# A Status Report and Upgrade Plans of the KURRI FFAG Facility

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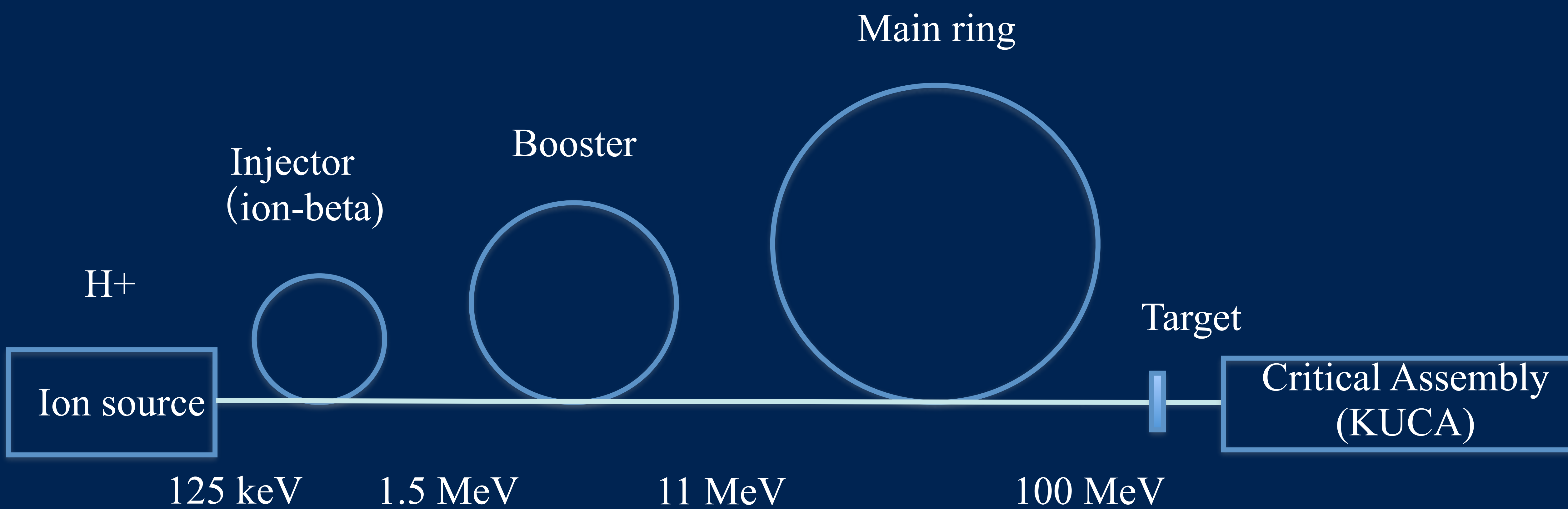
FFAG 15 at Kyushu University, Sep. 14 2015

# OUTLINE

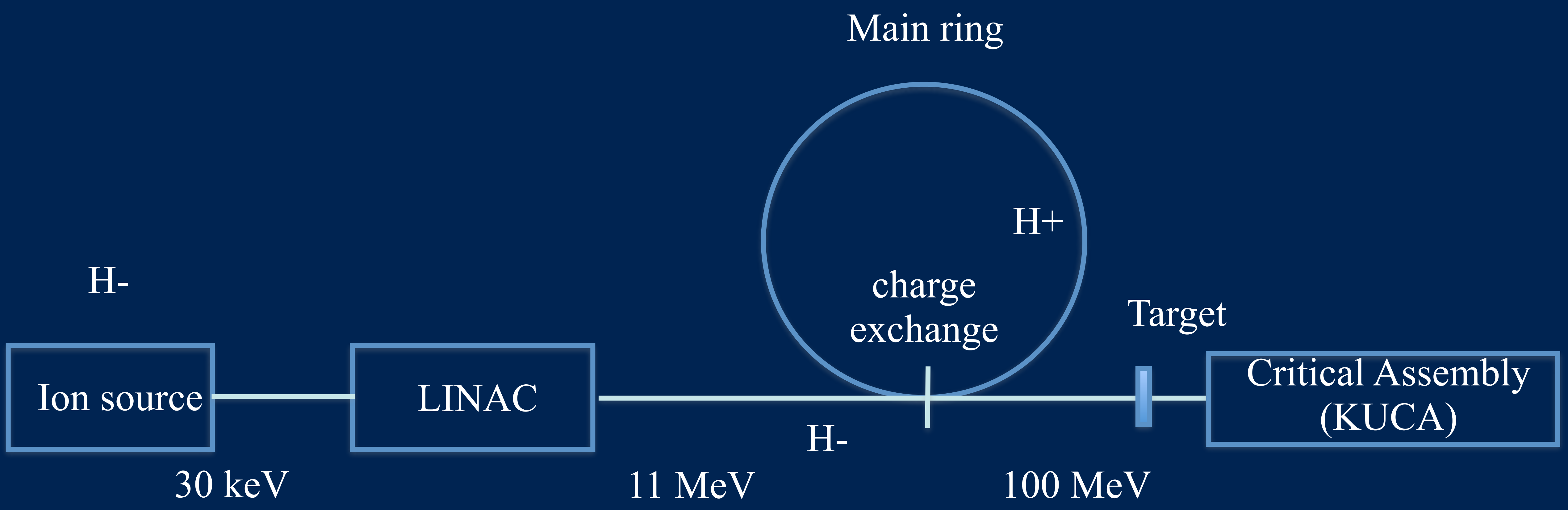
1. Present status of the KURRI FFAG facility
    1. Overview of the machine
    2. Beam users
2. Upgrade plans
    1. Present beam specs and target
    2. Things which limit the beam intensity
    3. Methods of the improvement
3. Summary

# Overview of the Machine

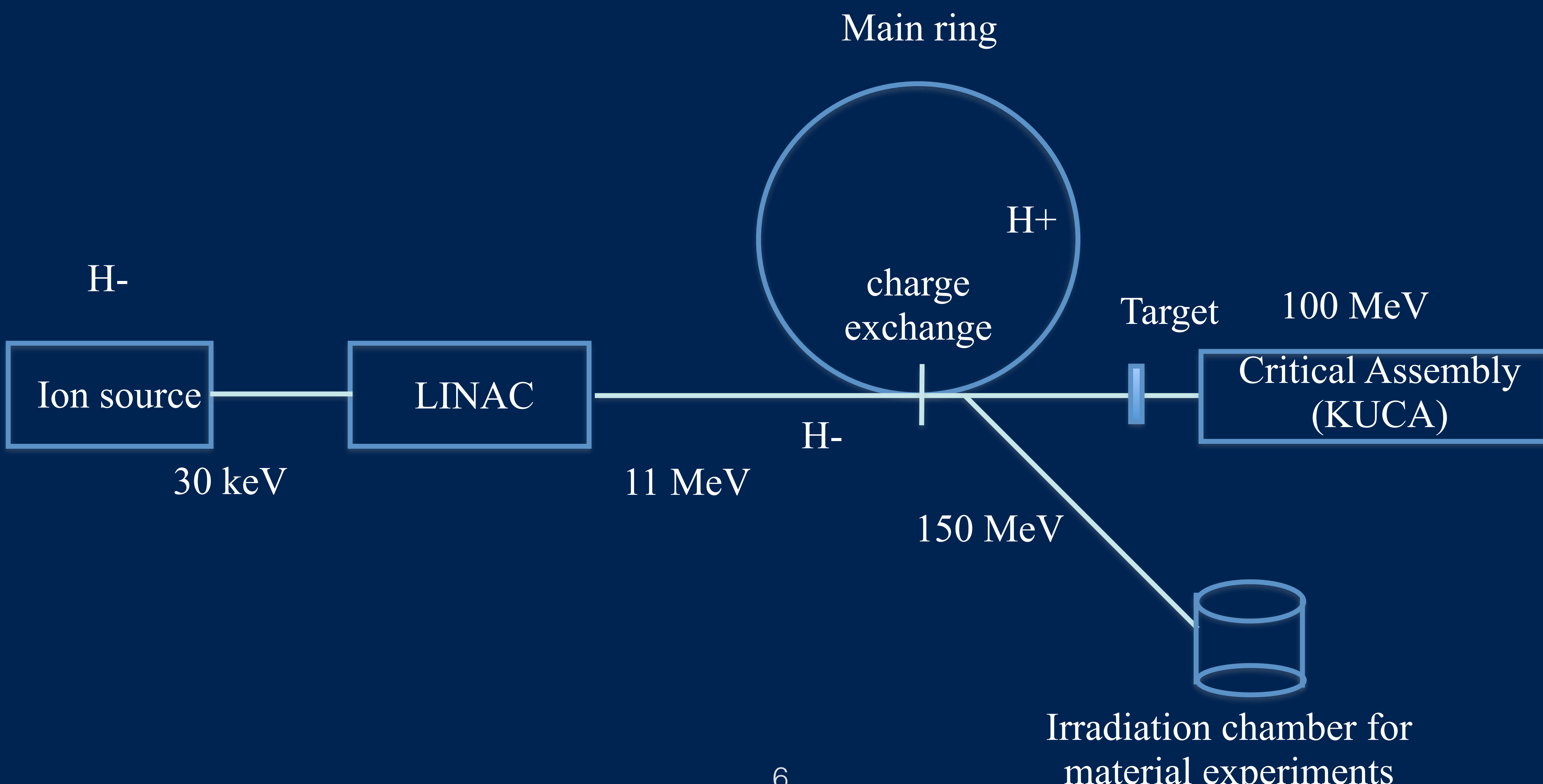
# FFAG – KUCA ADS system schematic diagram ( original ) 2008 - 2010



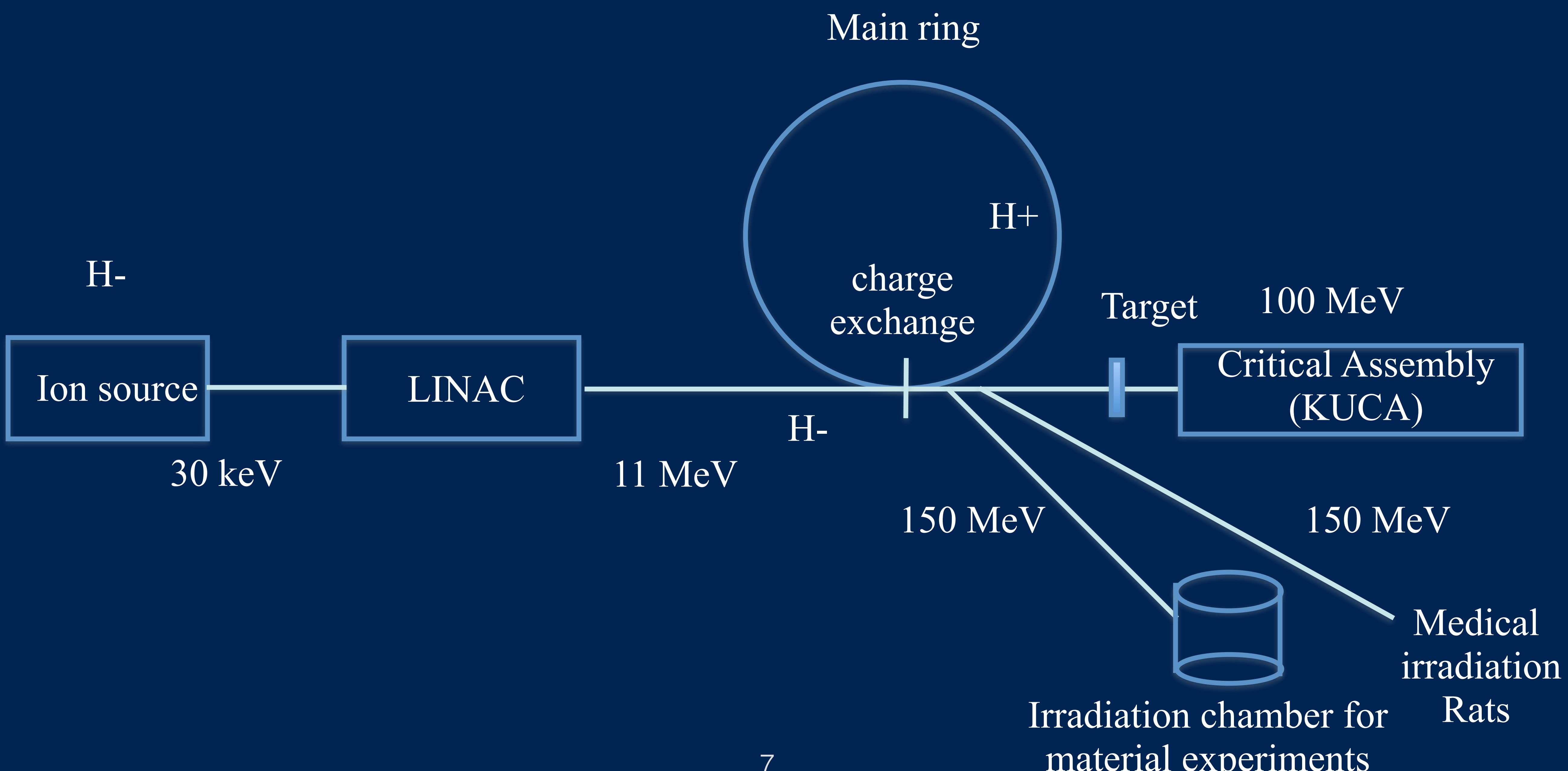
# FFAG – KUCA ADS system schematic diagram ( upgraded ) from 2011



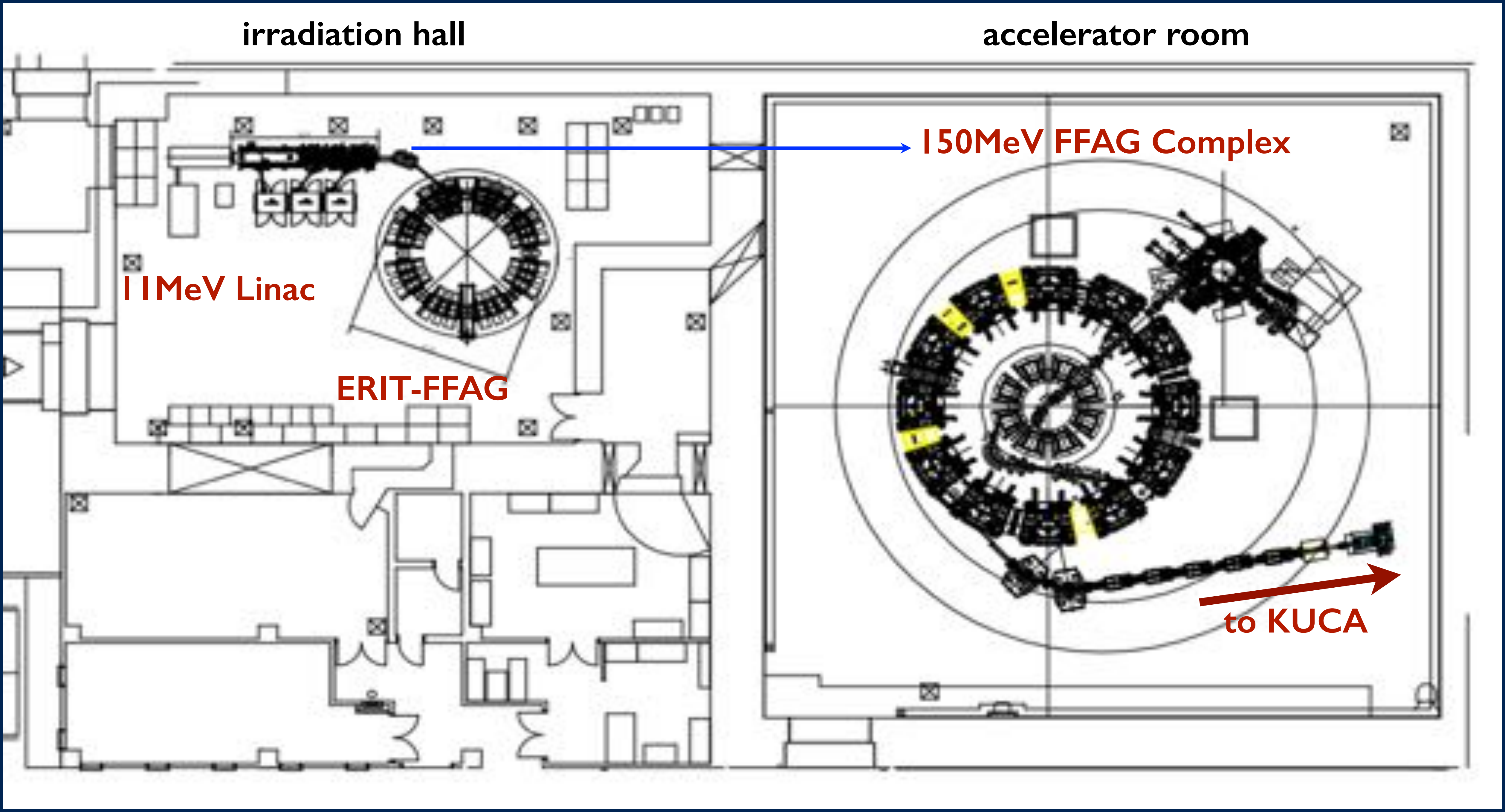
# FFAG – KUCA ADS system schematic diagram ( upgraded ) from 2012



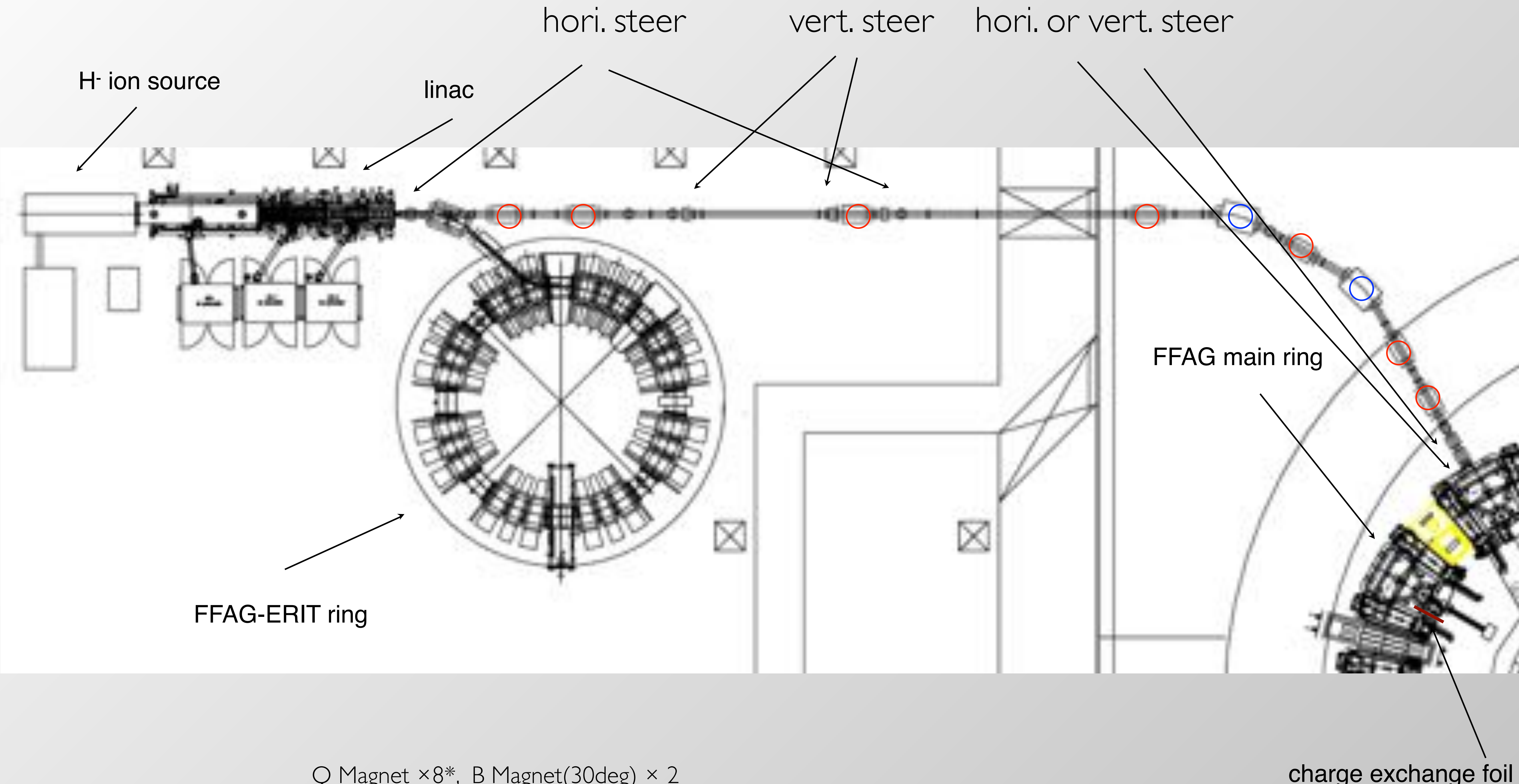
# FFAG – KUCA ADS system schematic diagram ( added medical port ) 2014



# Layout of accelerator complex in the Innovation Research Lab.



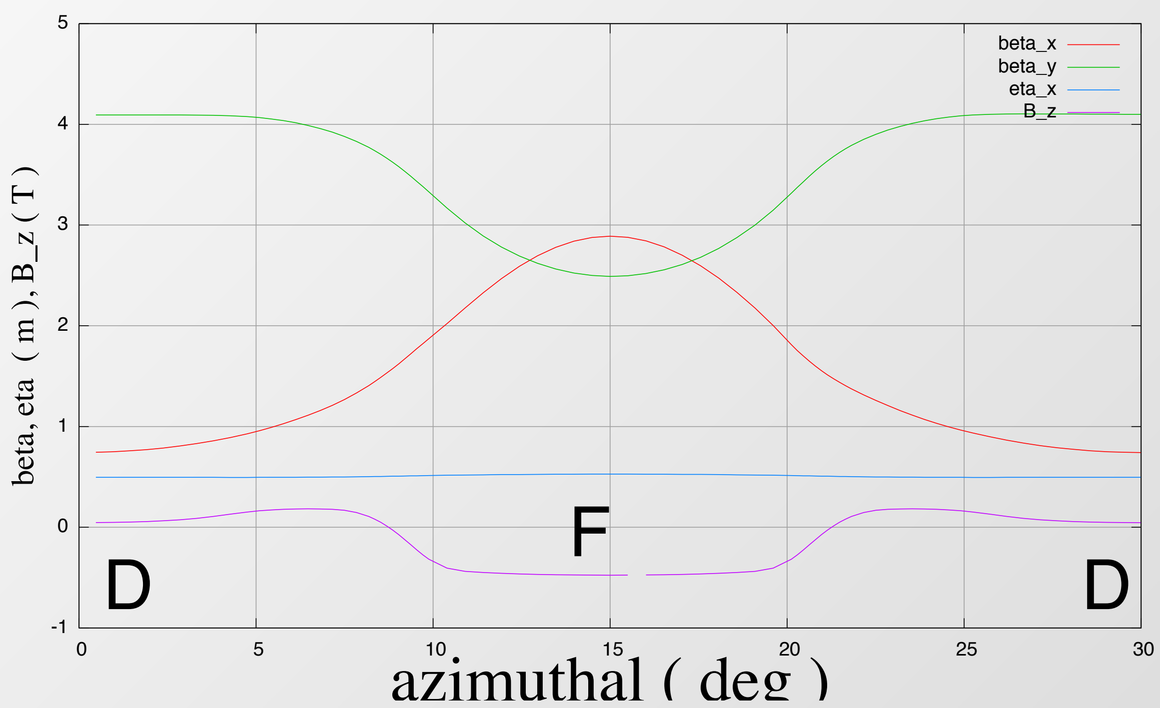
# Beam Line from Linac to MR



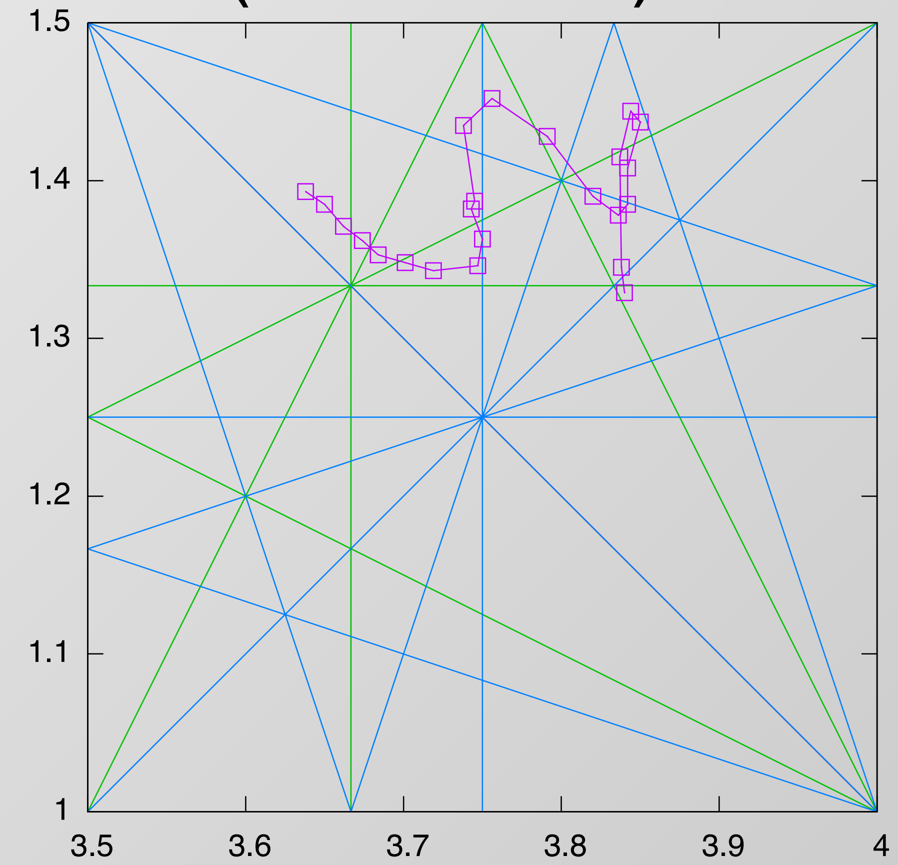

Q Magnet ×8*, B Magnet(30deg) × 2

* added one QM inMay 2011

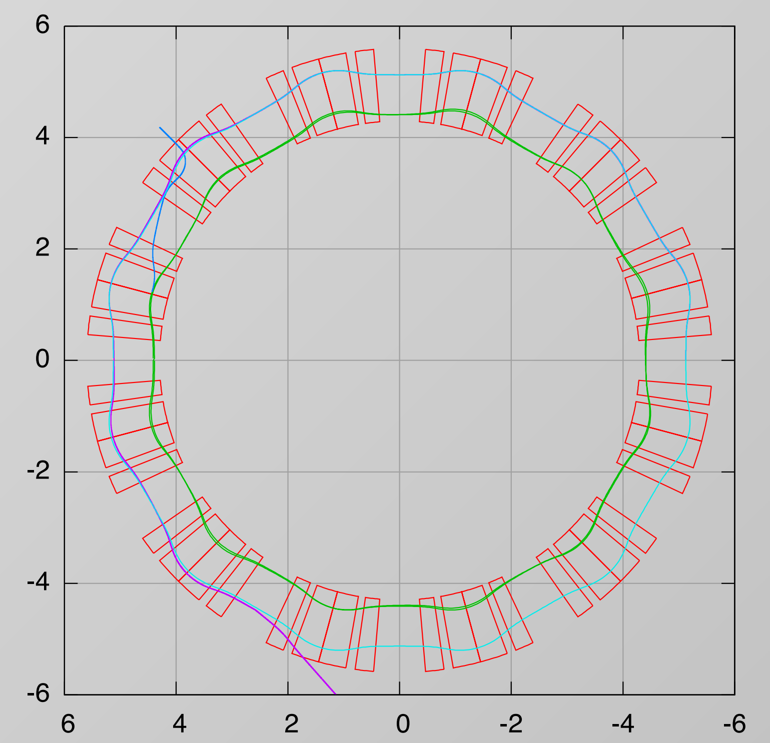
# Beta functions and B field in the main ring



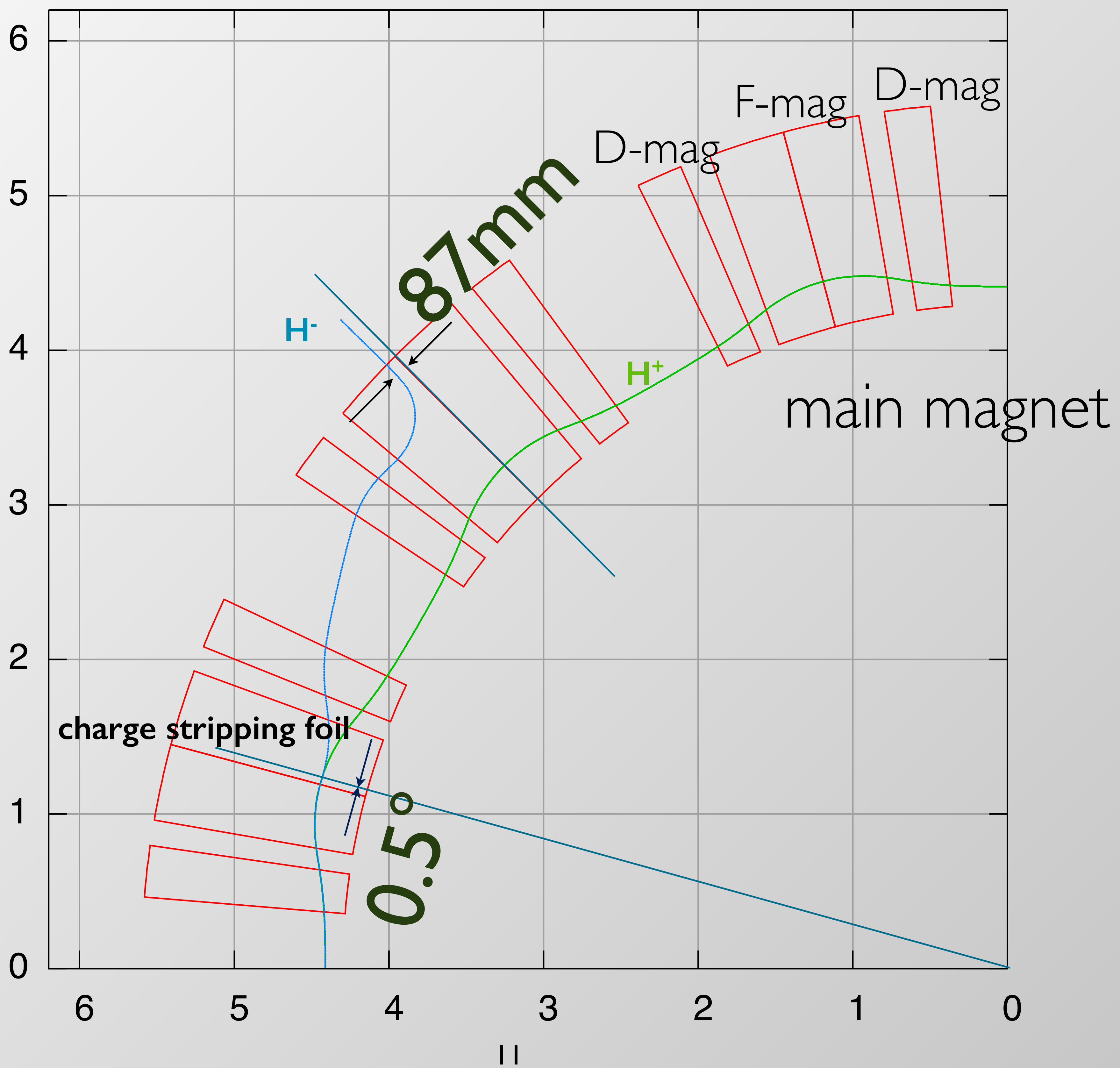

# tune variation (measured)



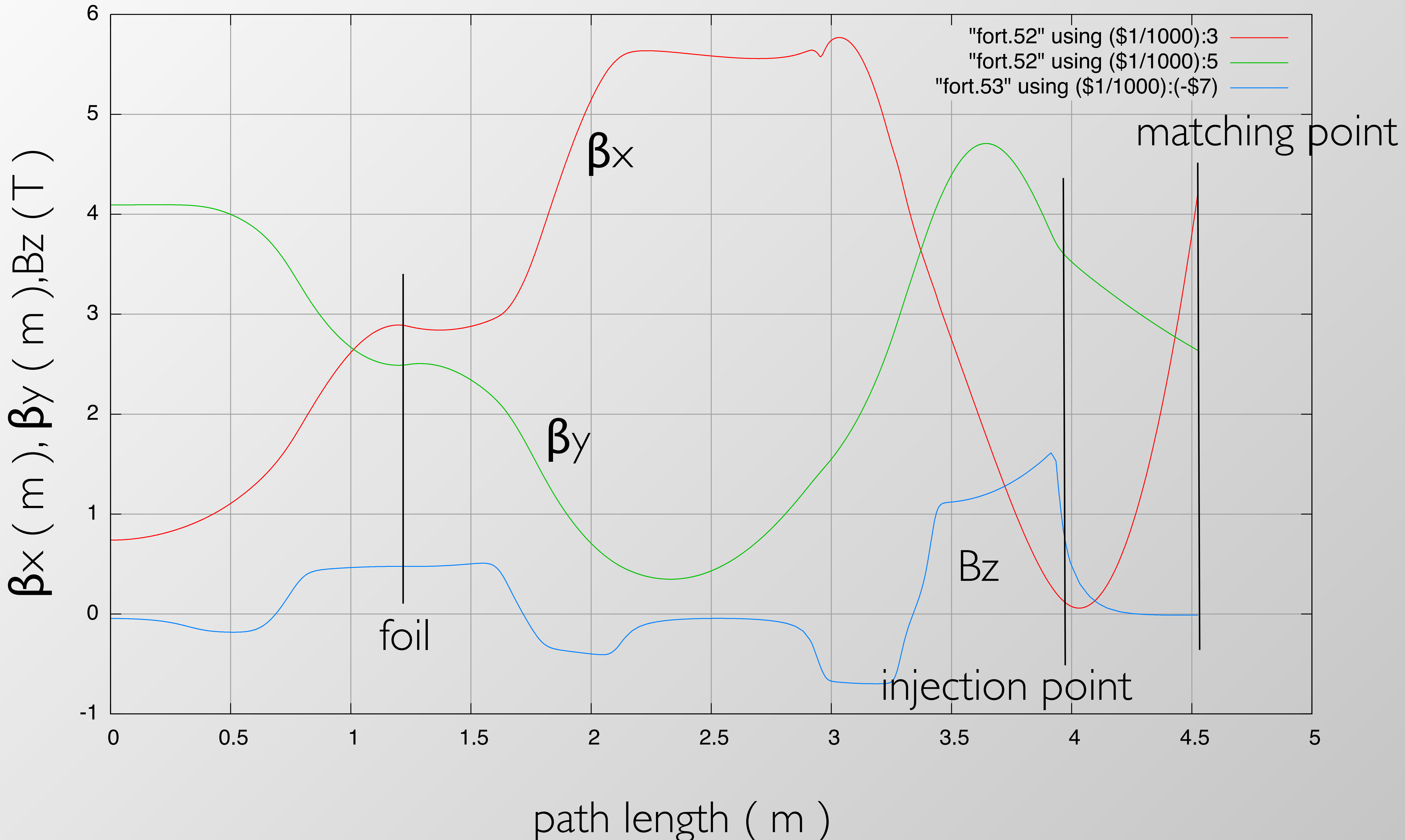

| | |
|---|---|
| Einj | 11MeV |
| Eext | 100/150MeV |
| frf | 1.6 - 5.2MHz |
| <R> | 4.57 - 5.4m |
| Bmax | 1.6T |



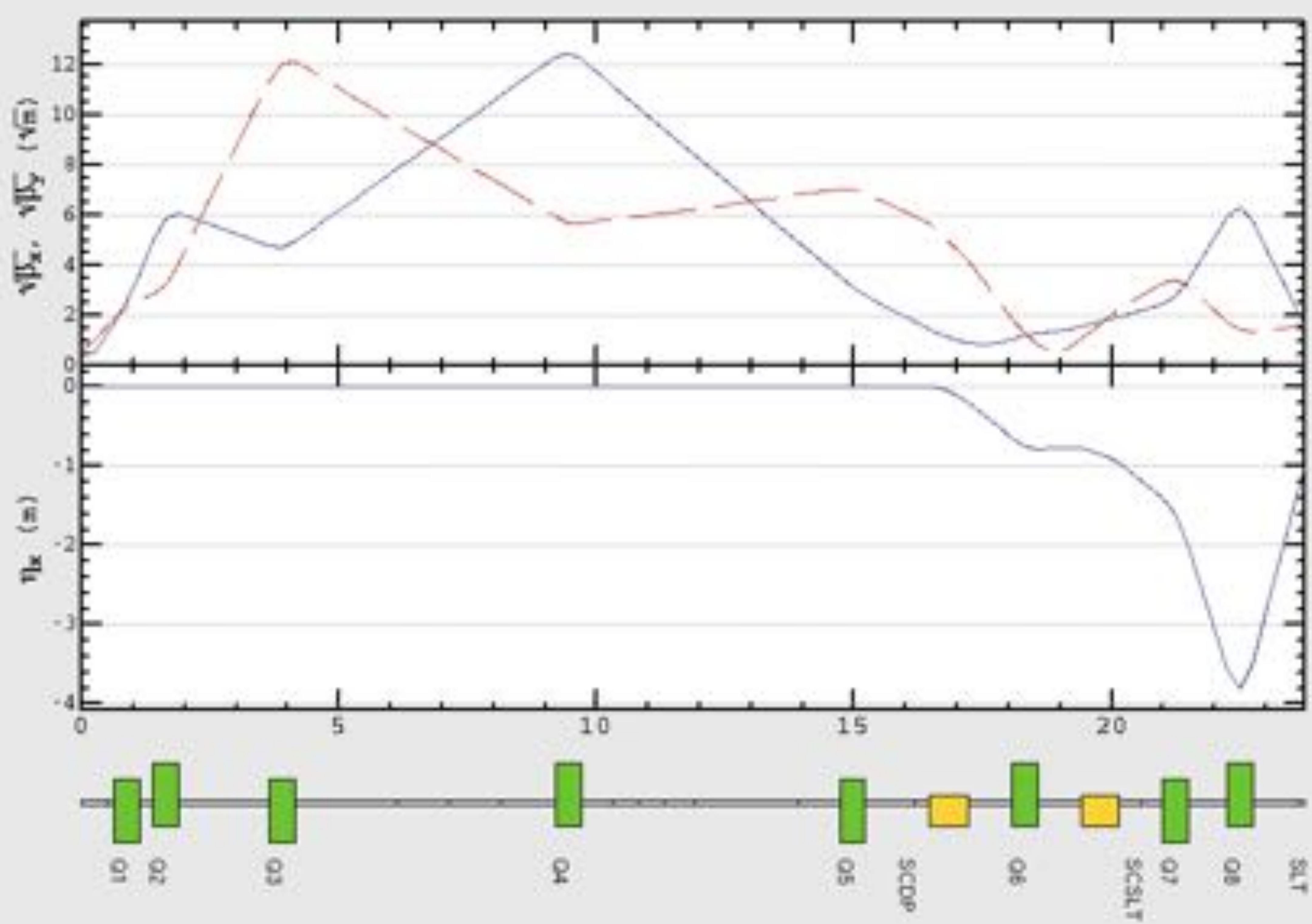
# Beam injection to the main ring



Beta functions calculated from backward tracking in the main ring



H- beam line beta functions calculated using SAD




foil

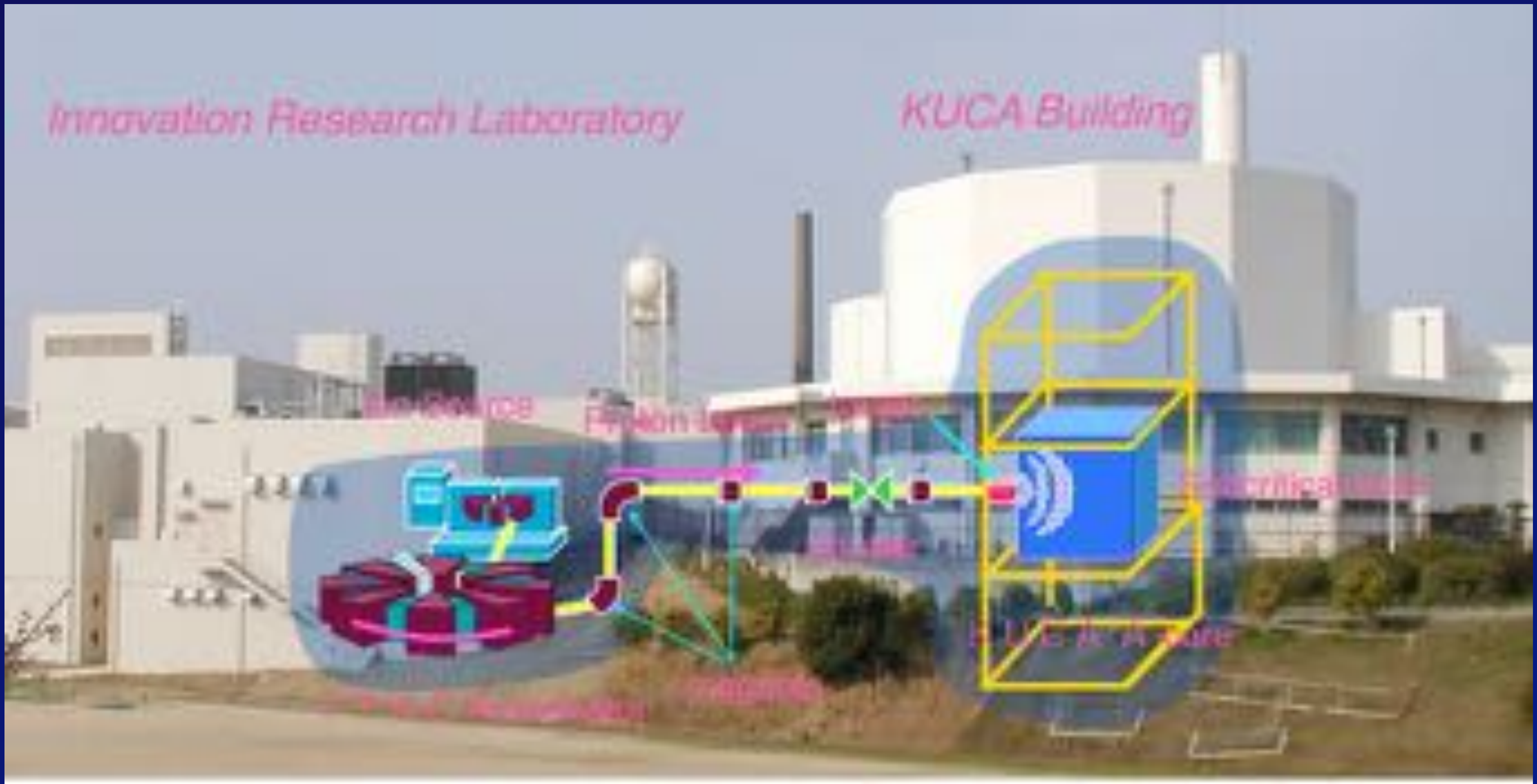
# Beam Line and Chamber for Irradiation Experiments

# Beam Users

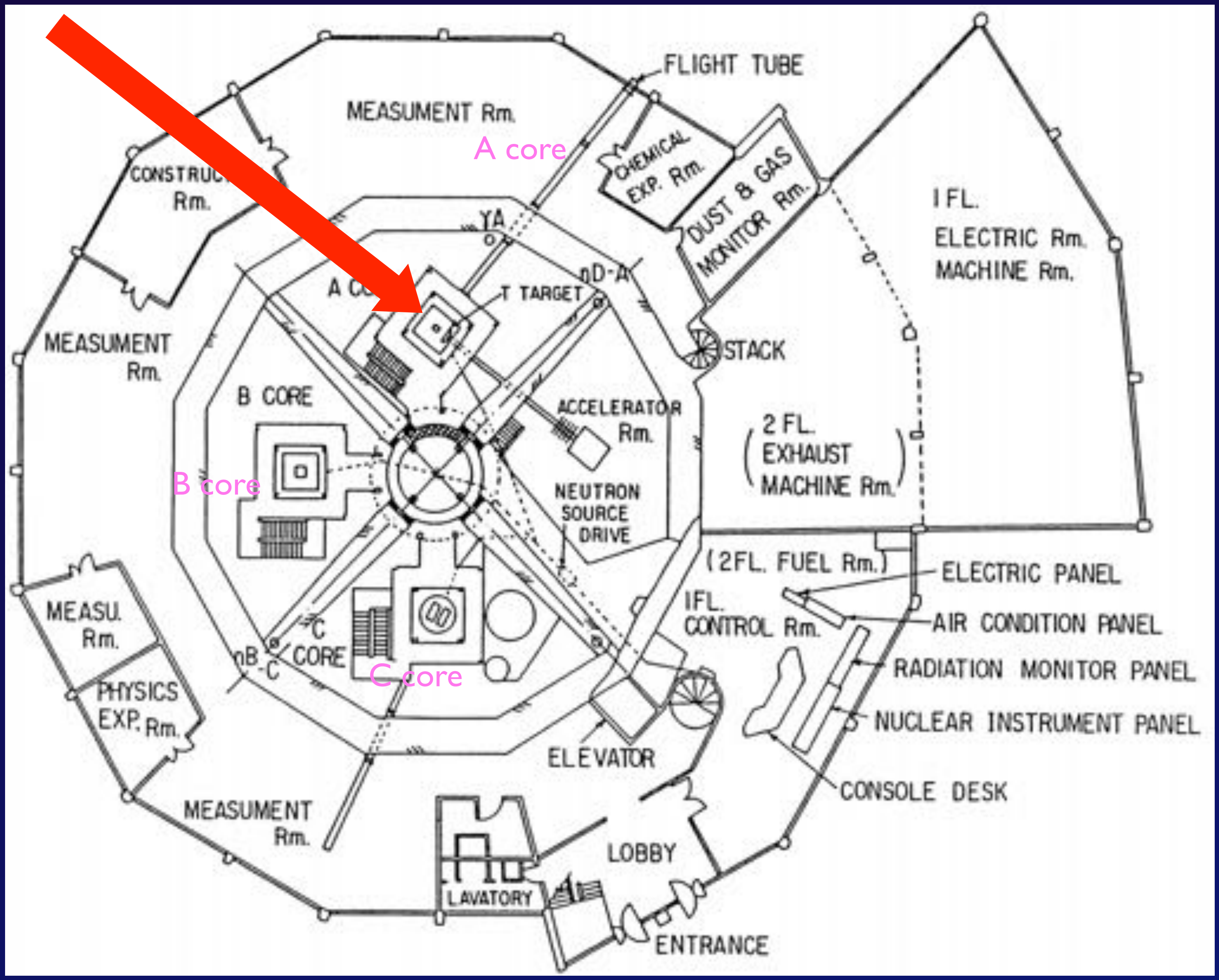
- ADS experiment
- Irradiation for materials
- Medical experiment ( irradiation to living rats )


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.


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



# KUCA




Output power ~10W
Neutron multiplication : $\alpha$=1/(1-keff).
If keff=0.99, $\alpha$=100
Beam power requirement not exceed < 0.1W!!
cf. For 100MeV proton beam, I<1nA

- **KUCA Configurations**

  -3 critical assemblies :

  i. A & B cores

  Polyethylene Mod./Ref.

  ii. C core

  $H_2O$ Mod./Ref.

  - 2 accelerator :

  i. Cockcroft-walton type

  (D,T) reaction

  14 MeV neutrons

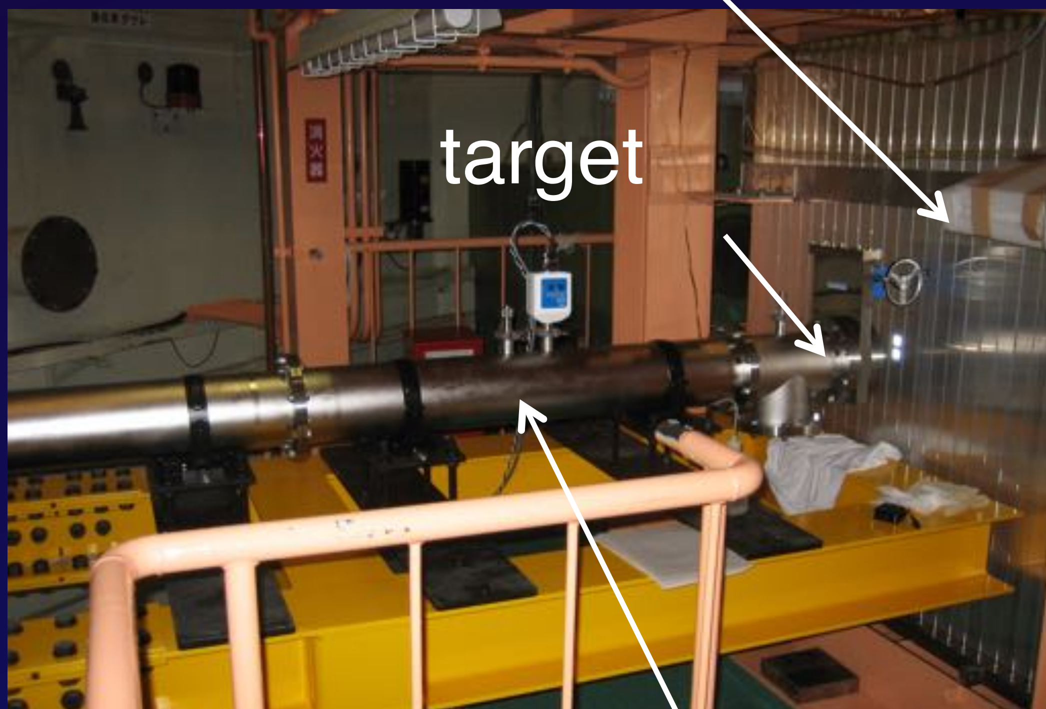
  ii. FFAG type

  100 MeV protons

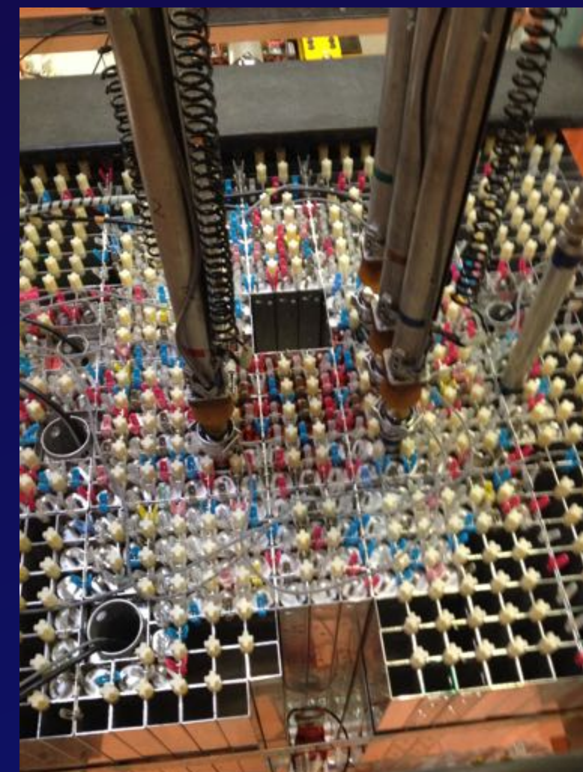
  from KUCA Outside

# ADSR Experiment Setup

Reactor core



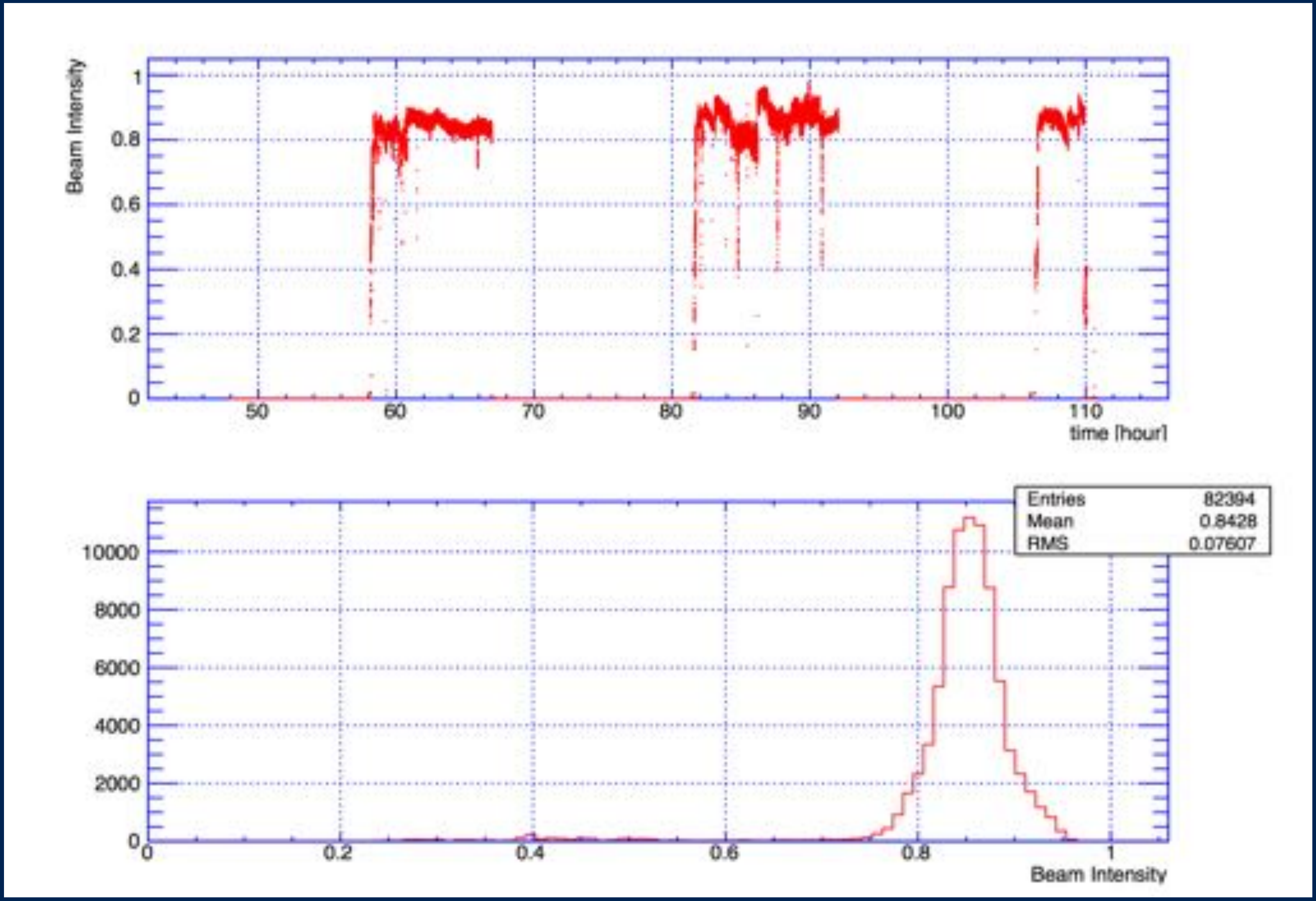

Beam transport line



Subcritical fuel system

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

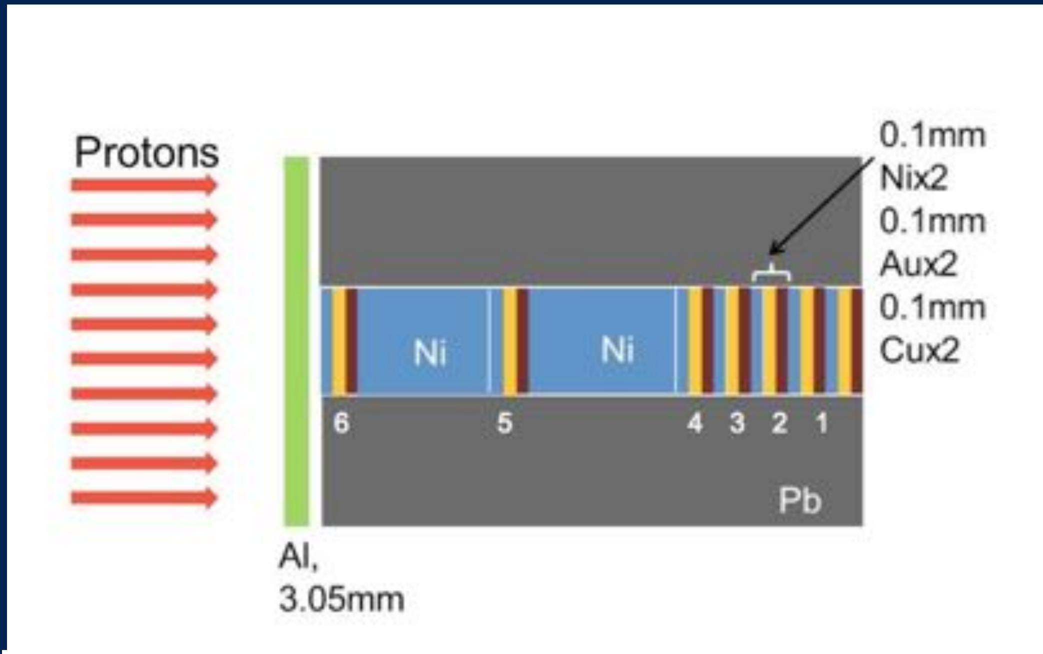
W or Pb-Bi target w/ read out as FC

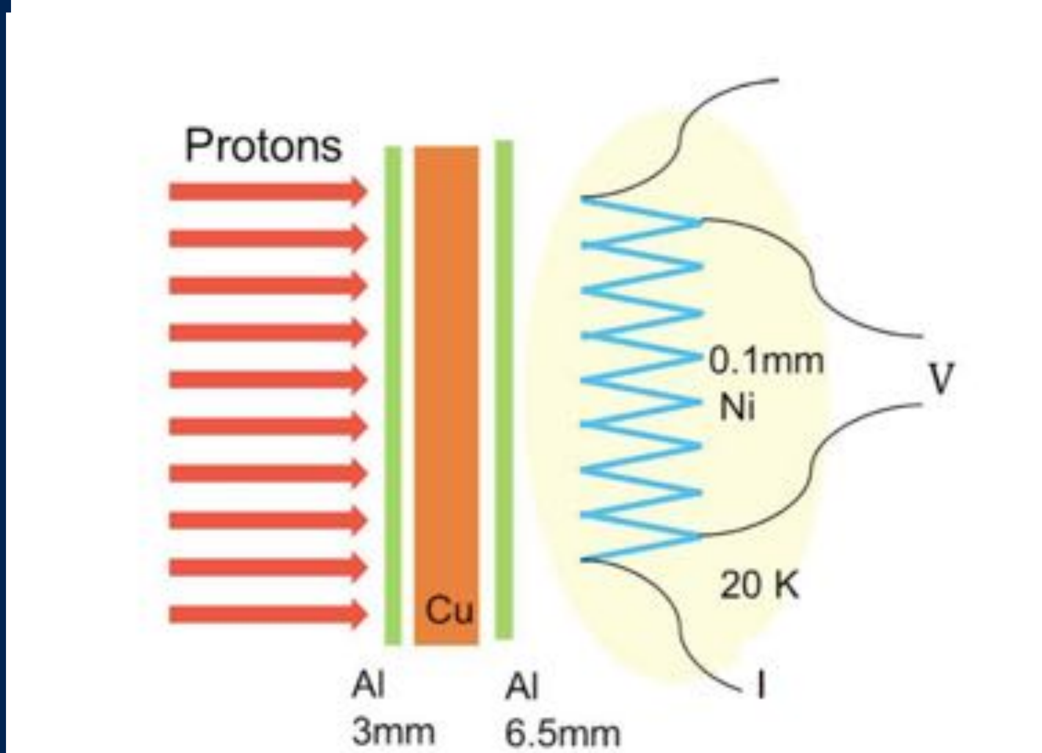



The stability of the beam current ~ 7%

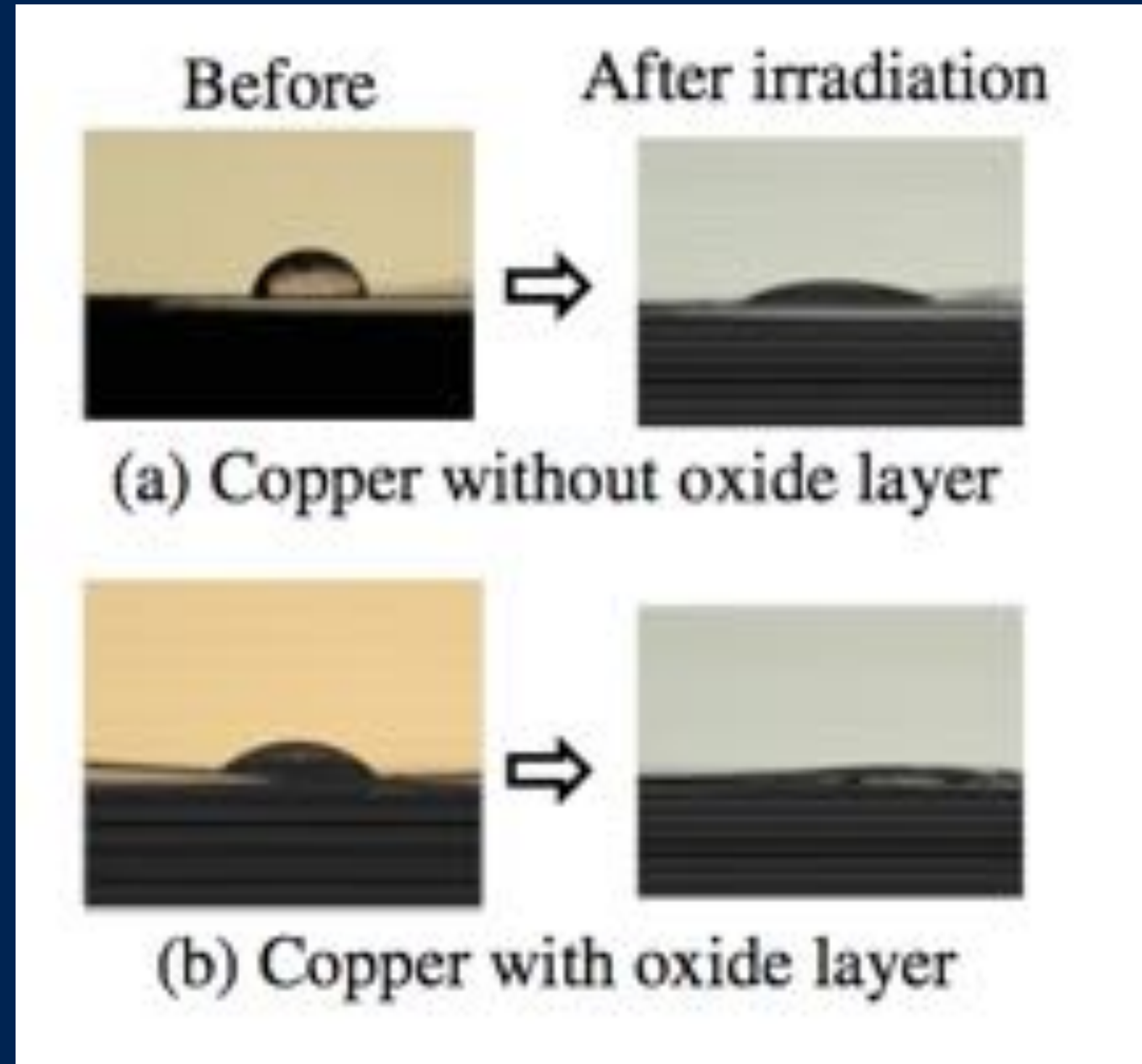
The irradiation port connected to the 150 MeV proton beam line.
It has cryogenics and traction control machine inside which realize measurements under irradiation of the proton beam.

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.

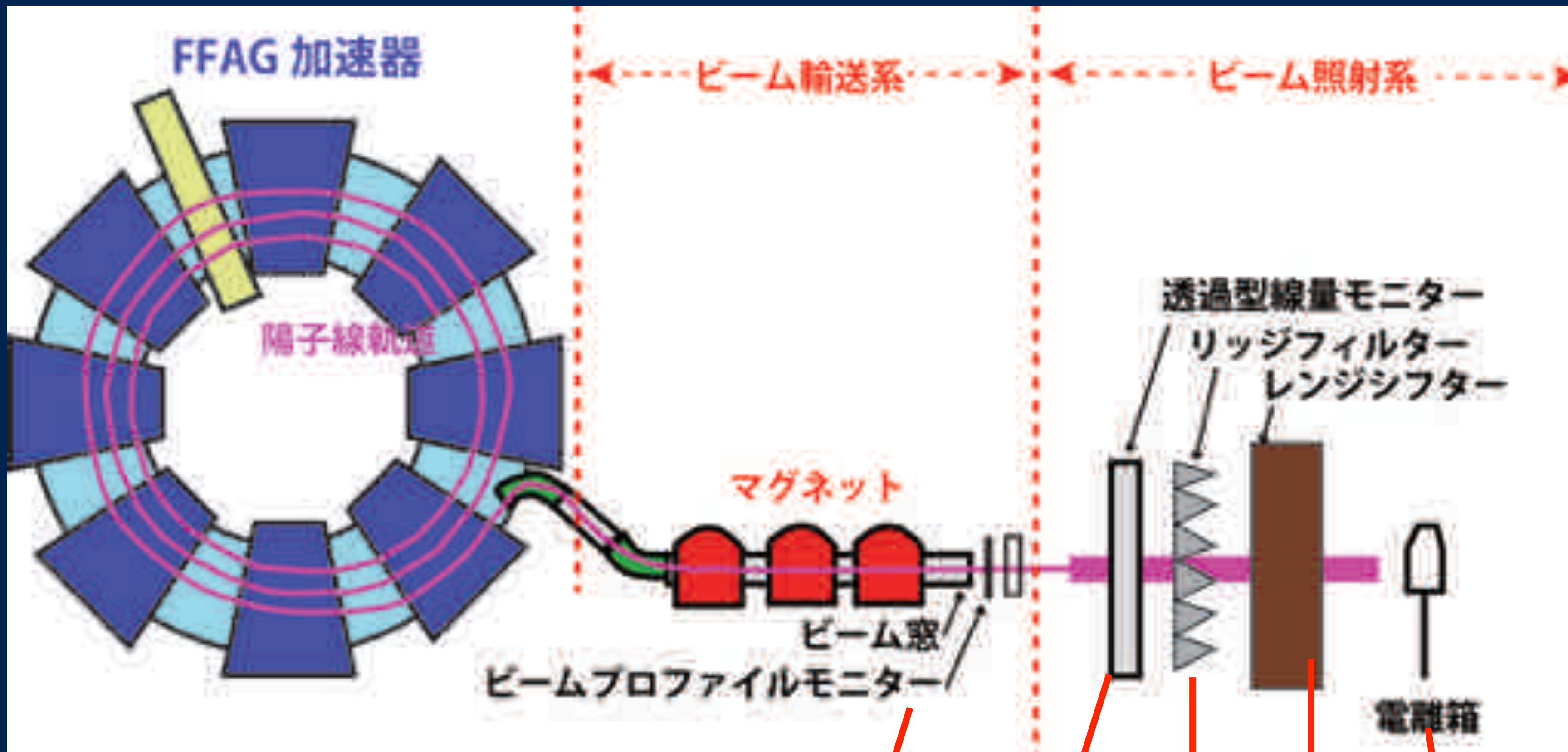


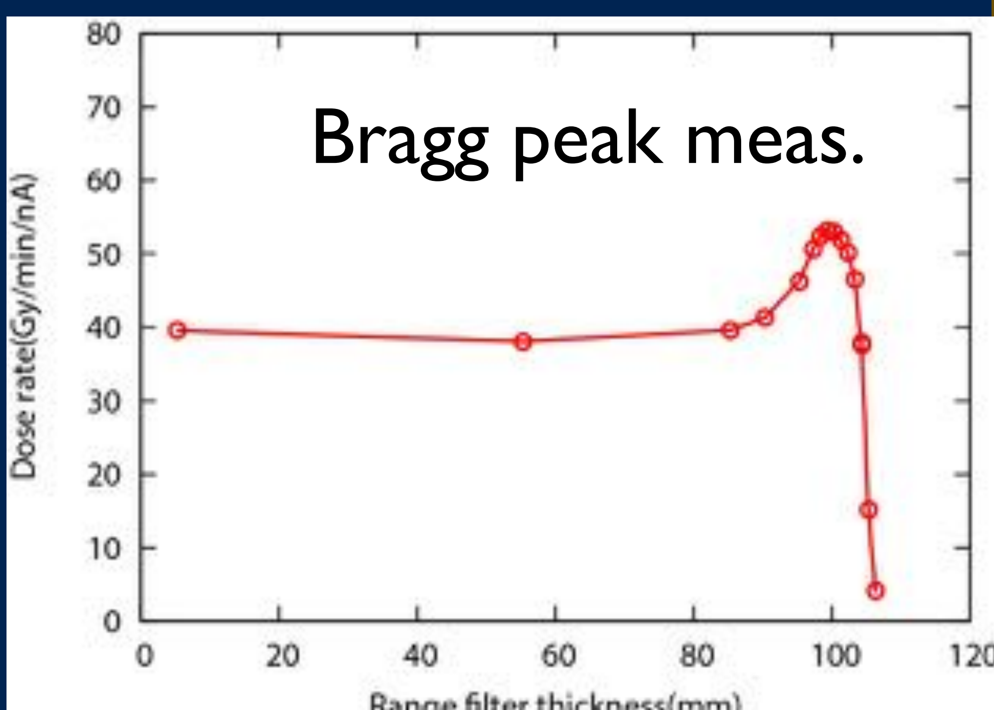

Discrepancies between measurements and theoretical calculations have been found in distributions of lattice defect in beam direction. They have used two different method i.e. positron life time measurement and electrical resistance measurements. Dr. Iwamoto ( JAEA; developer of PHITS) uses the machine time to understand these discrepancies.

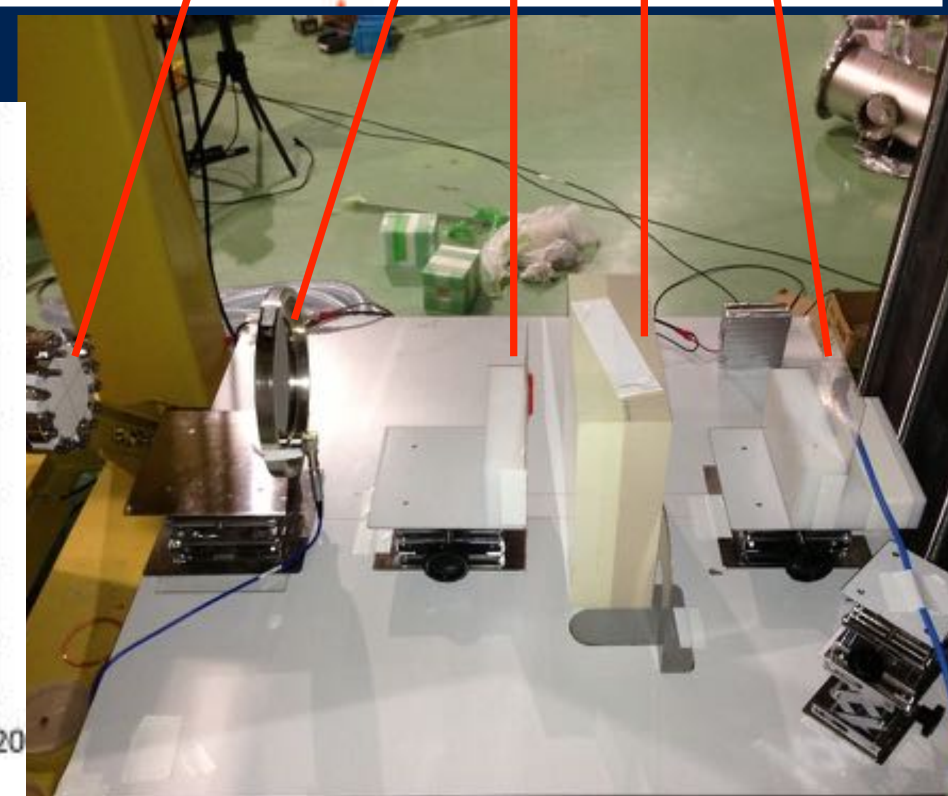


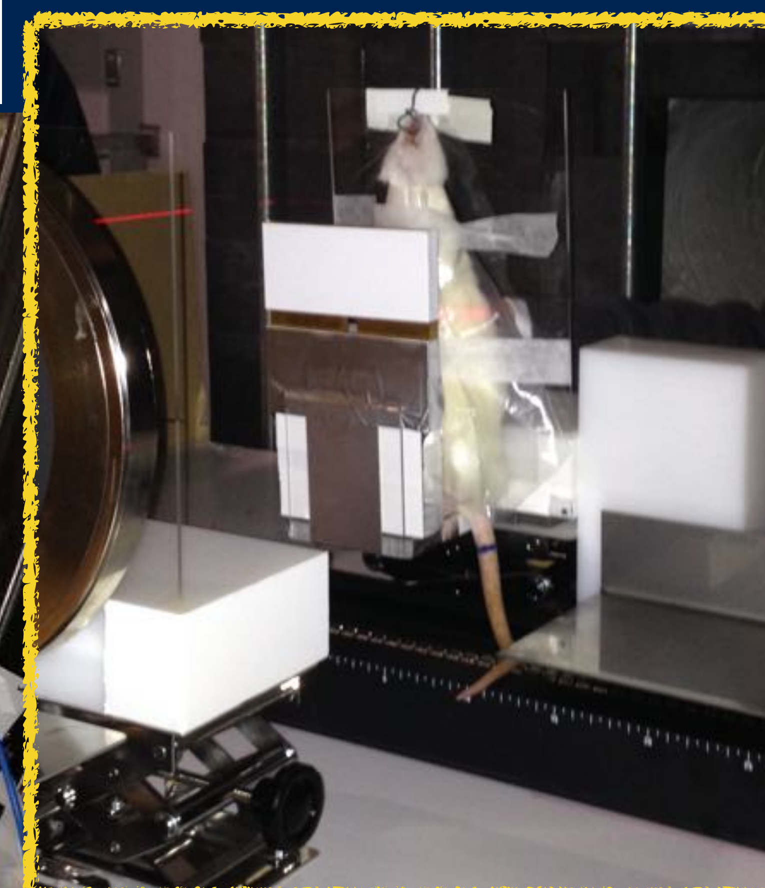

Using the FFAG accelerator, irradiation effects on wall wettability were investigated in this study. Pictures show the wettability change before and after 100 MeV proton irradiation with 4.7 nA for 50 h. The wettability on copper surfaces was enhanced by the proton irradiation regardless of the surface conditions.




a narcotised rat

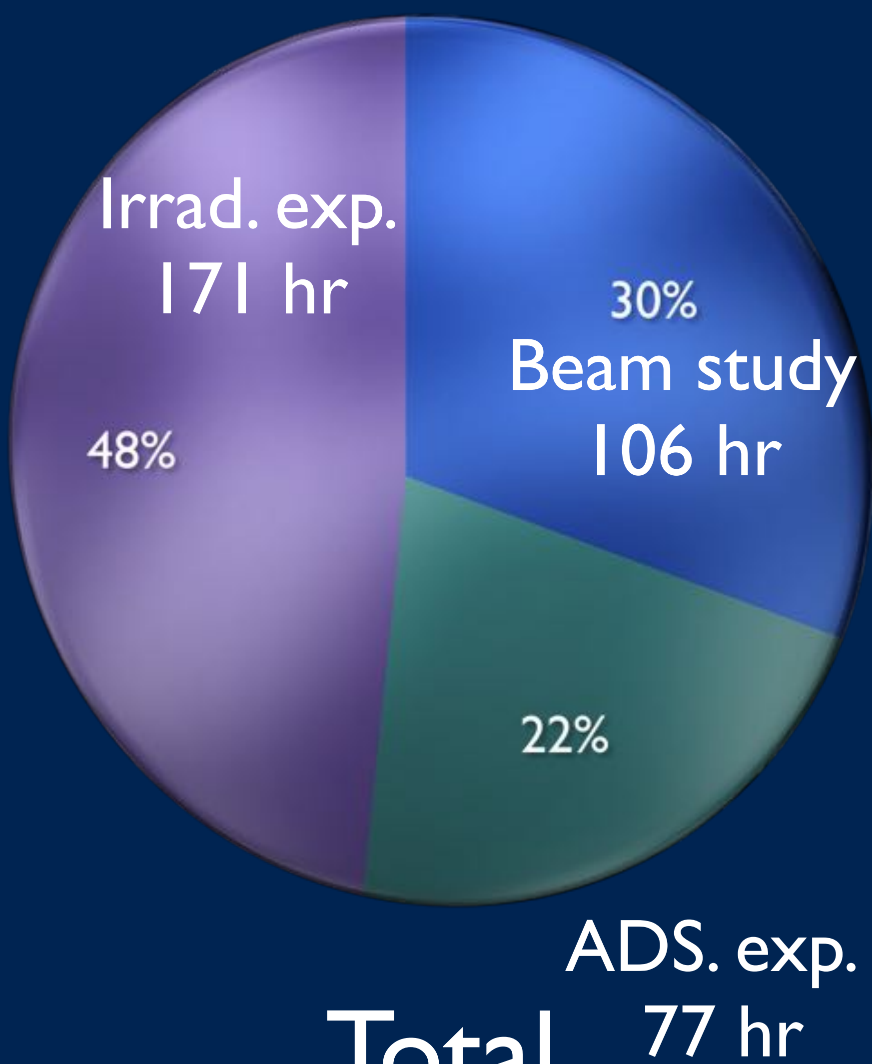




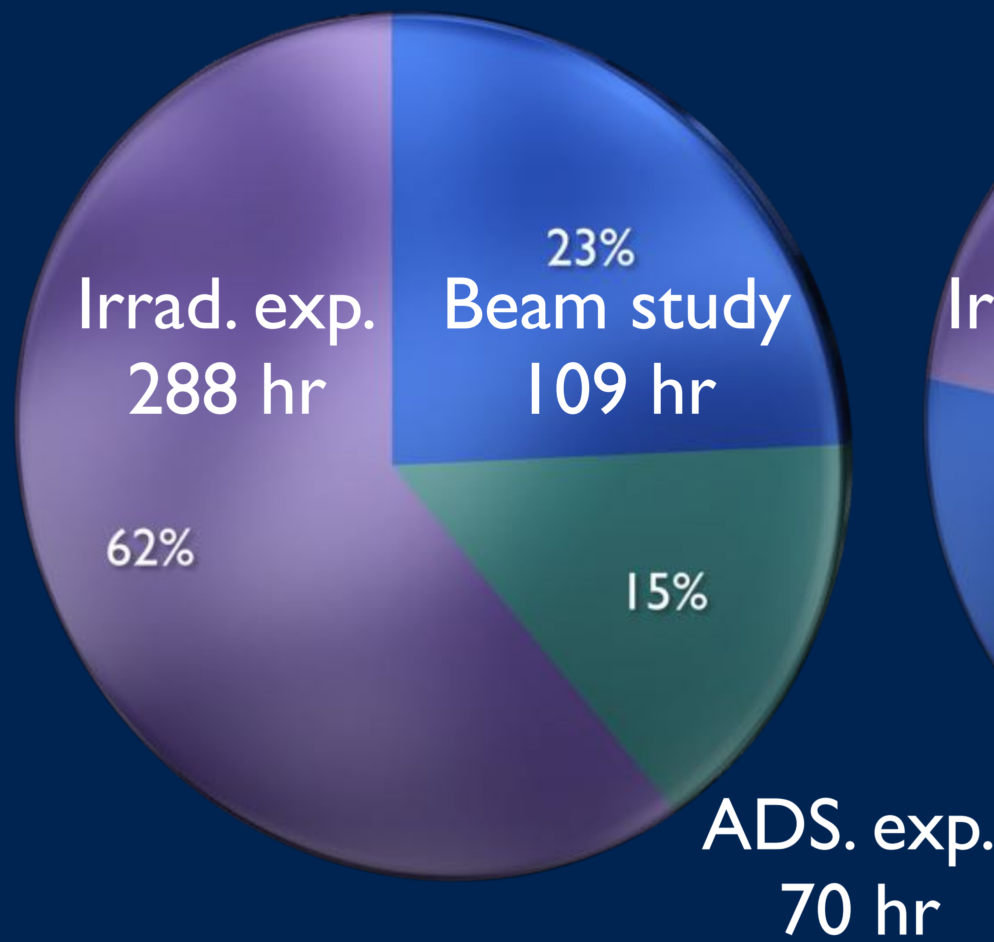
# Summary of Machine Time

## FY 2012



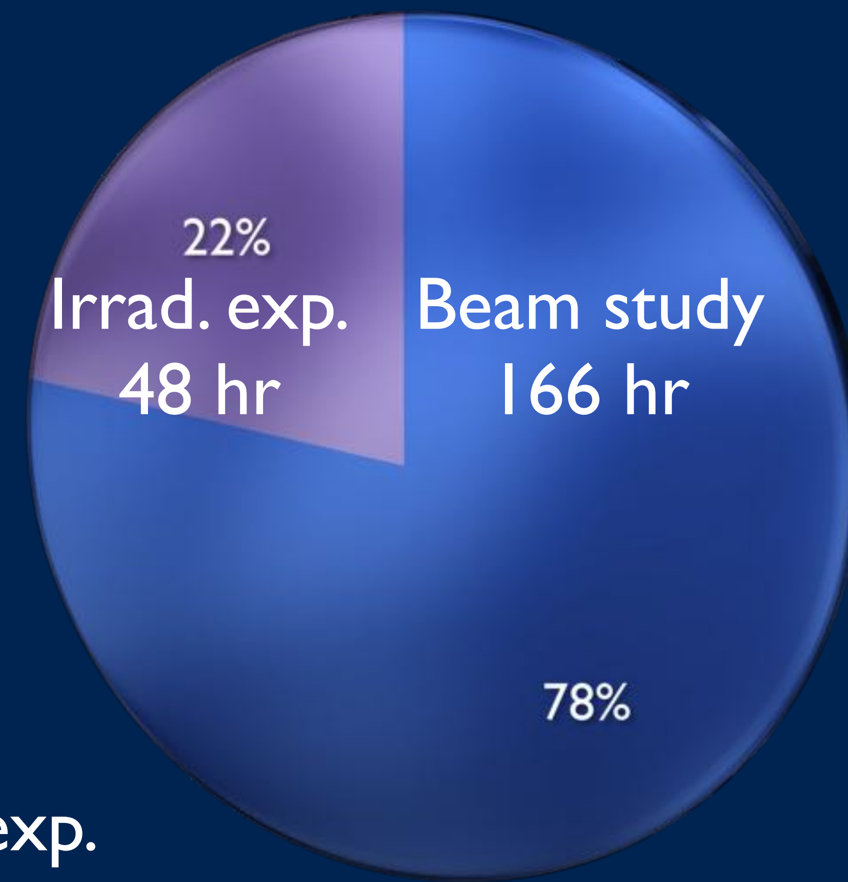

Total
354 hr

## FY 2013




Total
468 hr

## FY 2014




Total
214hr

# Upgrade plans

# Present beam specs

- Energy : 100 / 150 MeV
- Beam Current : 10 nA average
- Repetition rate : 20 / 30 Hz

# Target

- Energy : 100 / 150 MeV → 300 MeV*
- Beam Current : 10 nA → 1 uA average **
- Repetition rate : 20 / 30 Hz → 100Hz

* needs construction of new magnets ( designed by Okita-san, Motohashi-san )

** close to the space charge limit

We would like to make an official statement for the possibility of the upgrade path to the beam current of 1 uA by the end of this FY.

# Summary of the Main Ring transparency

- Incident current from the LINAC ~600 nA
- Injection efficiency ~ 40%
- Transparency up to 1 ms ~ 2.5 %
- Transparency from 1 ms to extraction timing ~ 25 % ( Beam losses due to the betatron resonances )
- Extraction efficiency ~ 100 % ( ? )
- Extracted current ~ 1.5 nA ( in some condition )

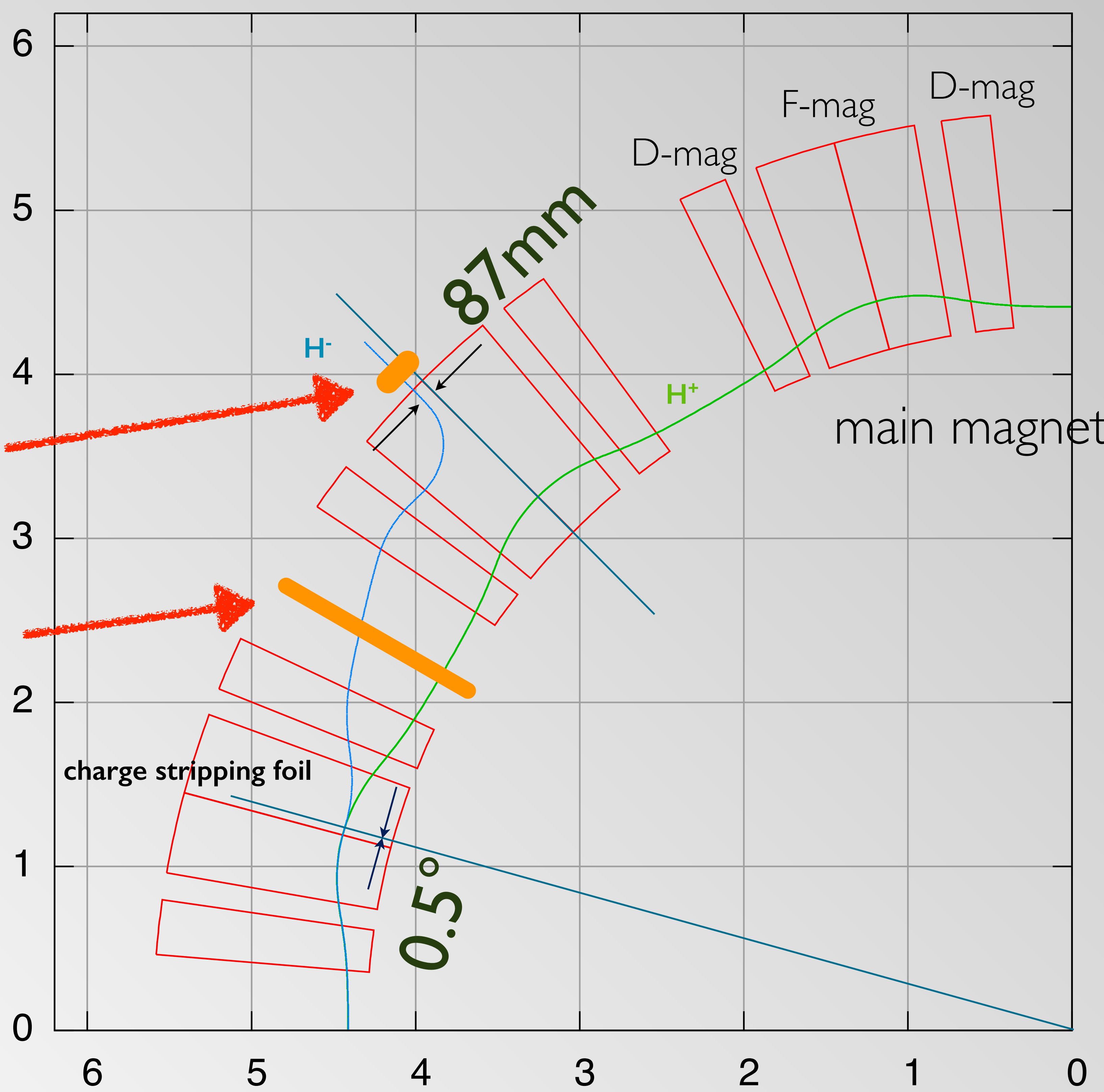
# Beam injection to the main ring

The aperture of the up stream Faraday cup might not be sufficient.

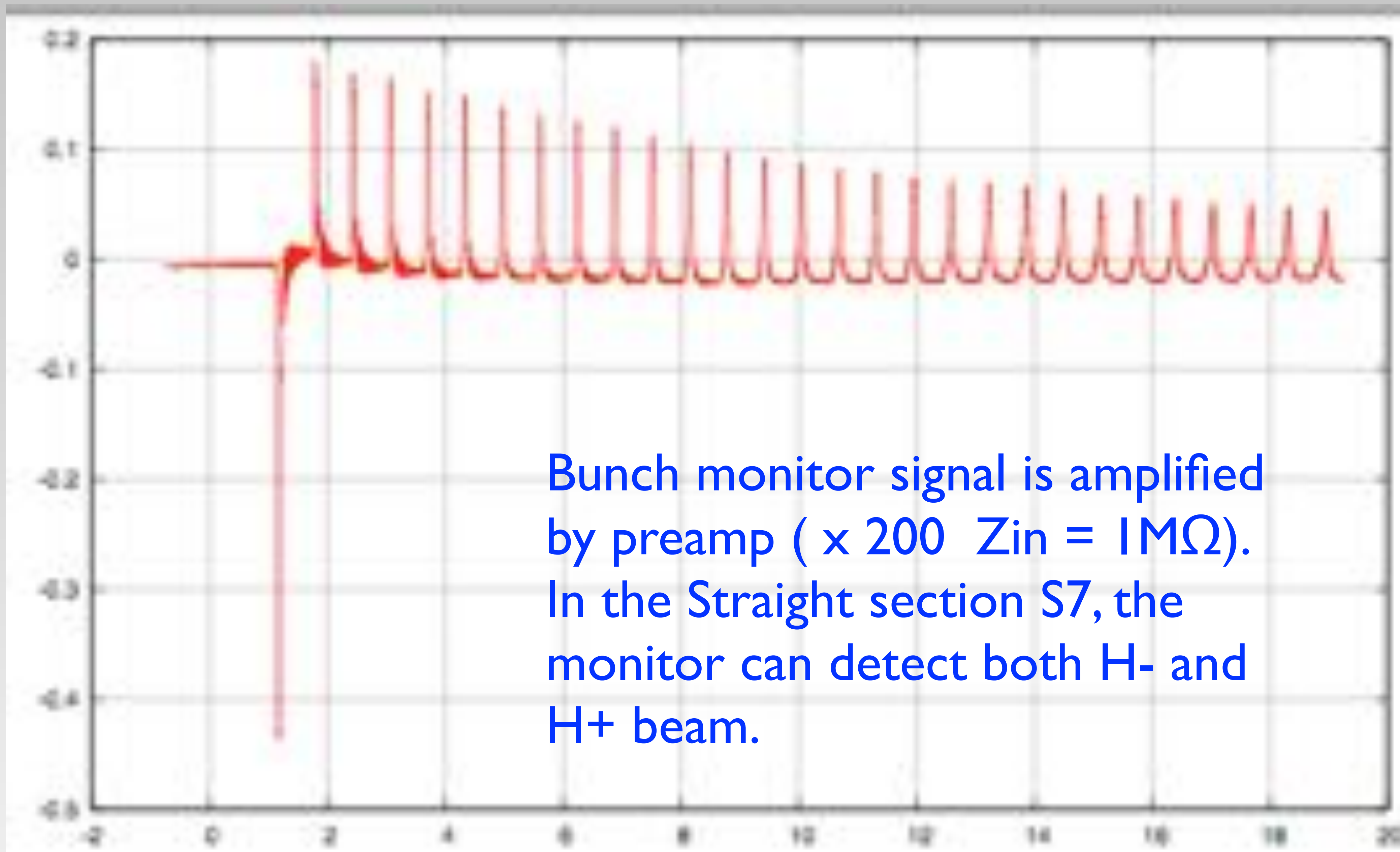
0.58 µA

0.59 µA

With this condition of the injection beam, extracted current is ~1.5 nA.



# Injection Studies in ADSR-FFAG Ring

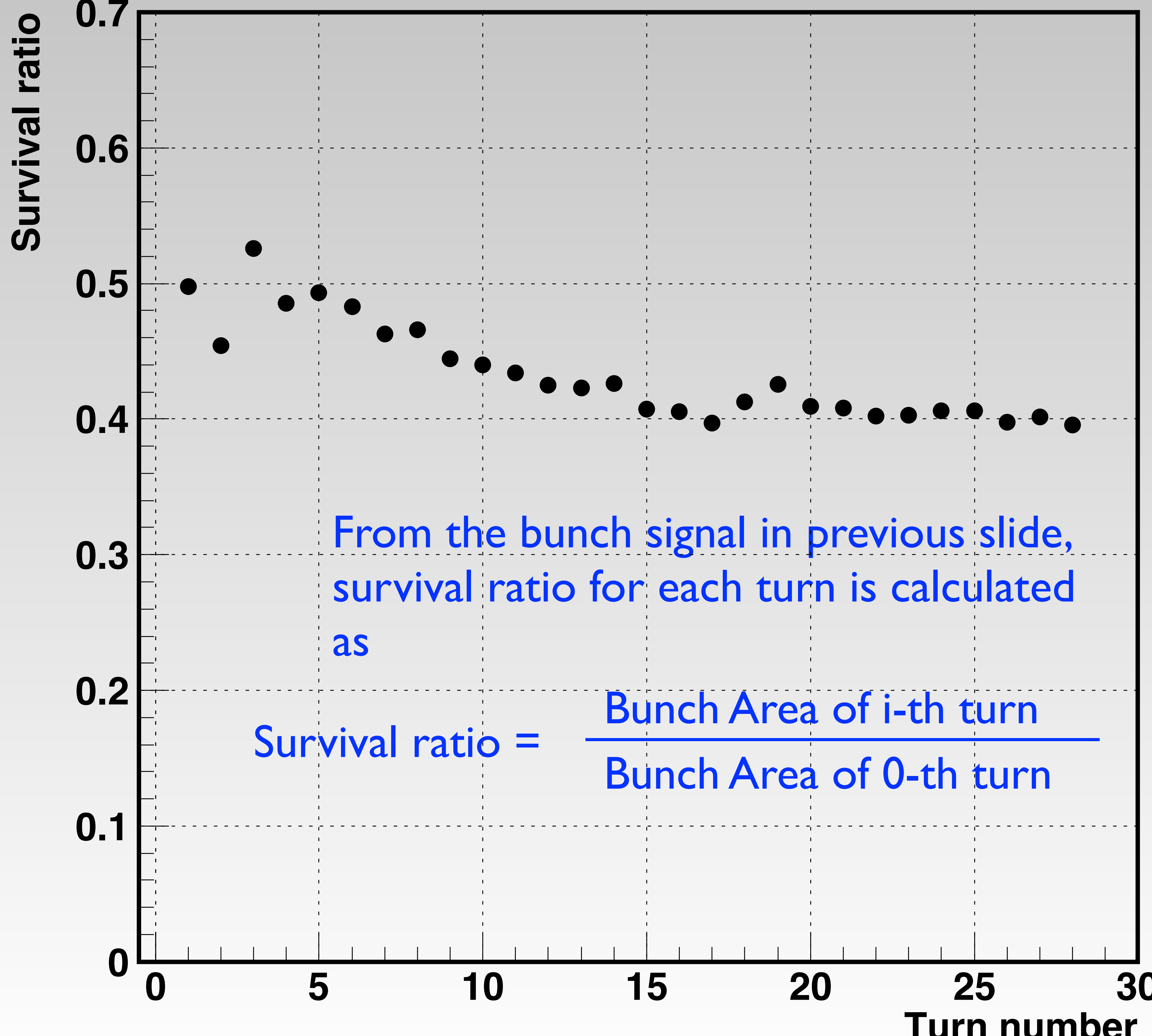



output voltage ( V )

t ( us )

## Beam signal from the bunch monitor

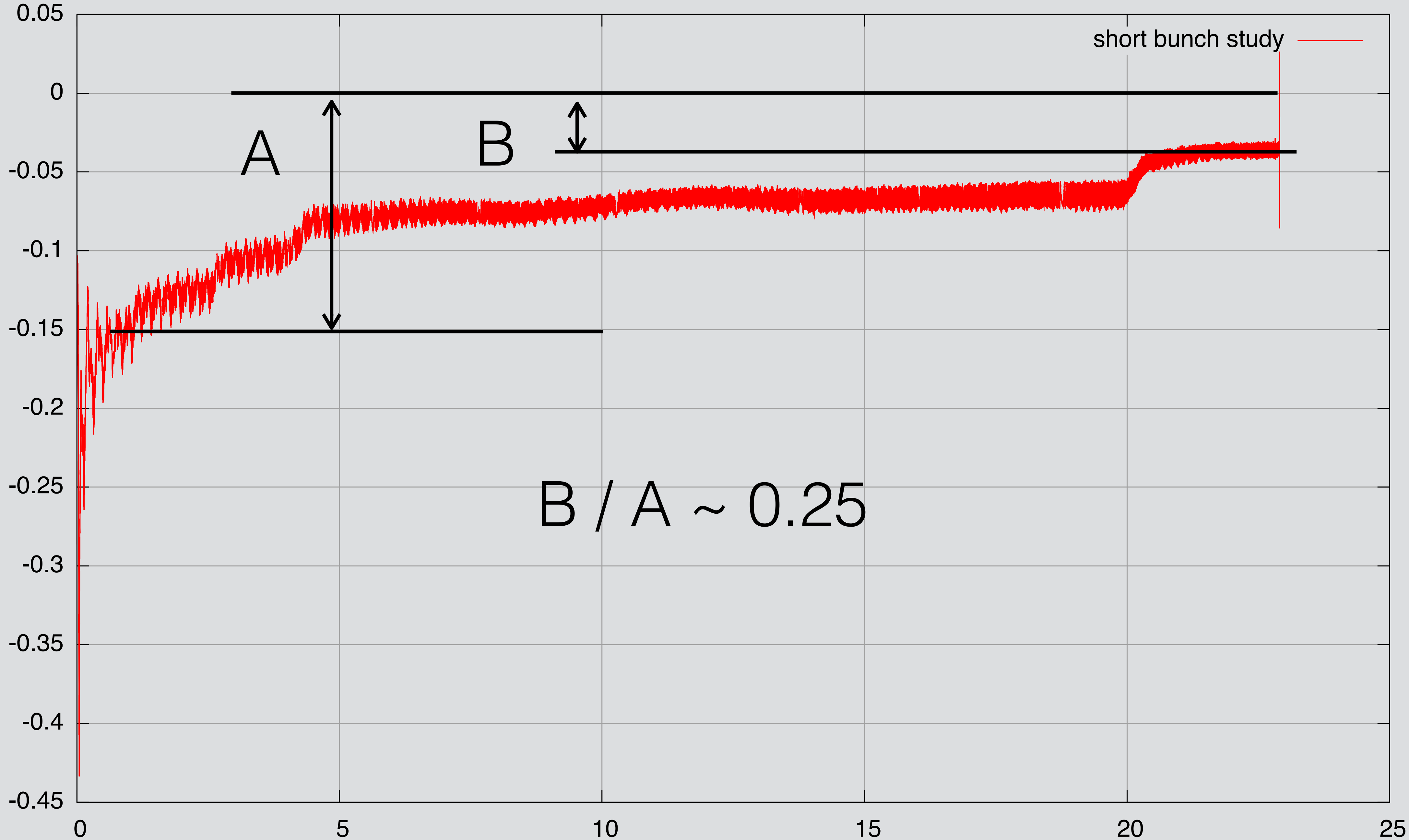
# Survival ratio vs turn number

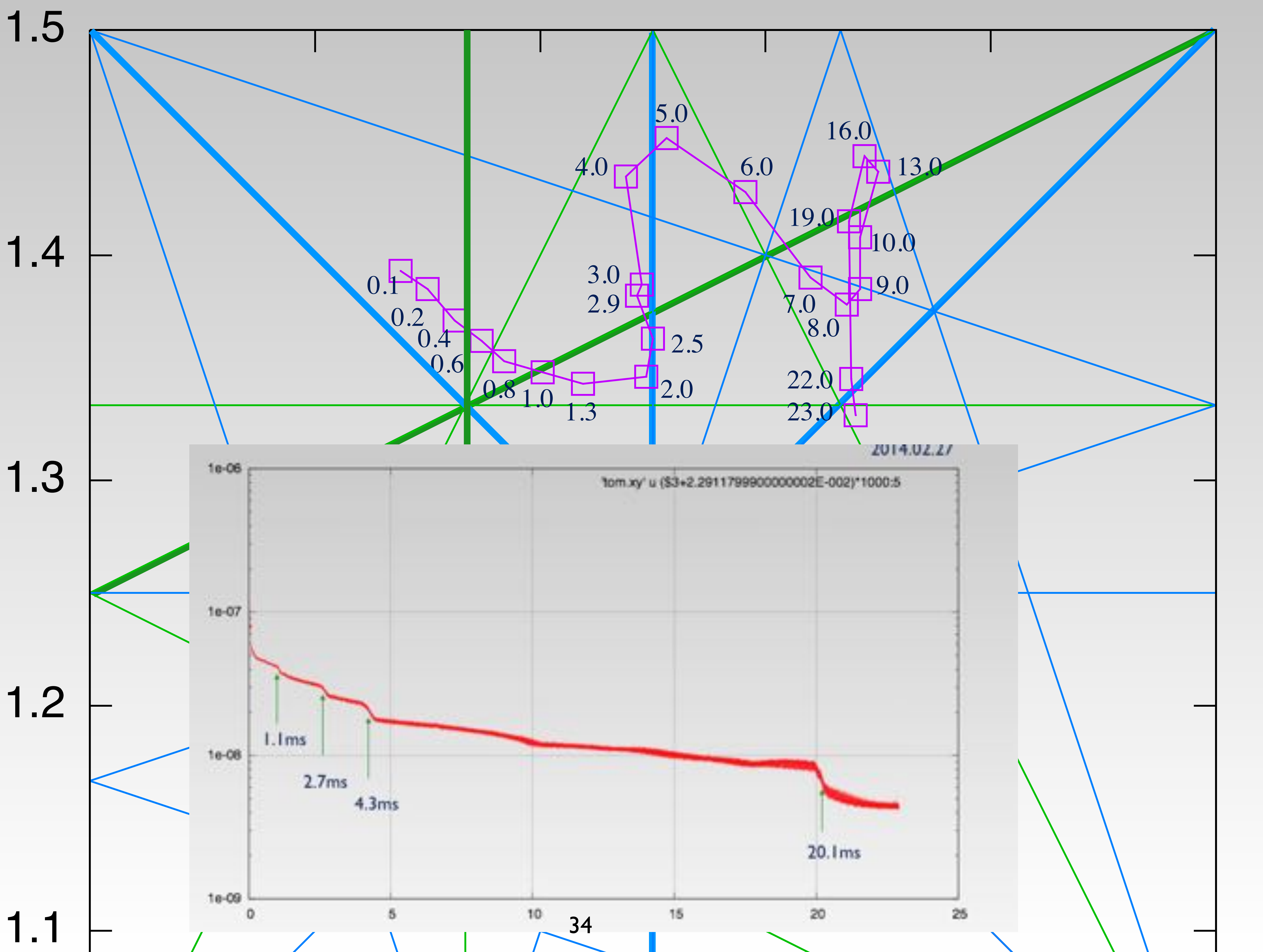



From the bunch signal in previous slide, survival ratio for each turn is calculated as

$$\text{Survival ratio} = \frac{\text{Bunch Area of i-th turn}}{\text{Bunch Area of 0-th turn}}$$

# short bunch survival





1.5
1.4
1.3
1.2
1.1
0.1
0.2
0.4
0.6
0.8
1.0
1.3
2.0
2.5
2.9
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
13.0
16.0
19.0
22.0
23.0
2014.02.27
'tom.xy' u ($3+2.2911799900000002E-002)*1000:5
1e-06
1e-07
1e-08
1e-09
0
5
10
15
20
25
1.1ms
2.7ms
4.3ms
20.1ms

# What happens in the first 1 ms?

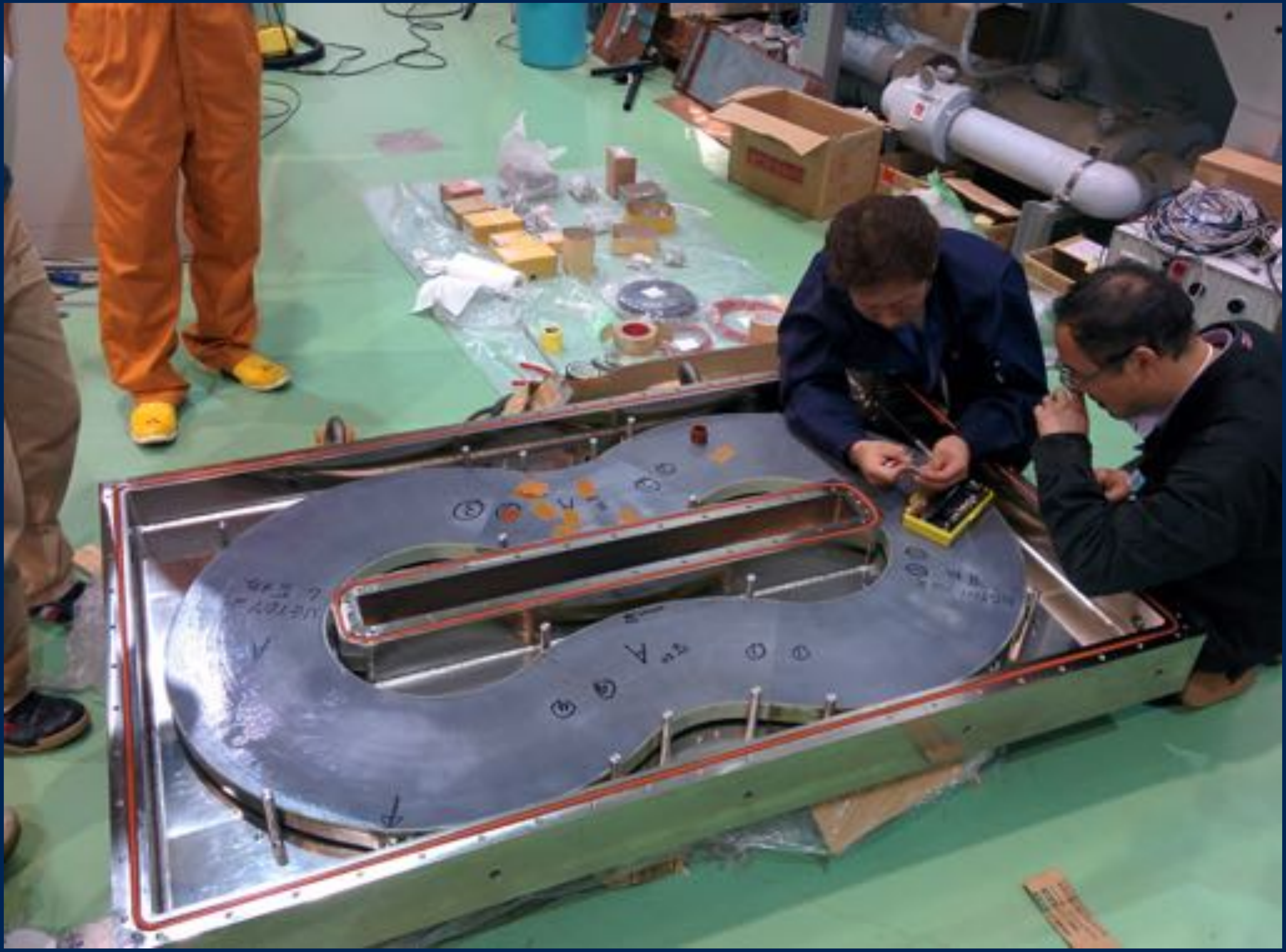
- Transverse
  - orbit mismatch
  - $\beta$, $\alpha$ mismatch
  - $\eta$ mismatch
  - emittance blow up due to the scattering with the foil
  - betatron resonance
- Longitudinal
  - rf backet < $\Delta p/p$
  - energy struggling due to the scattering with the foil
  - spill out of the moving bucket

Details are available in Kuriyama-san's talk today. Don't miss it!

# Solutions for the improvement

- Second cavity installation
  - enlarge the bucket height especially at the capture
  - higher rep. rate → higher average current
  - fast acceleration makes the crossing speed of the betatron resonances faster
- Ion source power up

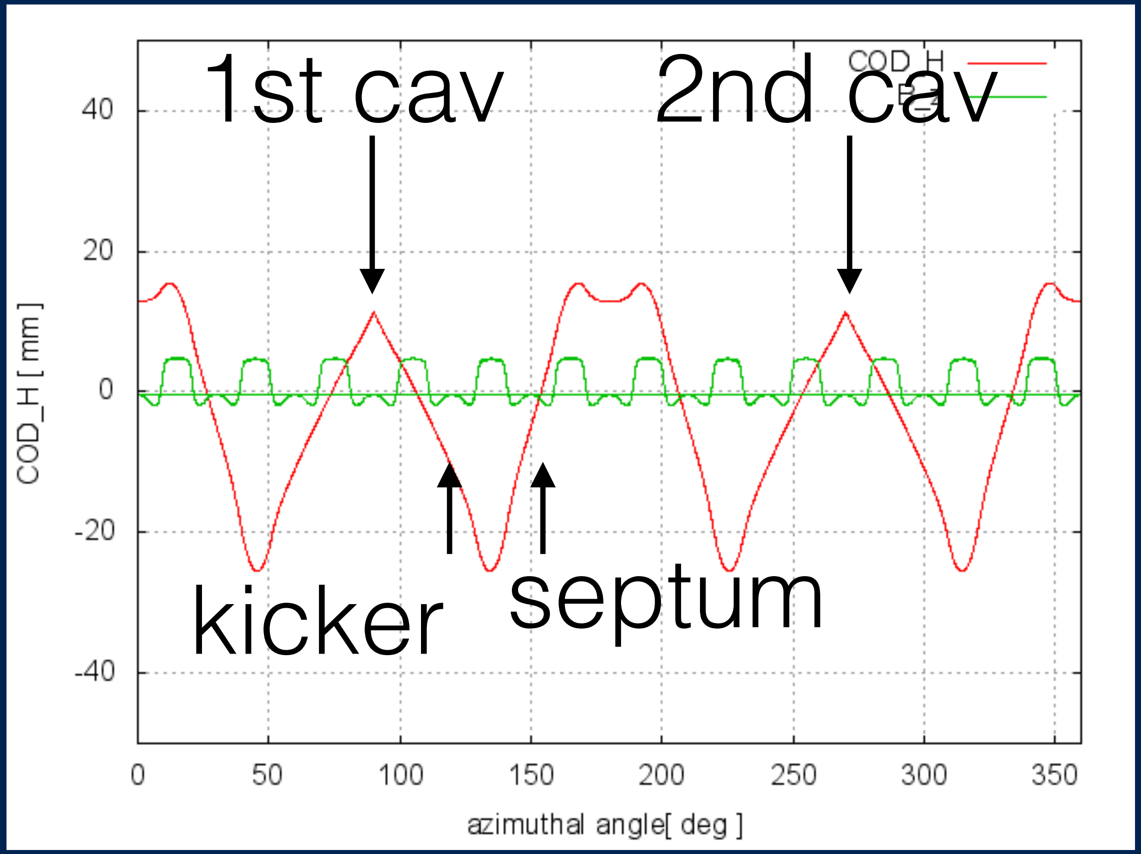
# Second cavity assembly



# Where should we install it?

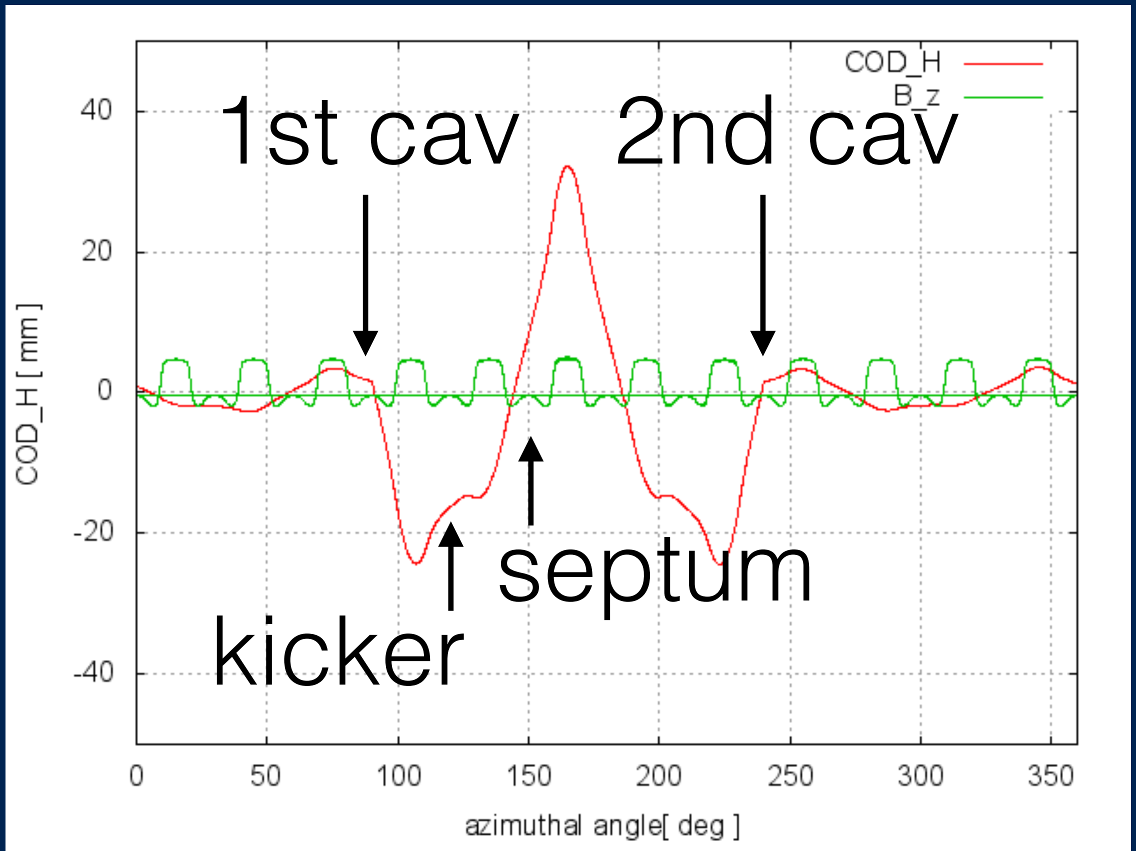
# COD with 2 cavities

6 cells




- suppress odd harmonics

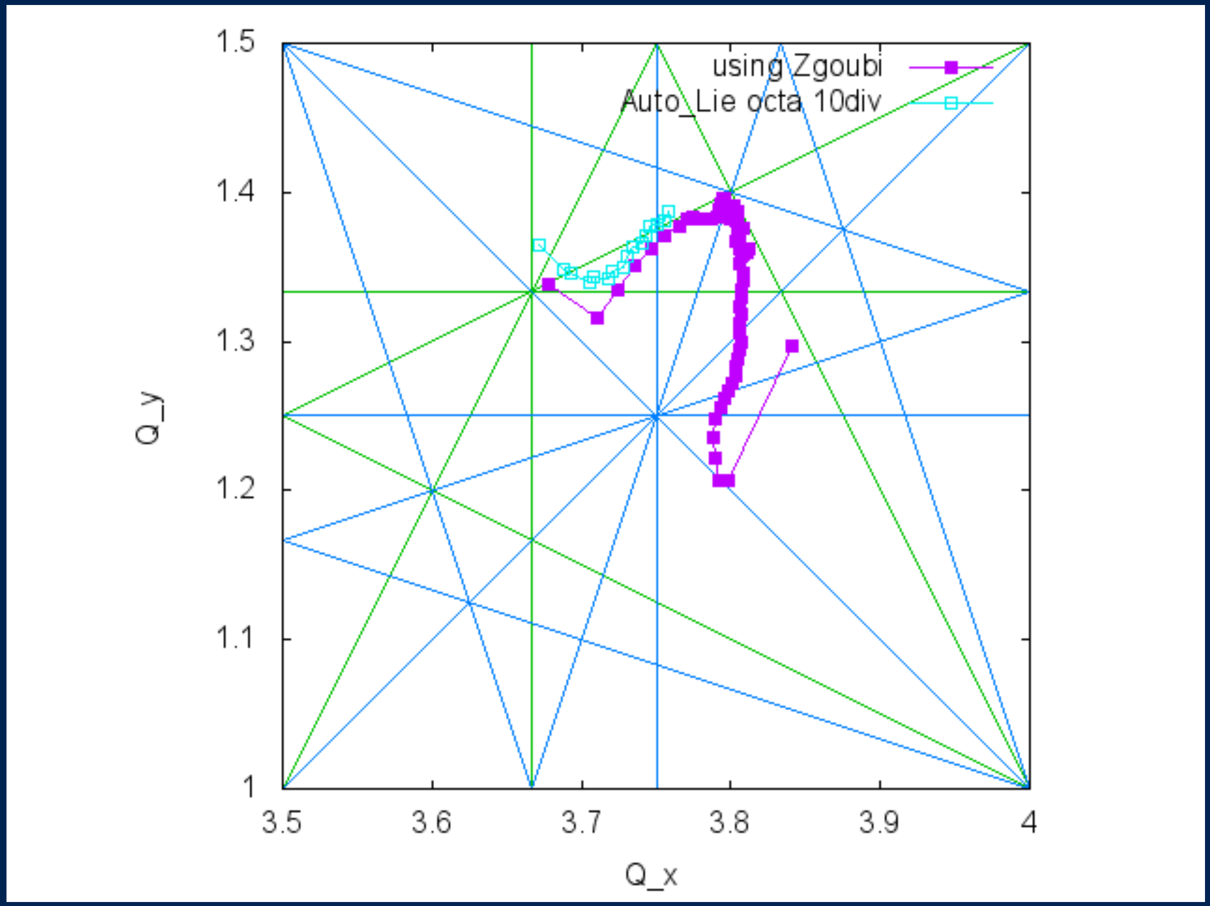
5 cells ( $3\pi$ bump )



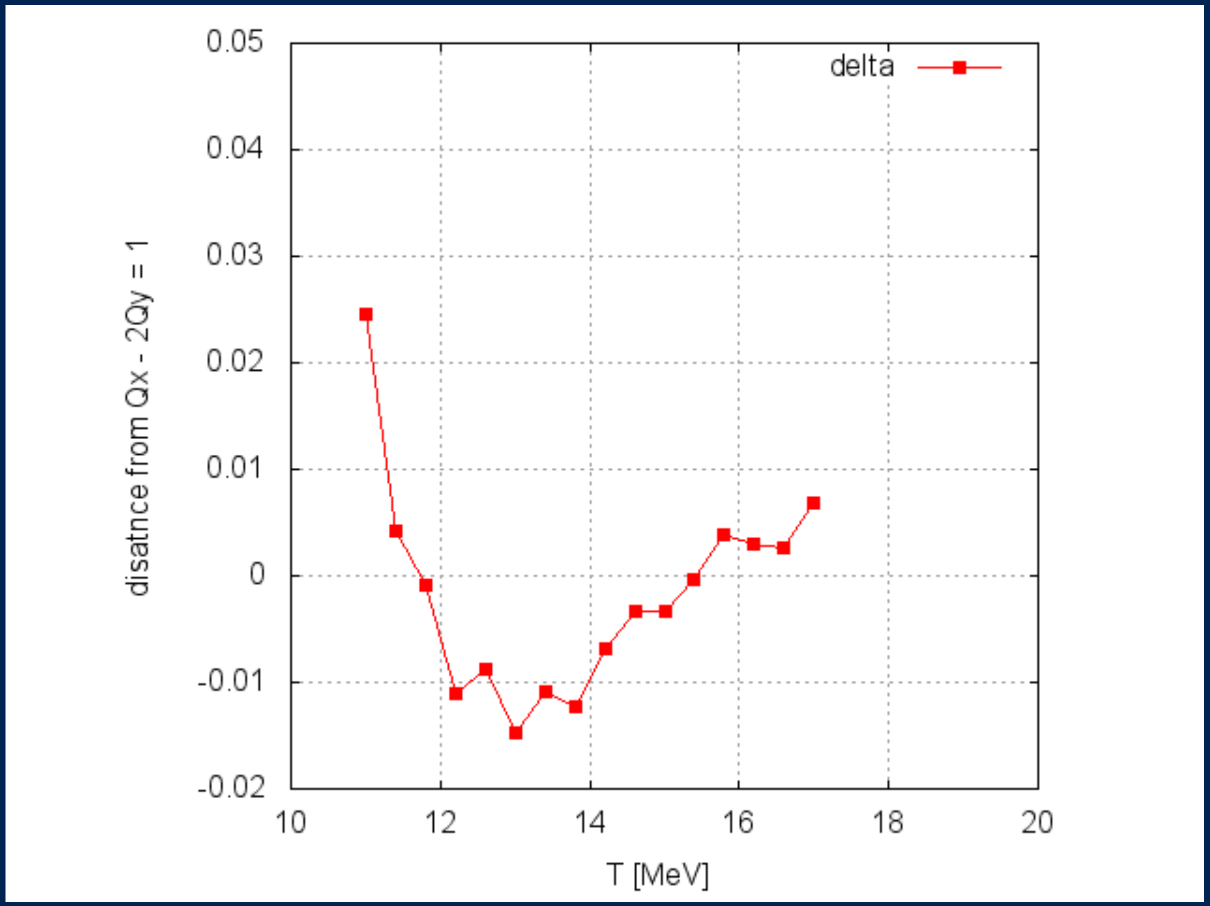

- no COD wave outside the bump
- large angle at the septum

# Simulation study for crossing $\nu_x - 2\nu_y = 1$

tune diagram ( simulation )

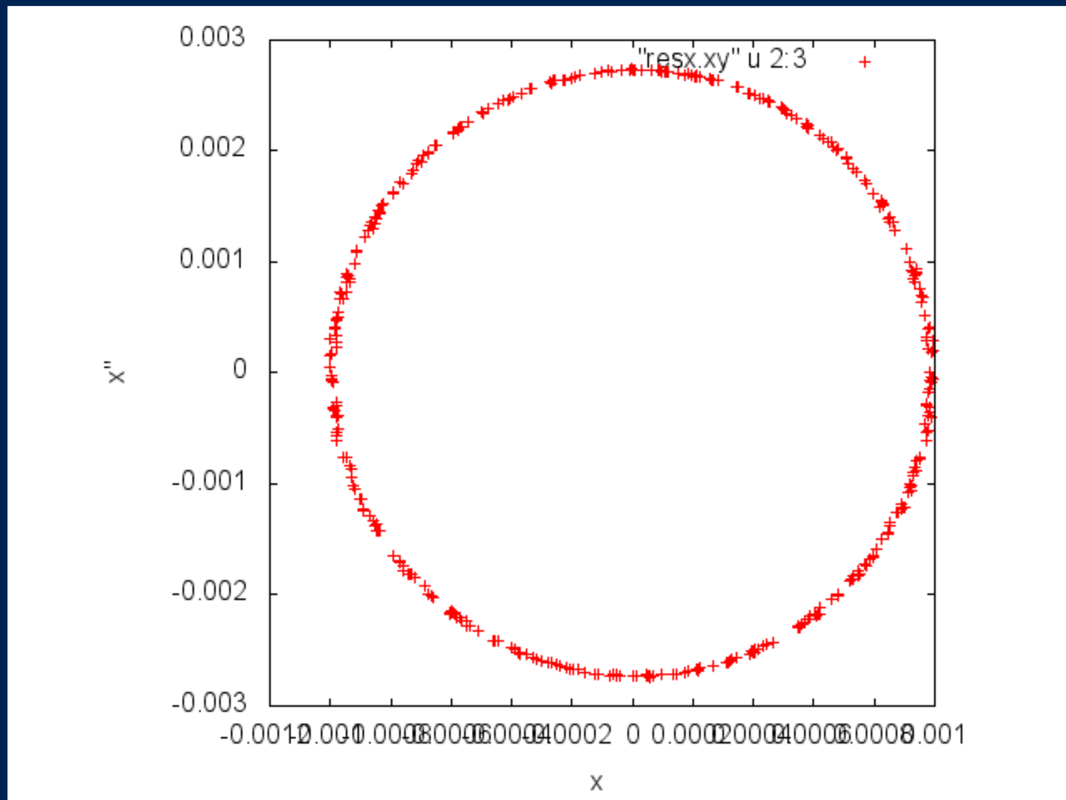


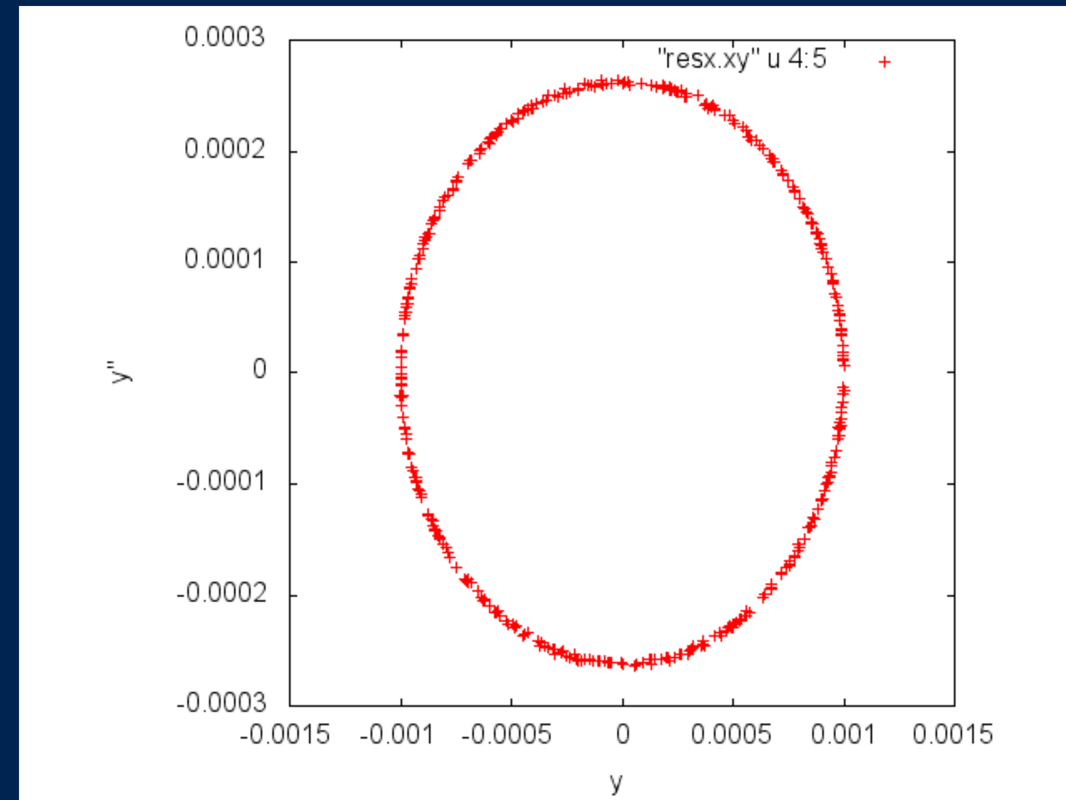

distance from the line

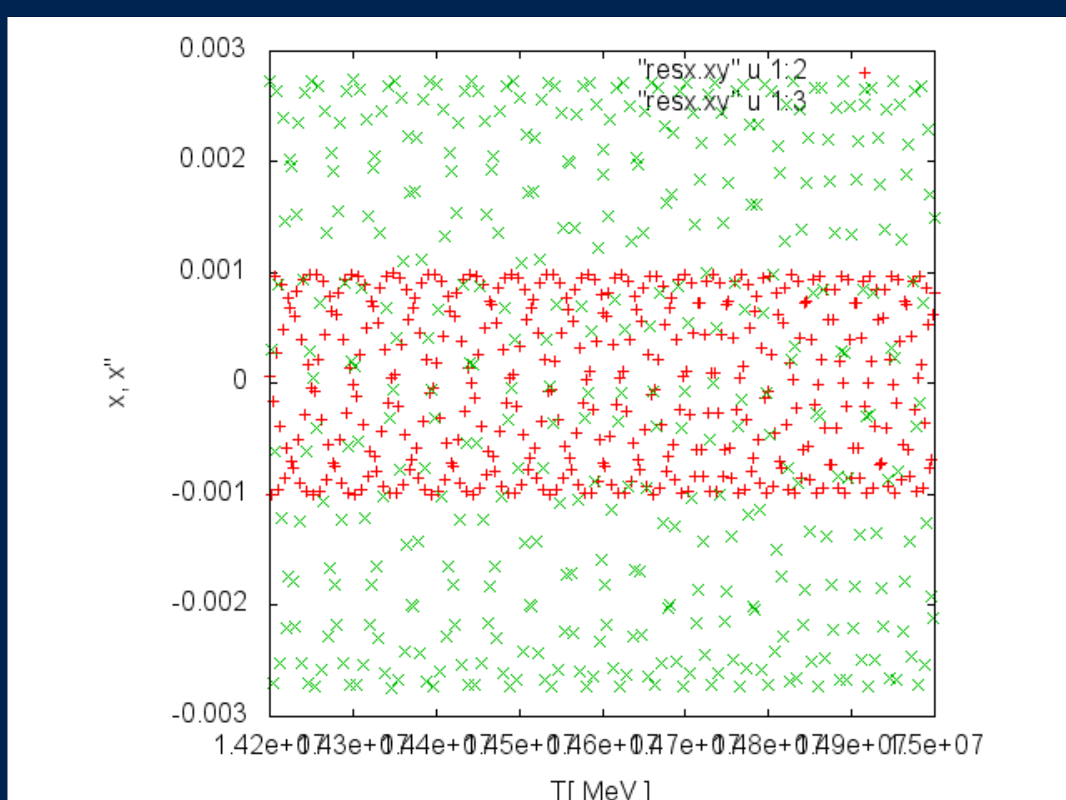


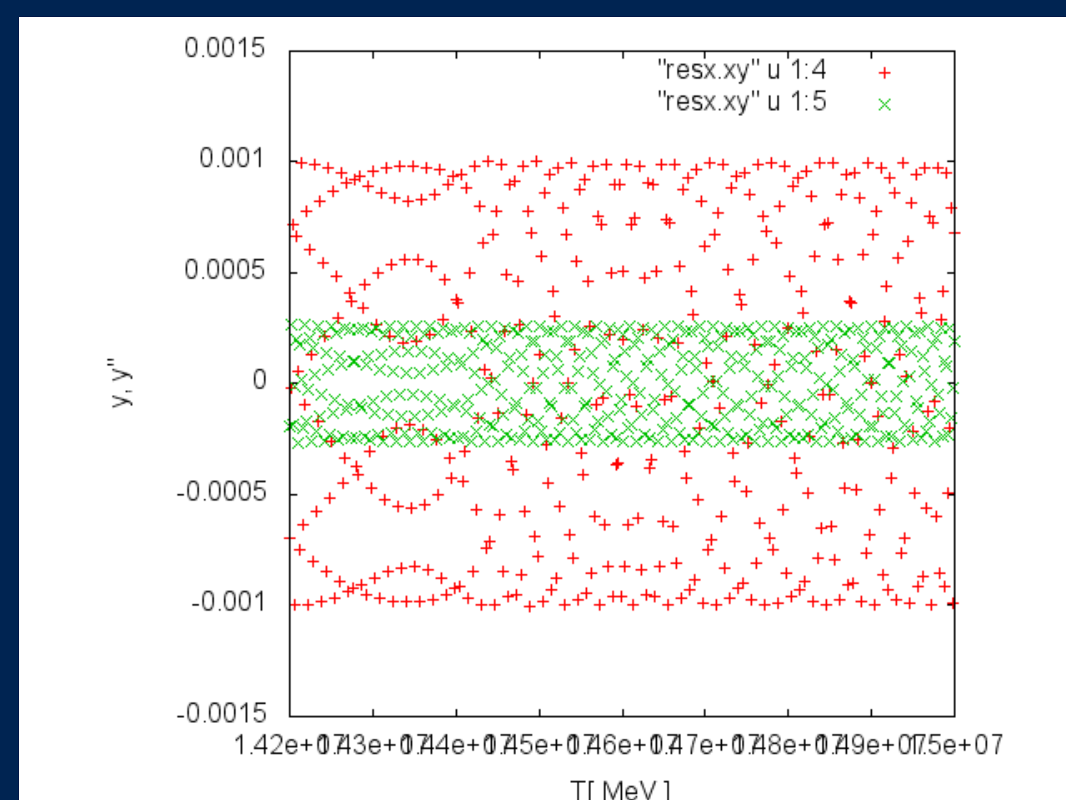

make conditions to simulate crossing
D field : 2 % up

# 6 cell : $x_0$ = 1mm, $y_0$ = 1mm

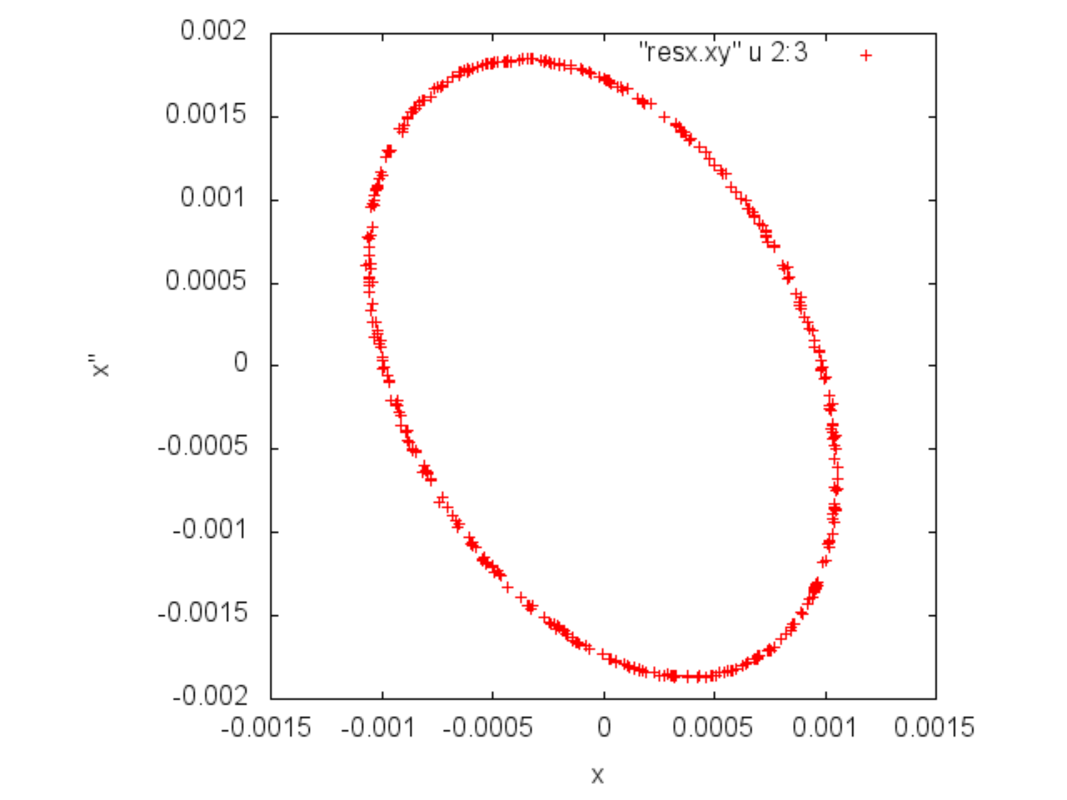


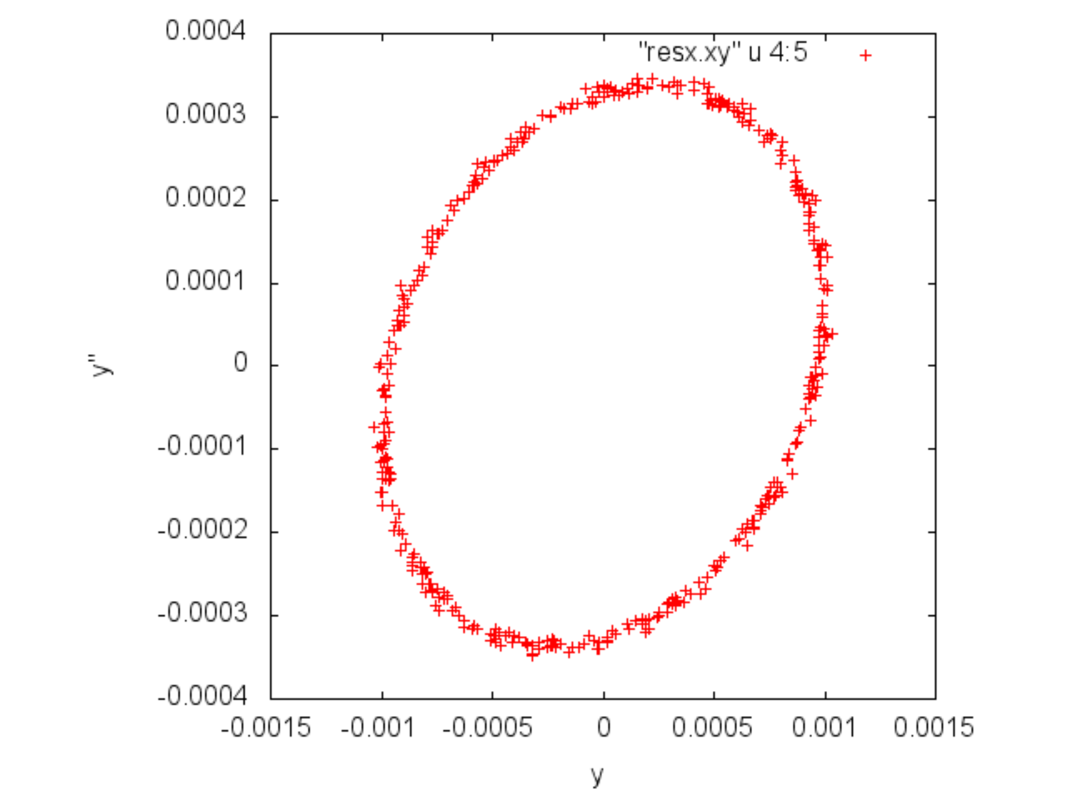



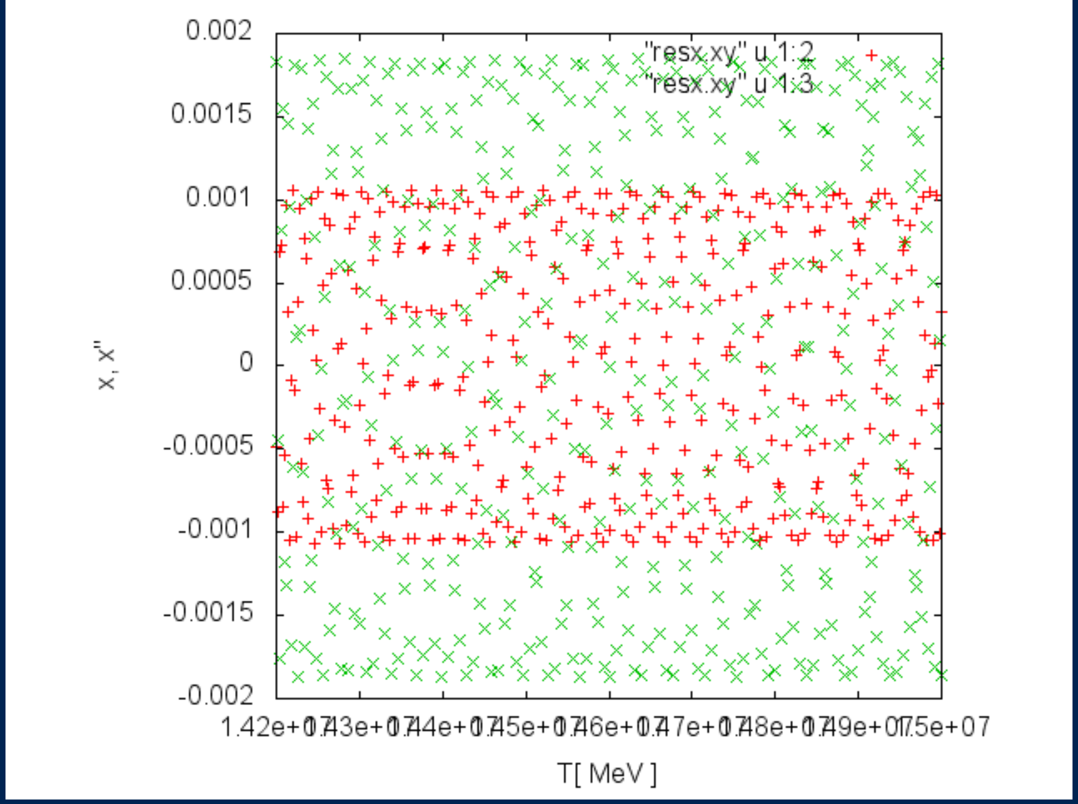



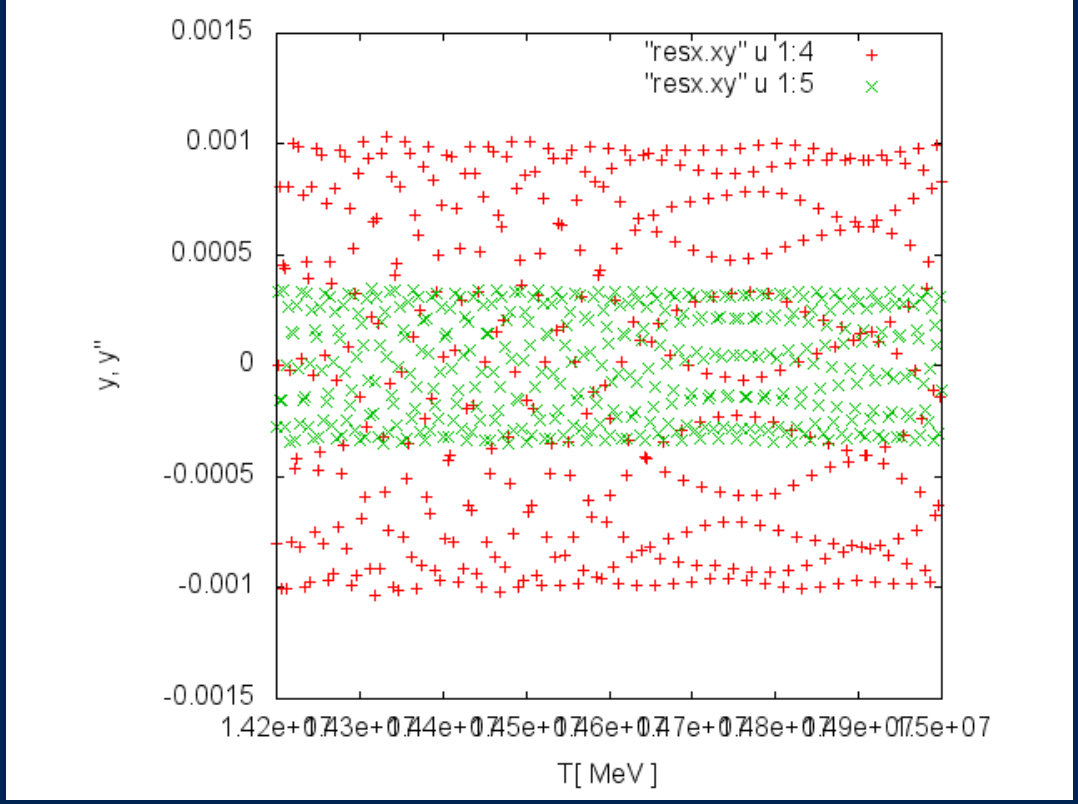



# 5 cell : $x_0$ = 1mm, $y_0$ = 1mm

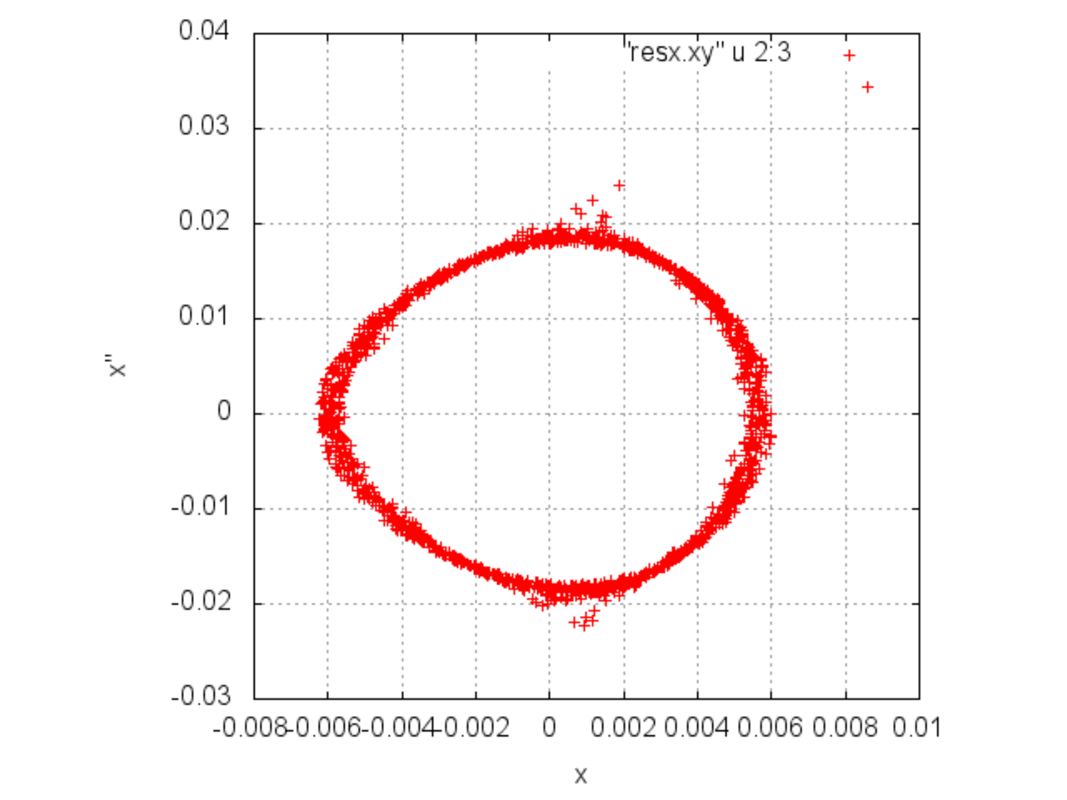


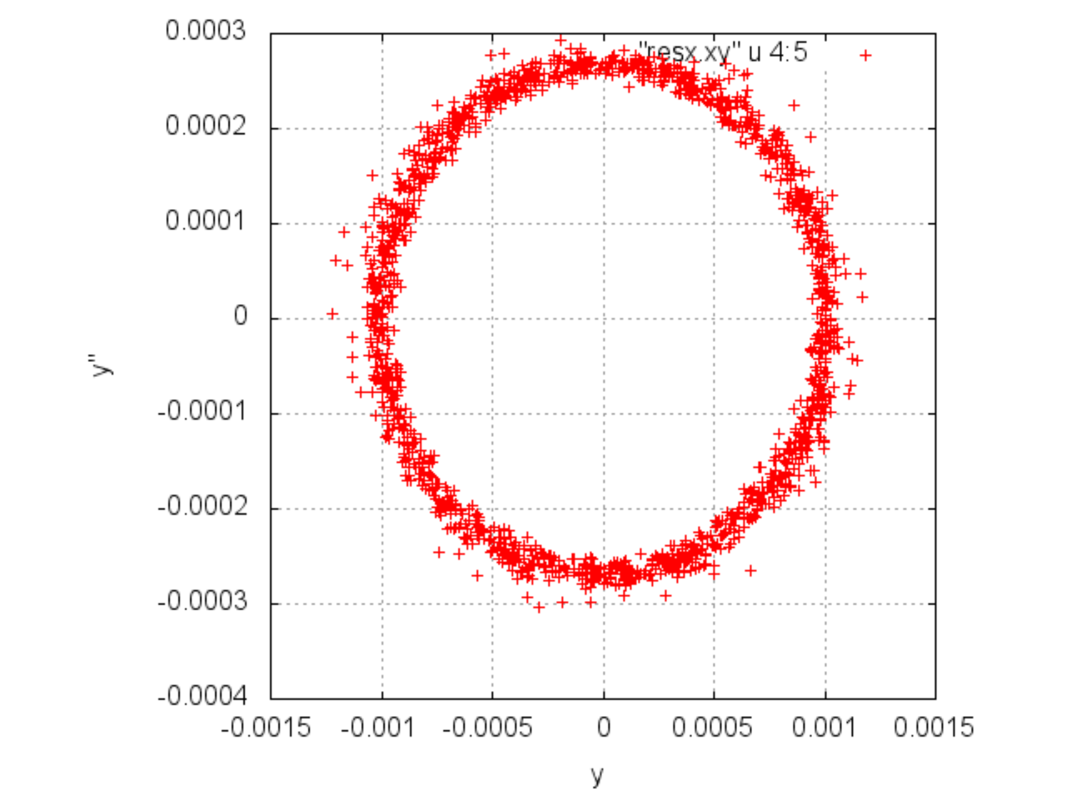



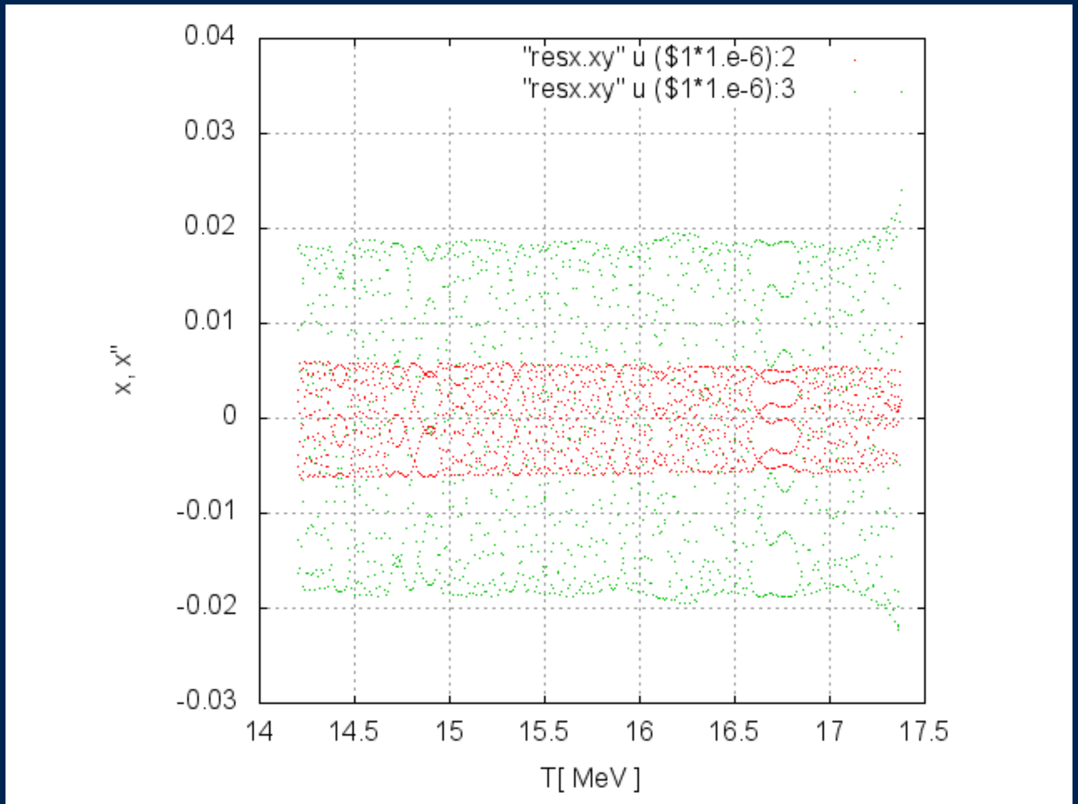



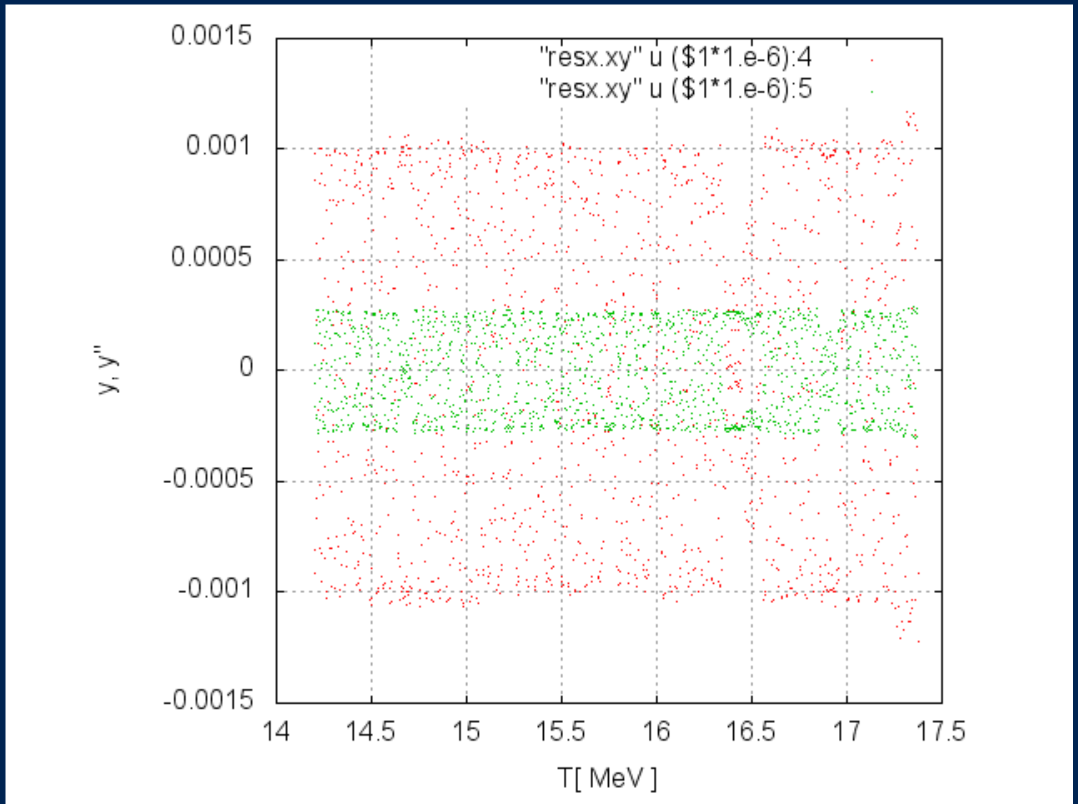



# 6 cell : $x_0$ = 6mm, $y_0$ = 1mm

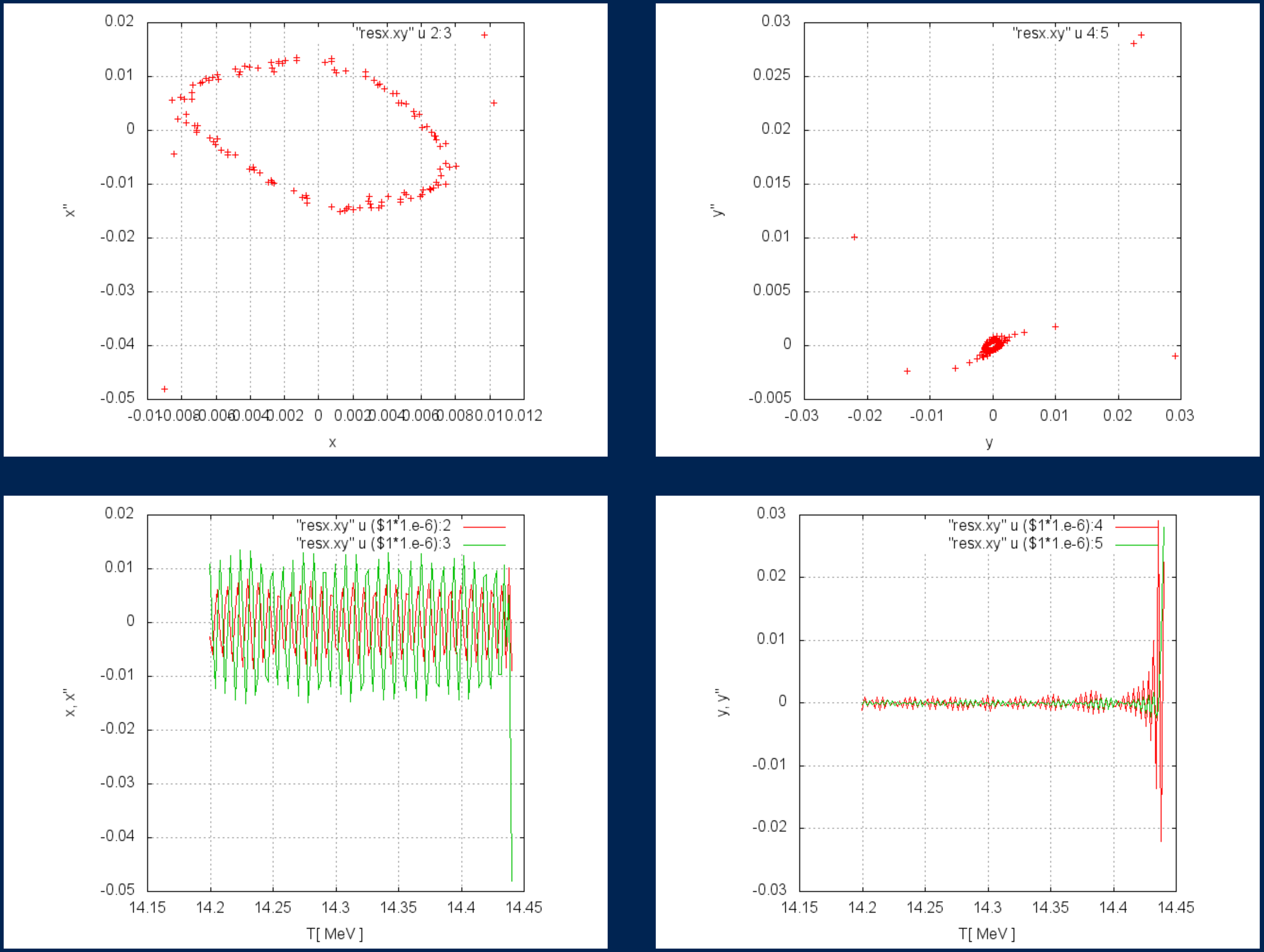


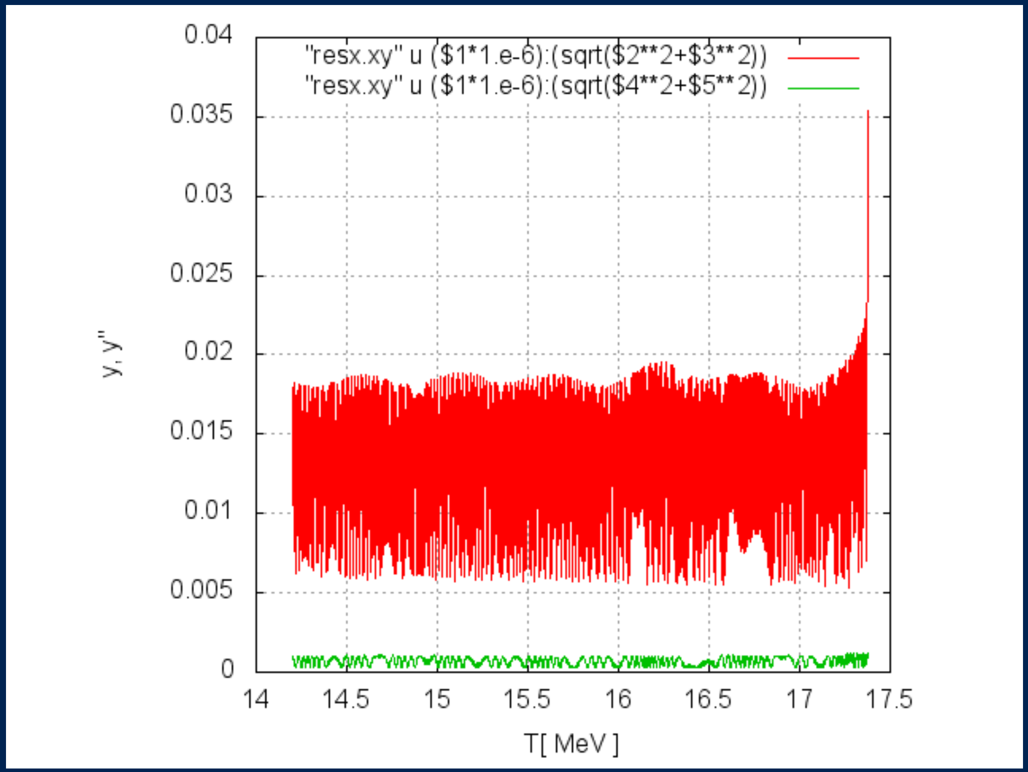



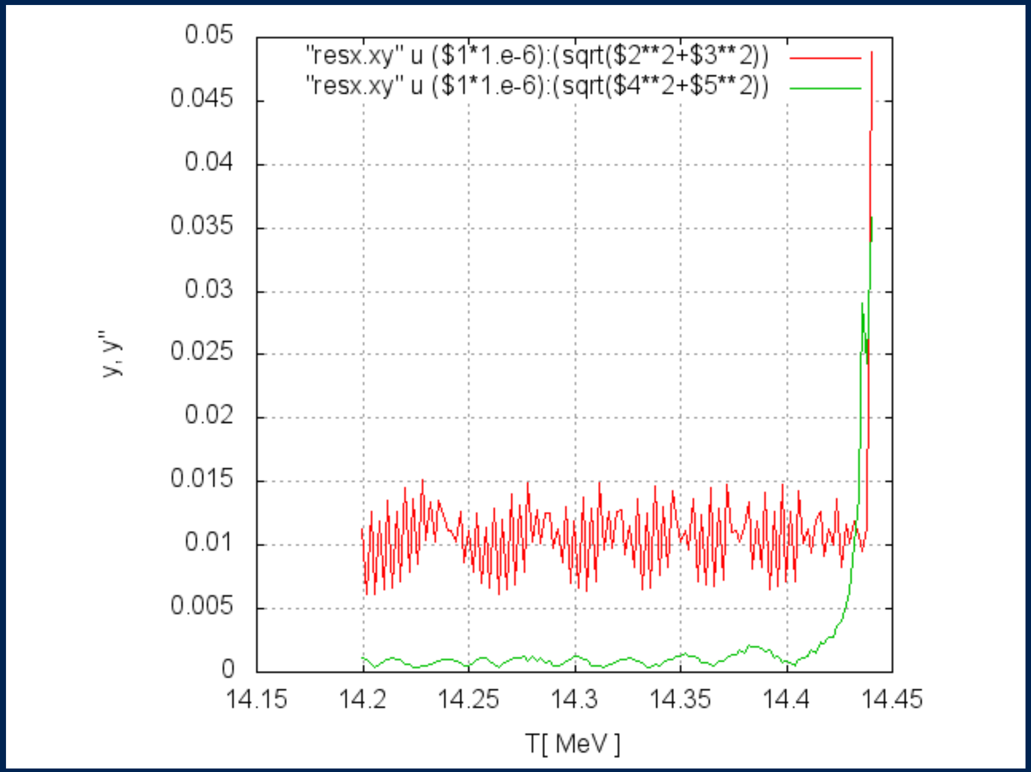
# 5 cell : $x_0$ = 6mm, $y_0$ = 1mm



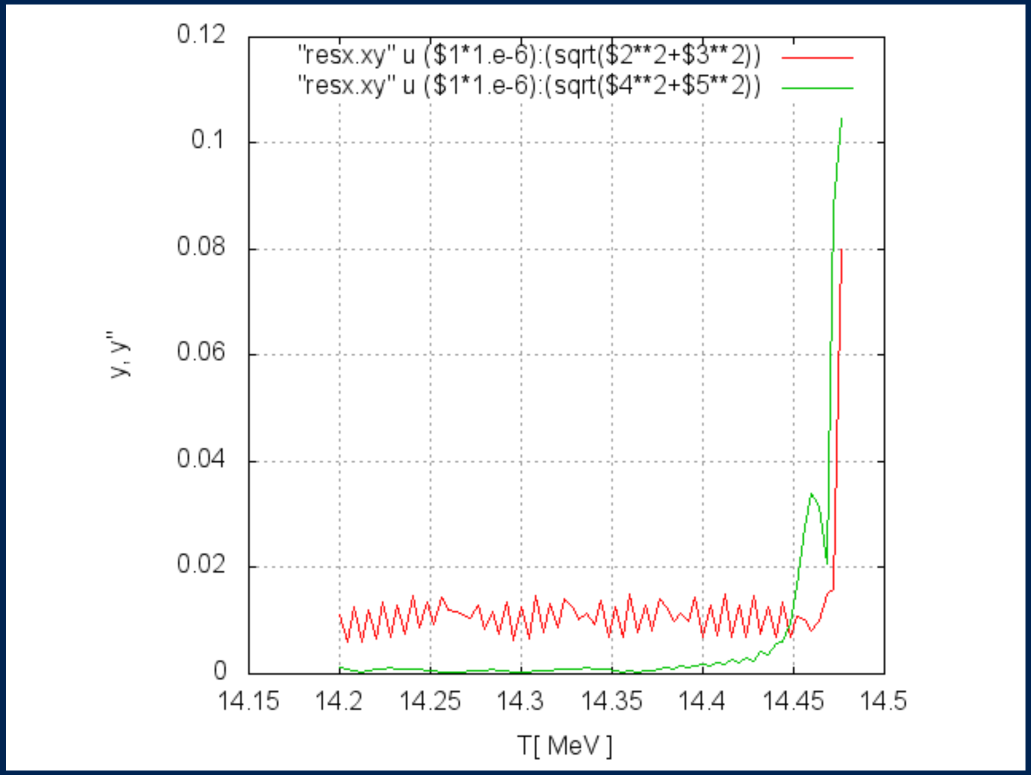
# 6cell $x_0$=6mm, $y_0$=1mm

# 5cell $x_0$=6mm, $y_0$=1mm



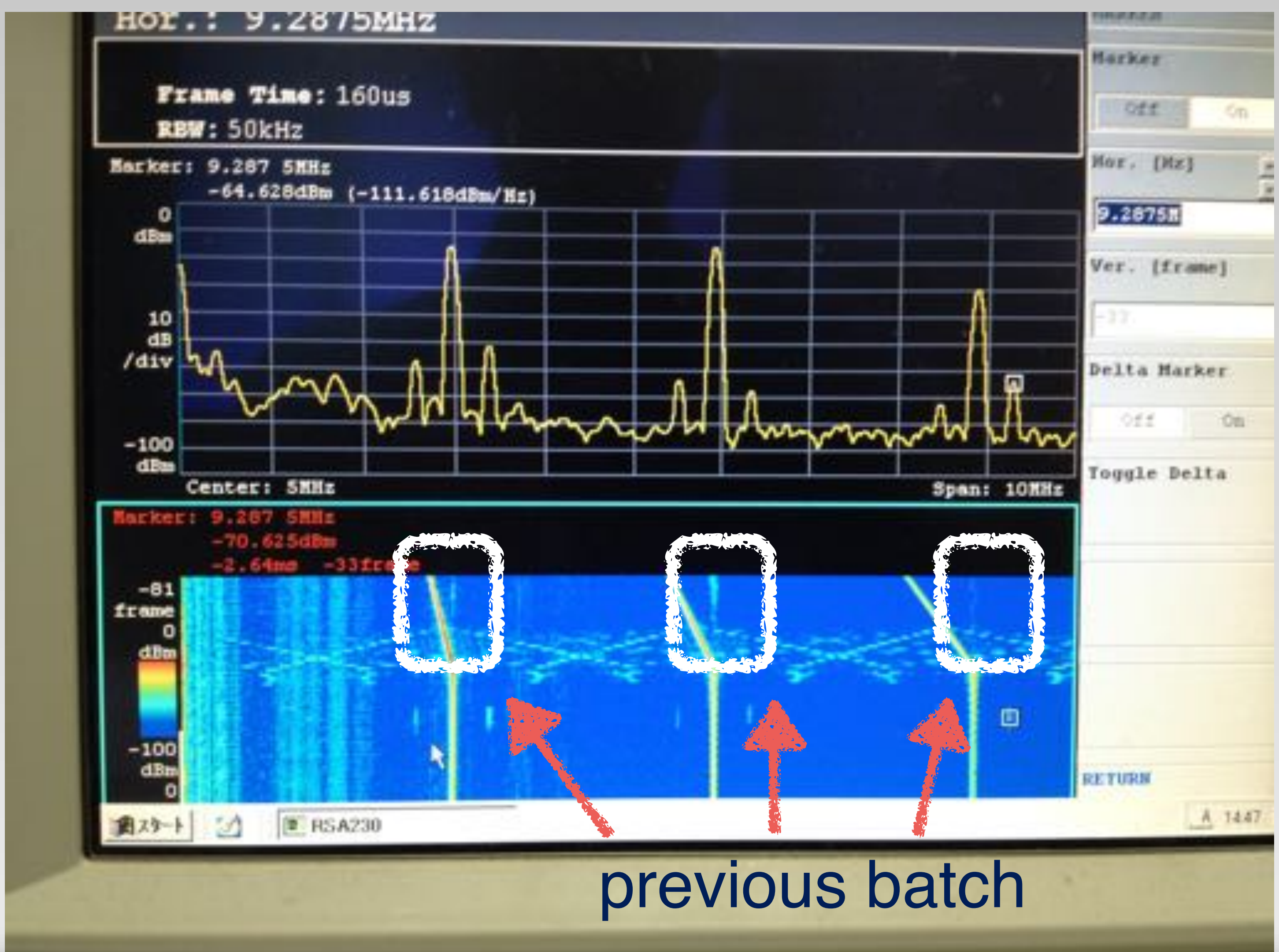



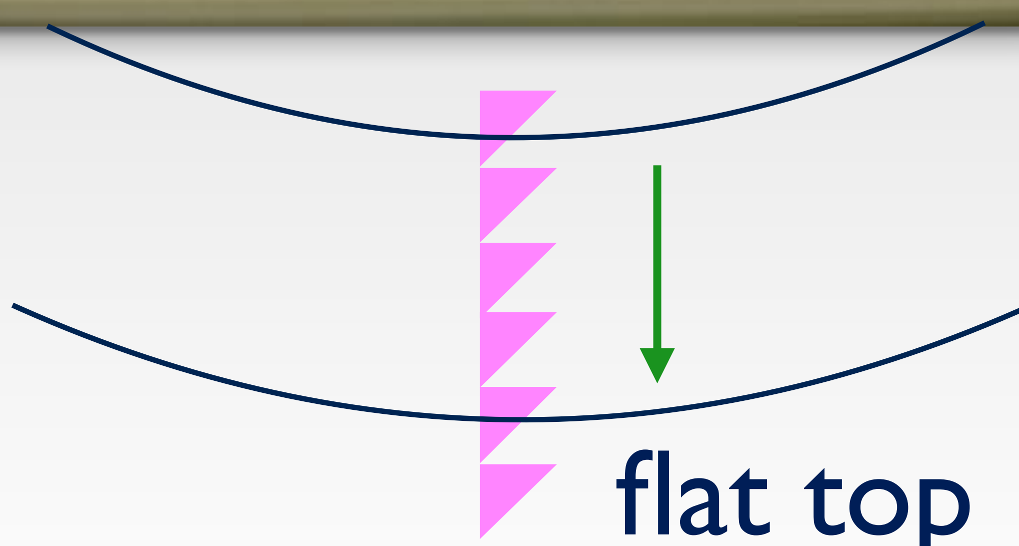

$V_{acc}$ = 2kV

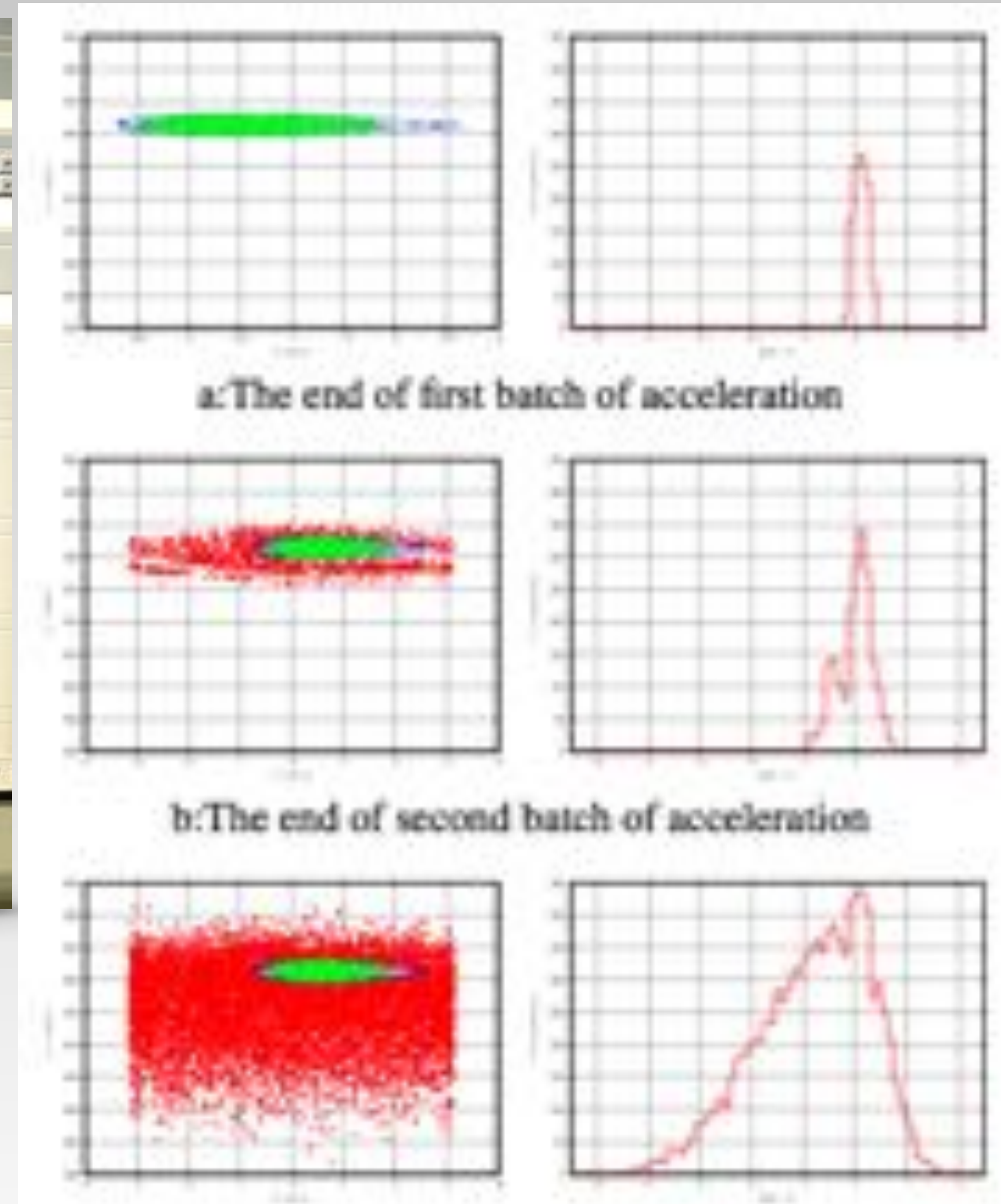



$V_{acc}$ = 4kV

# Sign of RF stacking

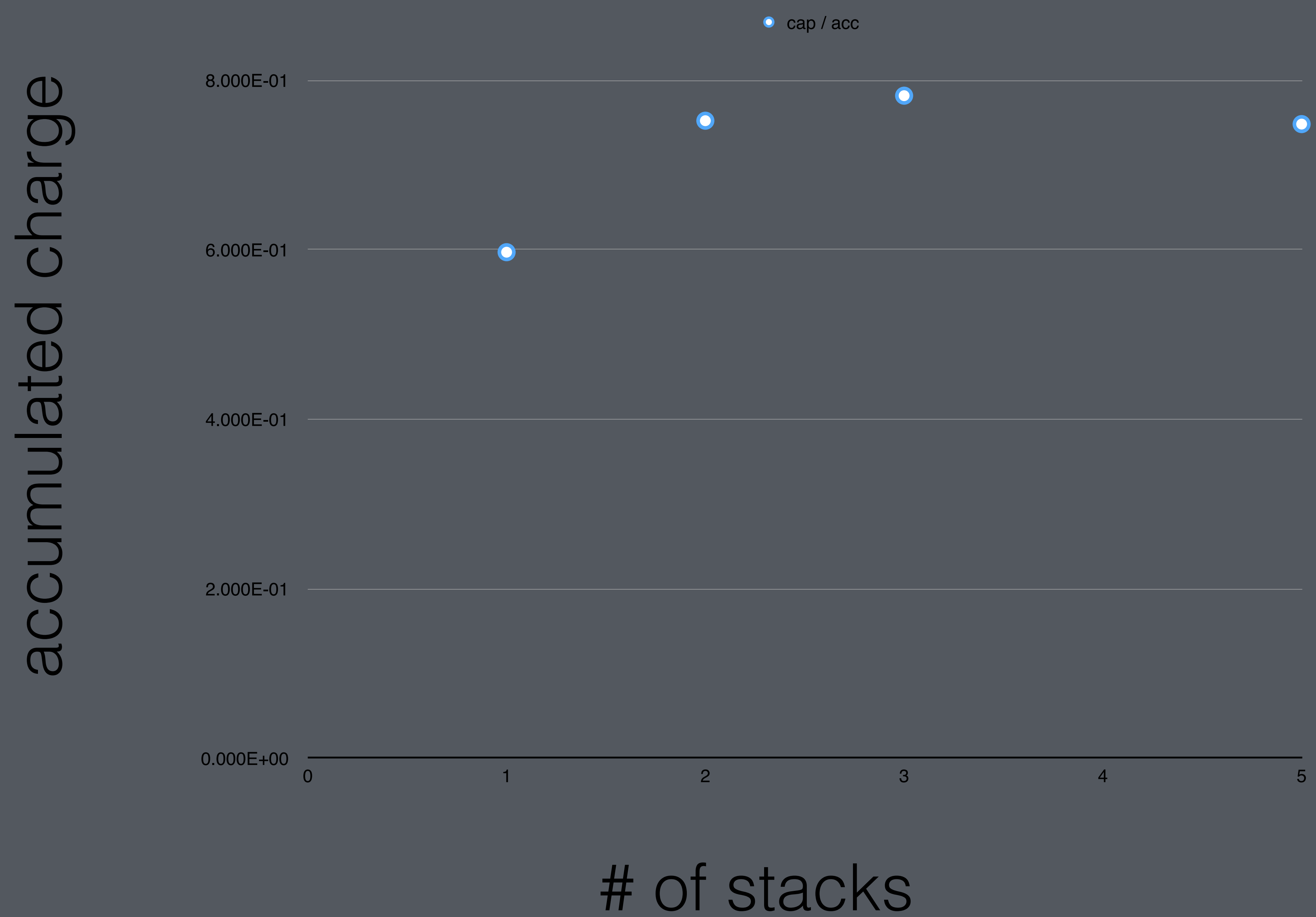


# First Stacking Exp. done

Kuriyama-san talking details



# Summary

1. Proton beams  from KURRI FFAG facility are utilised by various users.
2. If the beam losses due to betatron resonances are cured, the beam current will be improved by 4 times.
3. Similarly, if we understand the behaviour in first 1ms and cure the beam losses, the beam current will increase by 40 times.
4. The second cavity installation will be done soon.
5. First rf stacking experiments has been done.

Thank you for your attention.