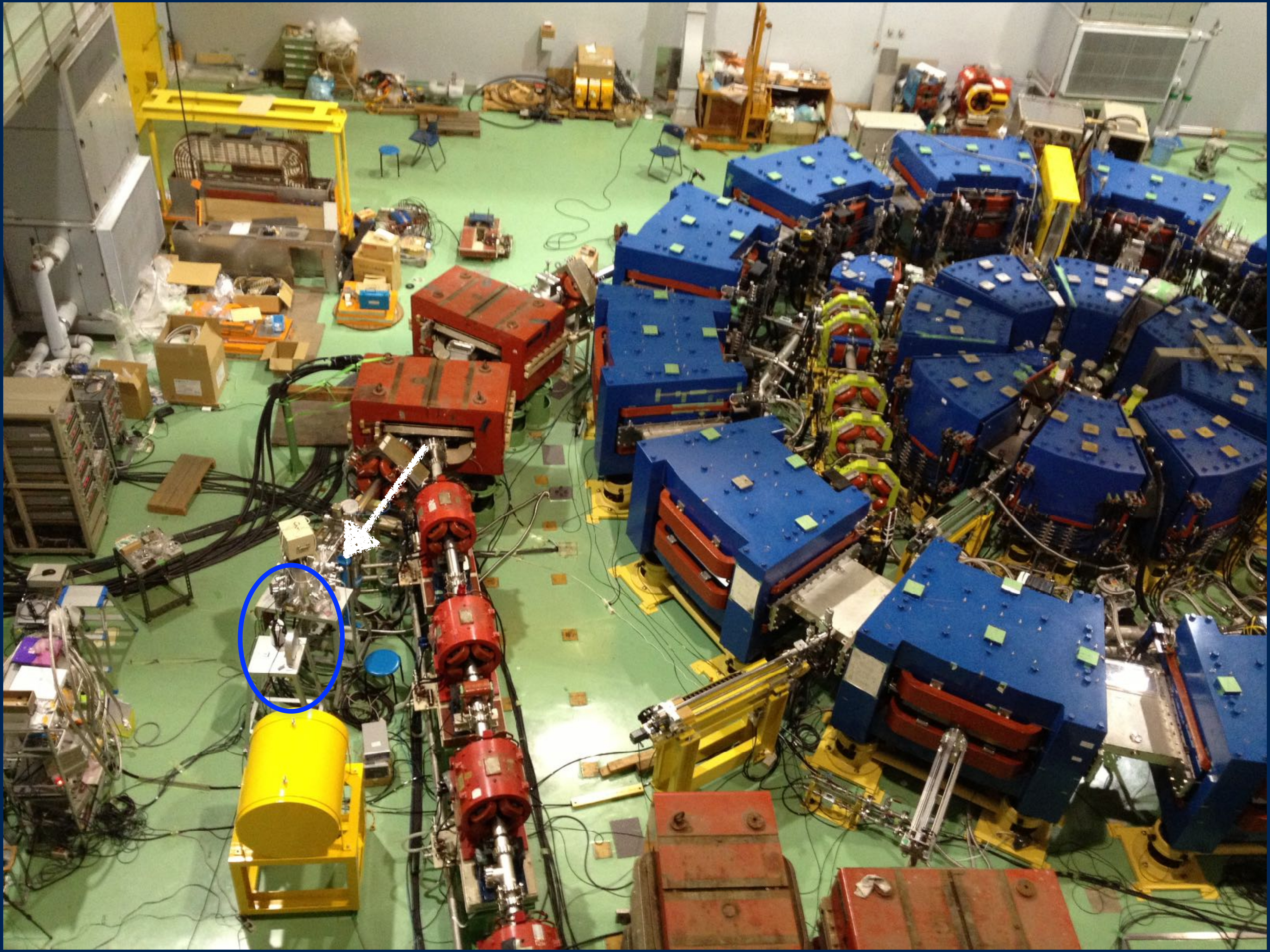


Subcritical fuel system



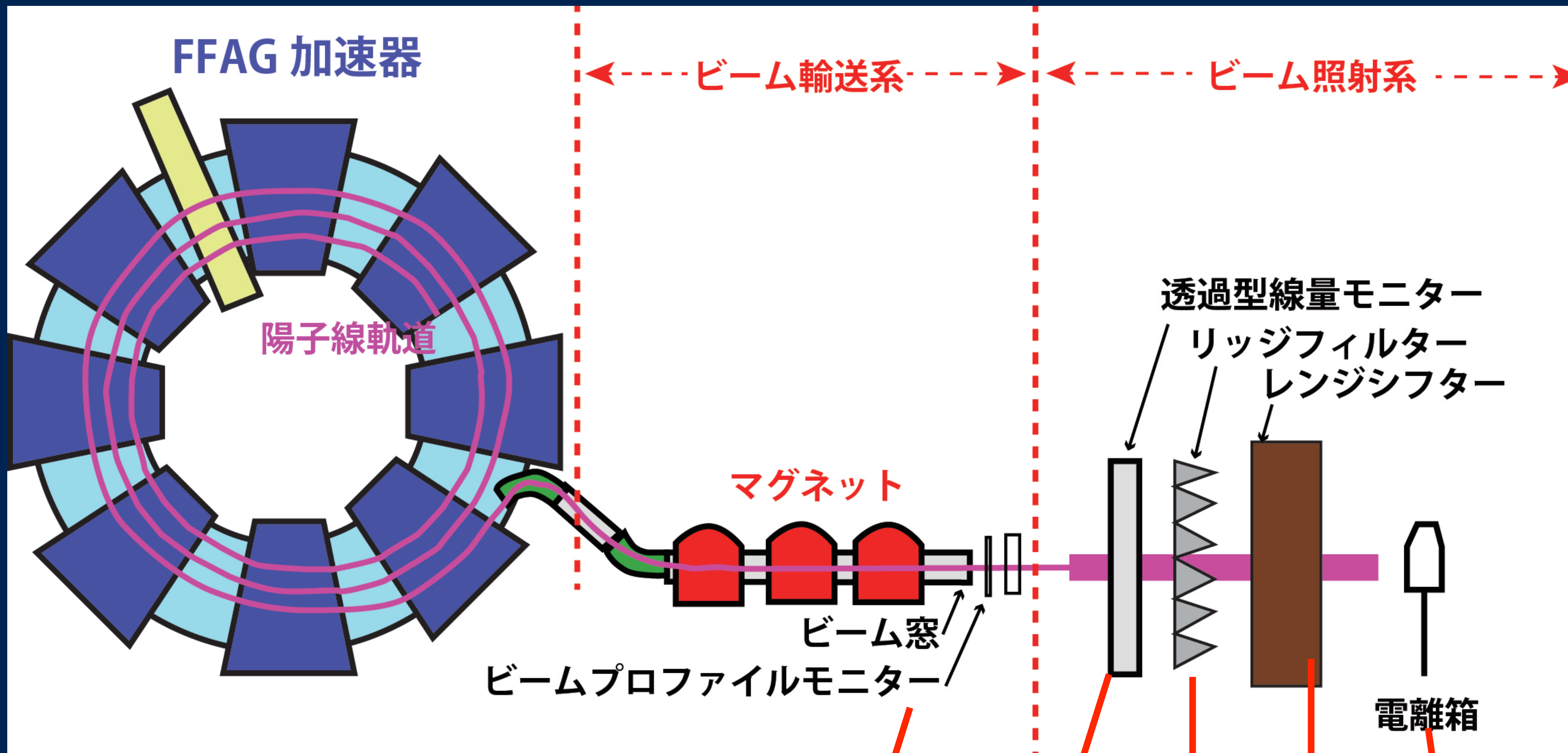
W or Pb-Bi target w/ read out as FC

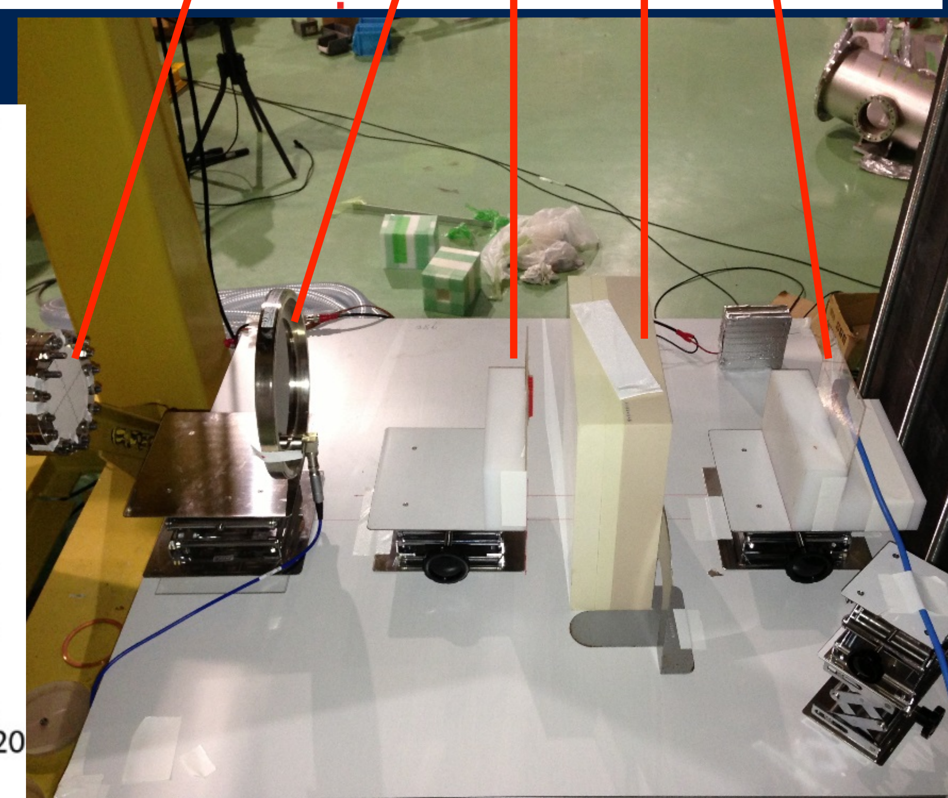
Beam Line and Chamber for Irradiation Experiments



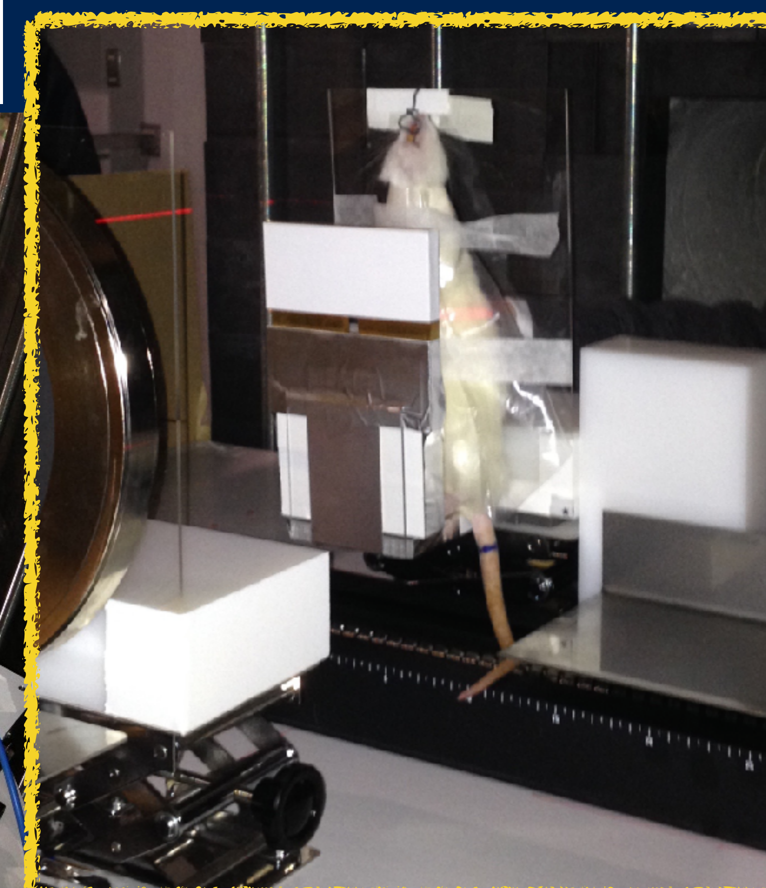
The irradiation port connected to the 150 MeV proton beam line.
It has cryogenics and traction control machine inside which realize measurements under irradiation of the proton beam.

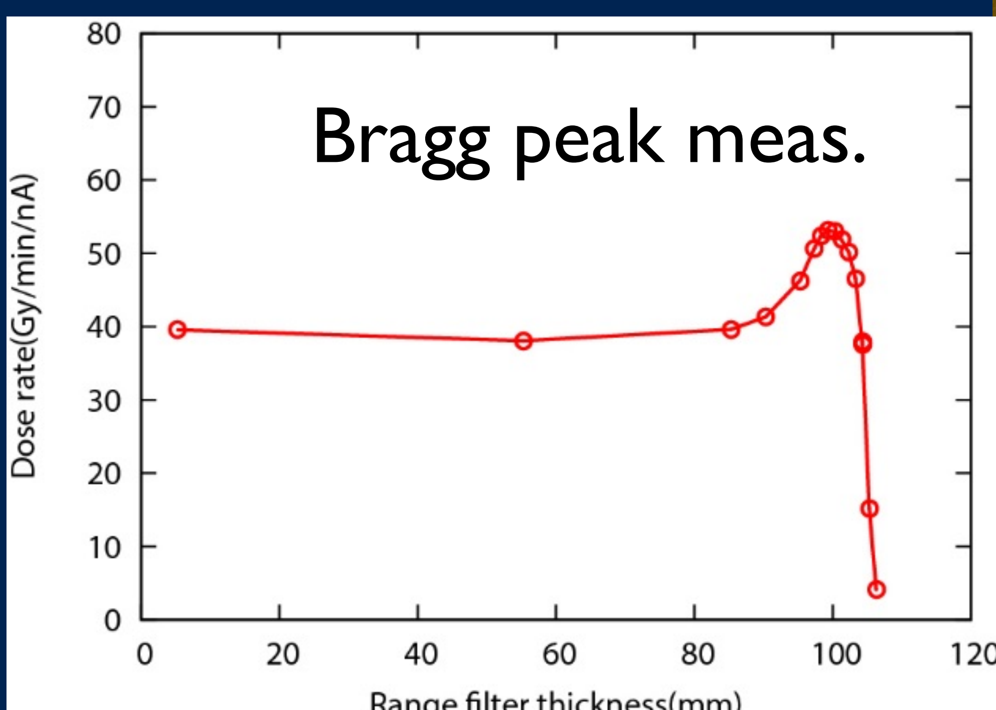
This study was a result of “Clarification of material behaviors in ADS by an FFAG accelerator” carried out under the Strategic Promotion Program for Basic Nuclear Research by the Ministry of Education, Culture, Sports, Science and Technology of Japan.





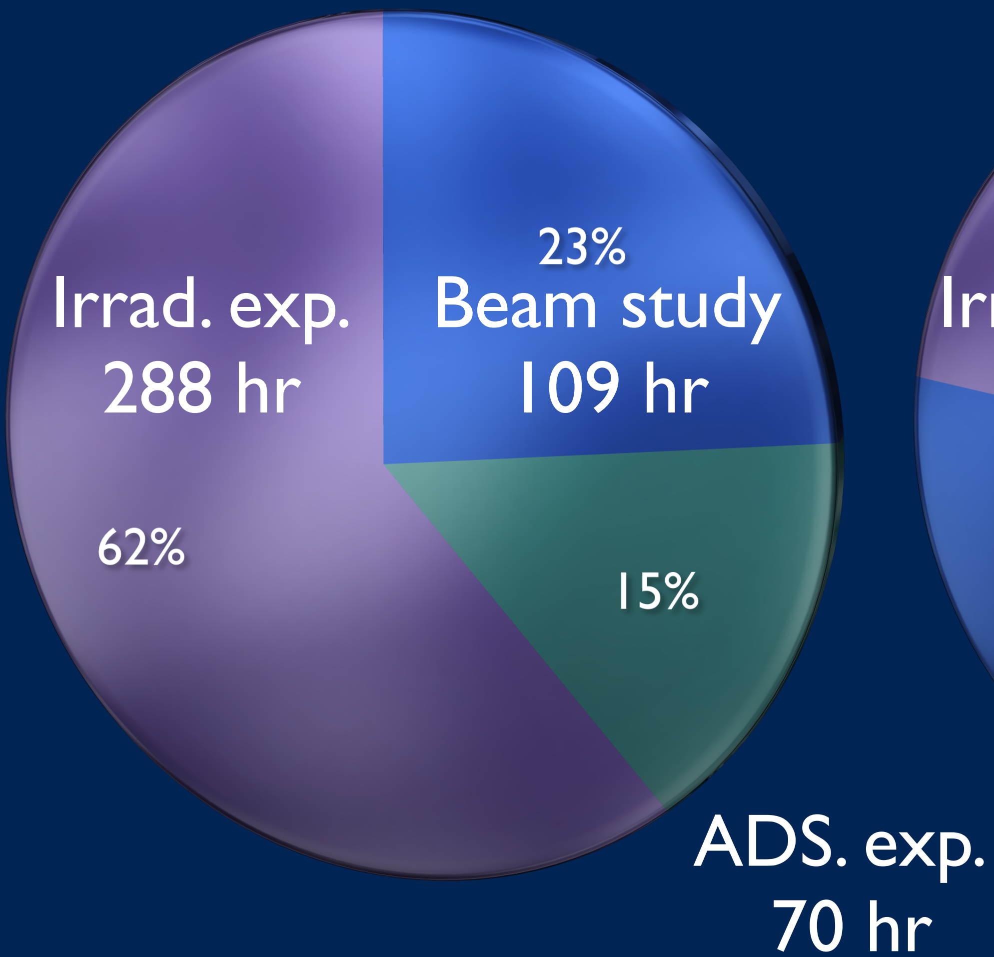
a narcotised rat





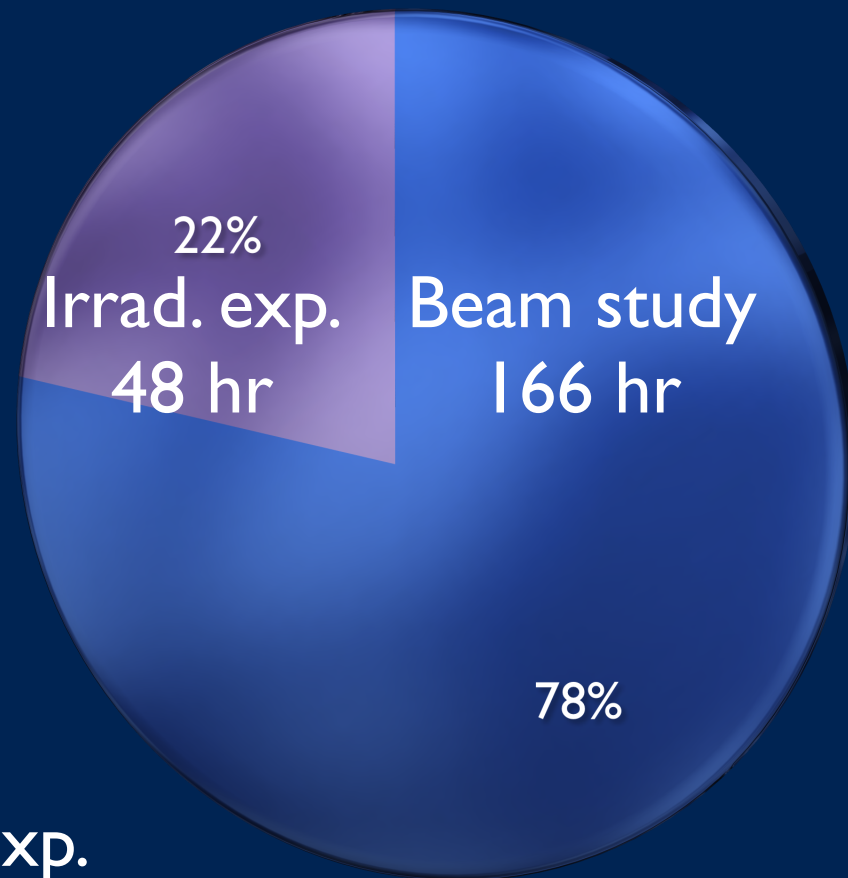
Summary of Machine Time

FY 2013



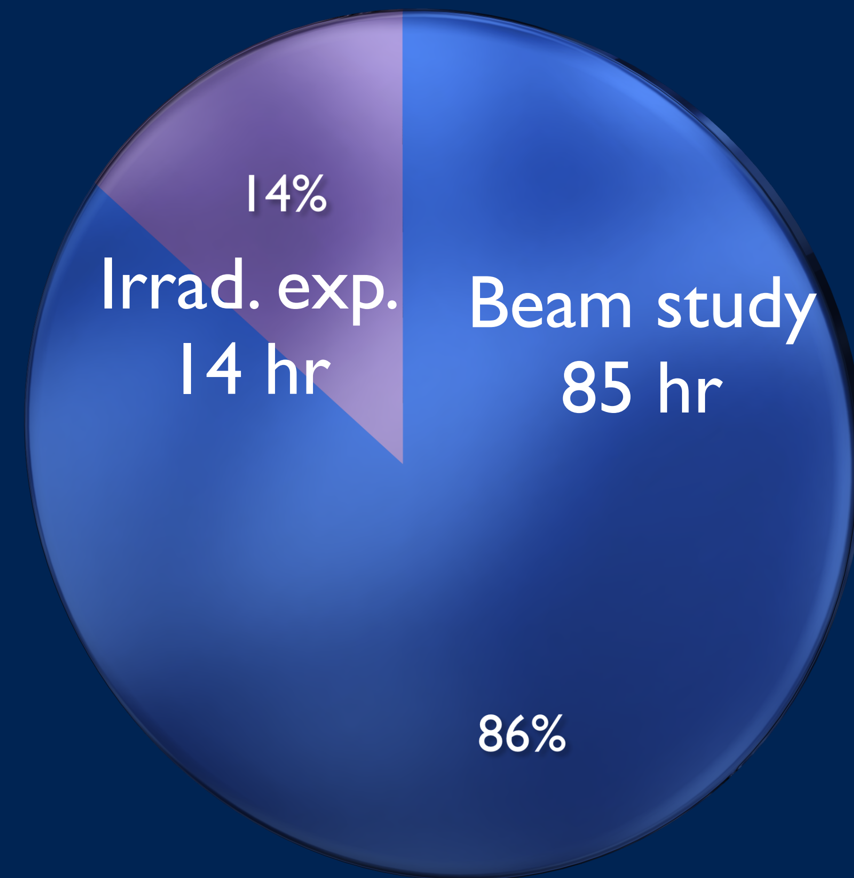
Total
468 hr

FY 2014



Total
214hr

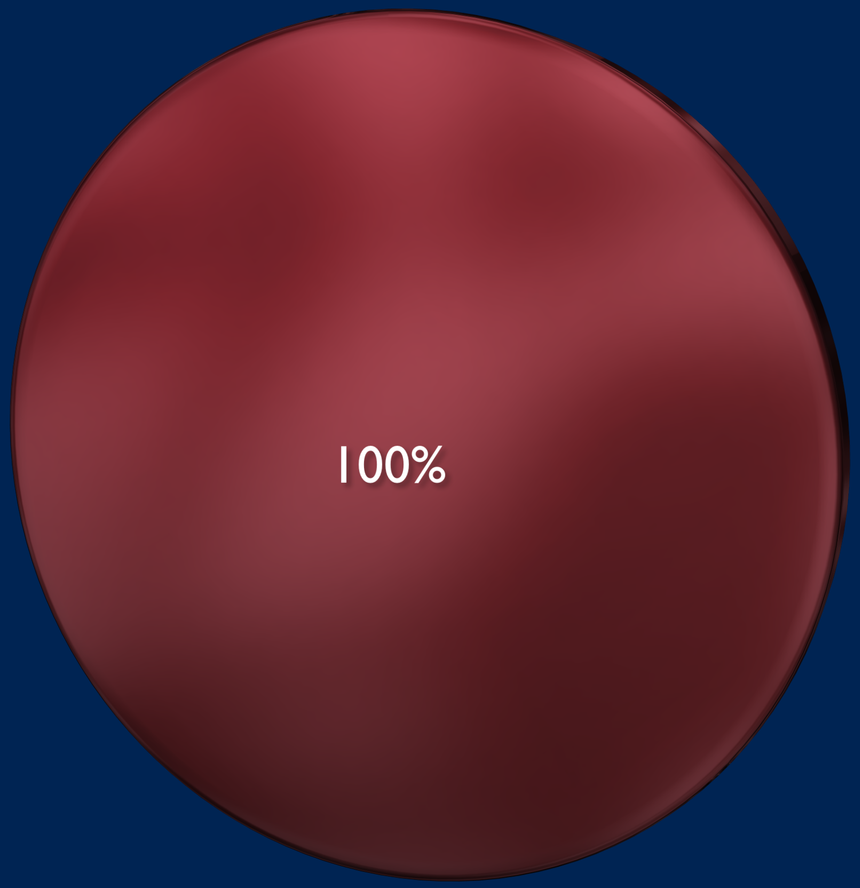
FY 2015



Total
100hr

Summary of Machine Time

FY 2016



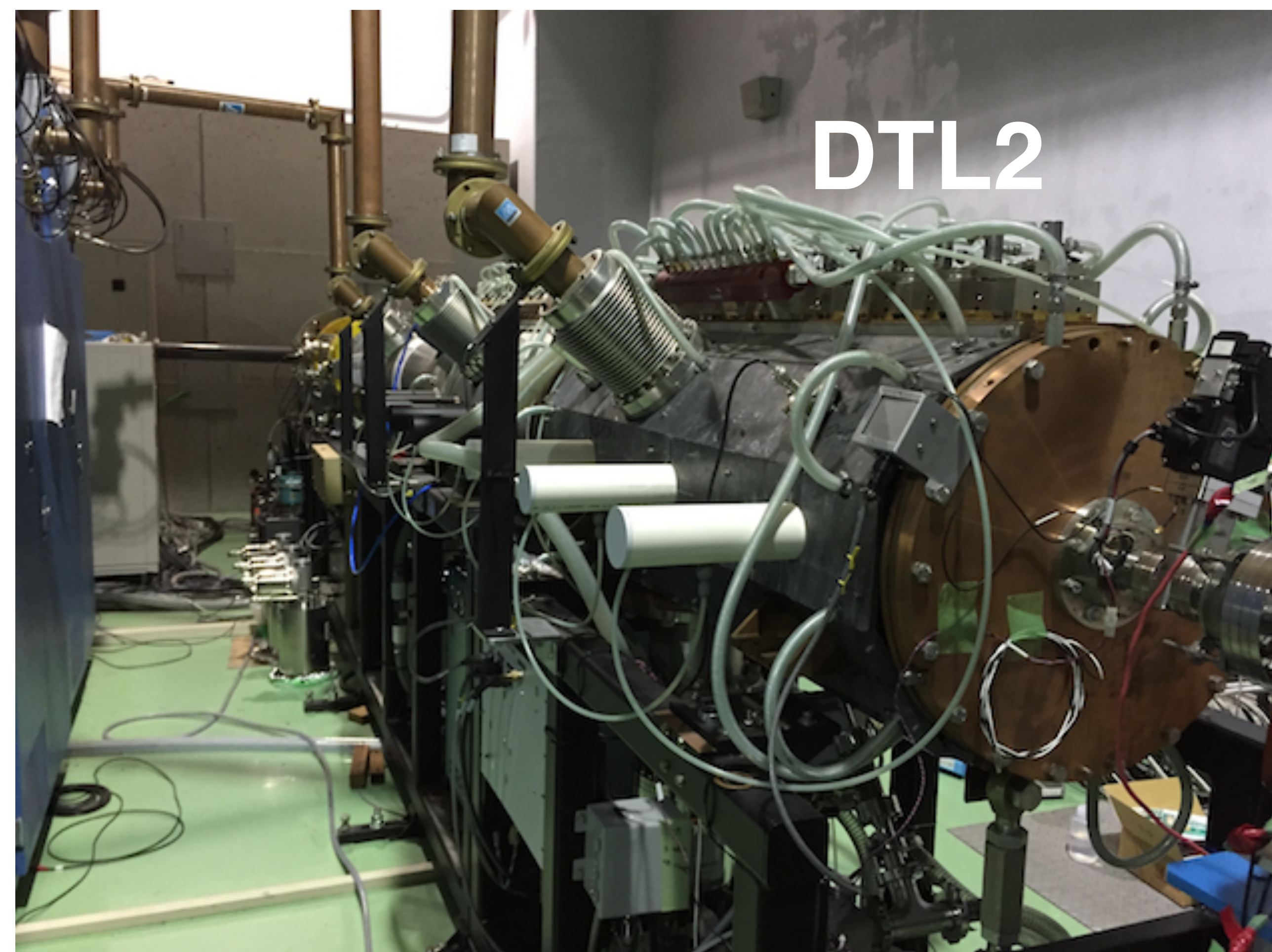
Total
0 hr

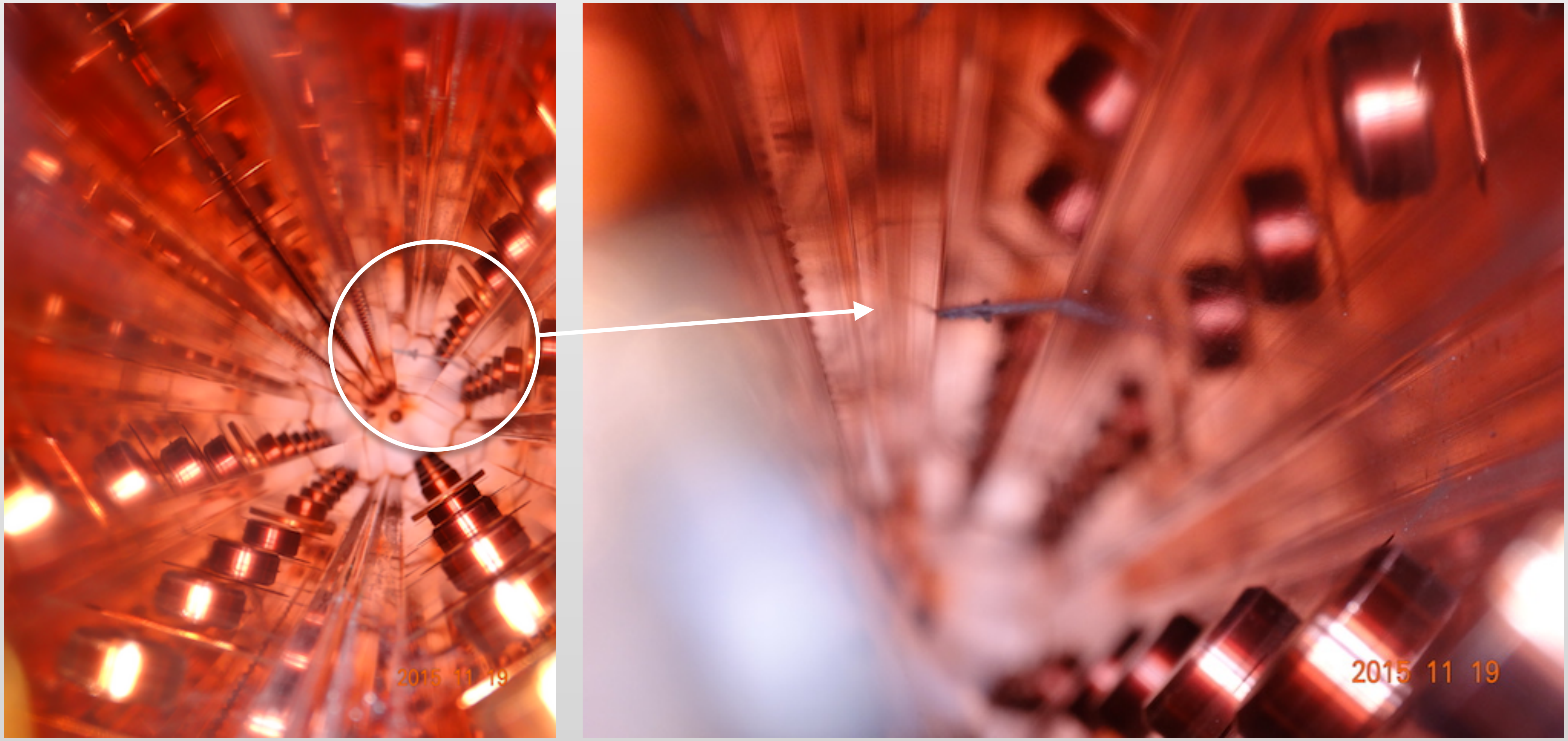
Serious trouble occurred in the injector

Recommissioning of the LINAC

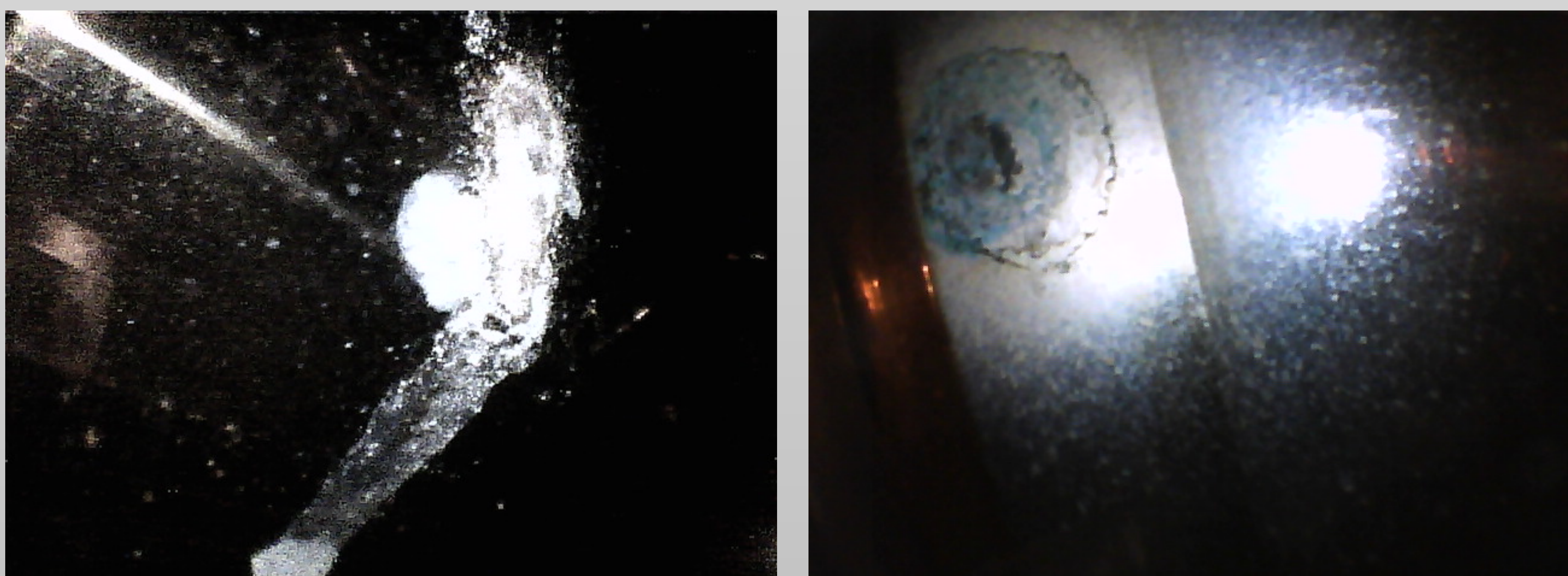
Review of Trouble in the RFQ

- Found the coolant leakage from the cooling channel to inside of the resonator at the end of October 2015.



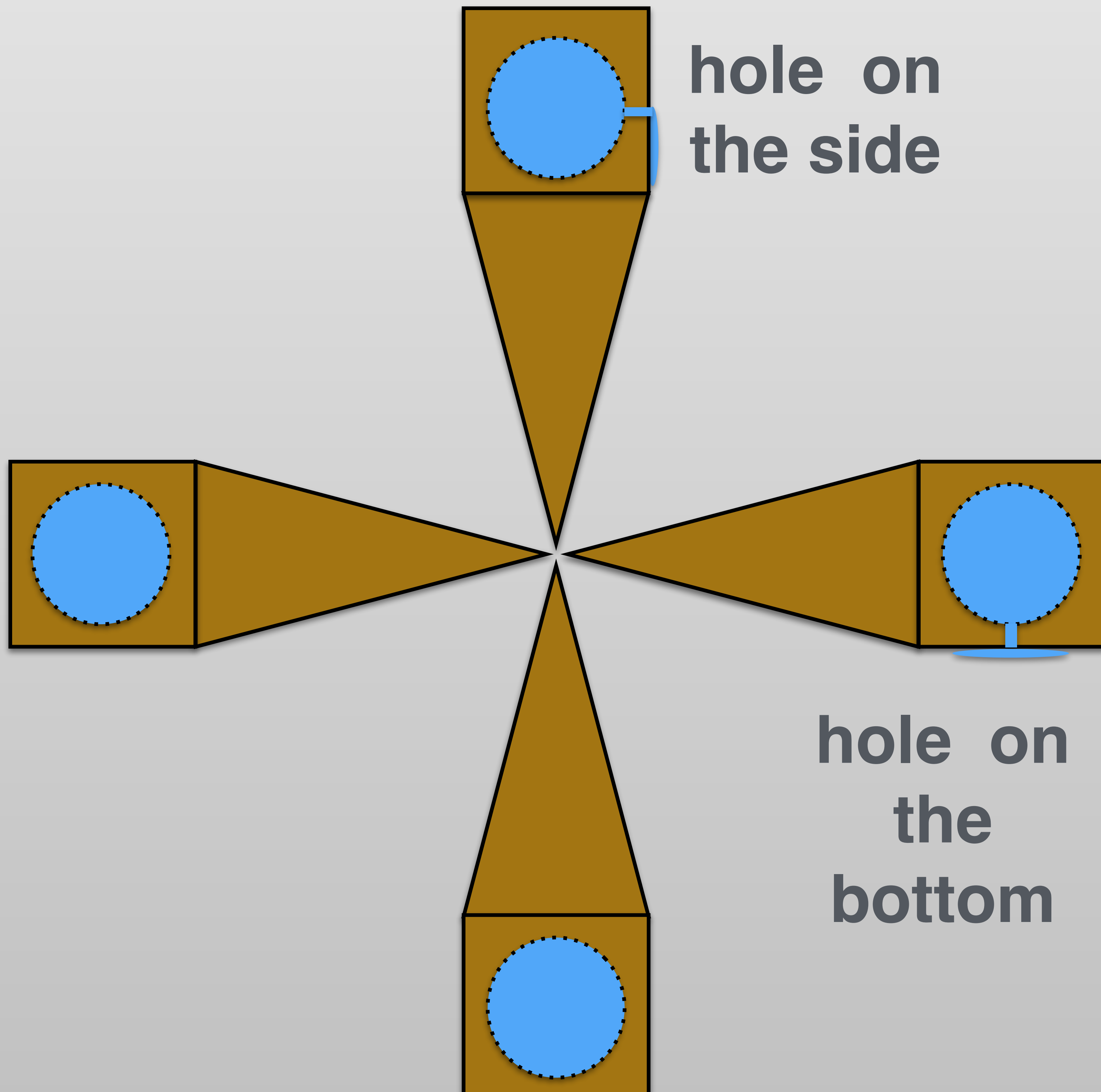


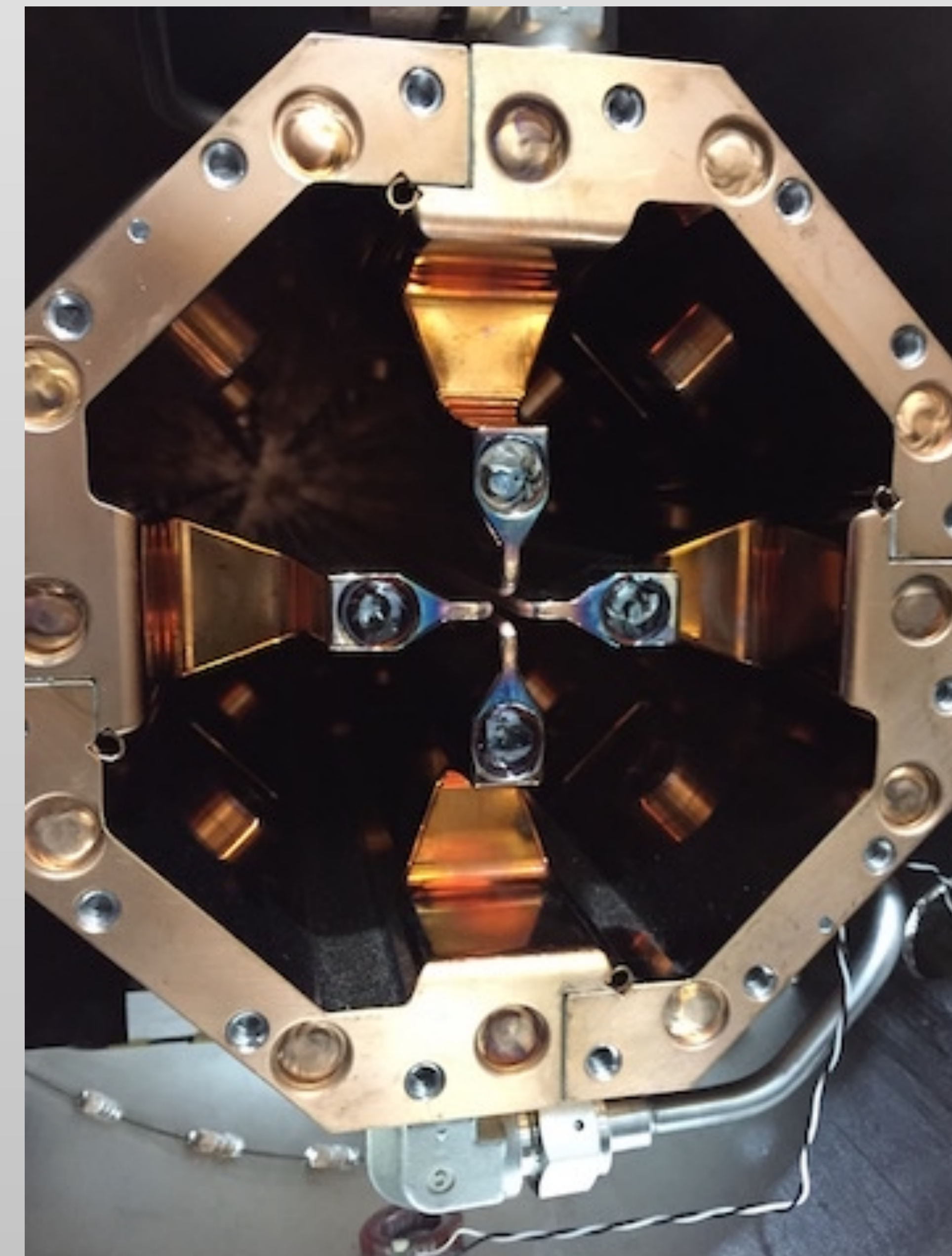
looking from the low energy end



bore scope pictures

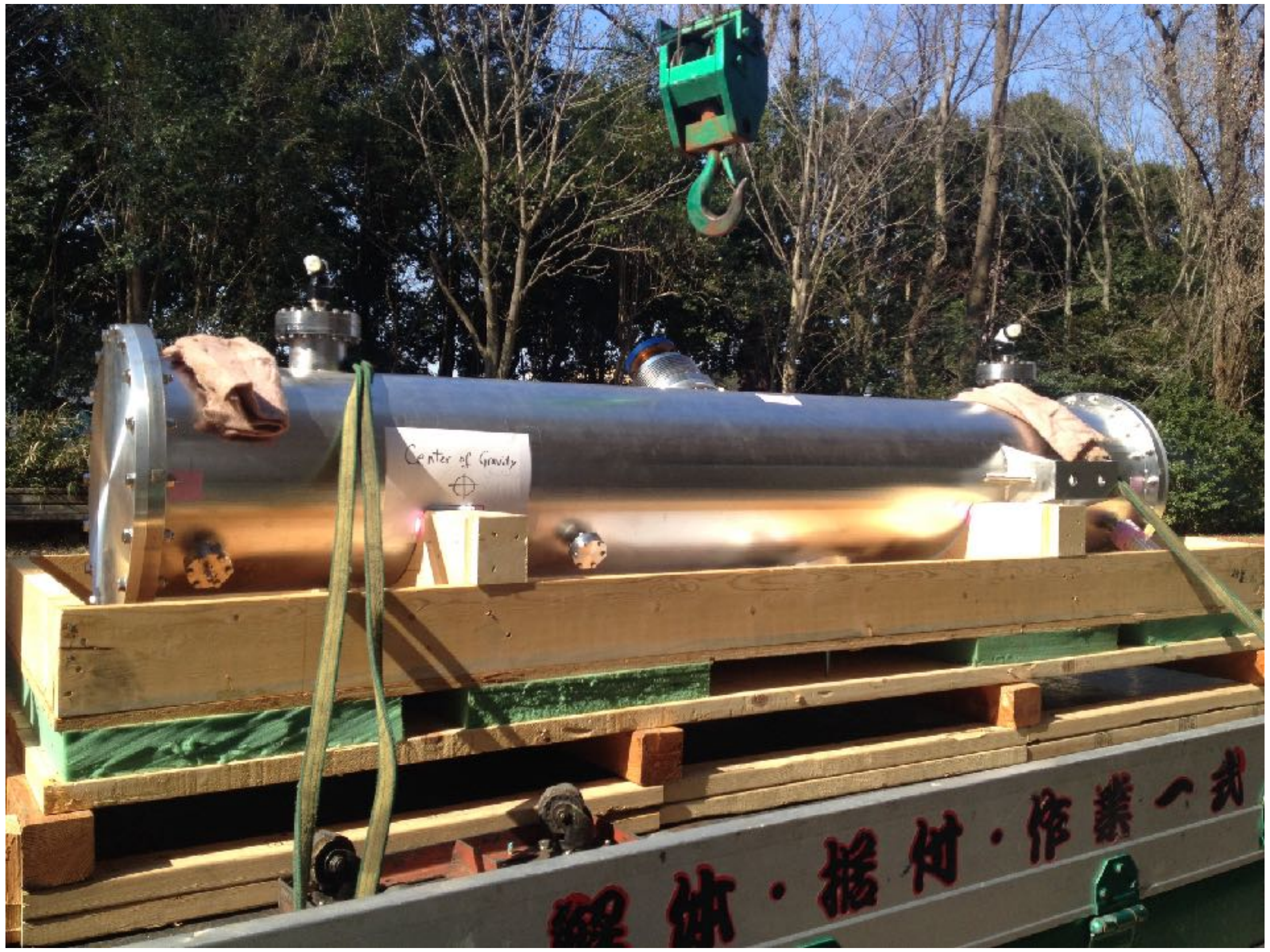
expected damage of the vane





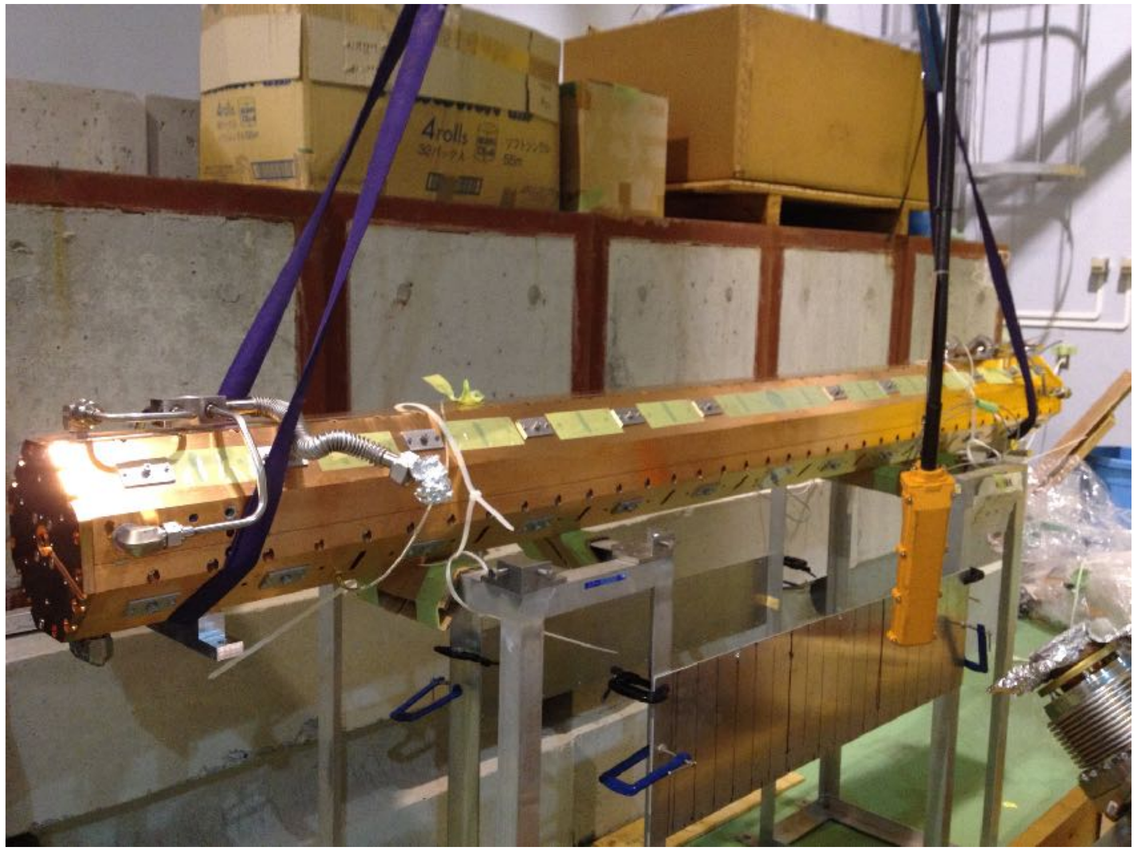
- Tried to repair the damaged resonator with sealant, but failed.
- Gave up repairing it.
- Borrowed an equivalent RFQ designed for a proton beam from the U of T.
- Need to adopt it to negative charged beams. The resonator should be rotated by 90 degrees to accelerate and focus the H- beam.

Carrying the similar RFQ from “U of T” to KURRI



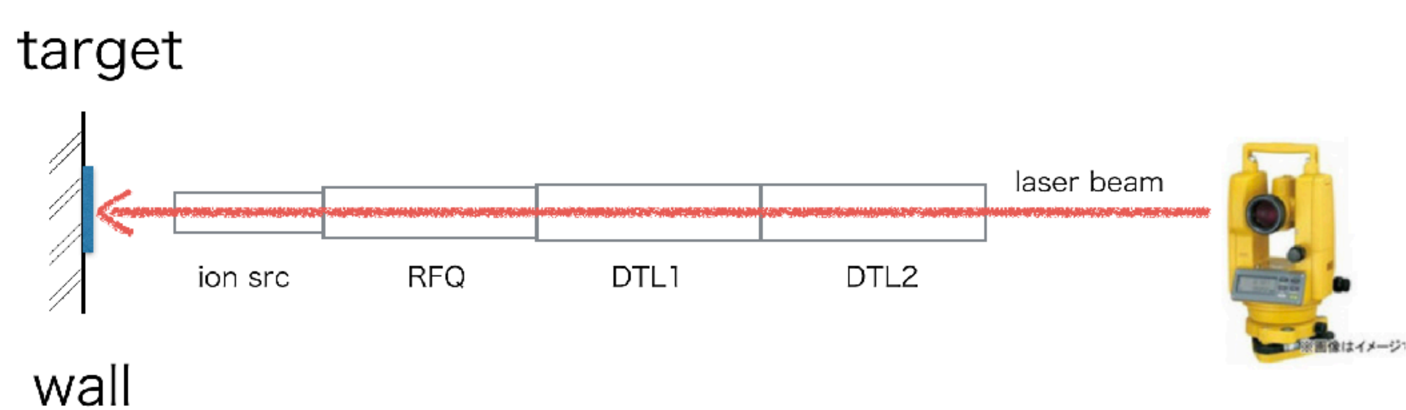
Uninstallation of the damaged RFQ.

The resonator used for investigations.

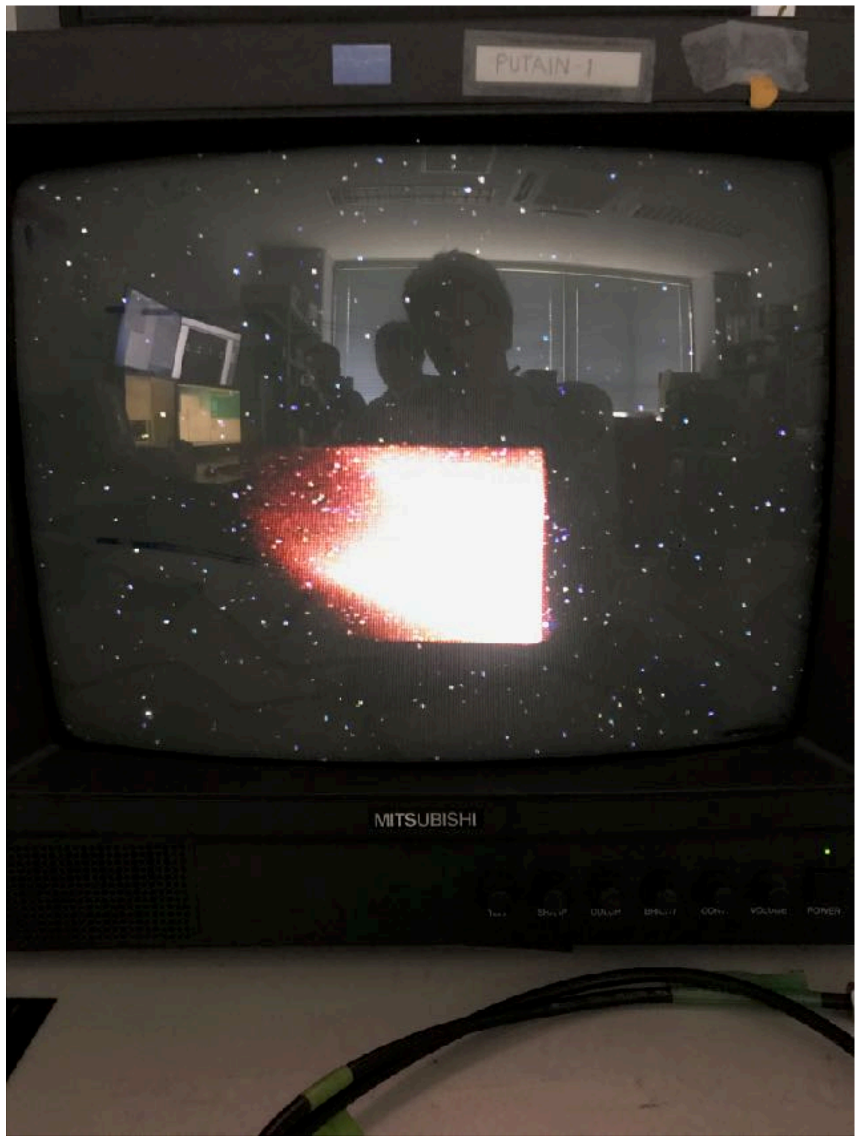


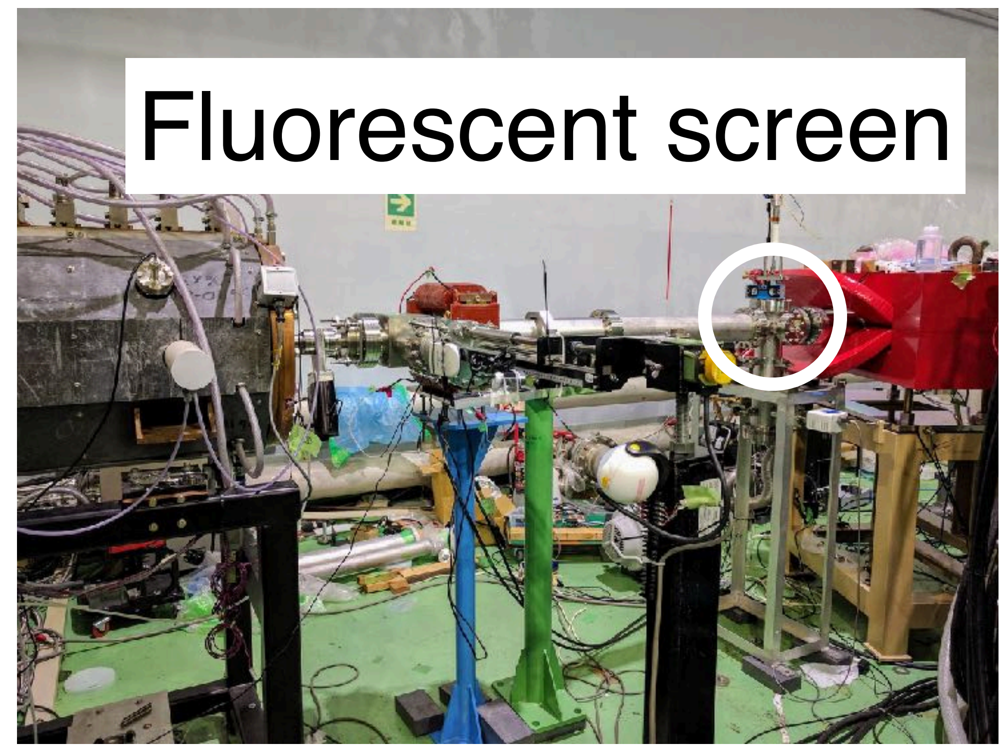
Things have been done for the recommissioning of the RFQ

1. Rotated the resonator by 90 degrees.
2. Installed resonator into the vacuum vessel.
3. Roll-in the whole RFQ into the beam line.
4. Put rf power to RFQ, DTL1 and DTL2. Confirmed they are all OK.
5. Roll-out the RFQ.
6. Did the fine alignment in the accuracy of 50um with respect to the vacuum vessel using a special jig. The jig and the alignment procedure should not be disclosure. → It needs an NDA agreement. It took a few month to make a contraction.
7. Roll-in again.
8. Align the whole LINAC to the beam line including the ion source using the laser beam.



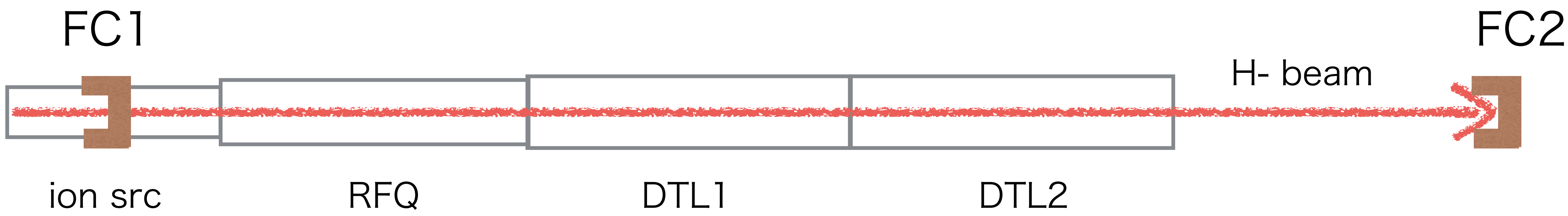
The first light in 2 years!

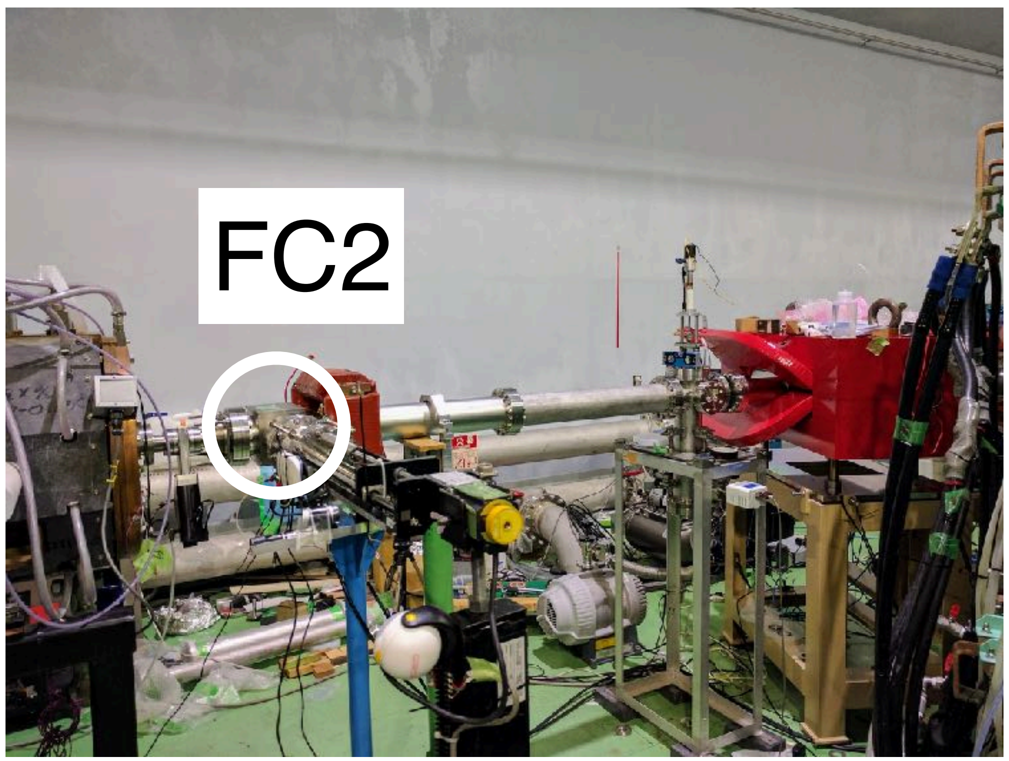


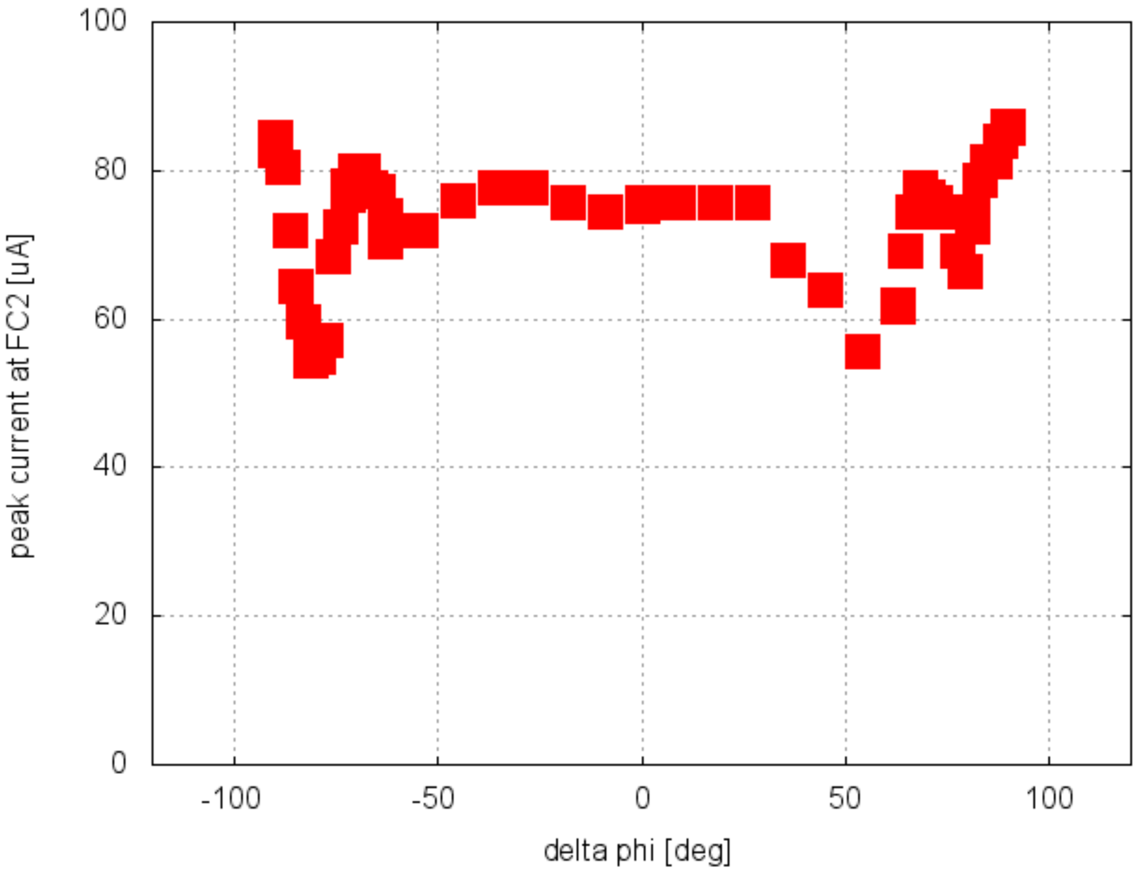


The beam image detected by the fluorescent screen

Beam intensity measurement



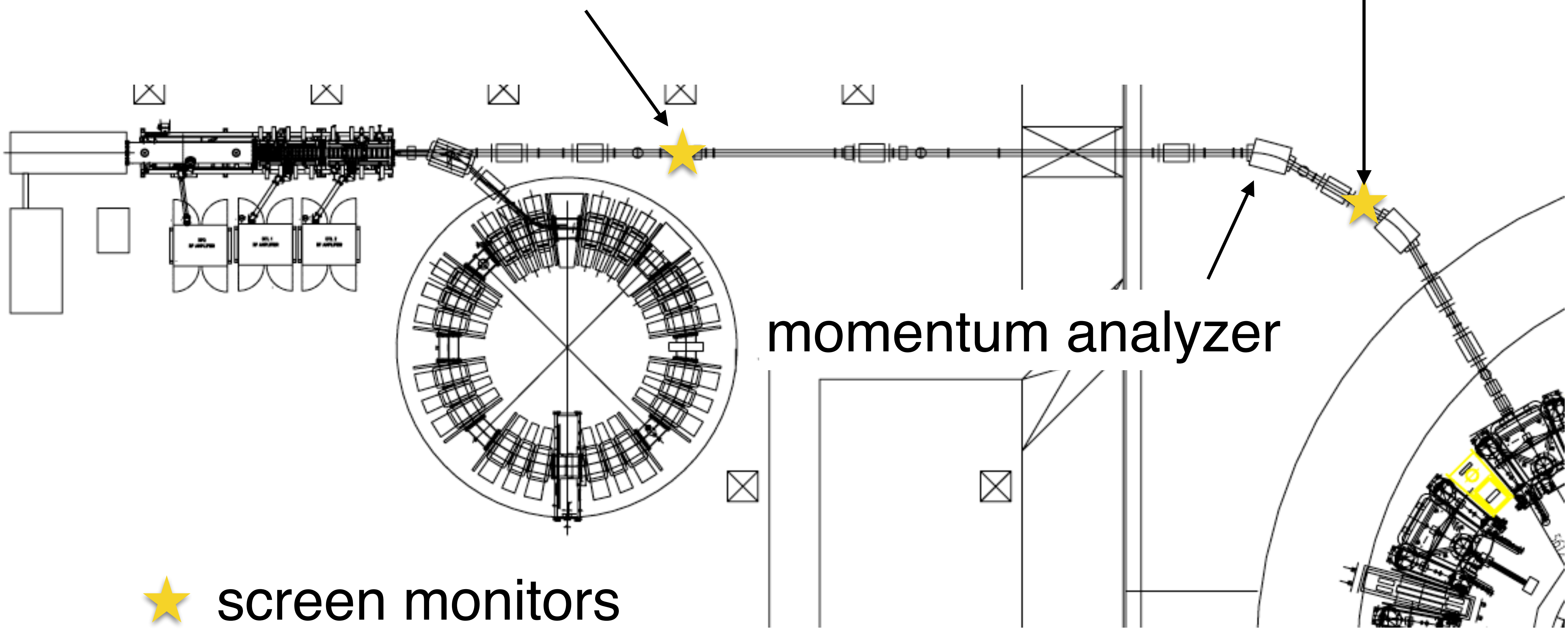




- phase adjustment between RFQ and DTL1
- FC1 : 1.2mA (peak), FC2 : 82uA (peak w/o DTL2) 14% as usual (w/ DTL2)

beam containing 3, 7 and 11 MeV of H0, H+ and H-

beam composed of only 11 MeV H-



★ screen monitors

Rough schedule

1. We are going to inject the H- beam into the main ring even with low intensity after this workshop.
2. We should be able to measure the betatron tune at the beginning of October.

Recommissioning scenario of the Main Ring

Tom Uesugi

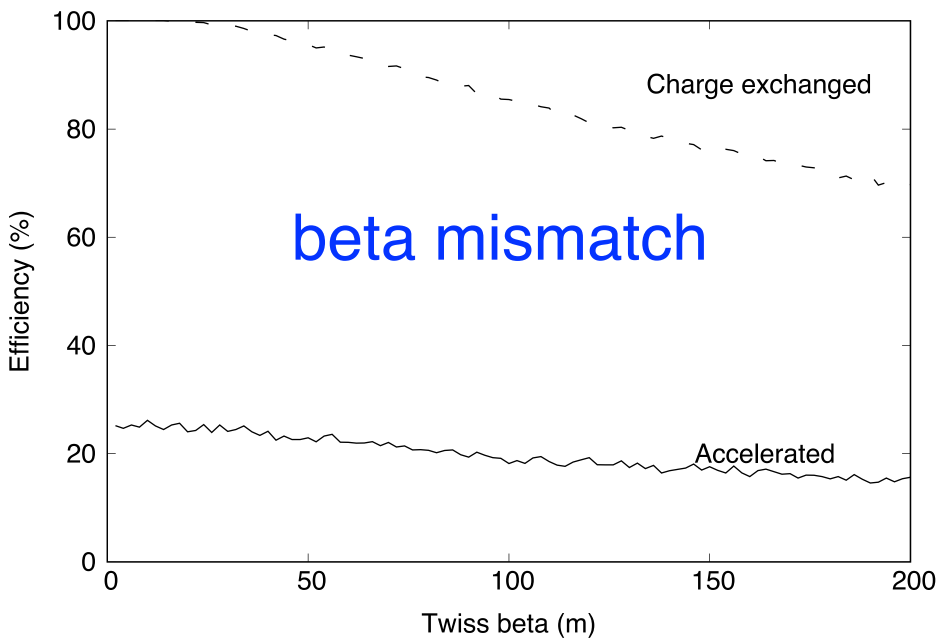
Parameters to be optimized

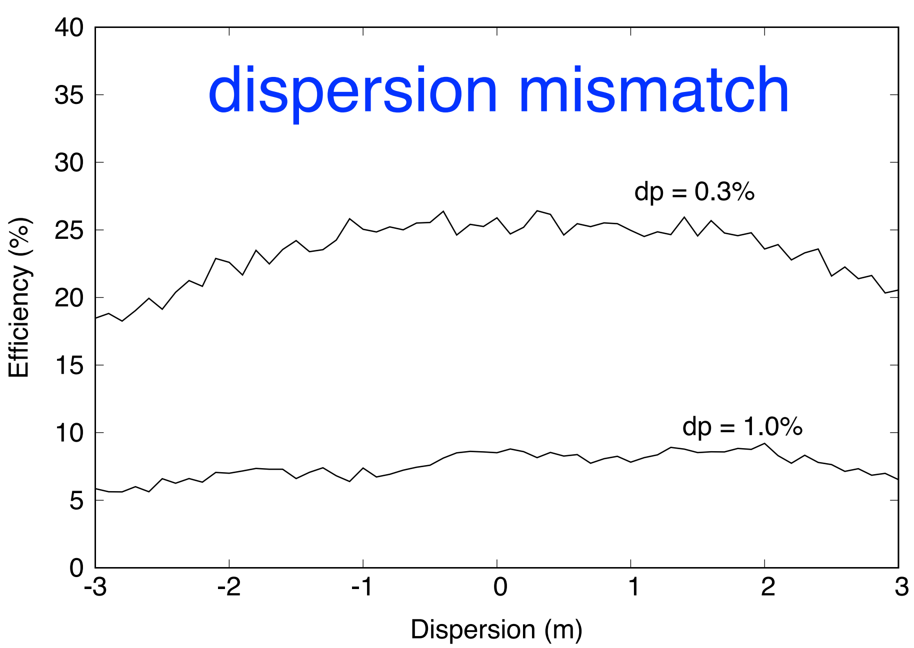
Goal: Beam particle distribution $f(t, E, x, x', y, y')$ $\in$ Ring 6D acceptance

statistic parameters		depends on	
center	E_0	Linac, (AND BM)	as high as possible
	(x_0, x_0')	HMBT ST	matched with ring
	(y_0, y_0')	HMBT ST	matched with ring
spread	δE	Linac	as small as possible
	(ϵ_x, ϵ_y)	Linac ? NIS?	as small as possible
	(β_x, α_x)	HMBT QM	matched with ring
	(β_y, α_y)	HMBT QM	matched with ring
coupling	(D_x, D_x')	HMBT QM, BM	

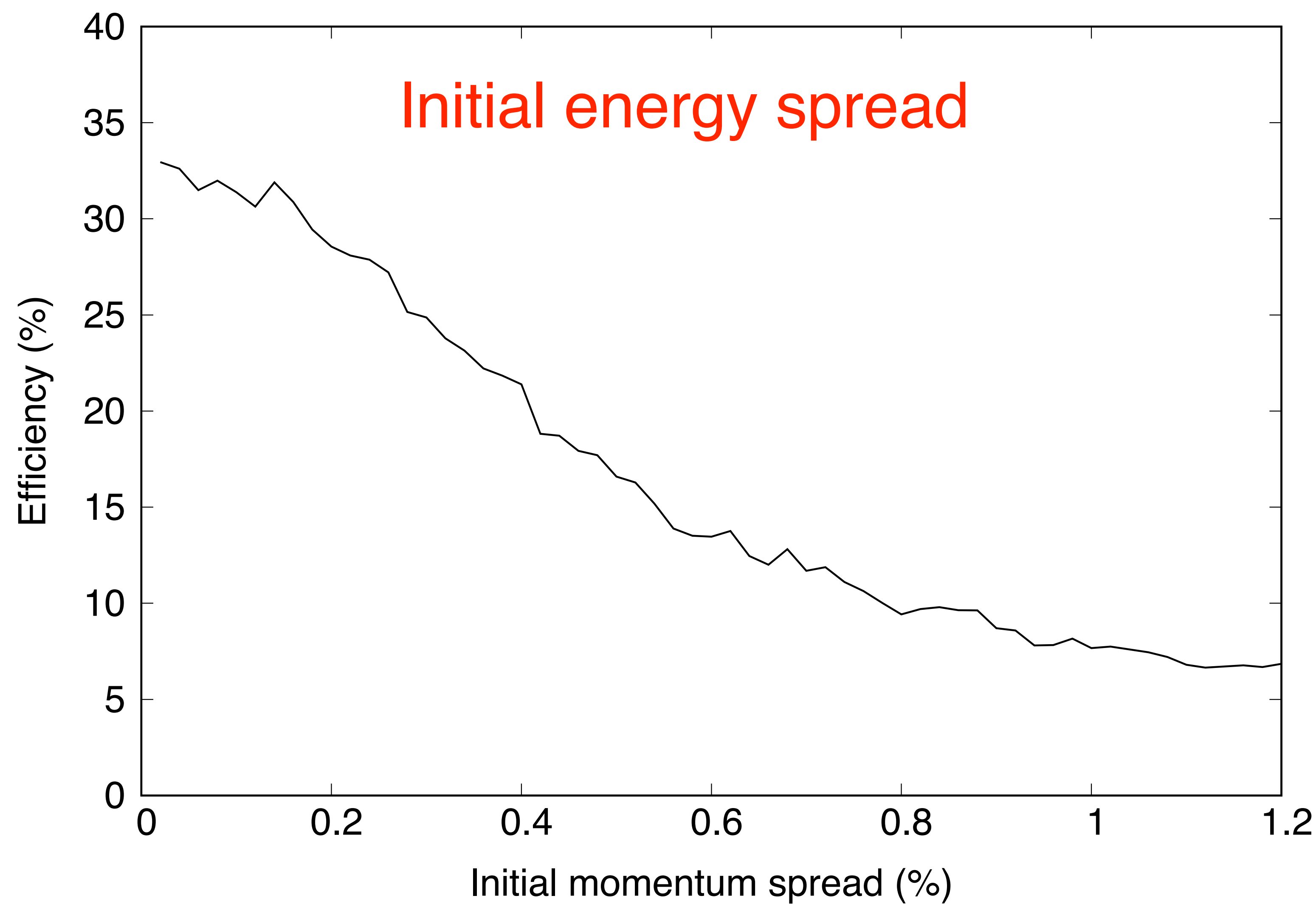
which parameter is the most important?

Past simulation result about capture efficiency





- Effect of Twiss-mismatch and dispersion mismatch are very small.
- Energy spread affects very much



Tom Uesugi, FFAG17, Cornell university, NY

Procedure

(0) First of all, verify that parameters of LINAC, or QMs of straight HMBT does not affect the beam axis.
Alignments of NIS, LINAC and QMs, if necessary.

(1) Maximize H- beam energy by linac parameters, such as tank field and relative phases. … ~2 days
We expect that the energy spread and emittance will be minimized, simultaneously. … 1~2 day

(2) Focusing at foil with HMBT-QMs to improve injection efficiency.

… 2~5 days ?

(3) Find the closed orbit and Injection axis matching by HMBT-STs.
Measure revolution frequency.

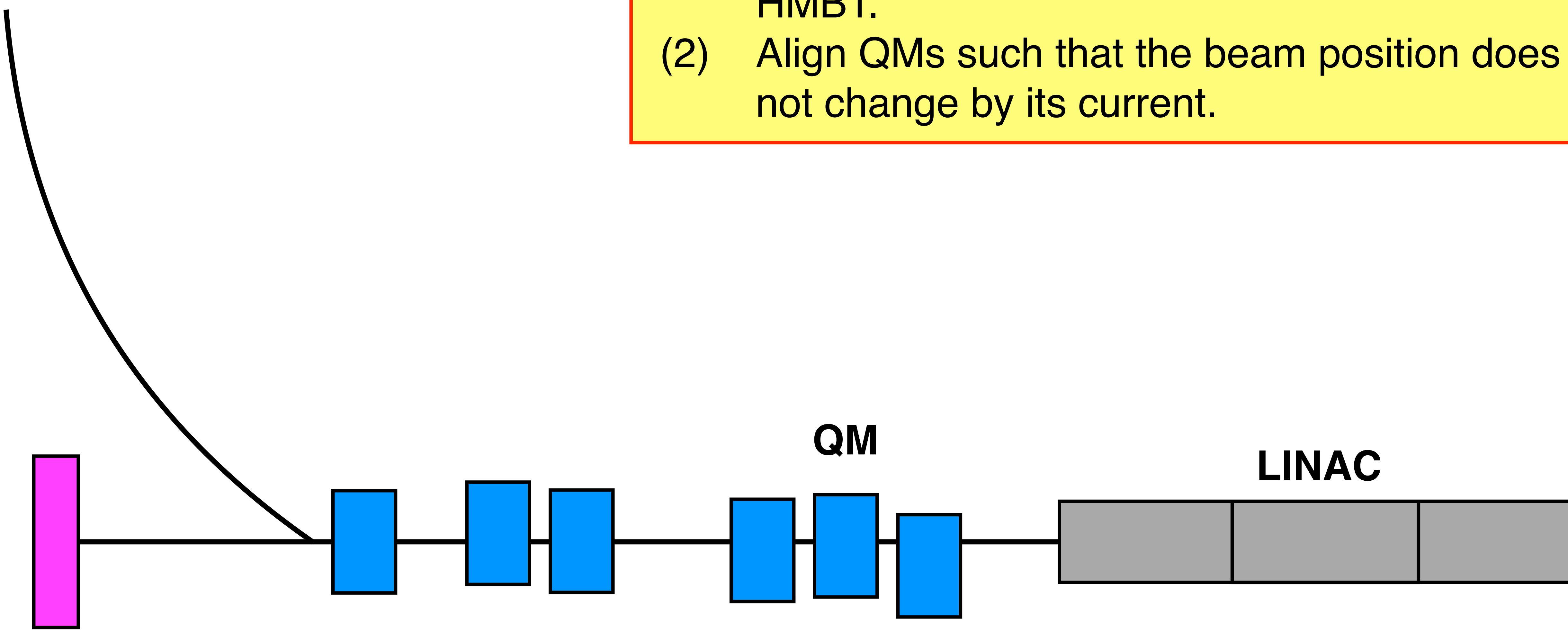
… ~2 day

(4) Accelerate beams and Optimize rf operation. … 2 ~ days

(0) Alignment of QMs of HMBT

~2 days

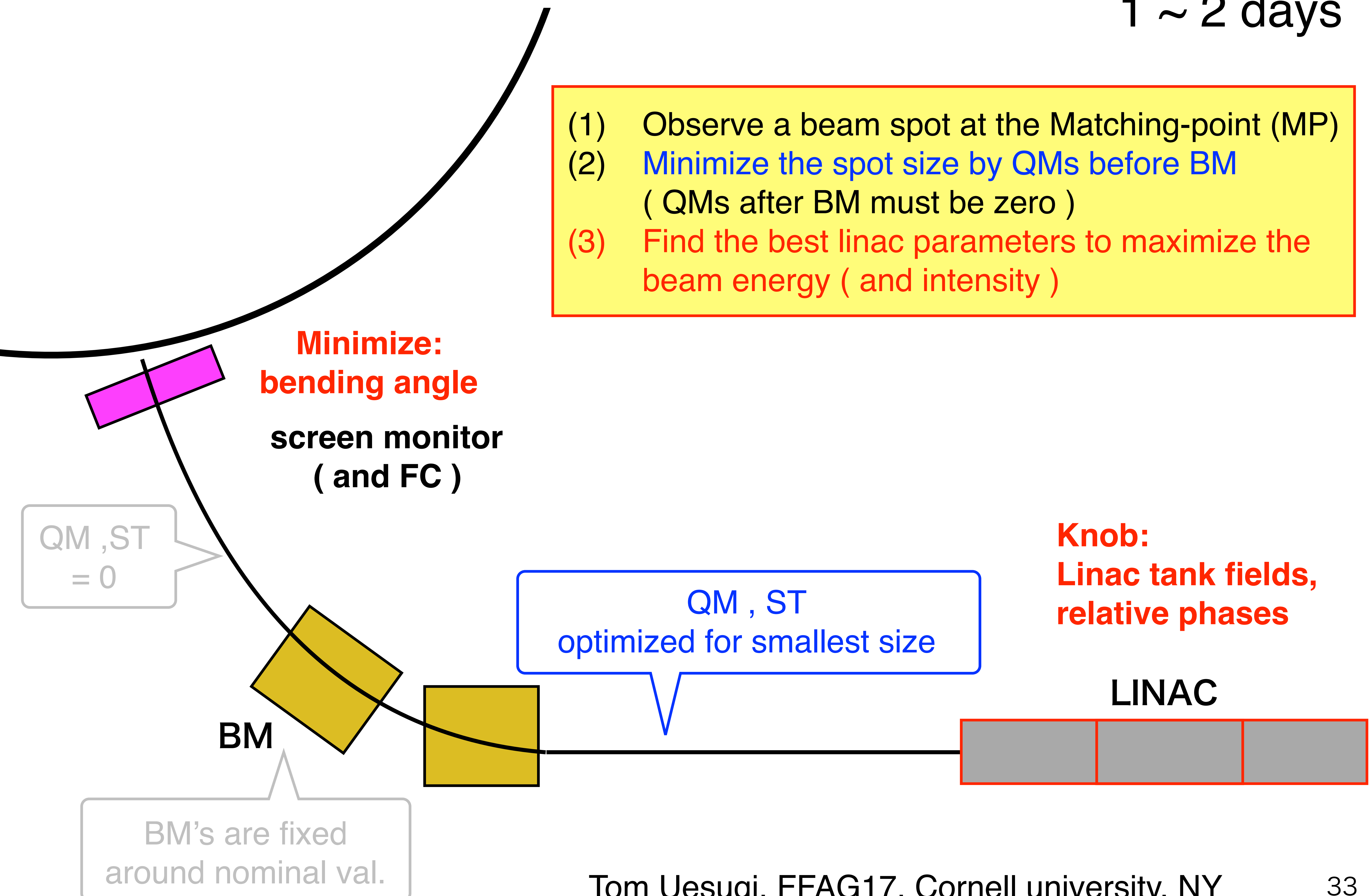
(1) Observe a beam spot at the straight end of HMBT.
(2) Align QMs such that the beam position does not change by its current.

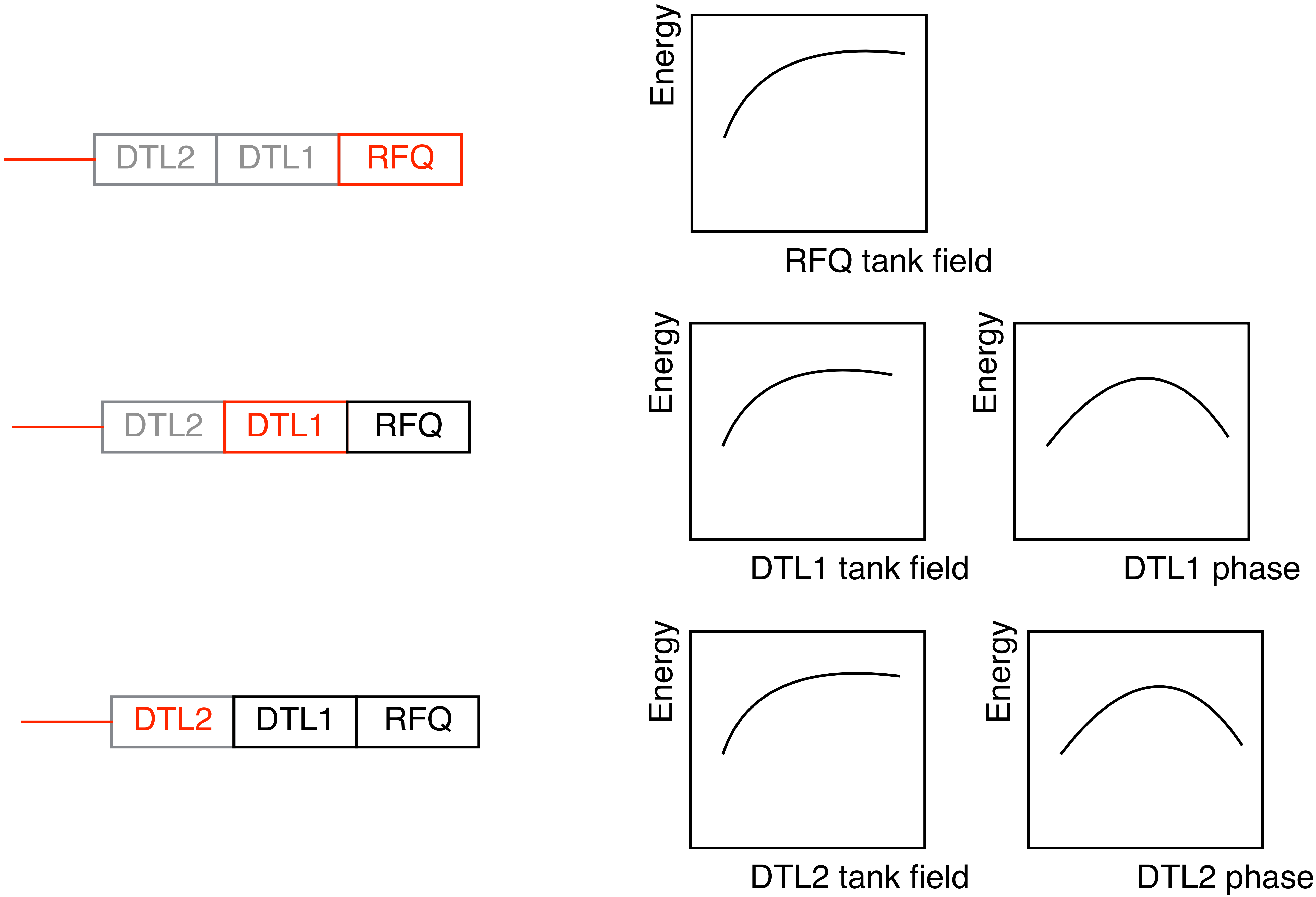


(1) Maximizing beam energy

1 ~ 2 days

(1) Observe a beam spot at the Matching-point (MP)
(2) Minimize the spot size by QMs before BM
(QMs after BM must be zero)
(3) Find the best linac parameters to maximize the beam energy (and intensity)

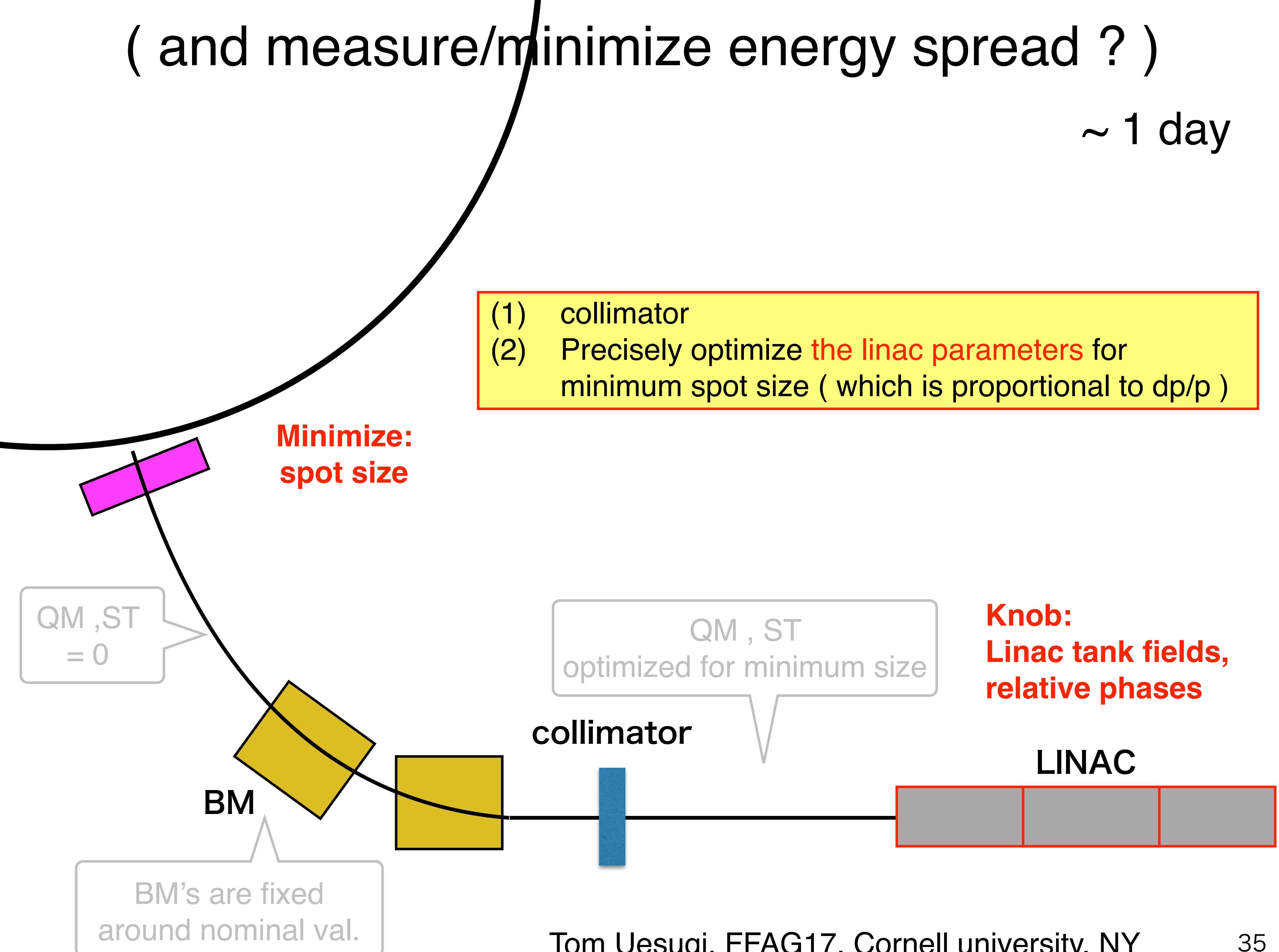



DTL2
DTL1
RFQ
Energy
RFQ tank field
DTL2
DTL1
RFQ
Energy
DTL1 tank field
Energy
DTL1 phase
DTL2
DTL1
RFQ
Energy
DTL2 tank field
Energy
DTL2 phase

(and measure/minimize energy spread ?)

~ 1 day

(1) collimator
(2) Precisely optimize the linac parameters for minimum spot size (which is proportional to dp/p)



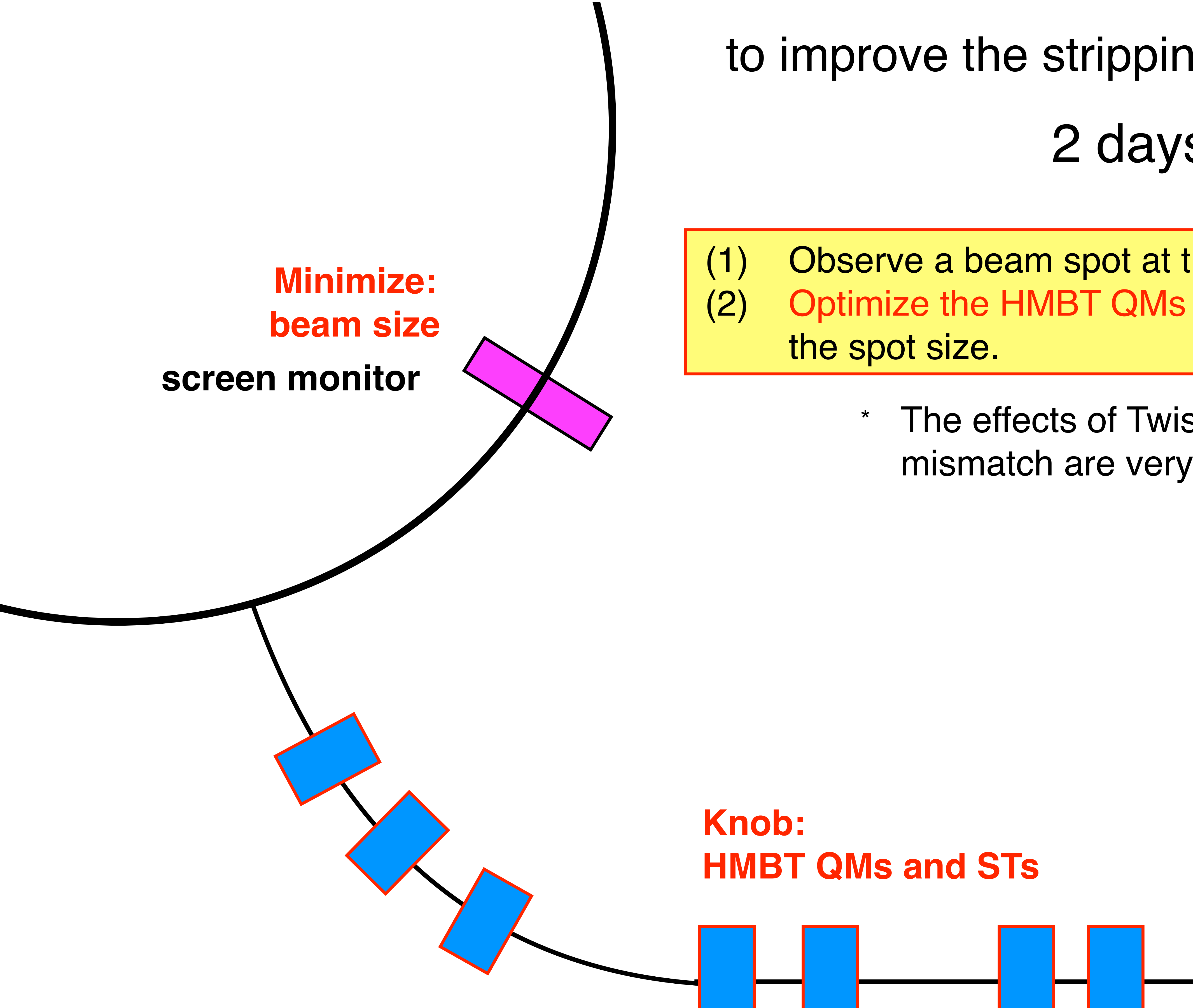
(2) Focusing the beam at foil

to improve the stripping efficiency

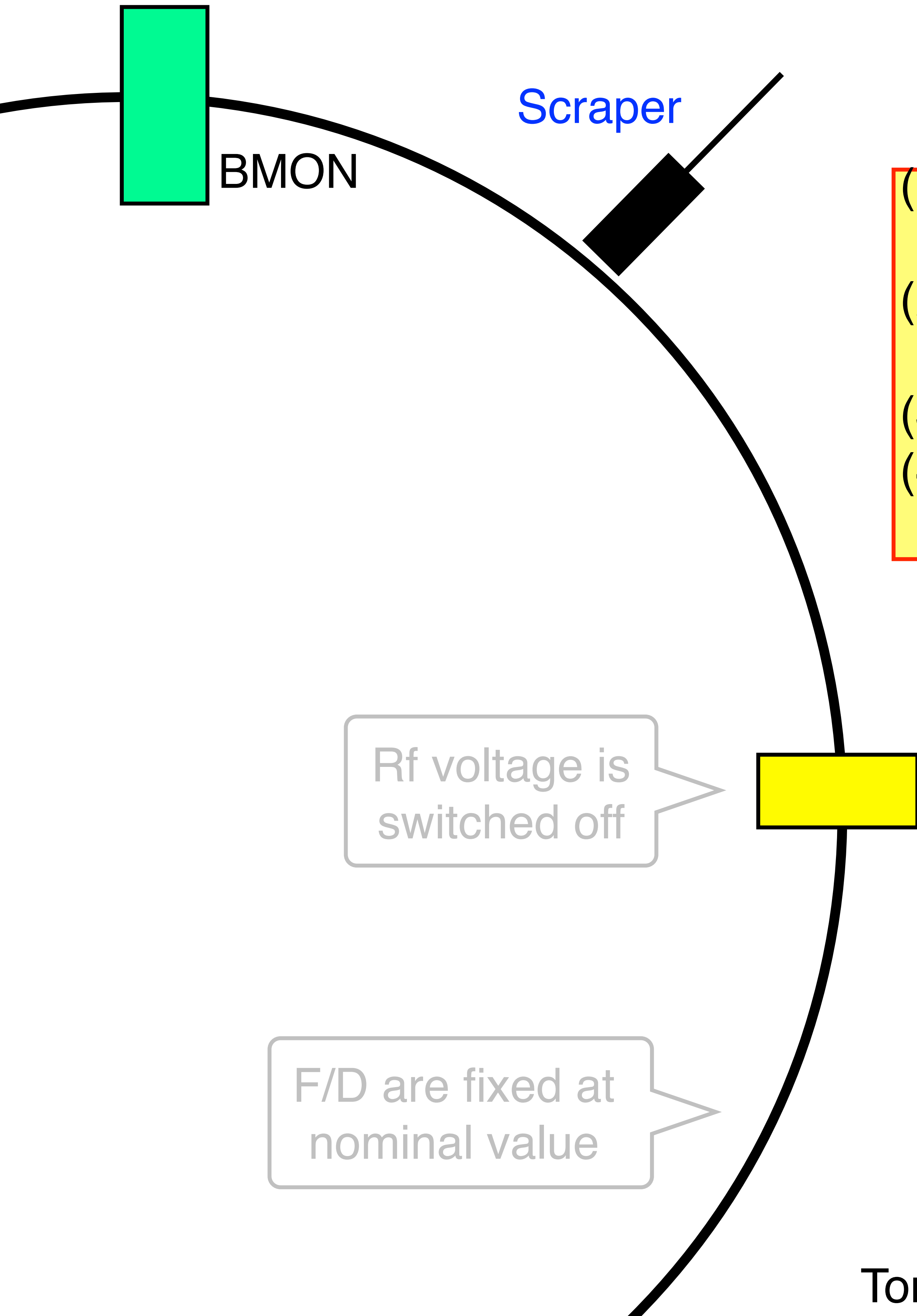
2 days ~ 1 week ?

(1) Observe a beam spot at the foil.
(2) Optimize the HMBT QMs to minimize the spot size.

* The effects of Twiss and dispersion mismatch are very small



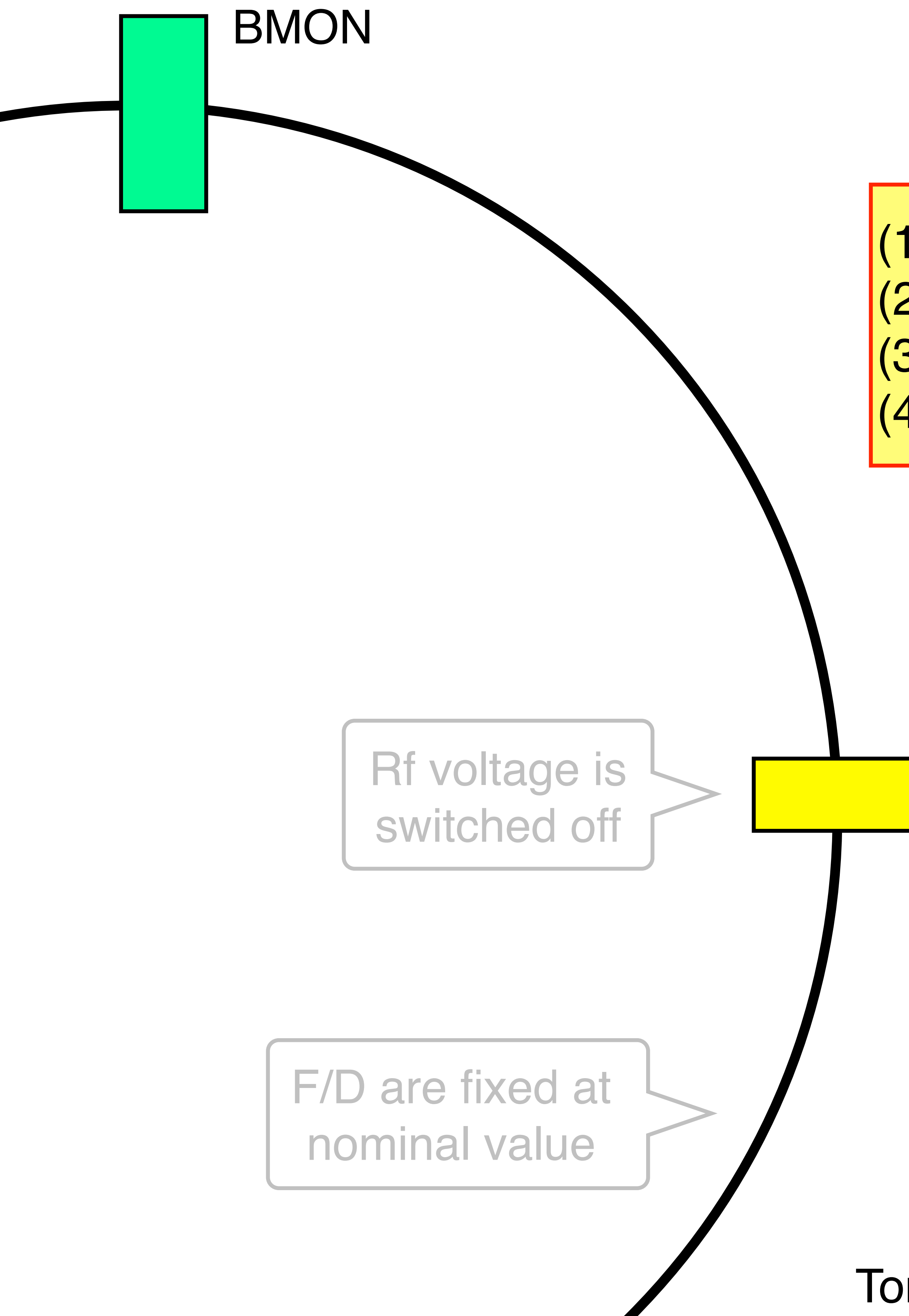
(3) Find closed orbit and Injection axis matching



~ 2 days ?

(1) Inject a chopped (< 0.5us) beam.
(Rf is switched off)
(2) Optimize the foil position (radius) and the HMBT-HMs to maximize the turn number.
(3) Insert a scraper in the ring and repeat (2).
(4) Measure the revolution frequency of the first ~100 turns.

(4) Optimize the rf capture parameters



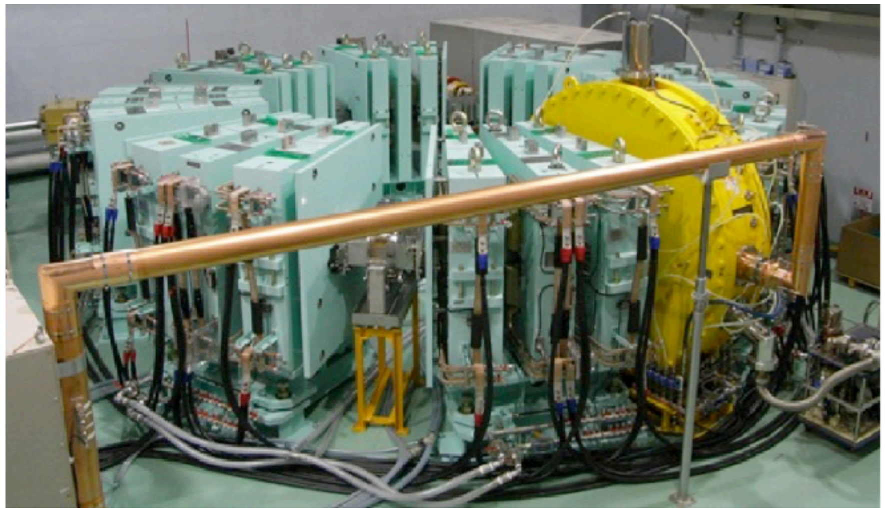
~ 2 days ?

(1) Inject a long pulse beam.
(2) Apply the acceleration rf.
(3) Optimize the foil position, trigger timing,
(4) Change accelerating phase …

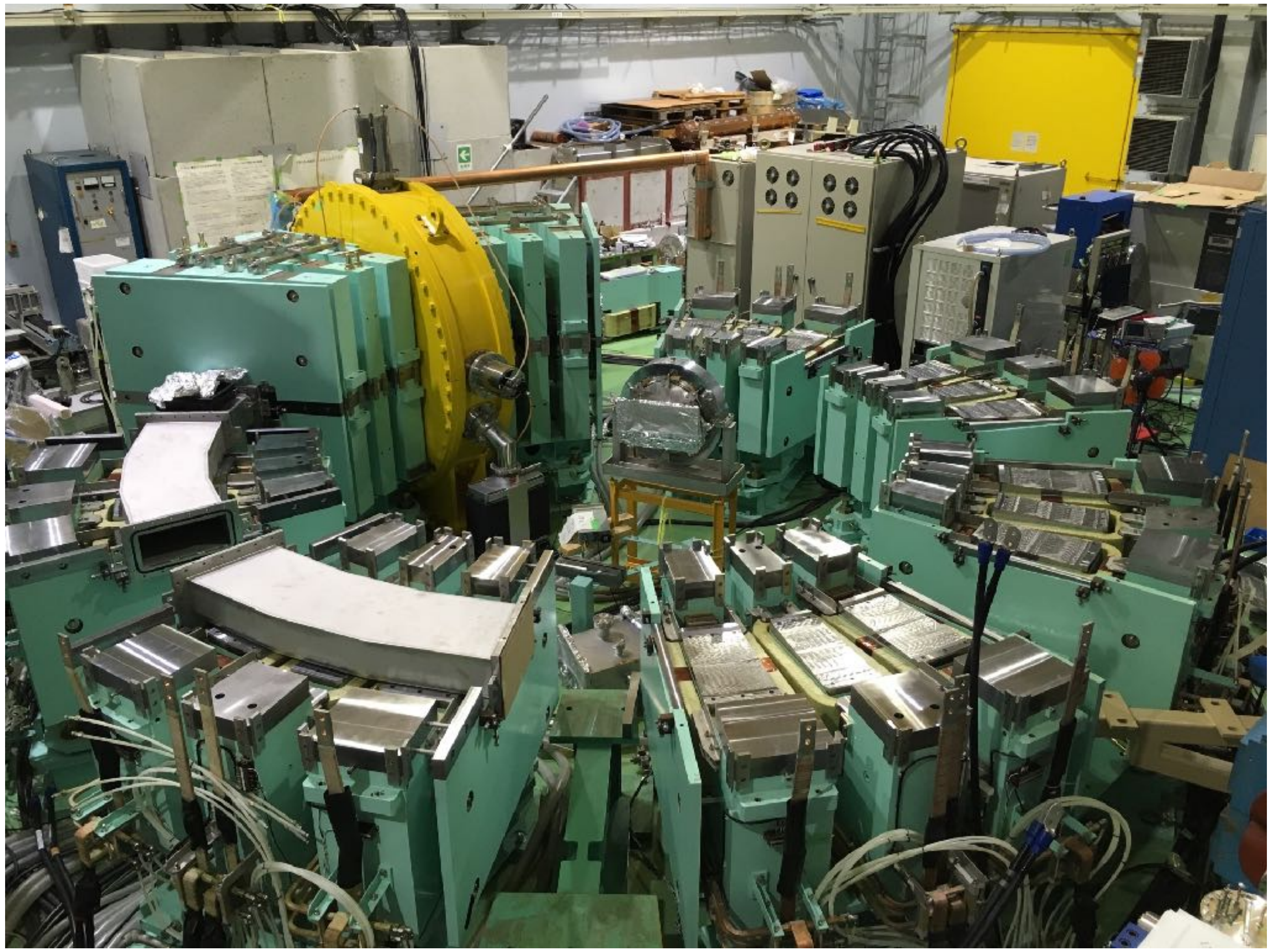
Upgrade of the Facility

On Going Project

Construction works for the modification of ERIT to MERIT have been done.



ERIT

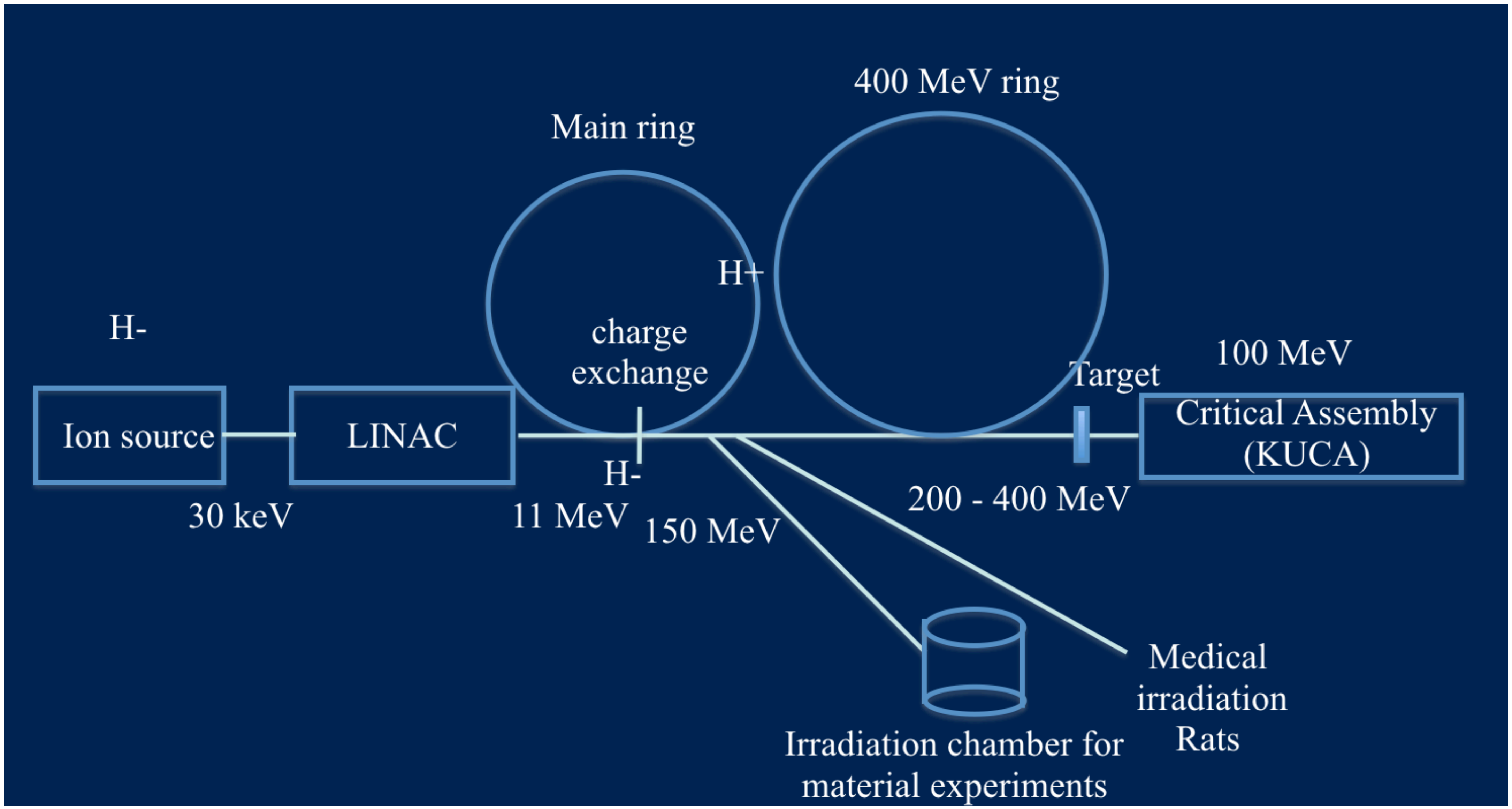


MERIT

The details will be presented by Mori-san and Okita-san.

Future Plans

Energy upgrade to 400 MeV



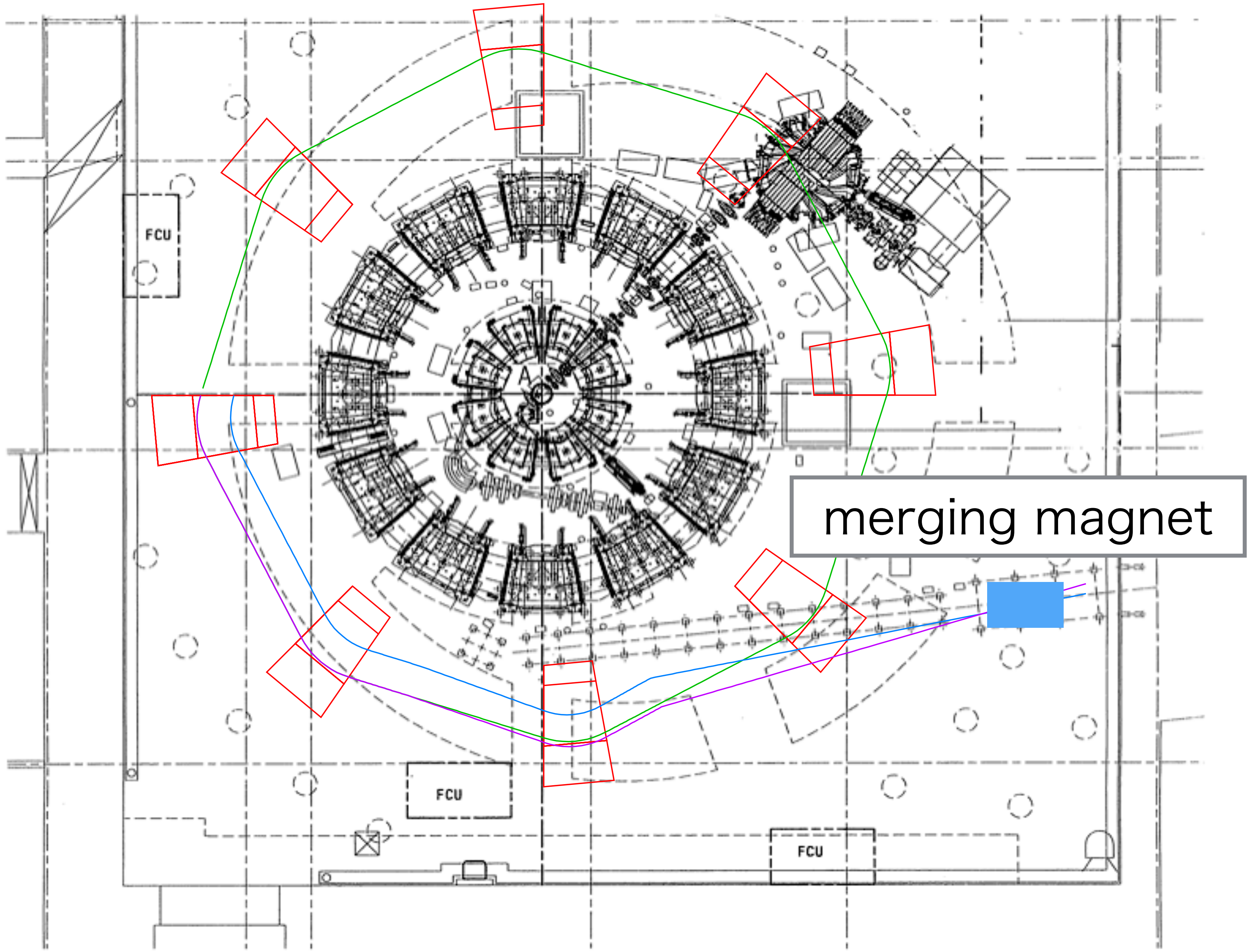
At JAEA, the transmutation experimental facility (TEF) is under consideration. They are planing to use 400 MeV proton beams to investigate physical characteristics in the ADS with rather low power proton beams (TEF- P) as well as the technical engineering with extremely high power beams(TEF-T). If the FFAG accelerator facility at KURRI can deliver the beams with the energy between 200 and 400 MeV to the KUCA, fruitful results are expected from the basic experiments on ADS. That is the motivation to design a new energy variable FFAG synchrotron. It is planned to be builded outside the existing 150 MeV main ring at the KURRI FFAG facility.

Design trial of two options for 400 MeV ring

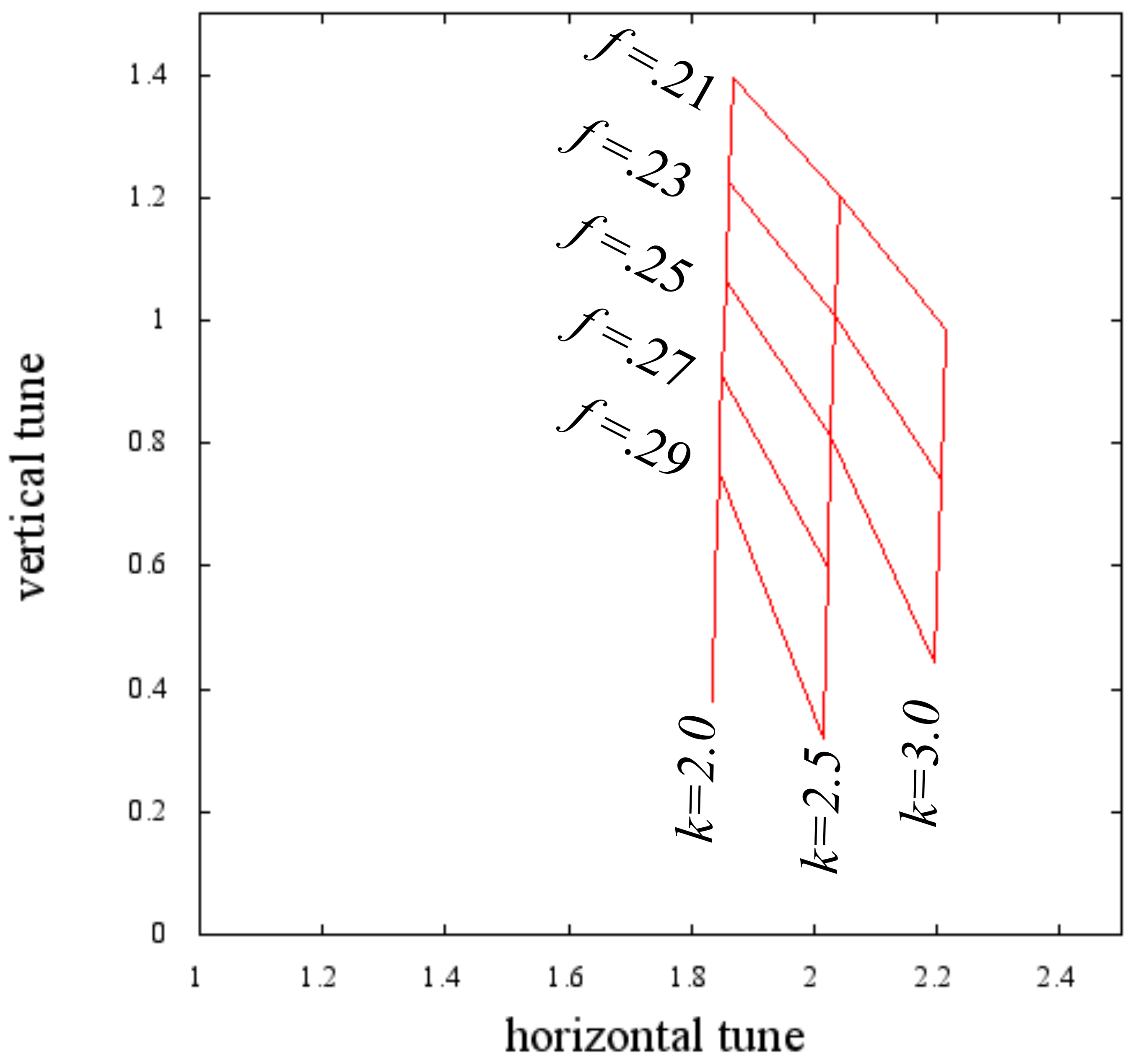
1. Variable energy (200 - 400 MeV) ring adopting an ordinary rf acceleration with frequency modulation.
2. MERIT type ring which uses serpentine acceleration aiming to produce secondary particles i.e. pions as well as ADS experiments.

Variable Energy Ring

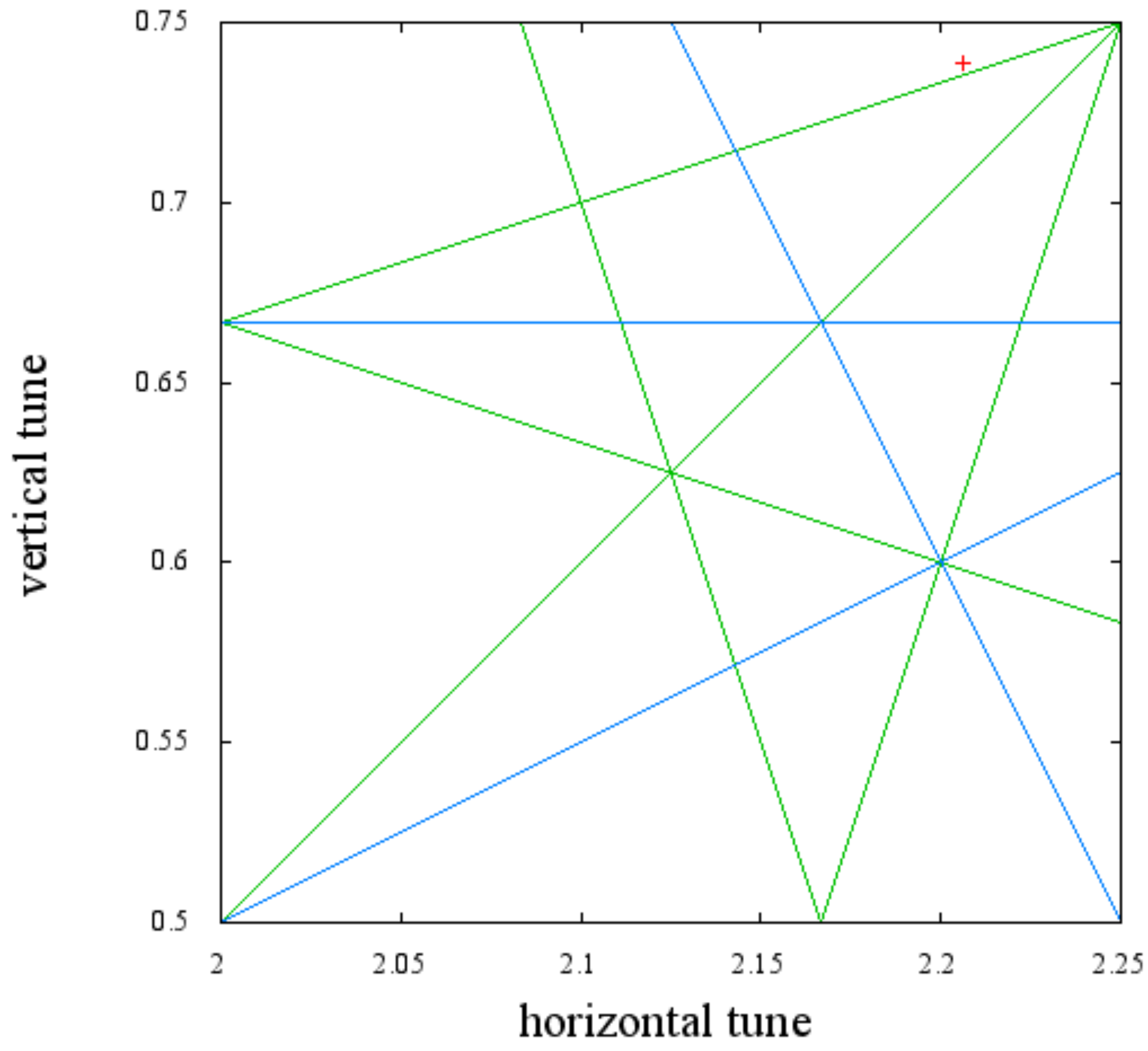
Variable Energy FFAG 200 - 400 MeV



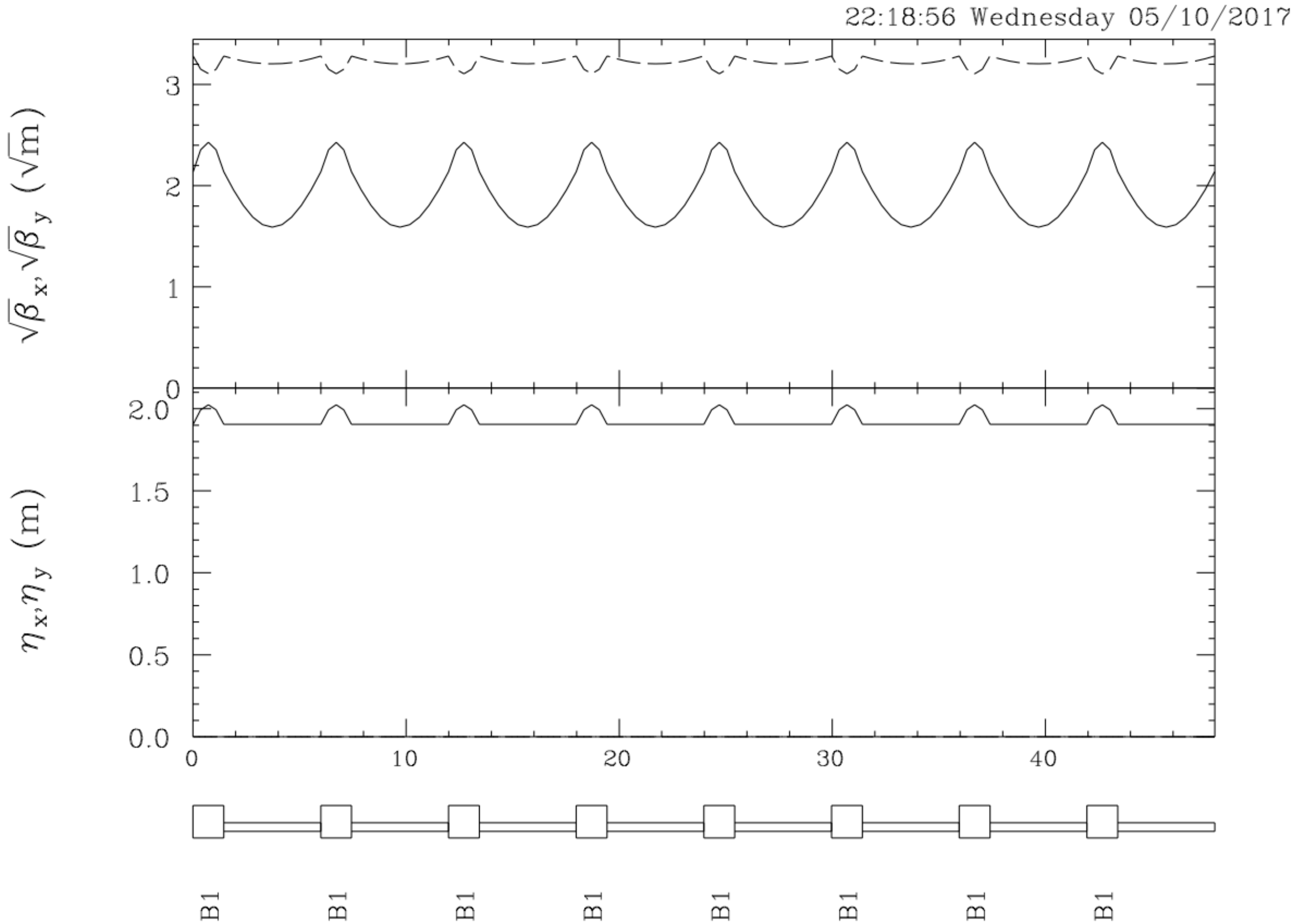
Footprint of the extracted beams. Red lines show the main magnets of the 400 MeV ring. The blue and purple lines show the trajectories of protons extracted at 200 MeV and 400 MeV, respectively. These lines are crossing at the merging magnet indicated by a blue box. By adjusting the magnetic field of the merging magnet, the beams with any energies between 200 and 400 MeV can be extracted and transported through the same beam line to the KUCA.



The tune variation with respect to the field index k and the packing factor f . Red lines are contour of those parameters. To avoid integer resonances and keep the beam excursion small , we have chosen parameters k and f as 3.0 and 0.23, respectively.

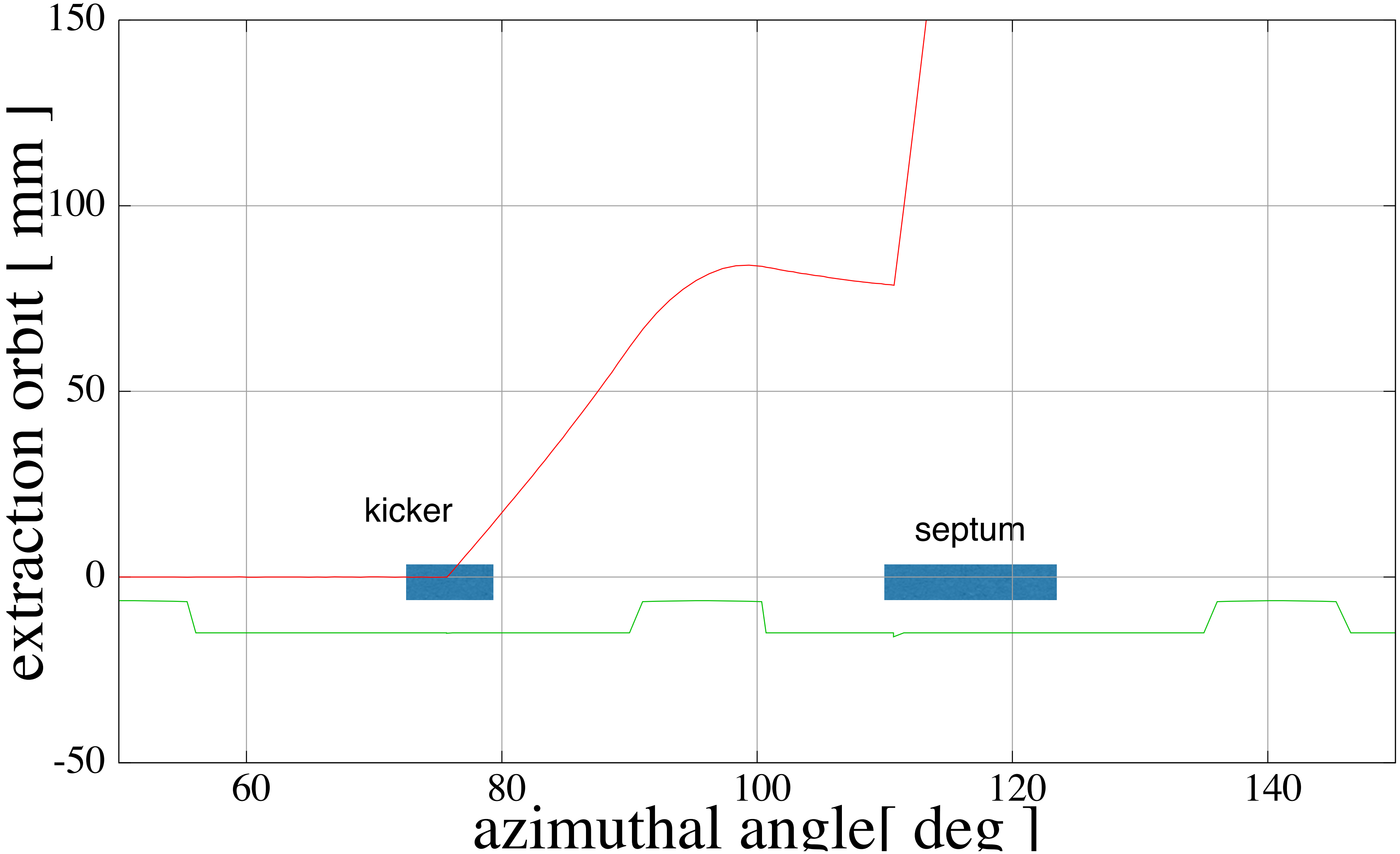


The tune diagram of the 400MeV ring. Blue and green lines are 3rd and 4th order resonance lines, respectively. The red cross is the operating point. Since it is close to the resonance excited by skew octupoles, it may be changed according to further investigations.



The lattice functions of the 400 MeV ring. Since the spiral angle is zero and no reverse bends are installed, vertical focusing force is generated by only edge focusing of the main magnets.

Beam species	Proton
Injection Energy	11 MeV
Extraction Energy	200 -400 MeV
Number of cells	8
Field index k	3.0
Packing factor f	0.23
Magnetic field	1.72 T (max.)
Tune	(2.21,0.74)
Radius of the orbit	7.0 - 8.0 m

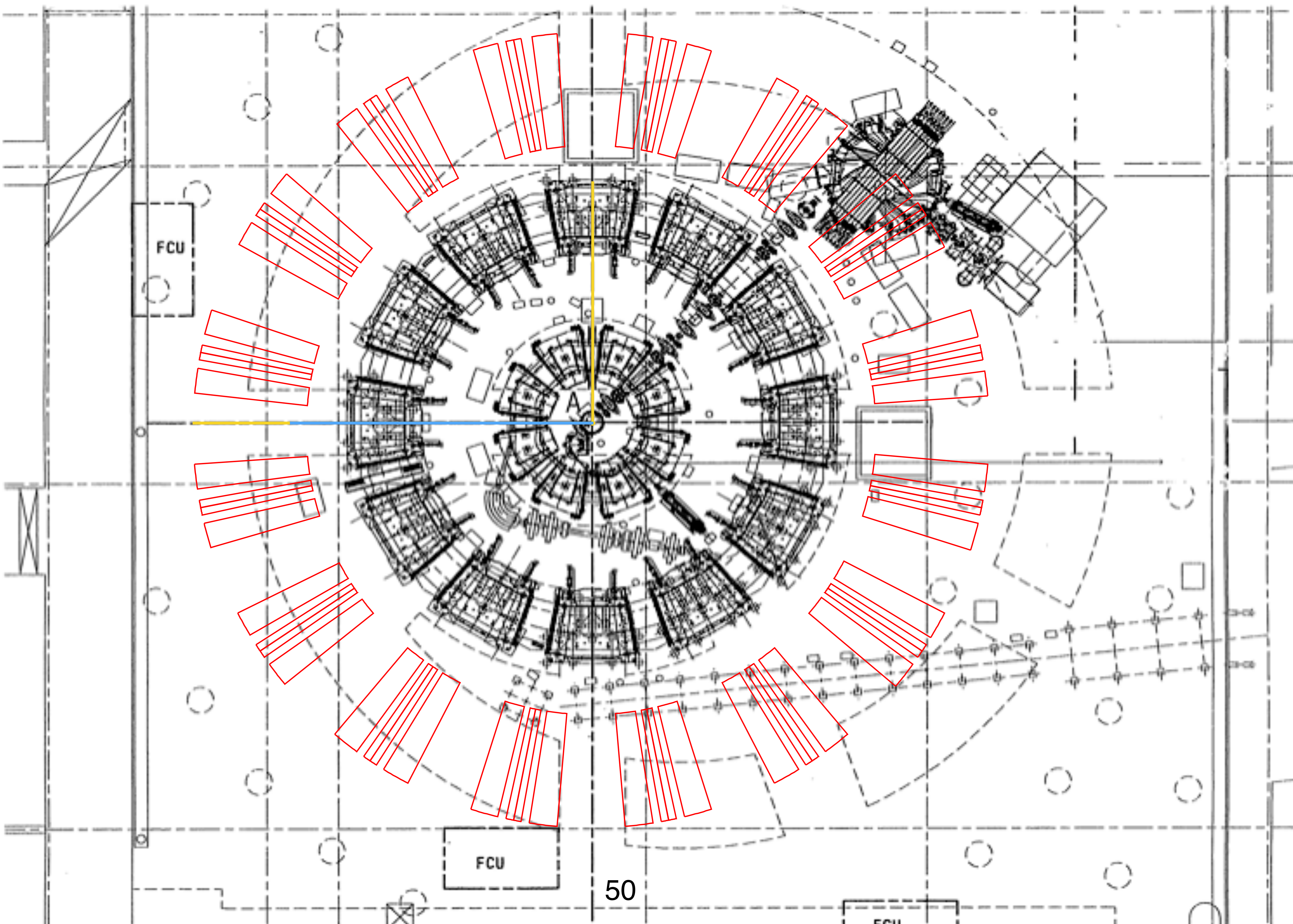


A scheme of the beam extraction from the 400MeV ring. The kicker magnet kicks the beam by 30 mrad with the magnetic field of 2kG to make 75mm turn separation at the septum magnet. The phase advance between the kicker and septum magnet is about 90○ . Both of them should be moved by remote controlled mechanism inside the vacuum chamber in order to extract the beams at different energies.

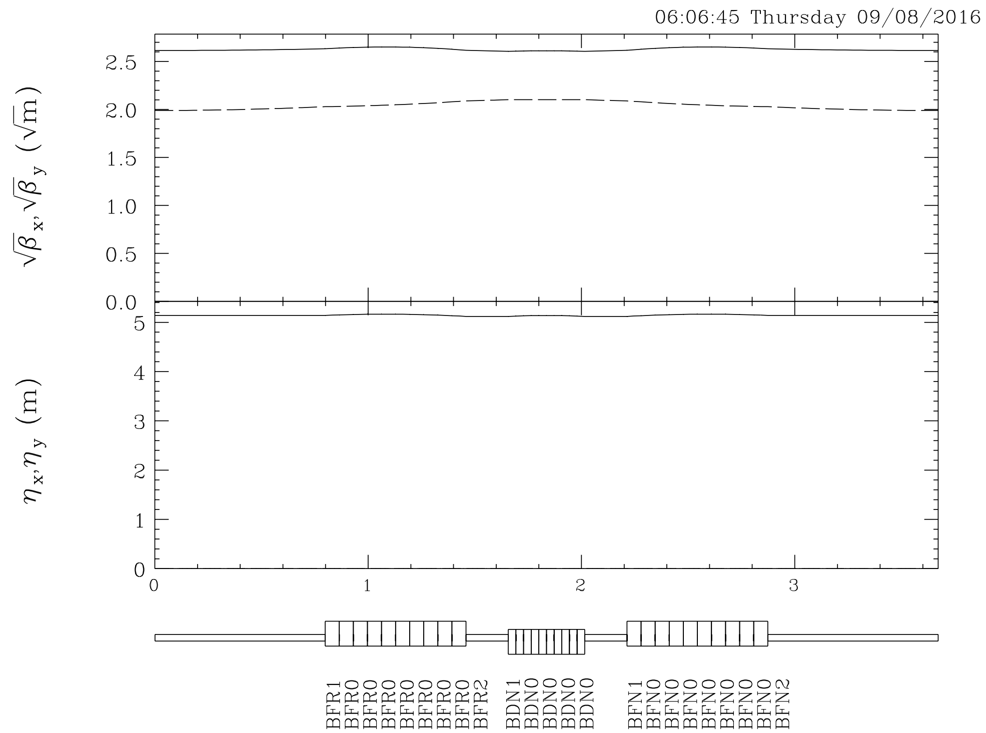
	Kicker	Septum
Magnetic field	0.2 T	0.7 T
Length	0.5 m	1.0 m
Kick angle	30 mrad	220 mad

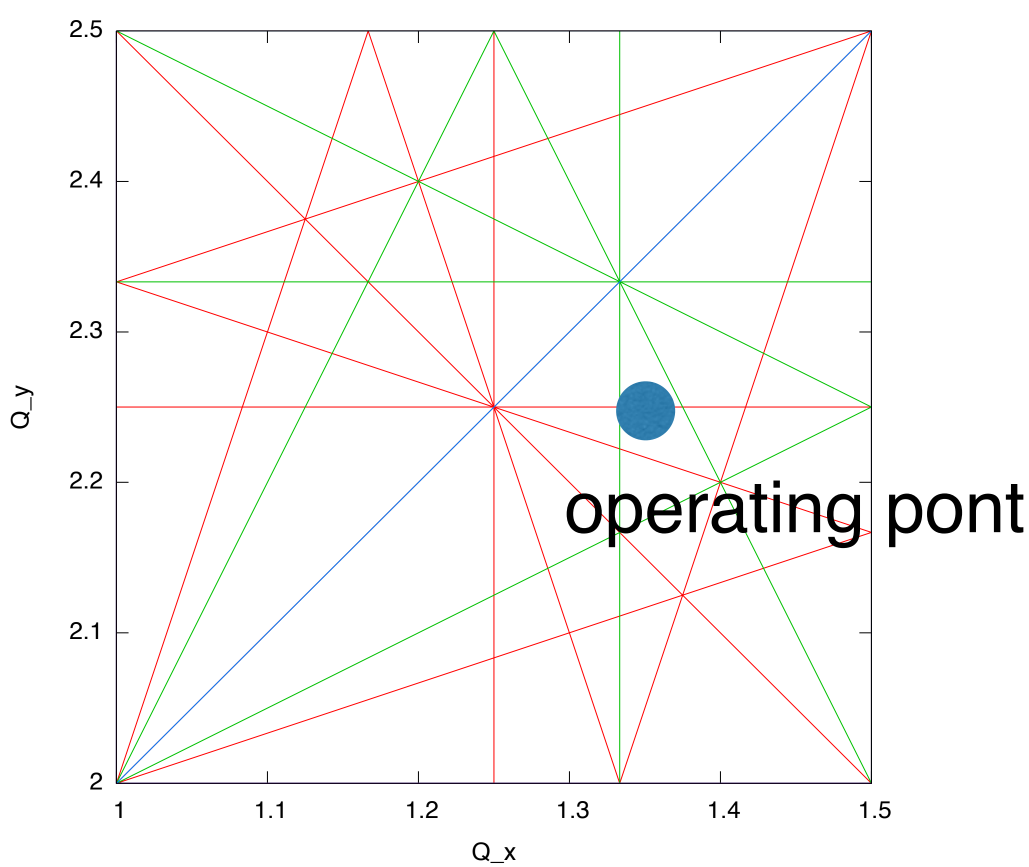
MERIT Type Ring

Newly designed 400 MeV FFAG ring.



Beta functions of the 400 MeV FFAG ring.





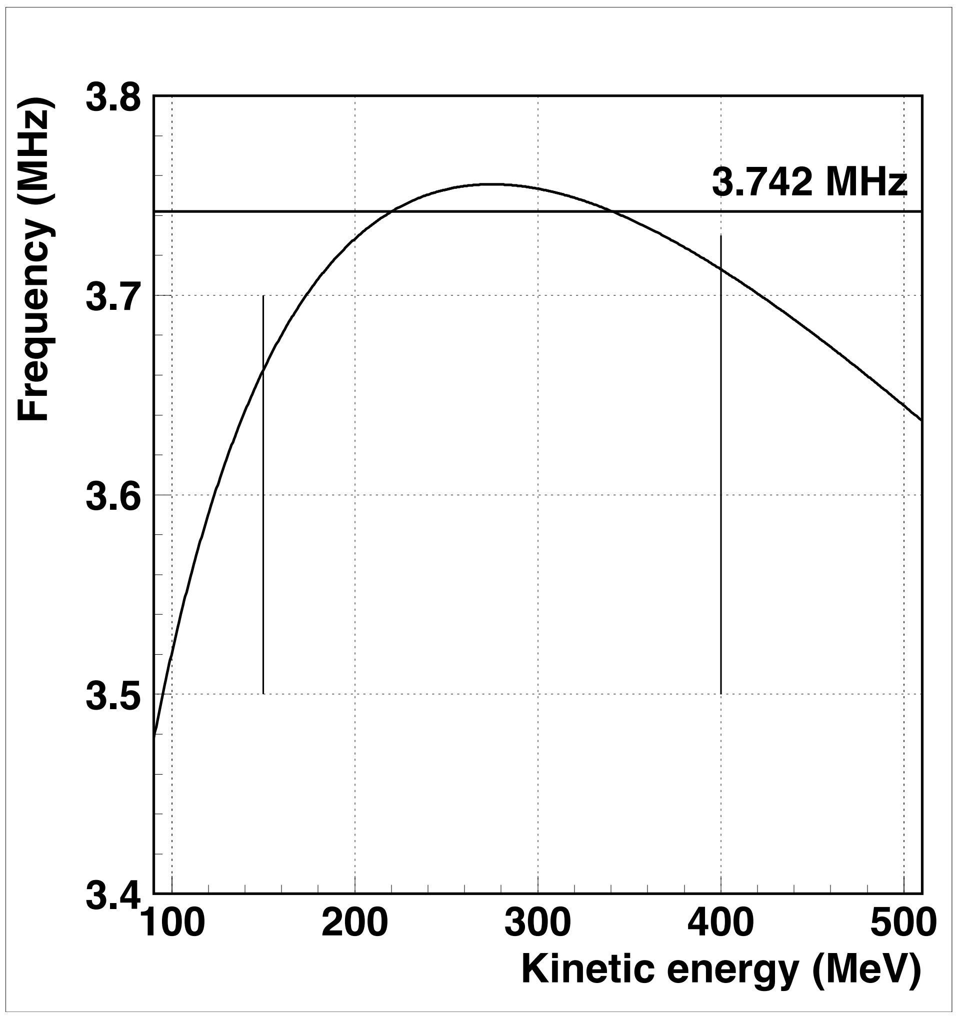
Basic parameters of the 400 MeV FFAG ring.

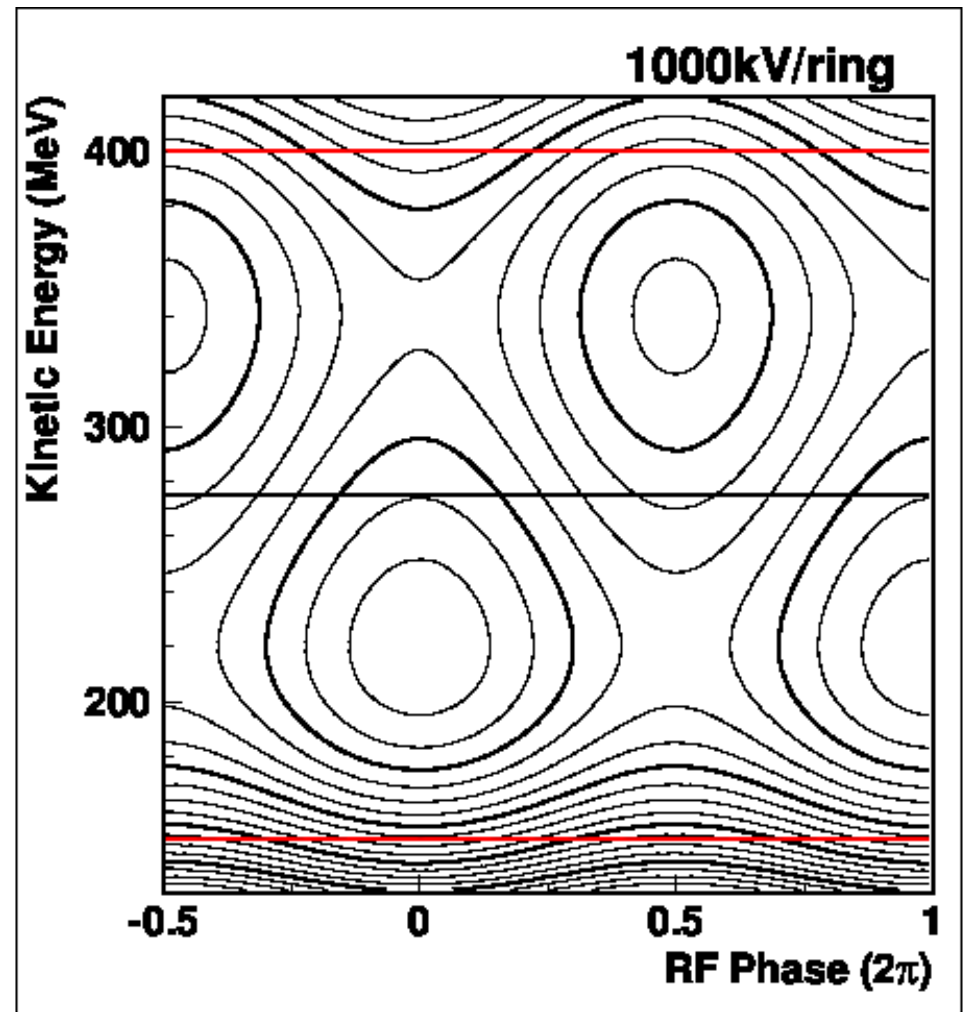
Lattice	FDF triplet
# of cells	16
k value	0.672
Energy	150 - 400 MeV
< R >	6.6 - 9.3 m
V rf / turn	5 MV
Tune	(1.356, 2.248)
Max. B field	1.3 T

The k is set to a rather small value of 0.672. This value of k makes a serpentine acceleration possible. Generally, the profits of this scheme are follows

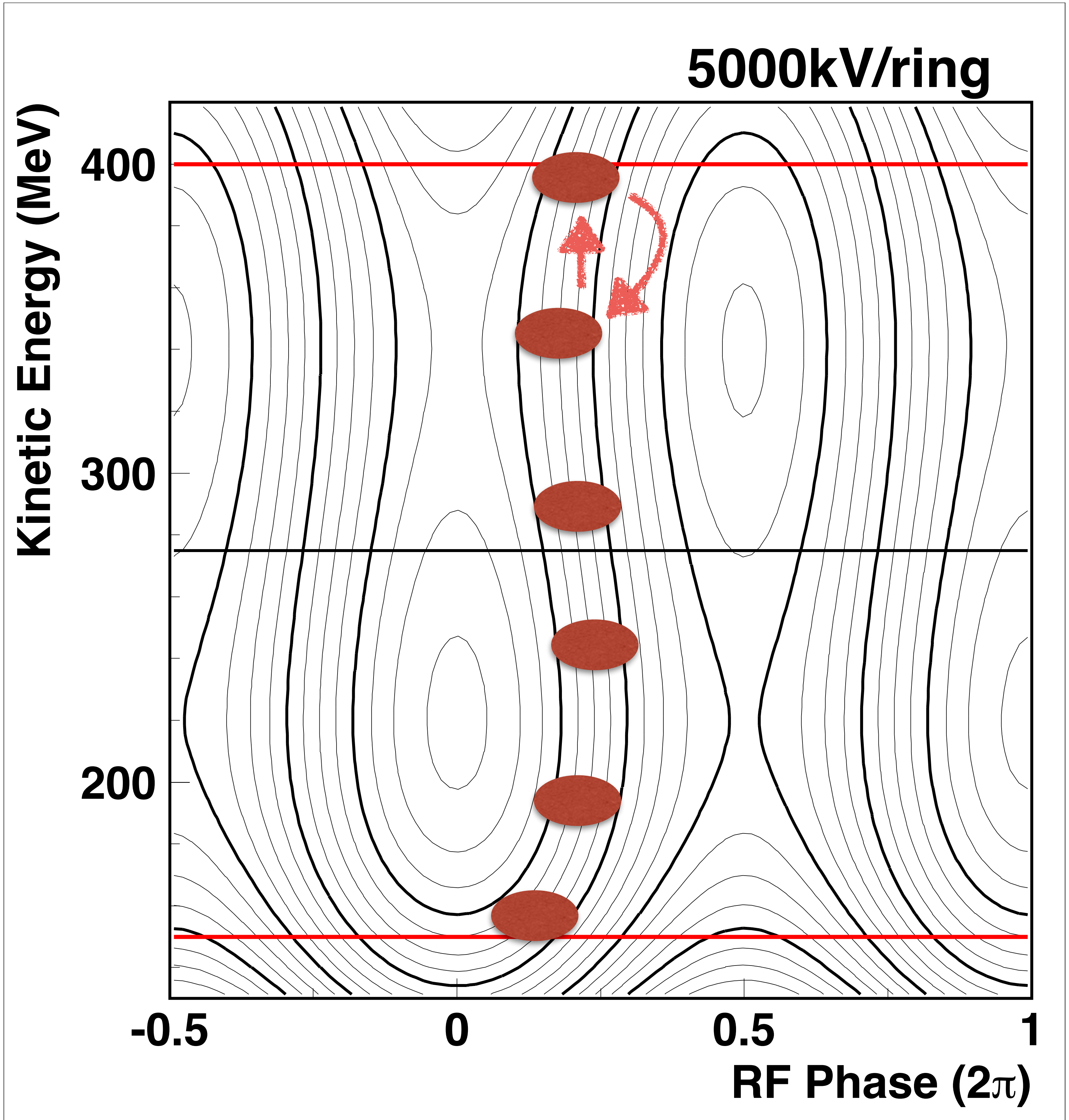
- Since a fixed frequency is used, high electric field of the acceleration cavity is easily obtained.
- This makes a fast and continuous acceleration possible.
- The ERIT mechanism can be applied to make secondary particles such as pions and their decay muons.

RF voltage condition for the serpentine channel





Extended ERIT mechanism



In the ordinary ERIT system, the ring is operated in a storage mode. However, in the extended ERIT system, the ring is in an acceleration mode. In this operation mode, since the beam hits the target at the maximum energy, the production efficiency of the secondary particles becomes high compared with the case of the storage mode.

Summary and Plans

1. Recommissioning of the linac is under going.
2. 11 MeV H- beam have been detected after a 30-degree bending magnet.
3. Recommissioning scenario of the main ring has been made.
4. Upgrade plans of our complex are under consideration.
5. Construction for the modification of ERIT to MERIT has been done.
6. Two types of 400 MeV ring have been proposed.

Thank you for your attention.