FFA activity in Japan and future projects

2022.9.30 y.ishi KURNS

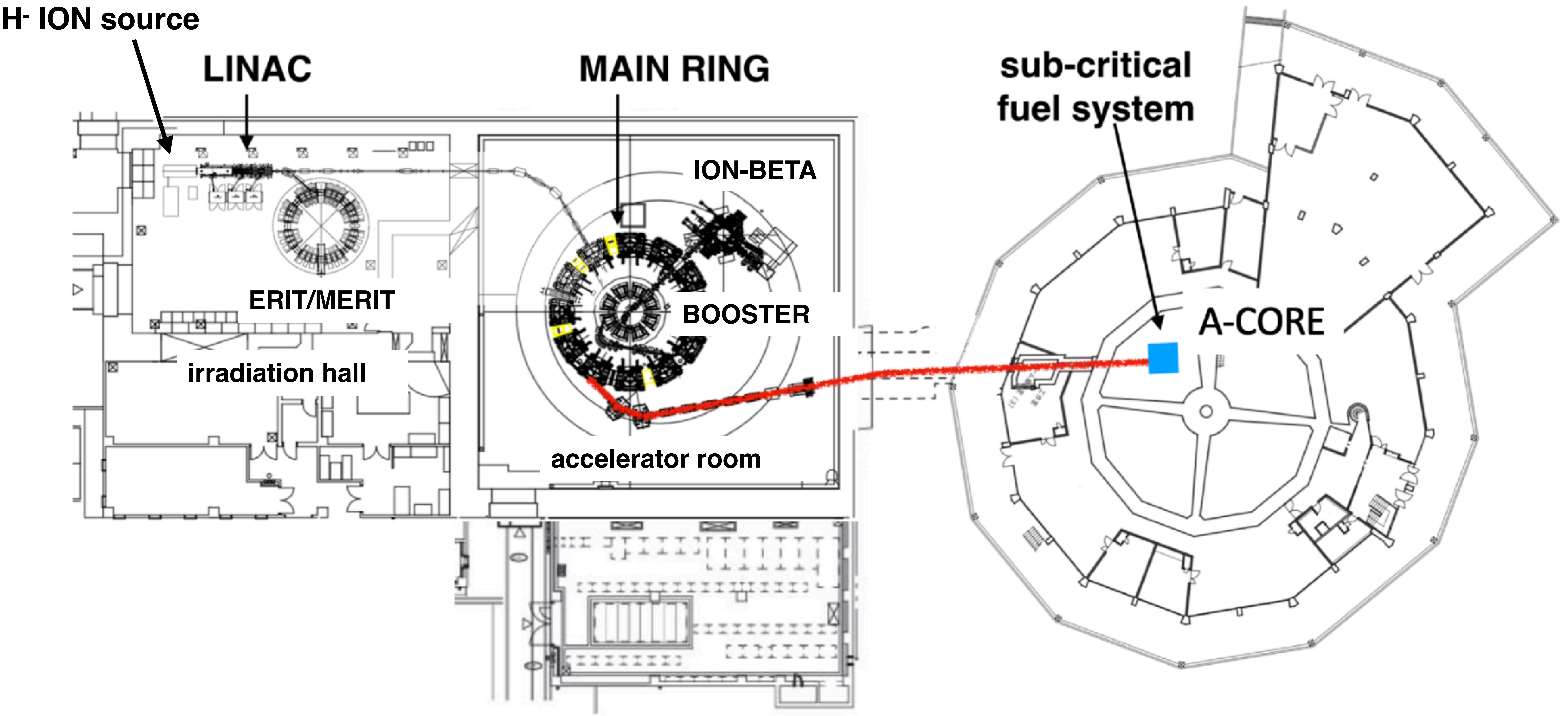
Slack archive of FFA21

https://www.rri.kyoto-u.ac.jp/beam_physics_lab/ffa21/slack/ffa21workshop.slack.com_log.general_2022_08_30_10_48_52.html

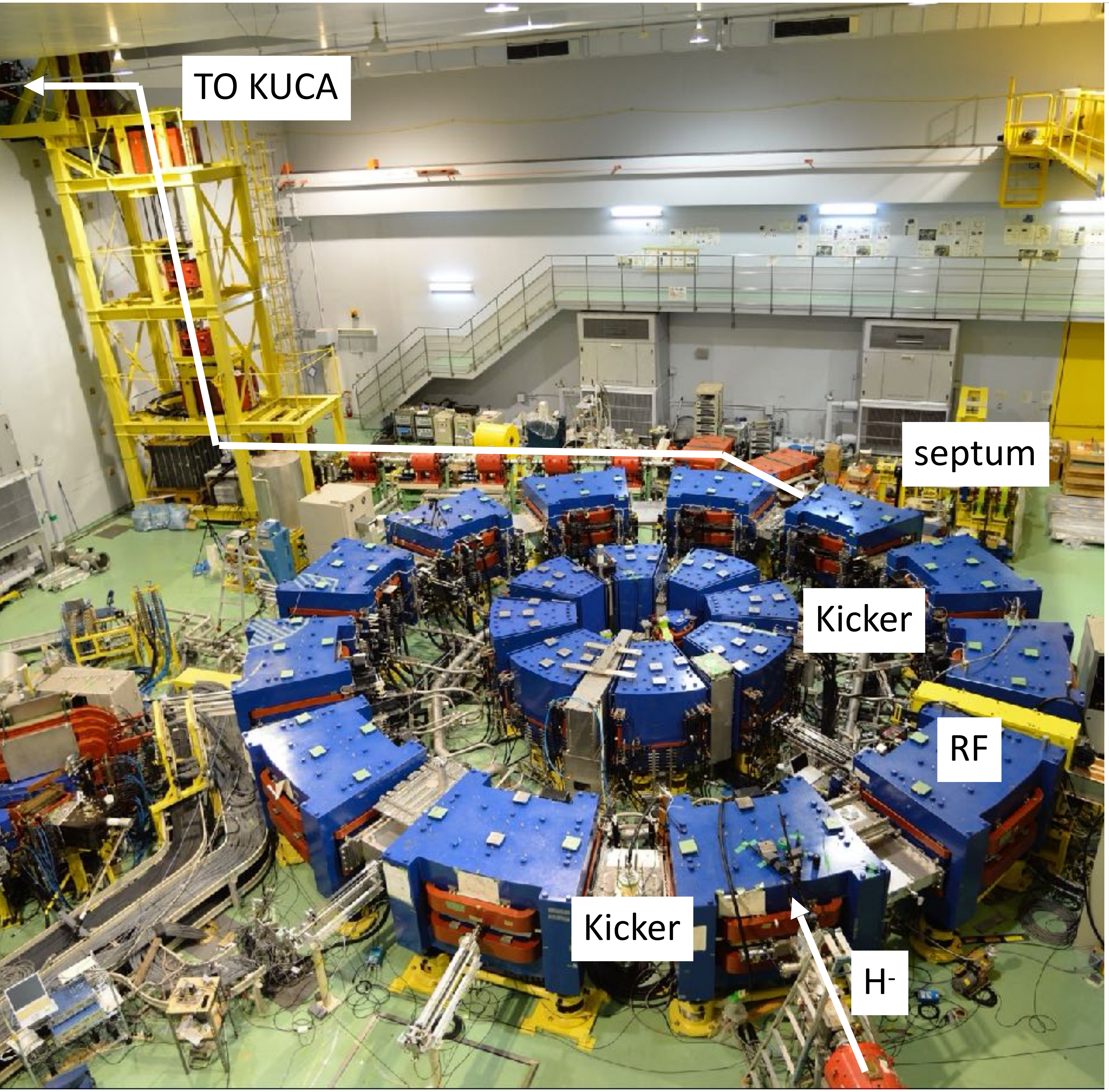
Outline

1. overview of the complex at KURNS
2. activity and plans
    - Kyushu university
    - KURNS FFA Main Ring remodeling
        - pion production ring
        - ERIT_SHE (ERIT for super heavy element)
3. summary

Layout of the accelerator complex at KURNS

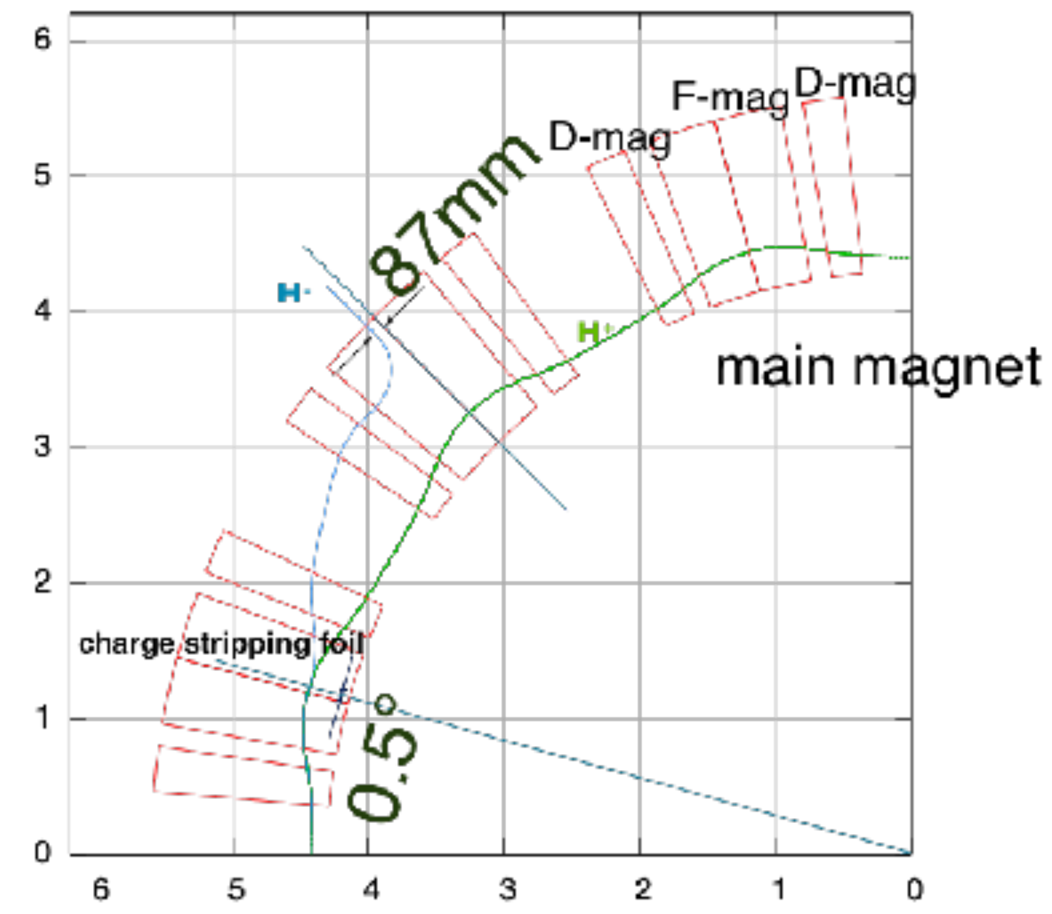


MAIN RING

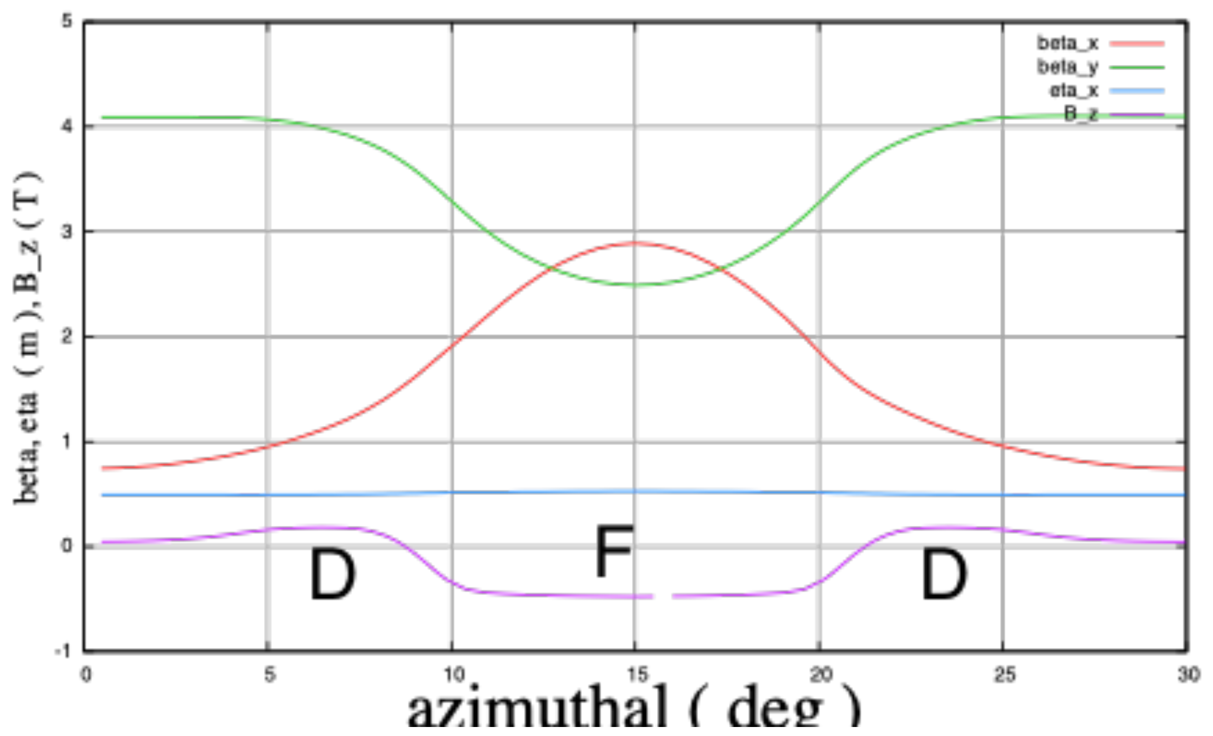


Beam species	: proton
Injection energy	: 11 MeV
Extraction energy	: 150 (100) MeV
Beam current	: 1 nA (safety reg.)
Lattice structure	: 12-cell DFD
Field index k	: 7.5
Average orbit radii	: 4.52 – 5.12 m

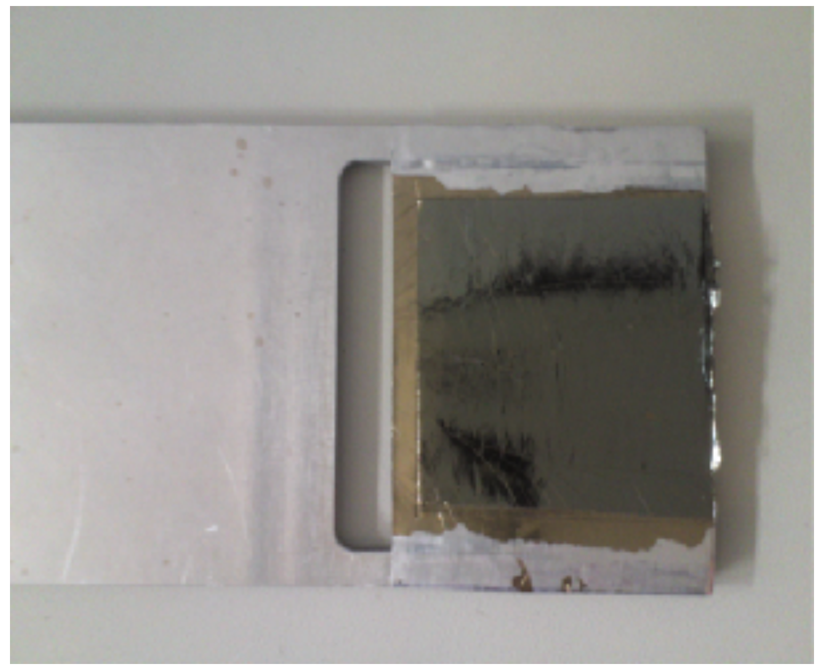
Beam injection



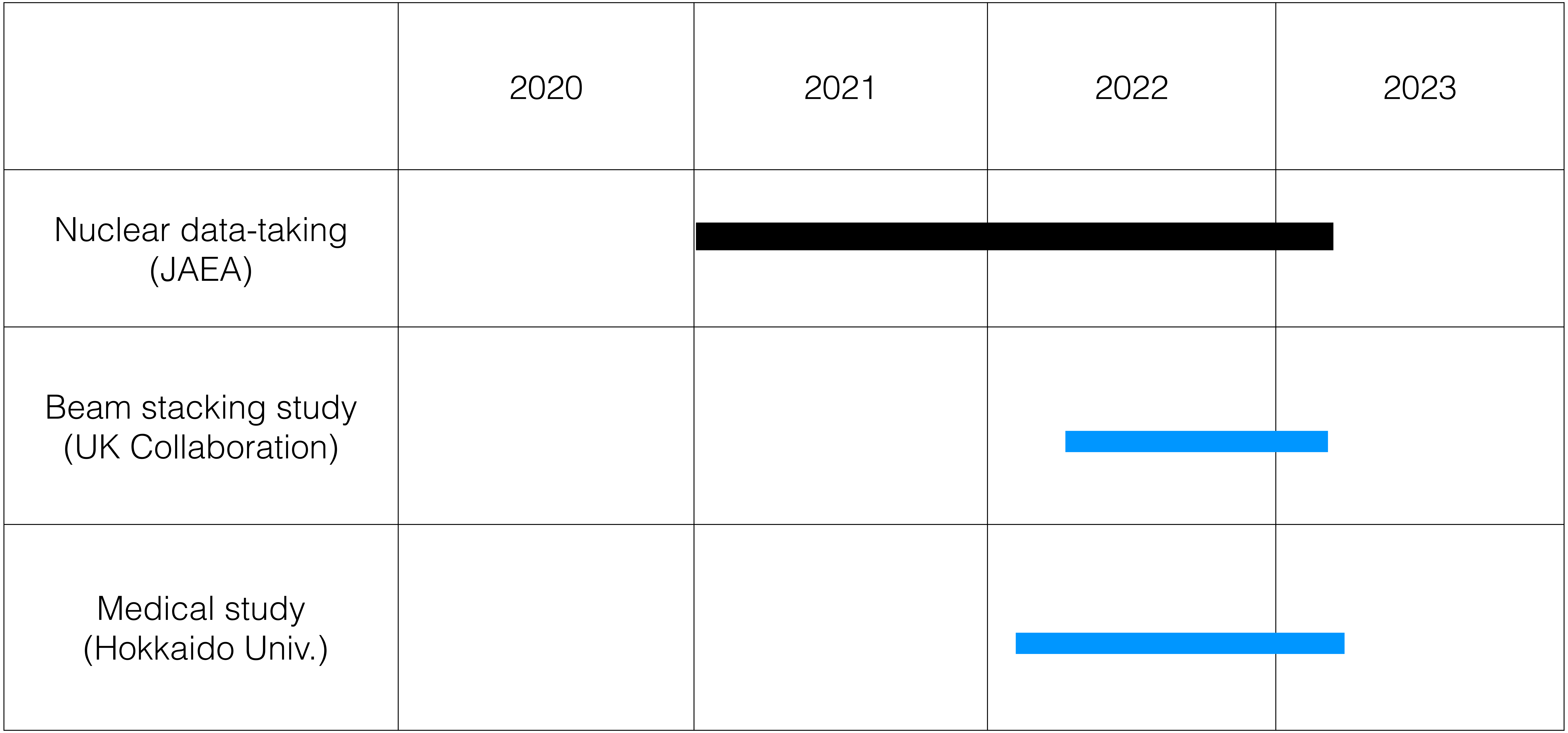
Betatron functions



Charge stripping foil



Machine time schedule



Future plans for the Irradiation Hall

The utilization plan of the entire facility and the future reuse of the accelerators installed in it are under consideration.

MERIT → Kyushu University

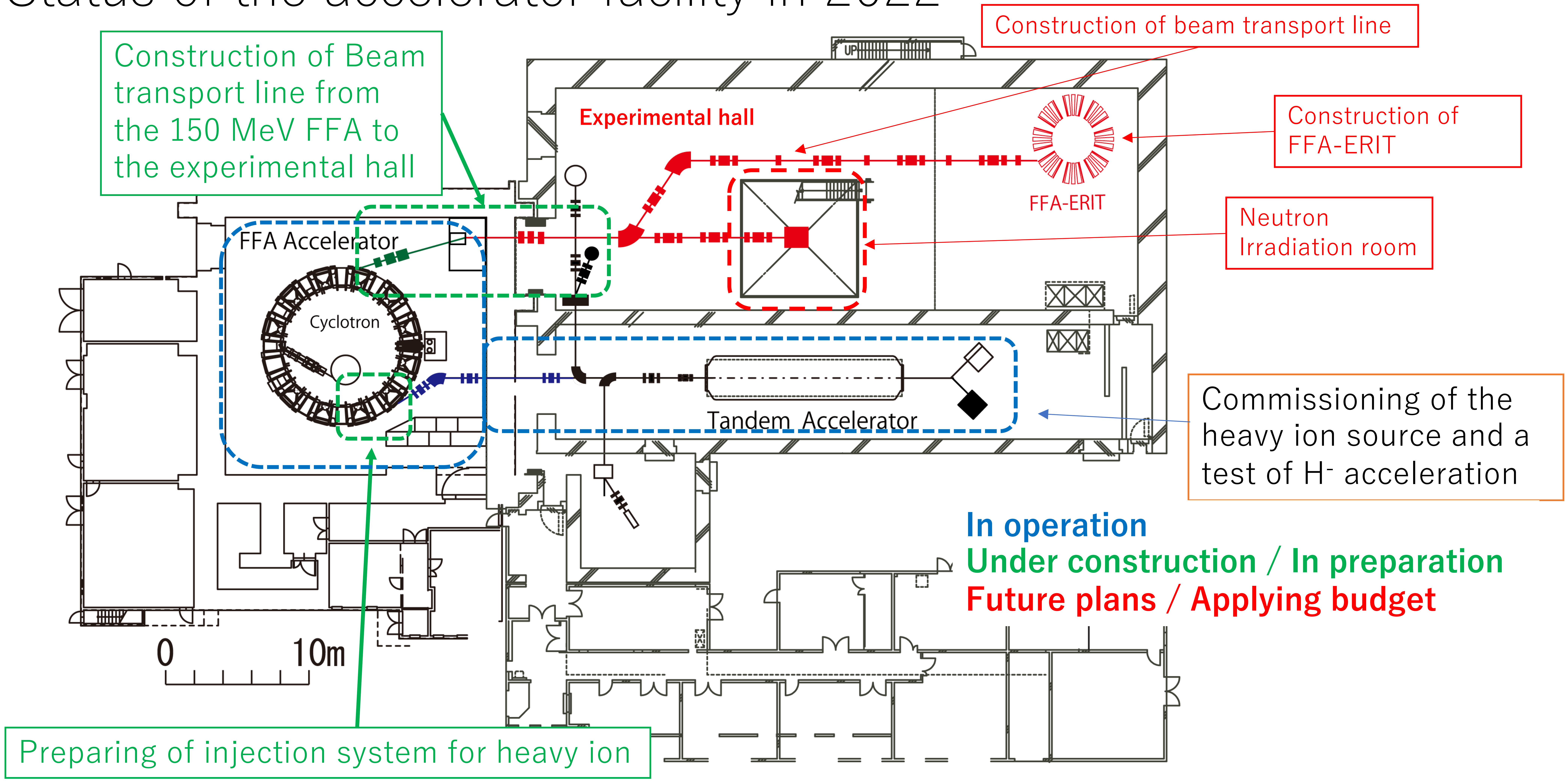
MAIN RING → PiPER（Pion Production ERIT Ring）

→ ERIT_SHE（Super Heavy ERIT）

ERIT has gone

Activity at Kyushu University

Status of the accelerator facility in 2022



In operation
Under construction / In preparation
Future plans / Applying budget

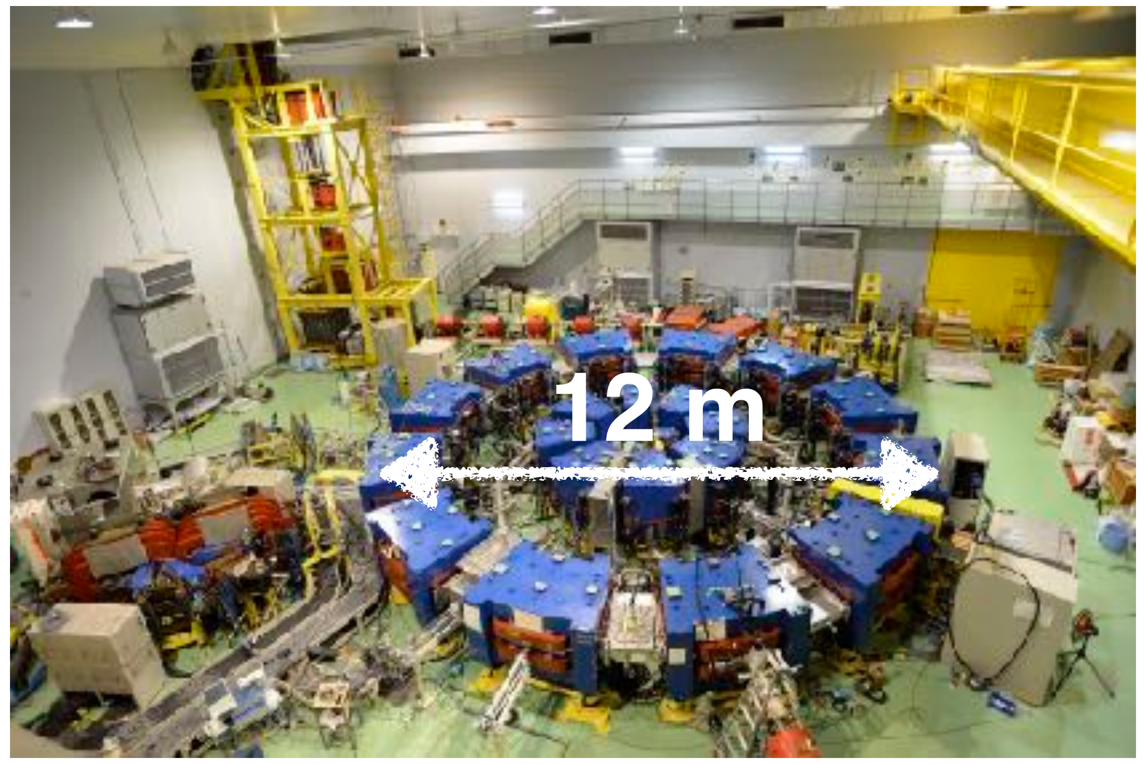
Y. Yonemura

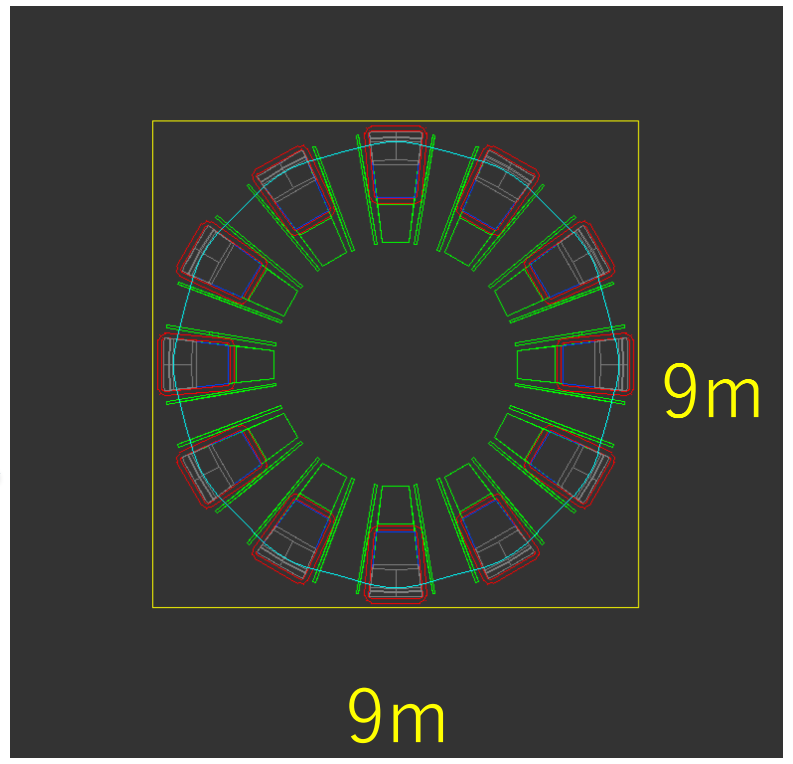
PiPER

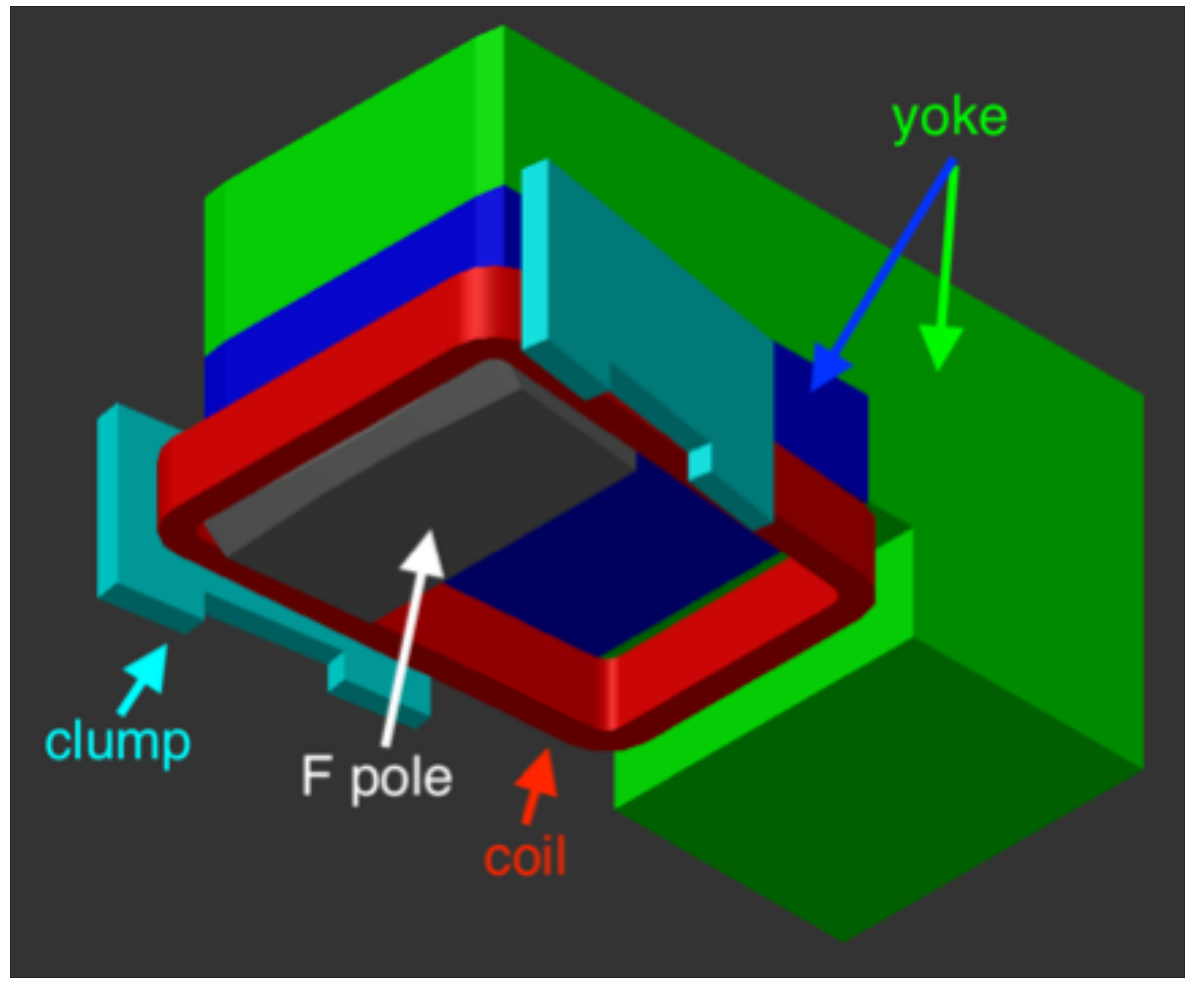
PiPER (Pion Production Erit Ring)

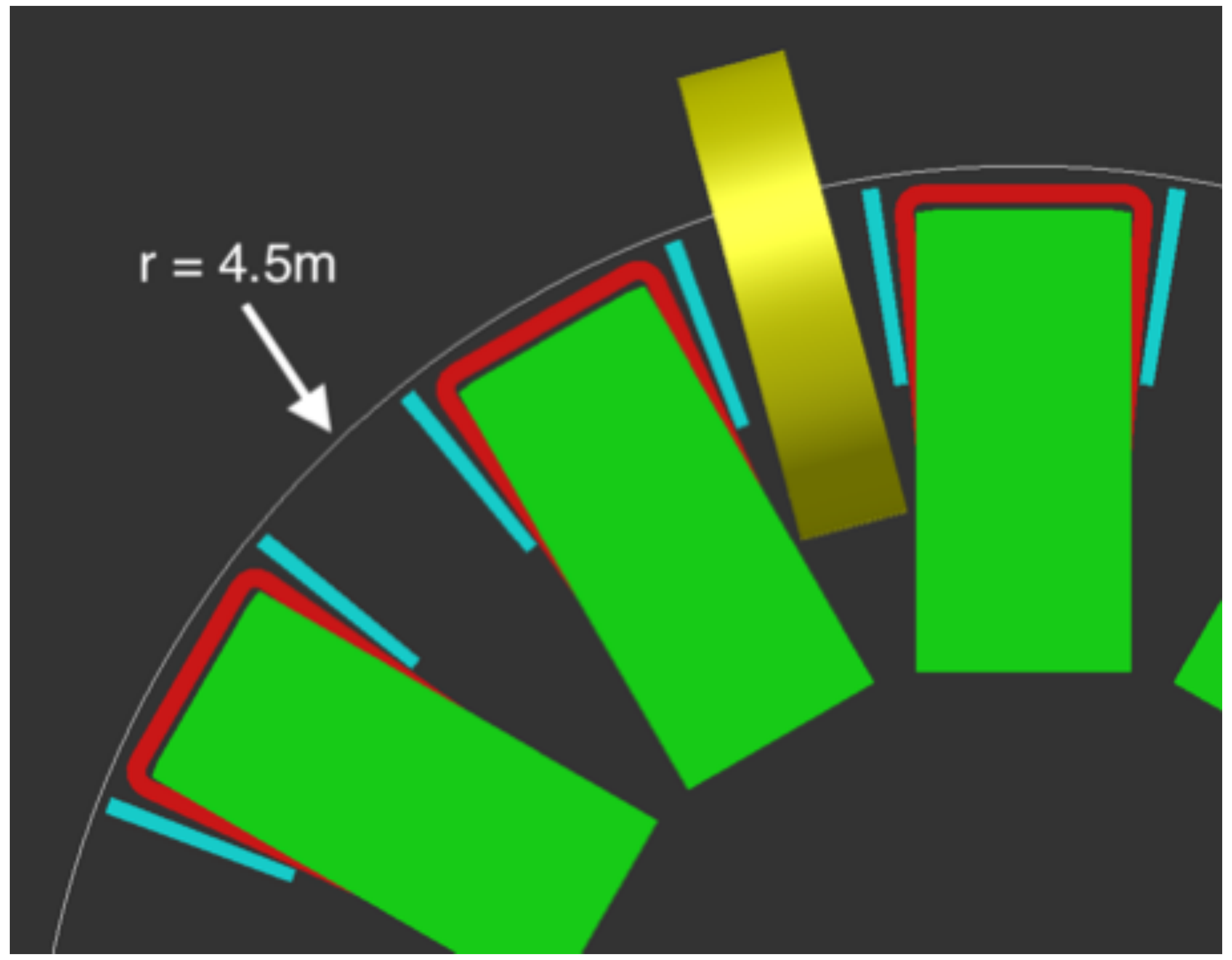
Concept and constraints

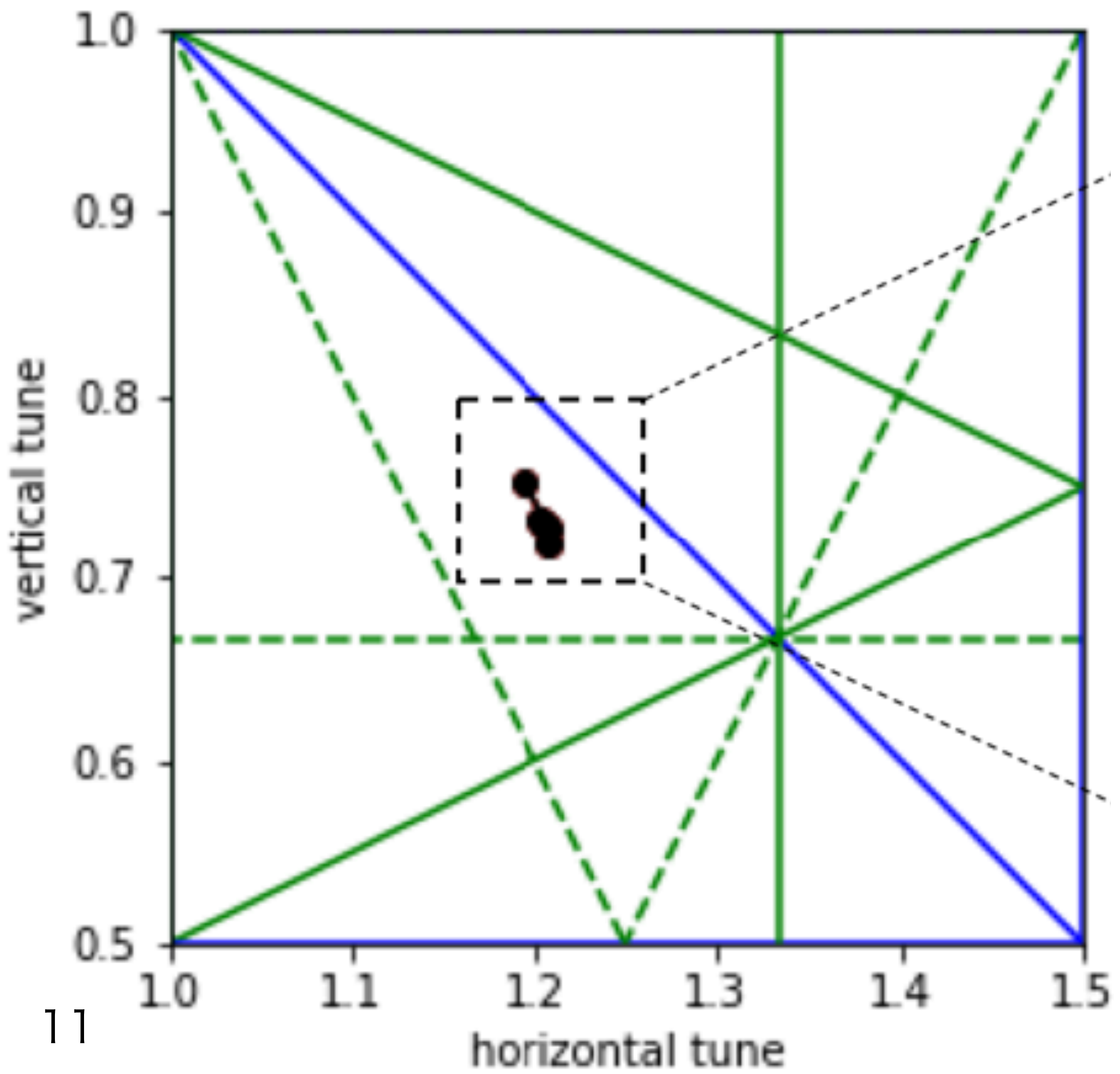
1. Dedicated to pion production
2. Use ERIT scheme i.e. no acceleration
3. Inject 330 MeV proton from AFV cyclotron at RIKEN
4. Fit to the existing building at RIKEN $R_{\mathrm{footprint}} < 5$ m
5. No reverse bending
    1. Use only F magnets
    2. Low k for the horizontal focusing
    3. Edge angle for the vertical focusing
6. Aiming design at small tune variations and small COD

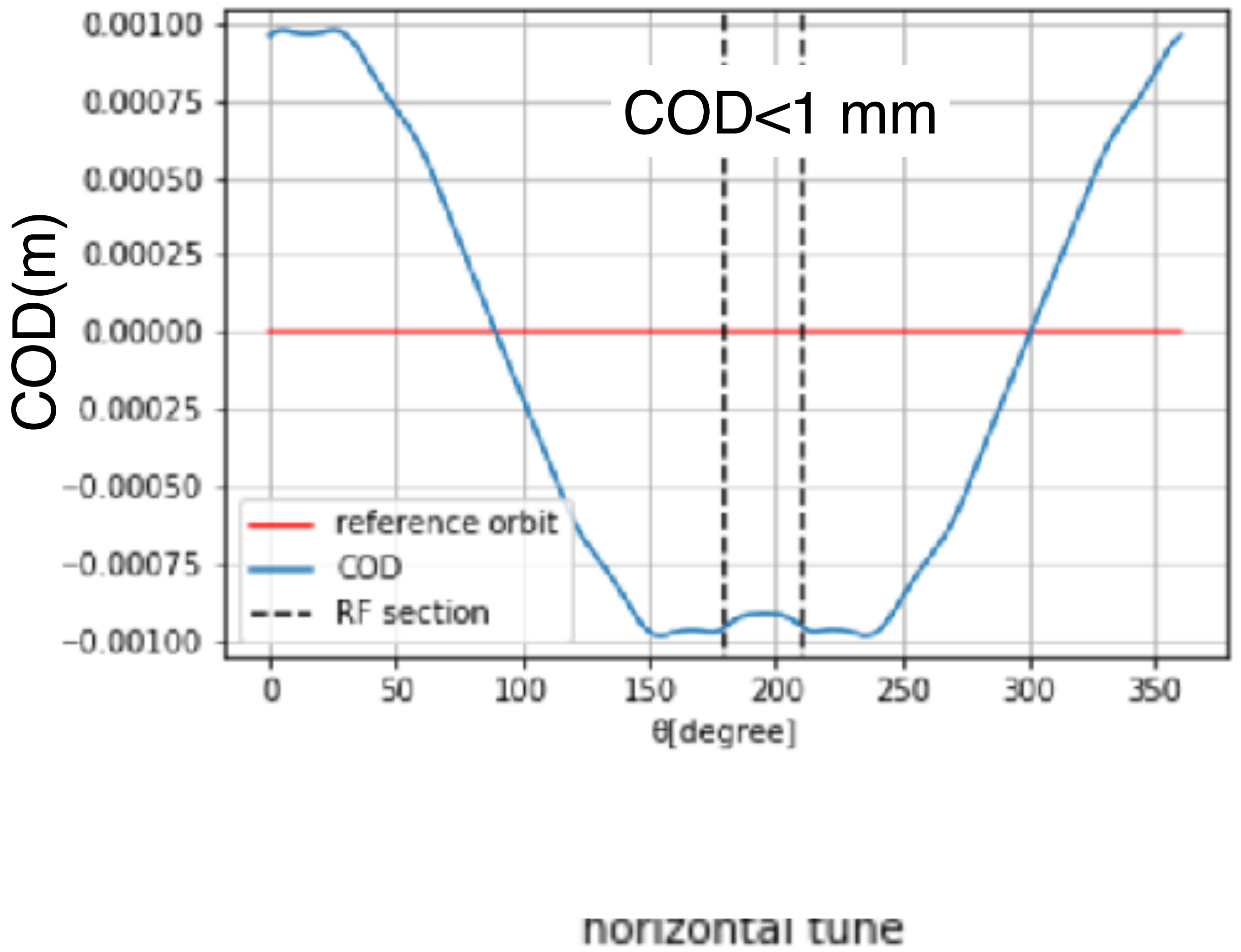












Parameters of the PiPER

beam species	proton
energy	330 MeV full-energy injection
radius of central orbit	4.07 m
tune	(1.21, 0.73)
β@ center of F	(3.5 m, 5.5 m)
minimum gap	142 mm
B field @ central orbit	1.48 T
I_{beam} from injector	1 pA
target thickness	100 μm
survival	100 turn
injected beam size	5 mm
production rate	200 π^-/s (1000 π^+/s)

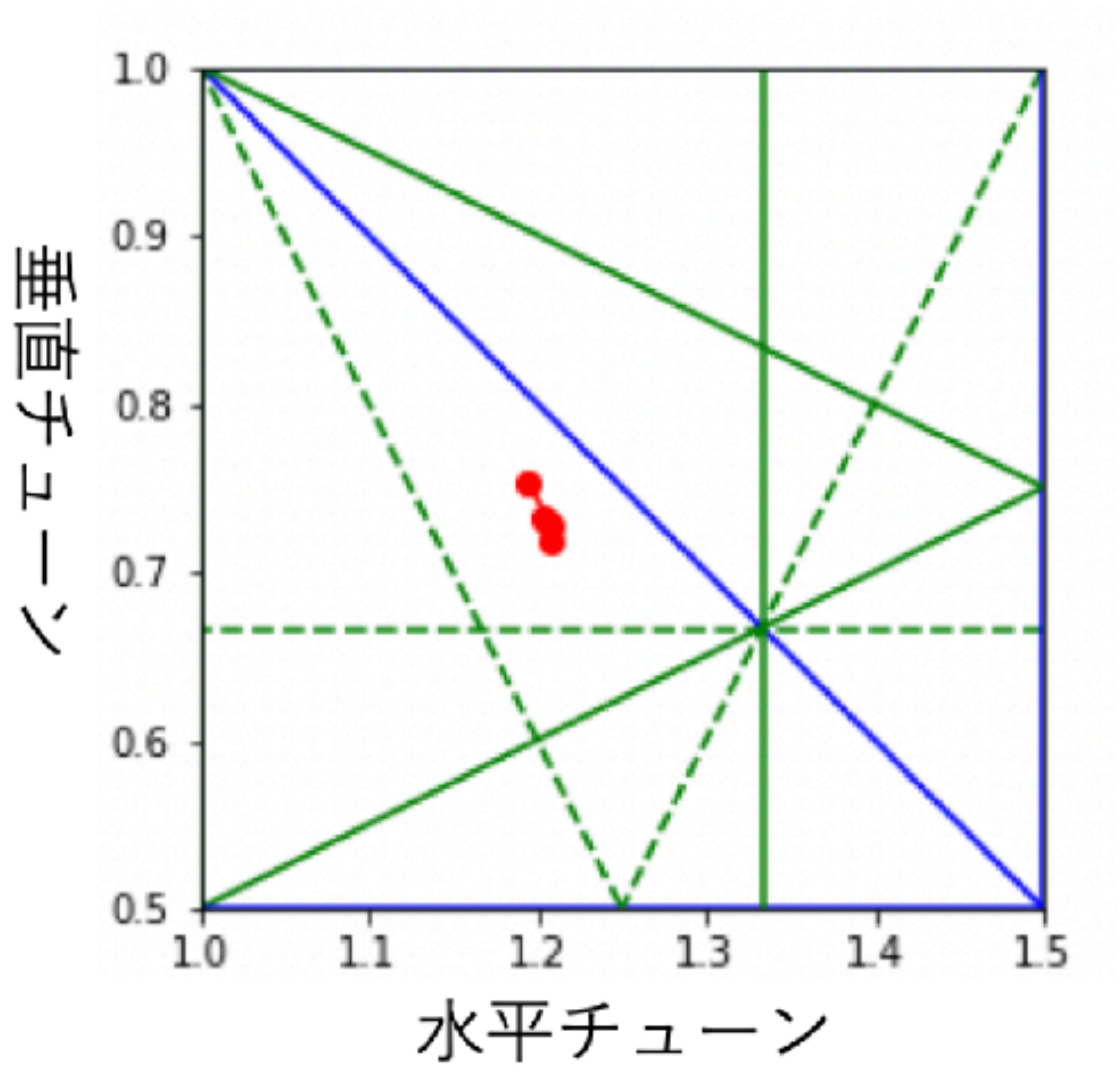
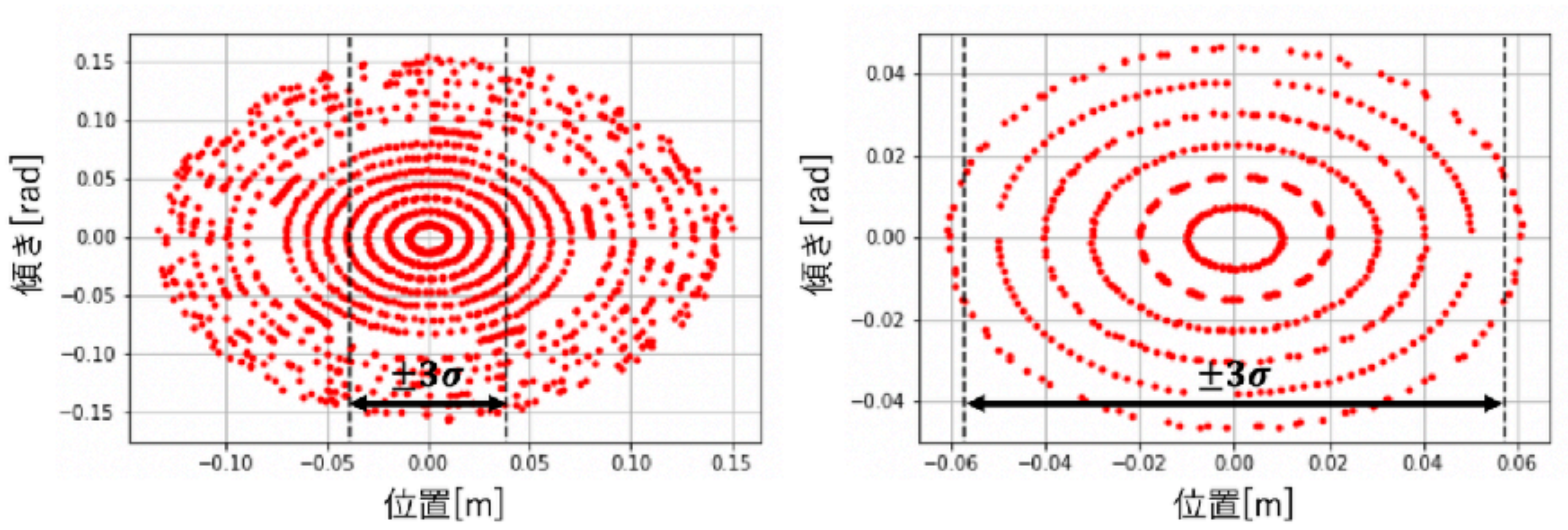


図 3.20　ミュオン生成リングのチューン（330 MeV ± 10 MeV）

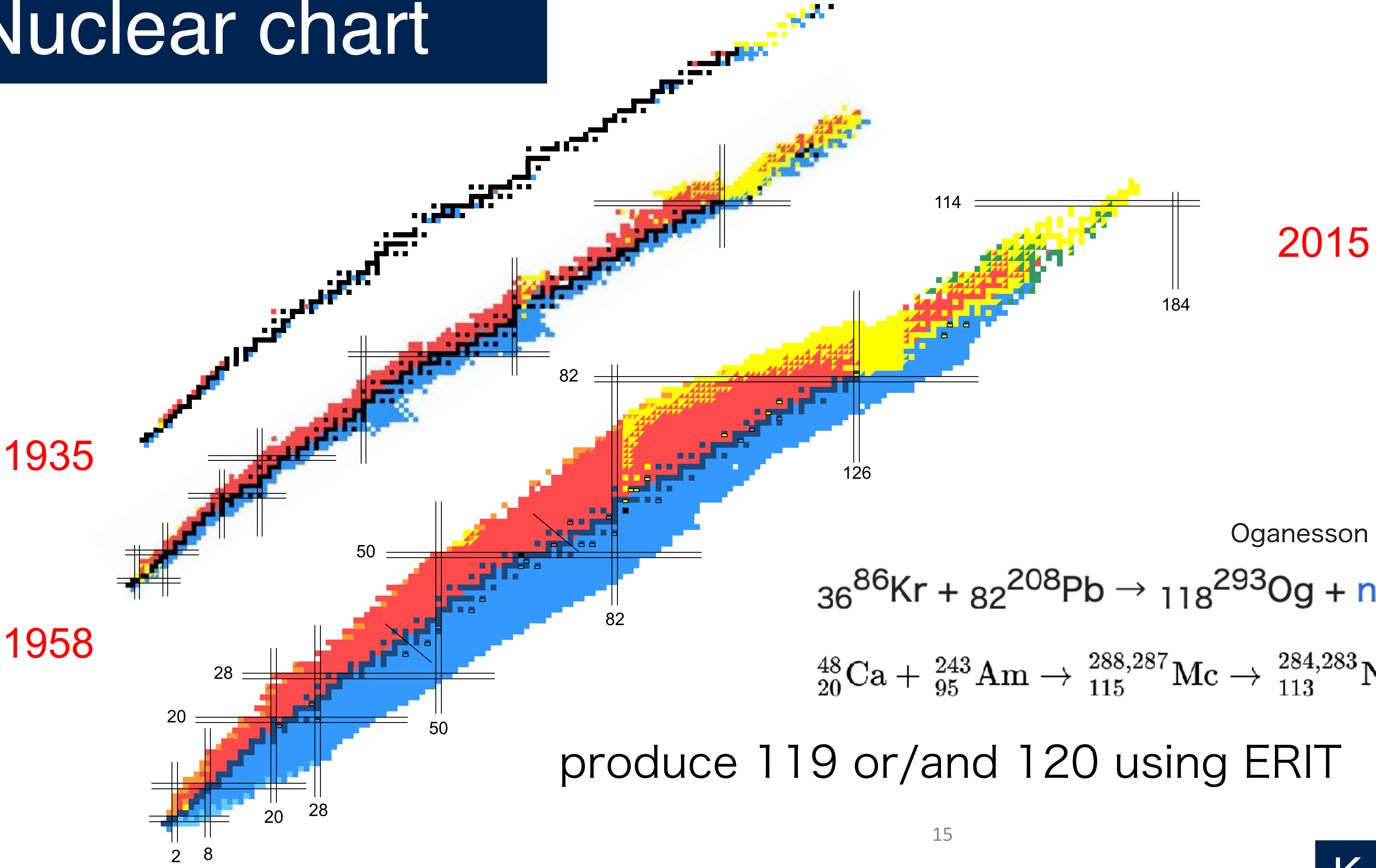


(a) 水平方向　　(b) 垂直方向

図 3.21　ミュオン生成リングのビームアクセプタンス

ERIT_SHE

Nuclear chart



Oganesson

$$ {}_{36}^{86}\mathrm{Kr} + {}_{82}^{208}\mathrm{Pb} \rightarrow {}_{118}^{293}\mathrm{Og} + n $$

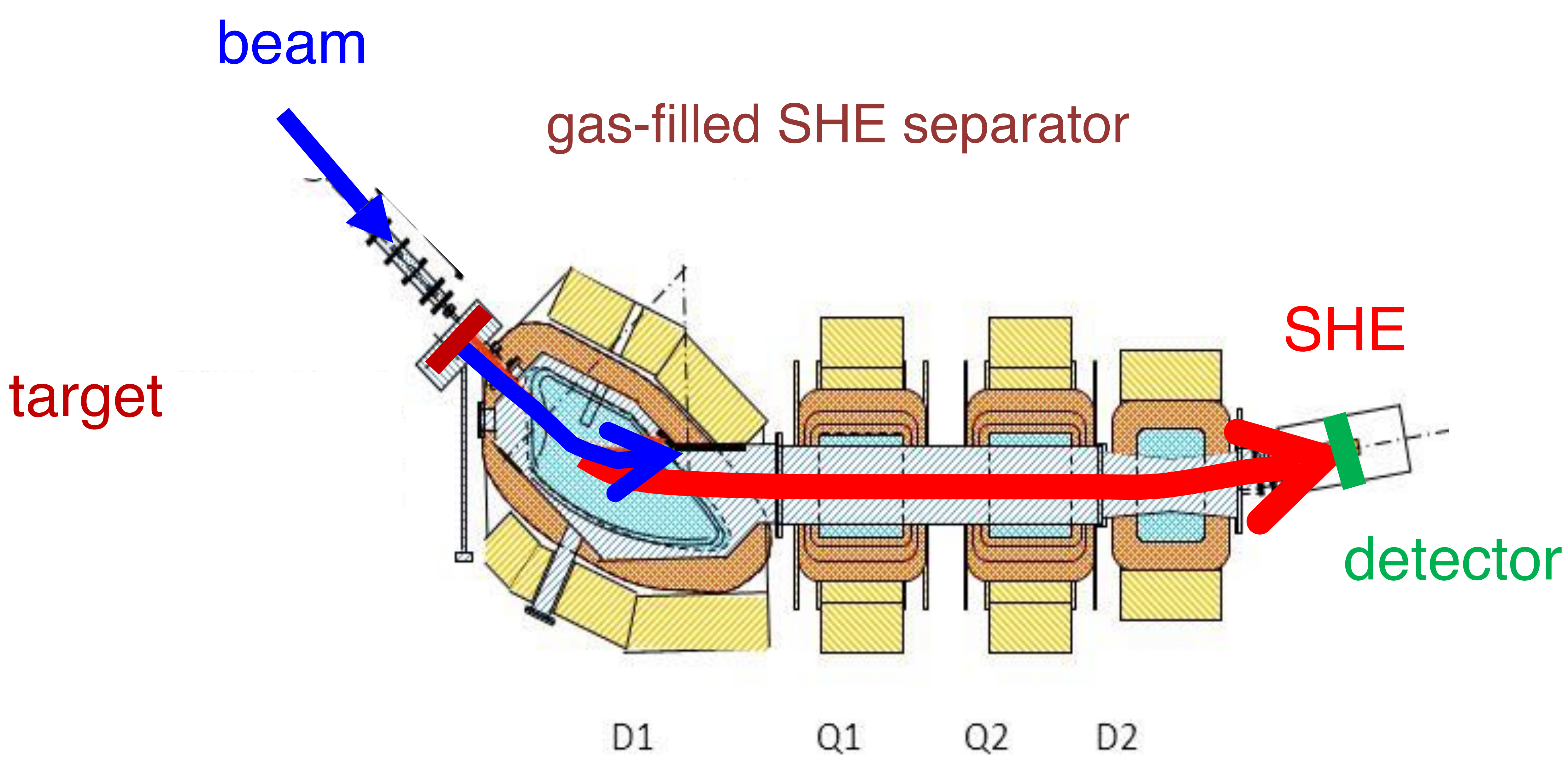
$$ {}_{20}^{48}\mathrm{Ca} + {}_{95}^{243}\mathrm{Am} \rightarrow {}_{115}^{288,287}\mathrm{Mc} \rightarrow {}_{113}^{284,283}\mathrm{Nh} $$

produce 119 or/and 120 using ERIT

K. Nishio

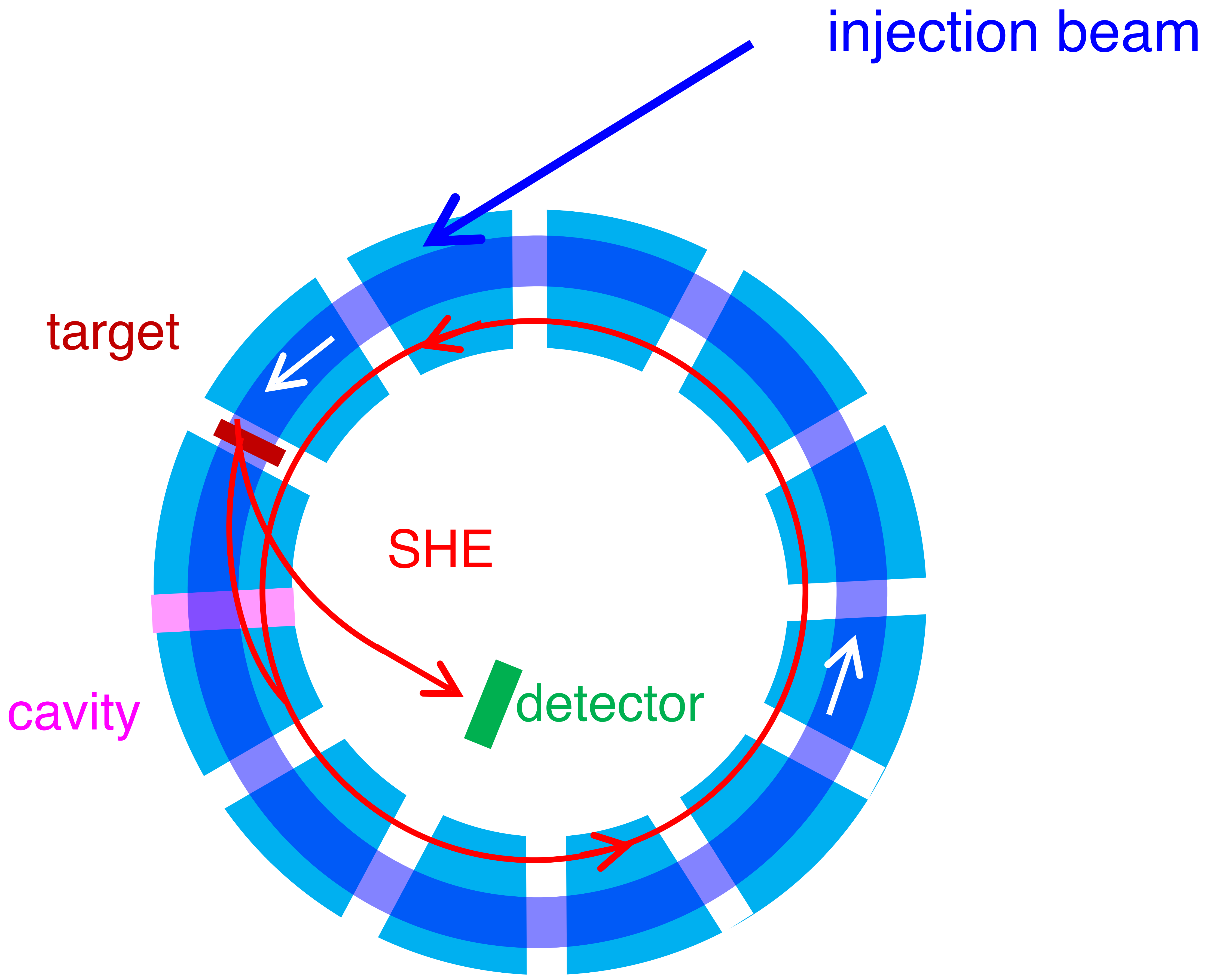
ERIT_SHE

conventional method



SHE: Super Heavy Element

new scheme



K. Nishio

Beam species, target for SHE

test run

$${}^{48}_{20}\mathrm{Ca} + {}^{238}_{92}\mathrm{U} \rightarrow {}^{286}_{112}\mathrm{Cn}$$

real run

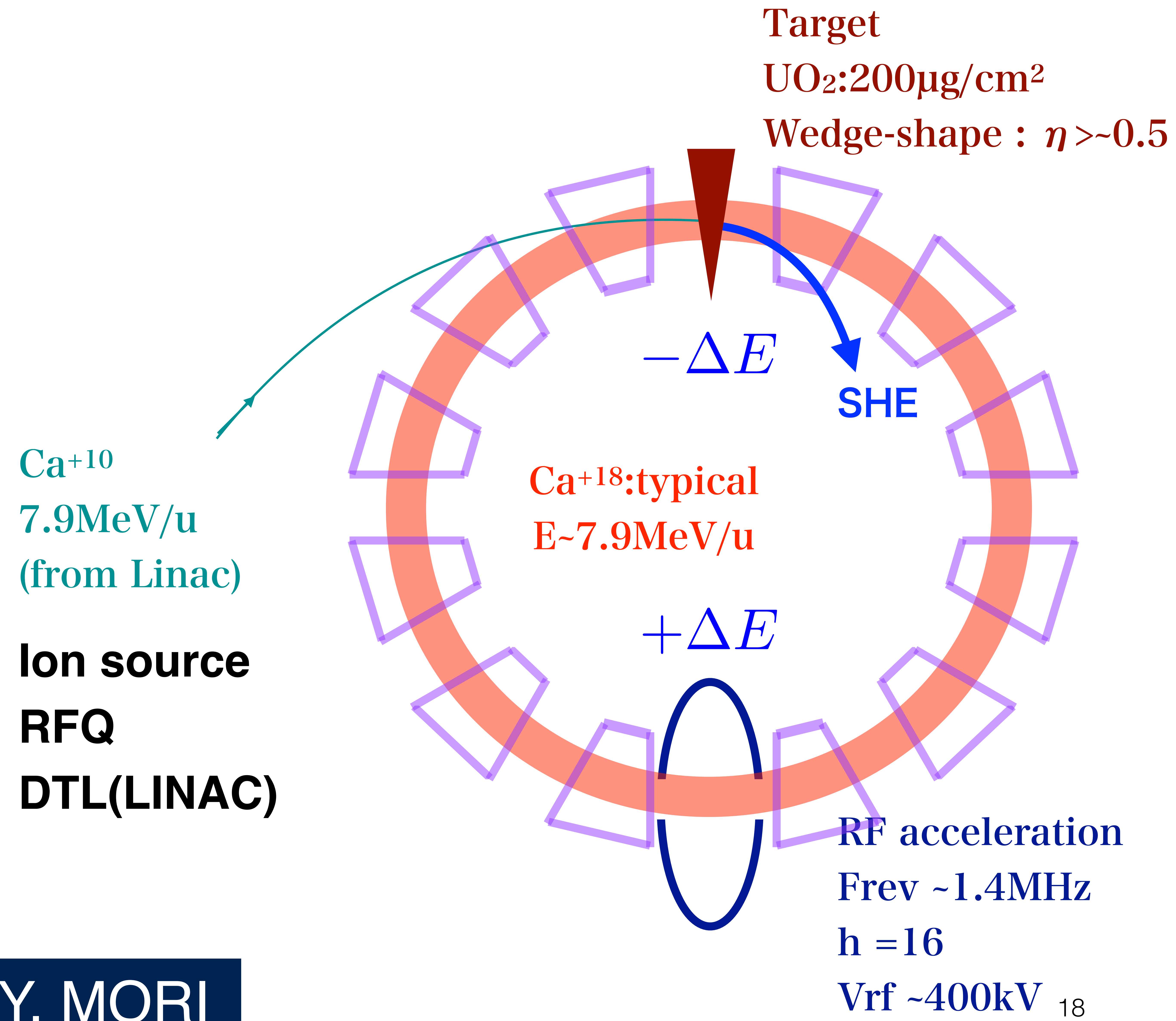
$${}^{51}_{23}\mathrm{V} + {}^{248}_{96}\mathrm{Cm} \rightarrow {}_{119}\mathrm{Xx}$$

$${}^{54}_{24}\mathrm{Cr} + {}^{243}_{95}\mathrm{Am} \rightarrow {}_{119}\mathrm{Xx}$$

$${}^{54}_{24}\mathrm{Cr} + {}^{248}_{96}\mathrm{Cm} \rightarrow {}_{120}\mathrm{Xx}$$

$${}^{55}_{25}\mathrm{Mn} + {}^{243}_{95}\mathrm{Am} \rightarrow {}_{120}\mathrm{Xx}$$

ERIT_SHE scheme



Ion source
RFQ
DTL(LINAC)

Injection current : 1 pμA (6.25E12 pps)

assumption :
- **1000 turn survival**
- **target thickness 200μg/cm2**
- **detection efficiency 10%**

Can detect 1 SHE in every 38 days

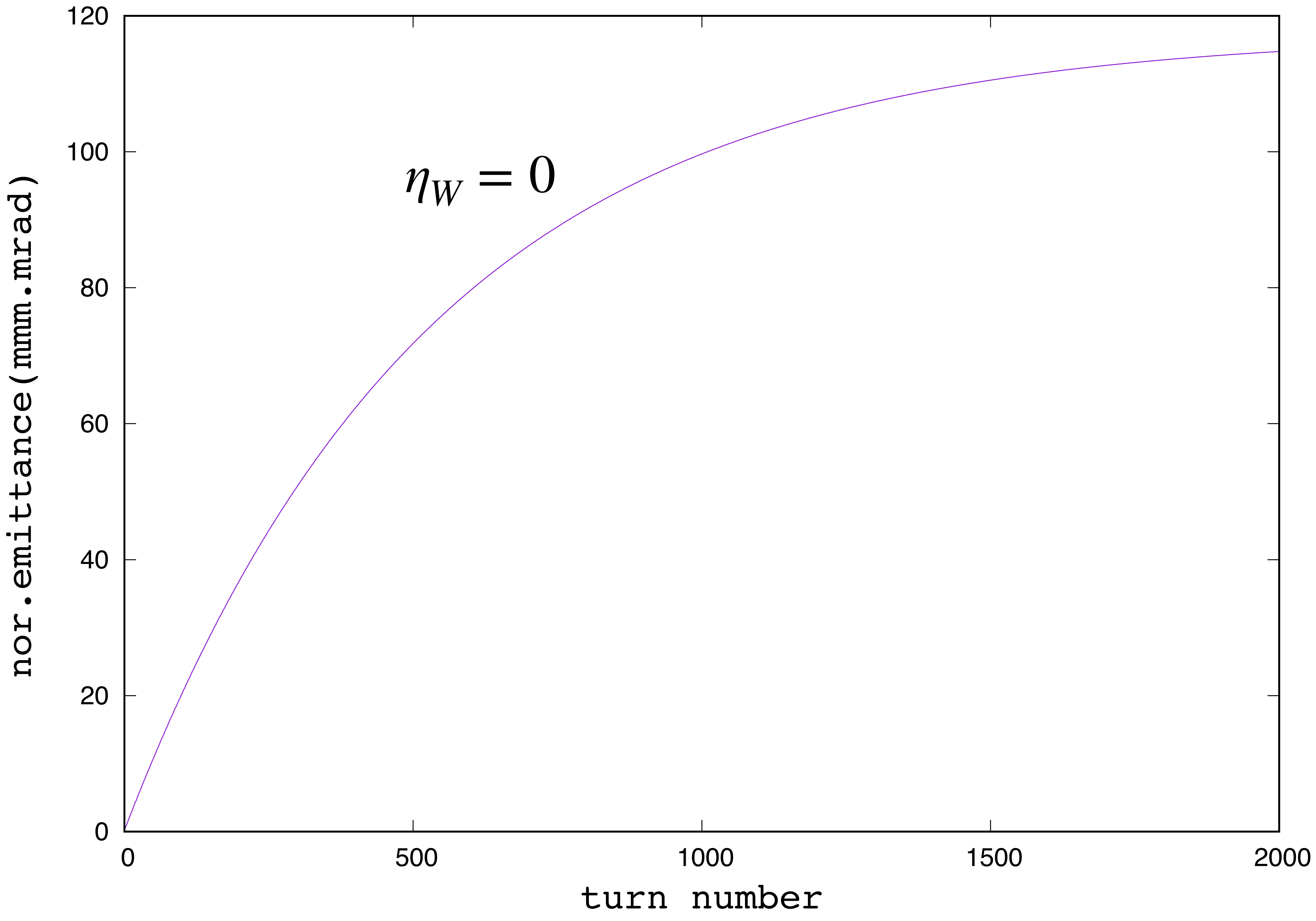
Continuous injection
- **continuous production**
- **continuous extraction**

Y. MORI

Emittance growth

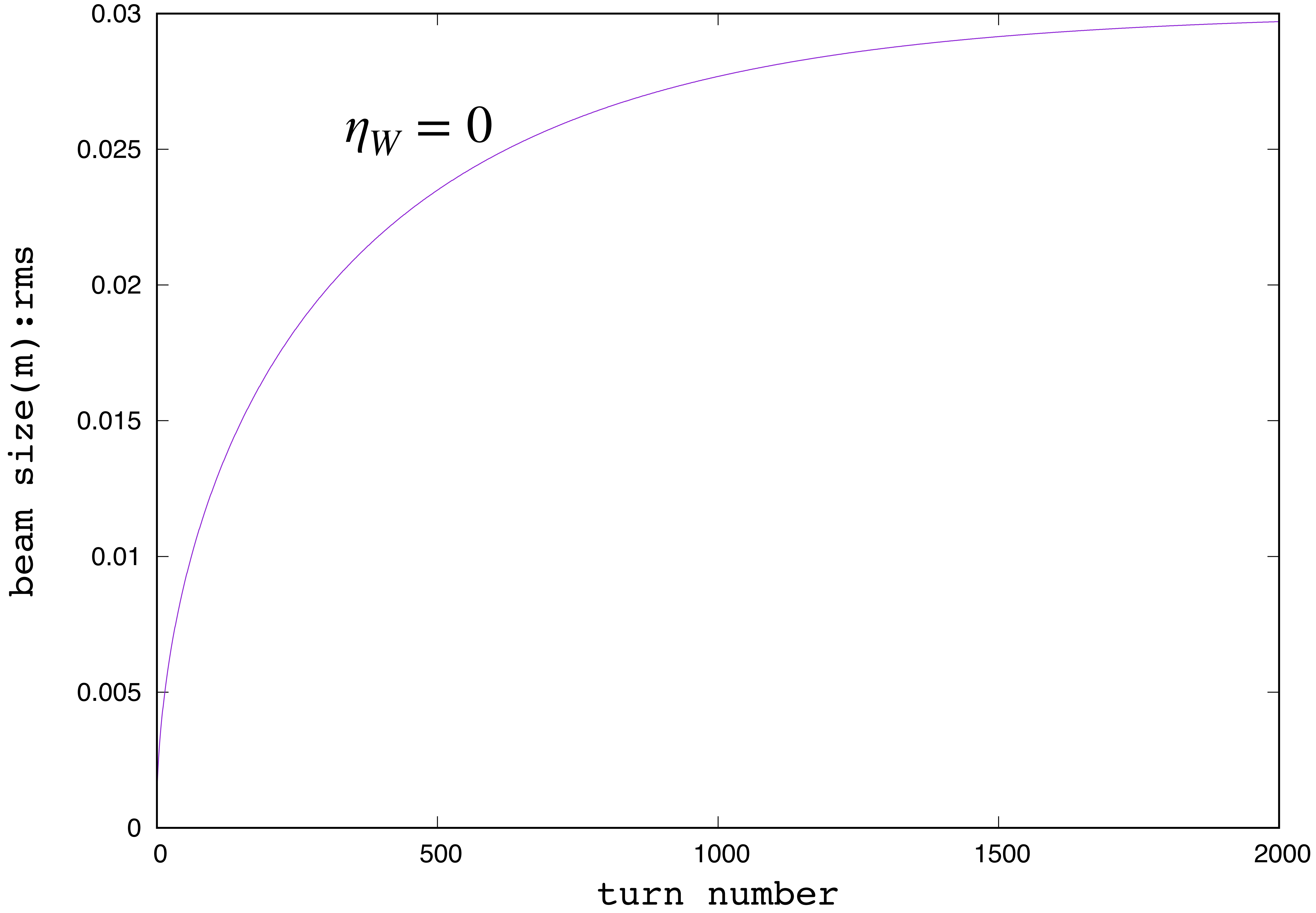
- Beam
  - 48Ca+18 ion, E=7.9MeV/u
- Target
  - 238U92, thickness=200μg/cm2
- ERIT Ring parameter
  - Beta function(transverse)   ; 1m
- ERIT works as “beam emittance cooling ring” with ionization cooling.

Transverse Emittance



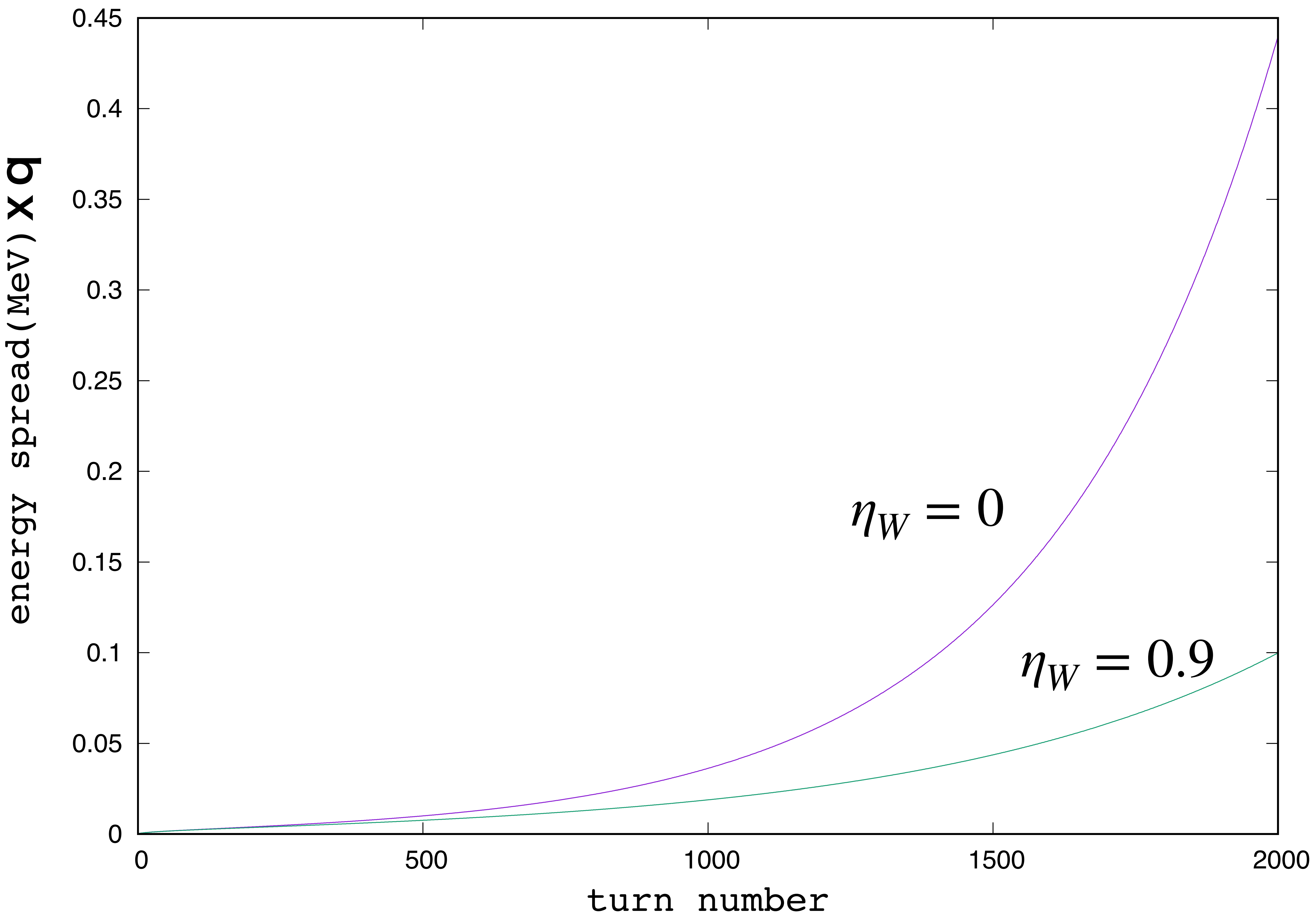
$$\eta_w = D\frac{\partial_R \rho}{\rho}$$

Transverse Beam Size



Y. MORI

Longitudinal Energy Spread



Y. MORI

Bucket height and RF voltage

$$E_{1/2} = \left[\frac{qeV}{h}\right]^{1/2} Y\beta \left[\frac{E}{\pi|\eta|}\right]^{1/2}$$

$$cf.$$

$$^{40}Ca^{+18}, KE = 7.9MeV/u, E = 40 \times (938 + 7.9)MeV$$

$$\eta = 0.5(k = 1), Y = 1.4$$

$$If, V = 400kV, h = 16 \rightarrow E_{1/2} = 30.6MeV$$

Summary of ERIT simulation

- Transverse emittance tends to constant value after 2000 turns due to the ionization beam cooling. →$\varepsilon_{N=}$115 mm.mrad
- As the beam cooling does not affect in longitudinal direction, energy spread increases. After 1000 turns→$\langle\sigma_E\rangle$~50*q keV
- Using wedge target, transverse-longitudinal coupling suppress the energy spread increase. η=0.9→ ε_N~350[mm.mrad], $\langle\sigma_E\rangle$~20*qkeV
  - Capable in terms of the ring acceptance.
- Cavity voltage
  - Assuming the target thickness is 200μg/cm^2, Energy loss ~ 36 MeV/turn (h=16).
  - cf. R.T. rf cavity（~10MHz）Vrf ~400kV（in ERIT case）

Y. MORI

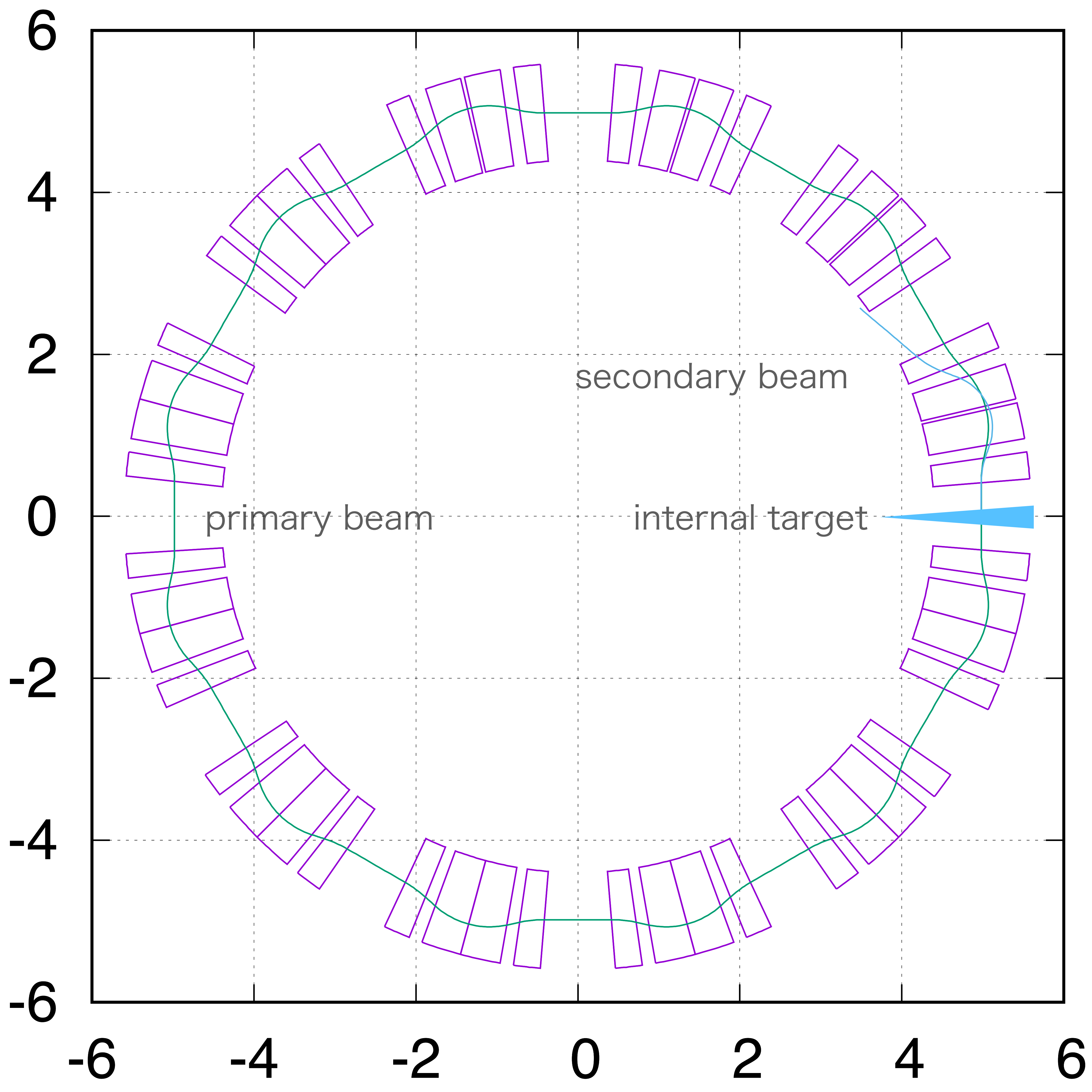
$^{48}Ca + ^{238}U = {}^{286}_{112}Cn$

```
Ca-48  Beam
A_meam (u)   =  48.0
Z_beam       =  20.0
E_beam (MeV) = 275.0
Av.  Charge  =  18.6
==========================================
Q(+)  Br(Tm)  Er(MV)  :
==========================================
15.0   1.1045  36.6667 |
16.0   1.0354  34.3750 |
17.0   0.9745  32.3529 |**********
18.0   0.9204  30.5556 |**************************************
19.0   0.8719  28.9474 |********************************************
20.0   0.8283  27.5000 |****************
21.0   0.7889  26.1905 |
22.0   0.7530  25.0000 |


 Acomp      (u)  =   286.00000
 Erec     (MeV)  =    40.30000
 Vcomp  (cm/ns)=      0.52141
 Aset       (u)  =   283.00000
 Zset            =   112.00000
 ======================================================================
 Q(+)   Br(Tm)   Er(MV)
 ======================================================================
 Energy(MeV)=39.877
 ----------------------------------------------------------------------
 Average Charge  =  21.00 , Standard Deviation=   2.33
 15.0  0.8551  5.3170 |
 16.0  0.8016  4.9847 |*
 17.0  0.7545  4.6914 |***
 18.0  0.7126  4.4308 |********
 19.0  0.6751  4.1976 |************
 20.0  0.6413  3.9877 |*****************
 21.0  0.6108  3.7978 |*******************
 22.0  0.5830  3.6252 |*****************
 23.0  0.5577  3.4676 |************
 24.0  0.5344  3.3231 |********
 25.0  0.5130  3.1902 |***
 26.0  0.4933  3.0675 |*
 27.0  0.4750  2.9539 |
 Sum of the Yield below Br=0.6500 ----->      0.73938
```

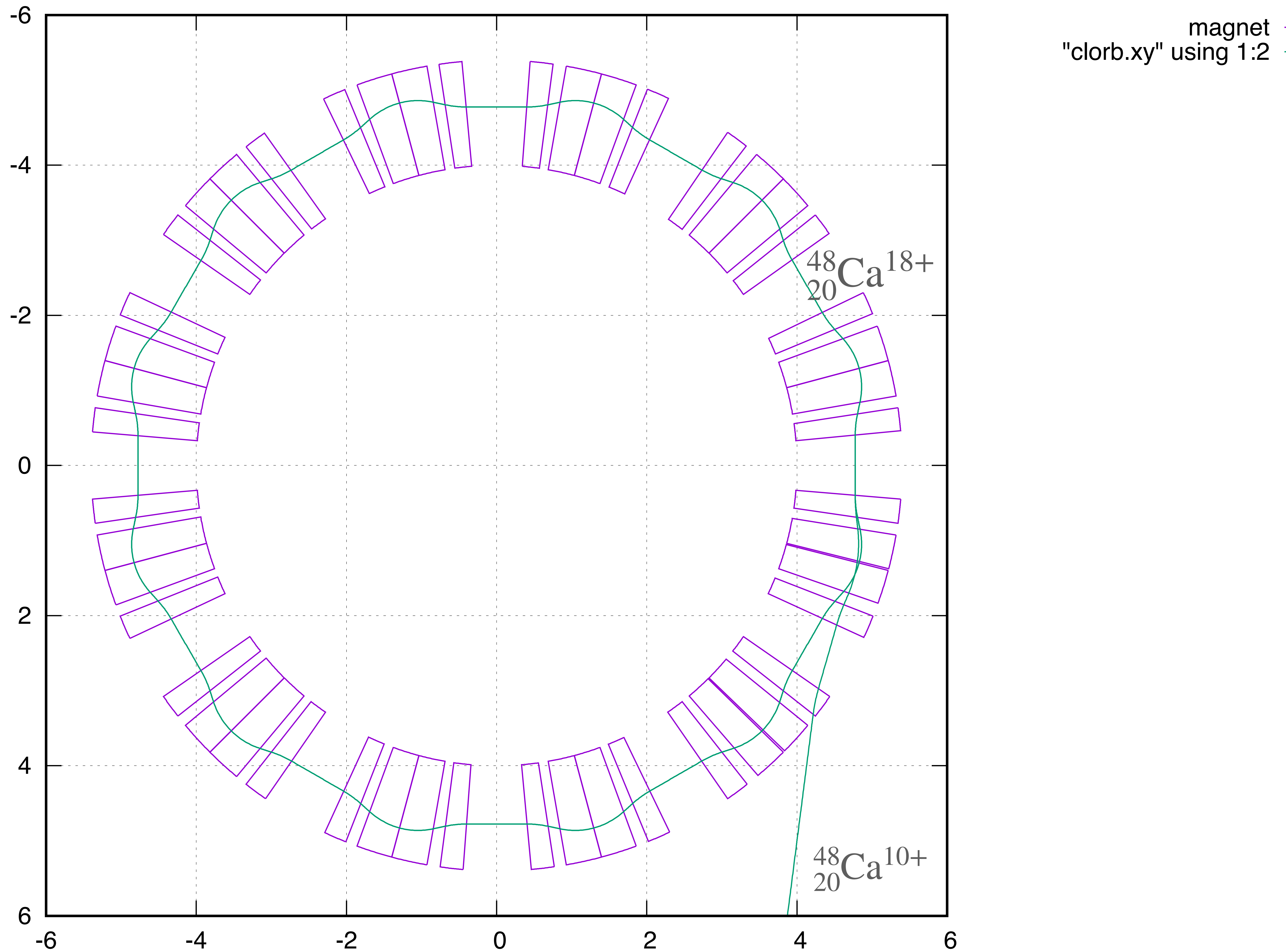
Main Ring

Main Ring から外れる



injection orbit

$$^{48}_{20}\mathrm{Ca}^{10+} \rightarrow \; ^{48}_{20}\mathrm{Ca}^{18+}$$

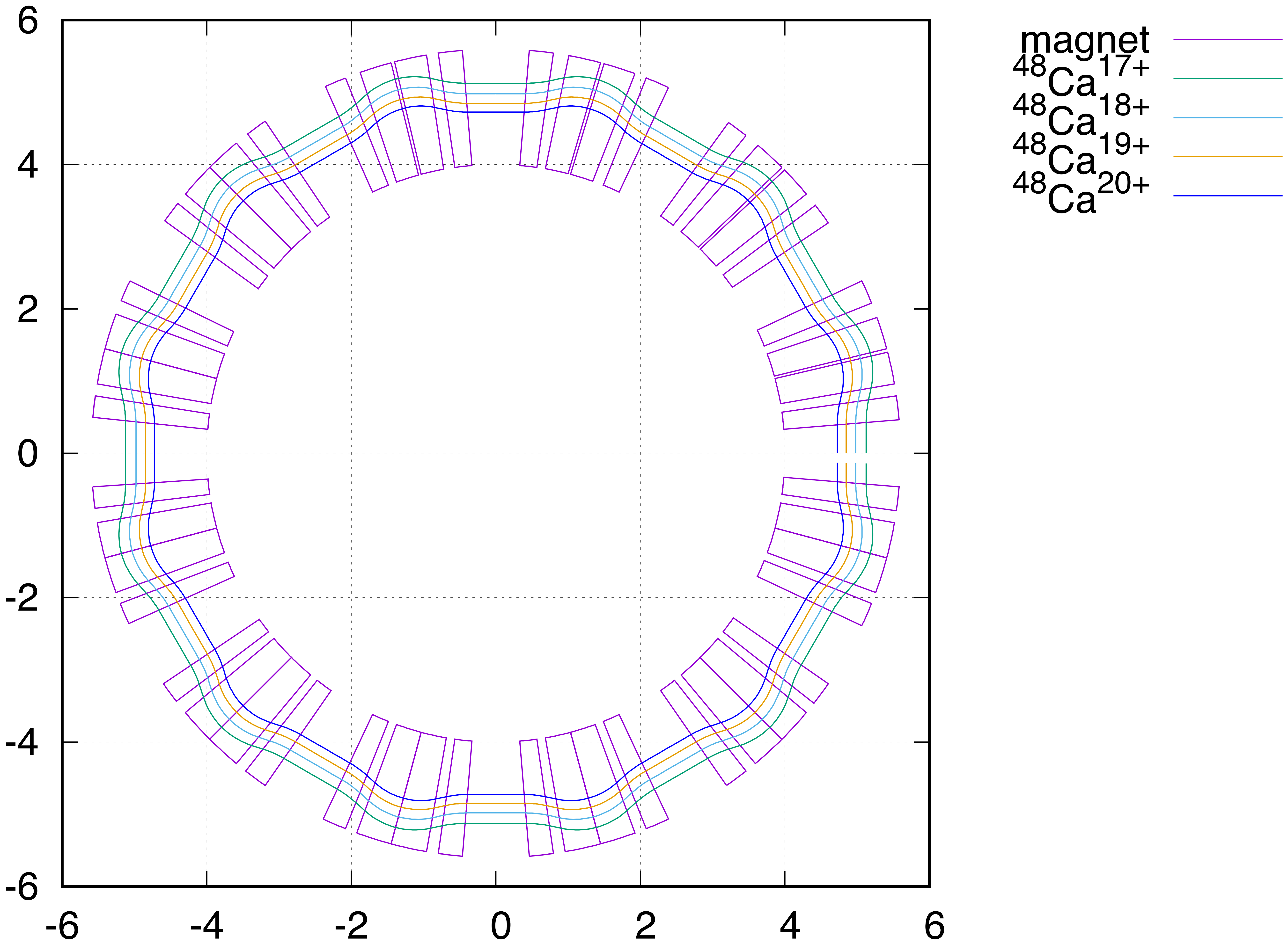


closed orbit of different charge state

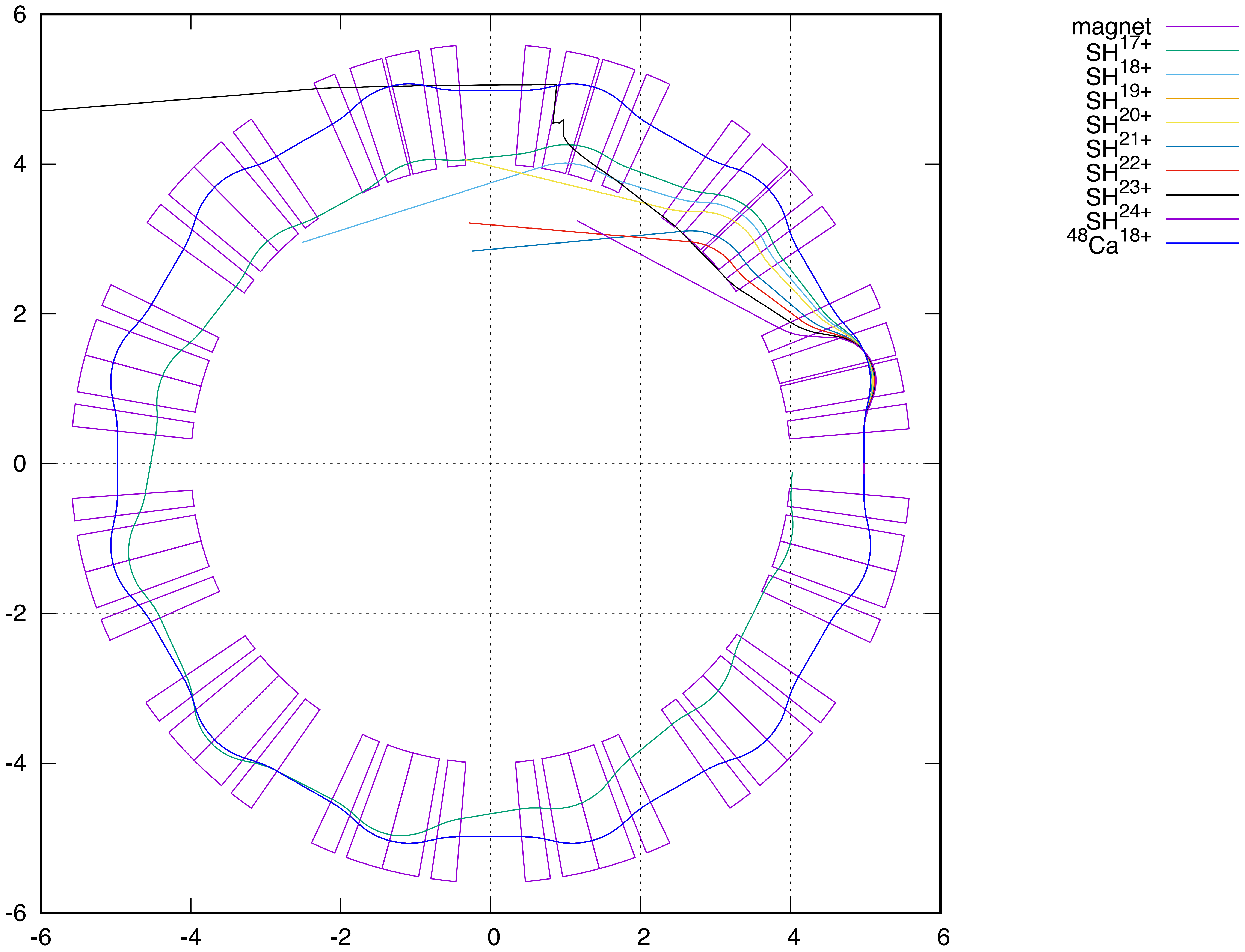
- Scaling FFA

$$\frac{r}{r_0} = \left(\frac{q_0}{q}\right)^{1/k}$$

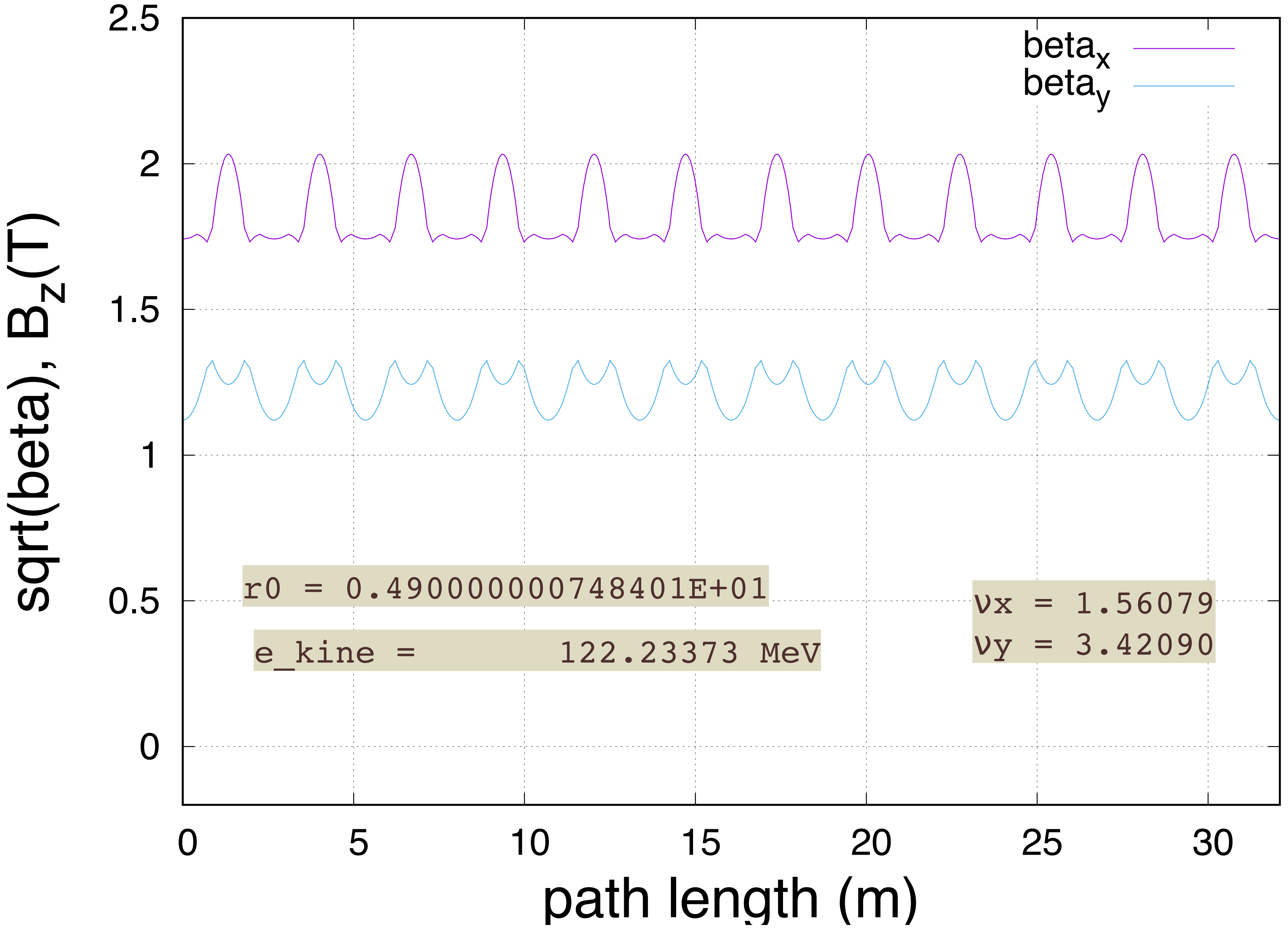
- cf. k=1
  - q_0=+18, q=+19
  - → r/r_0=0.95 r_0=4m →3.8m

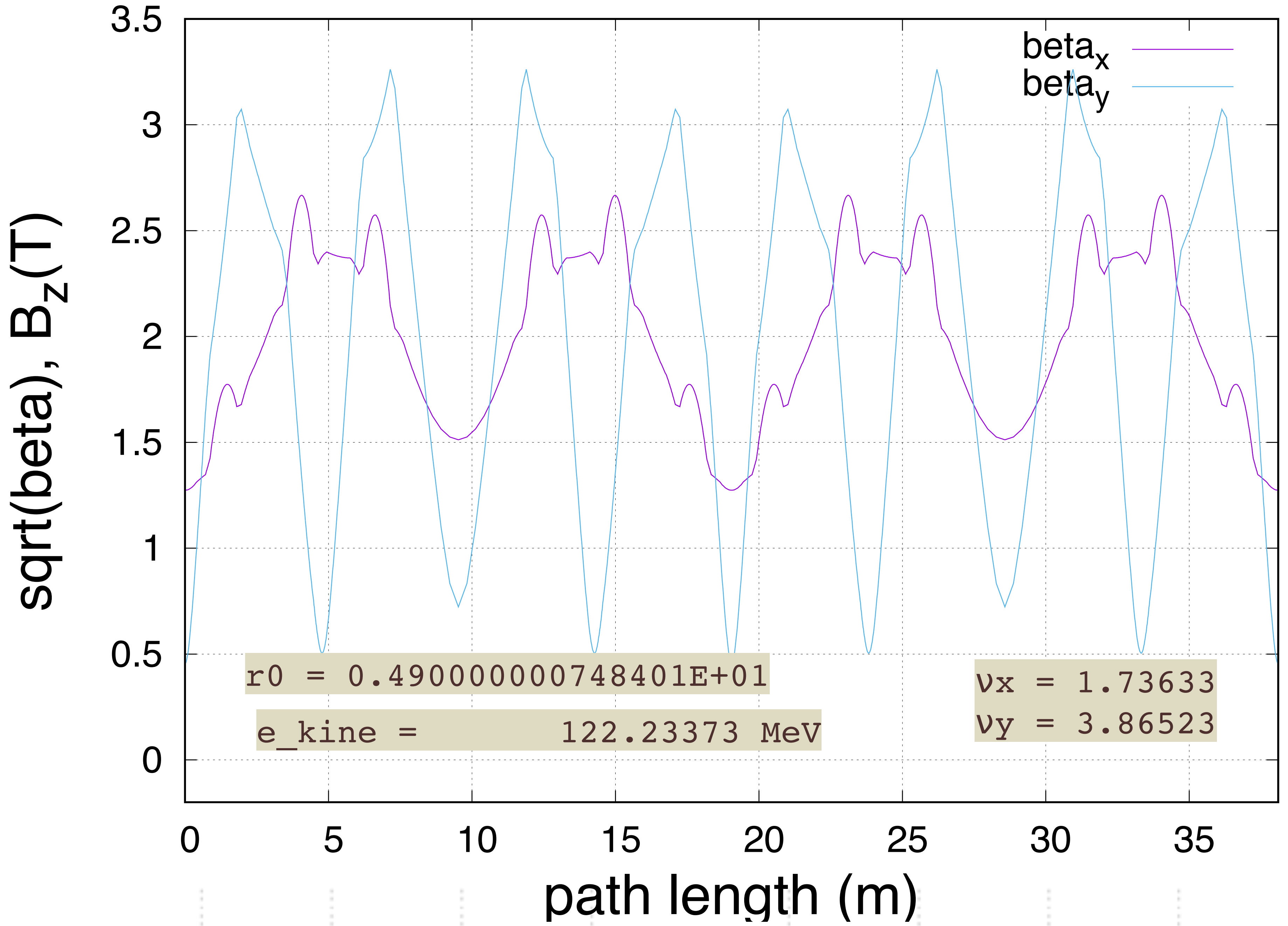


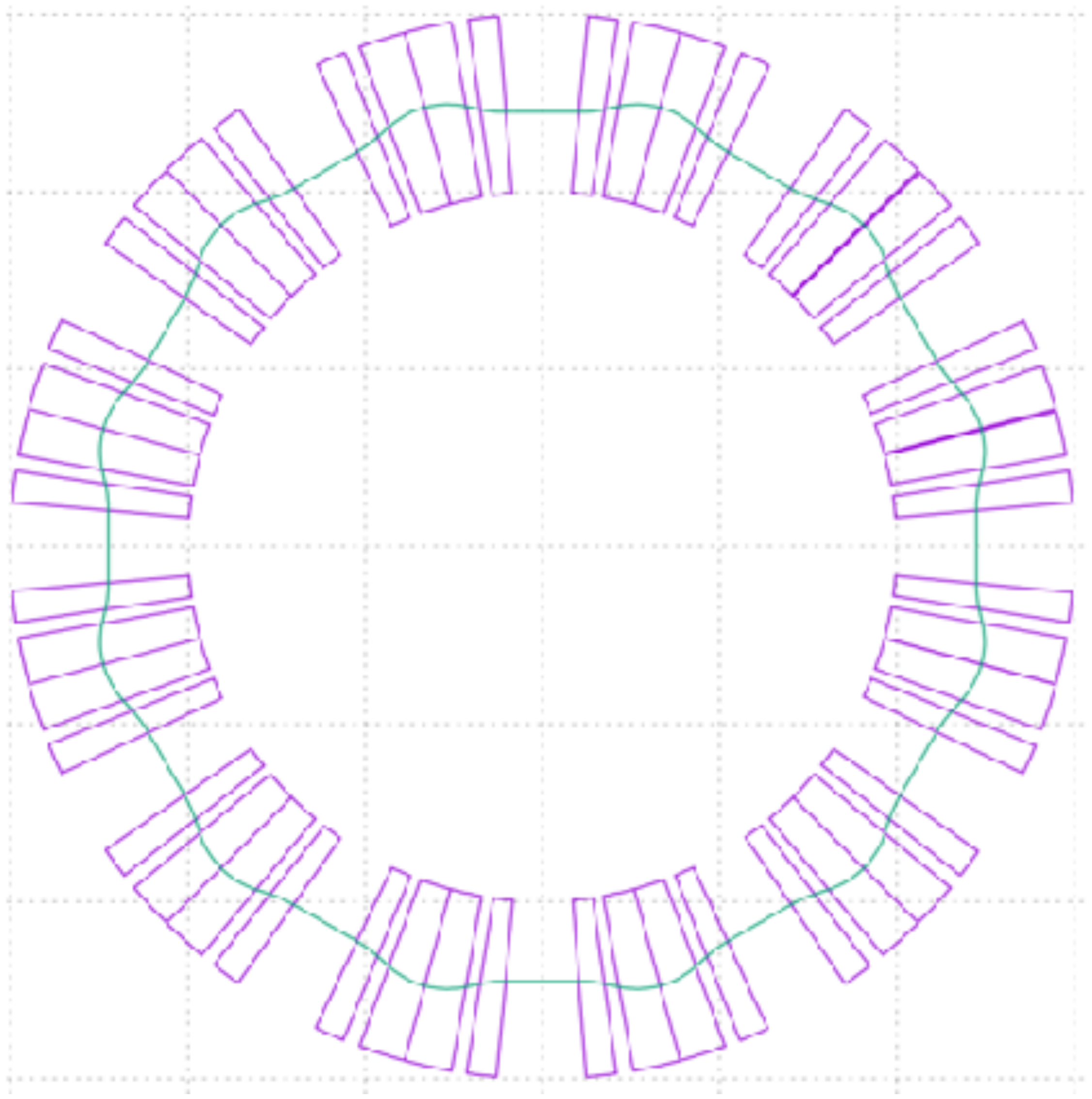
extraction orbit of different charge state

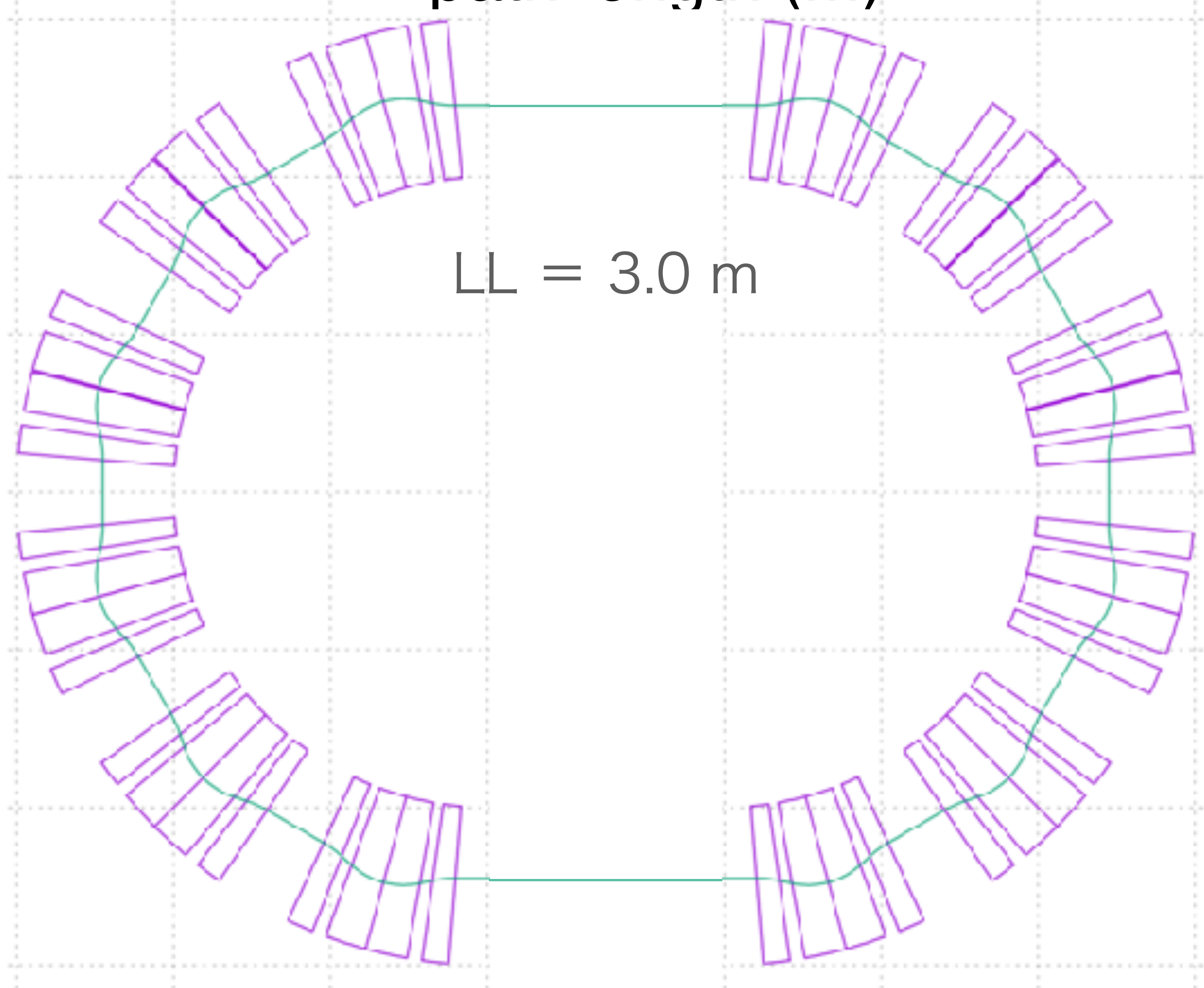


long drift

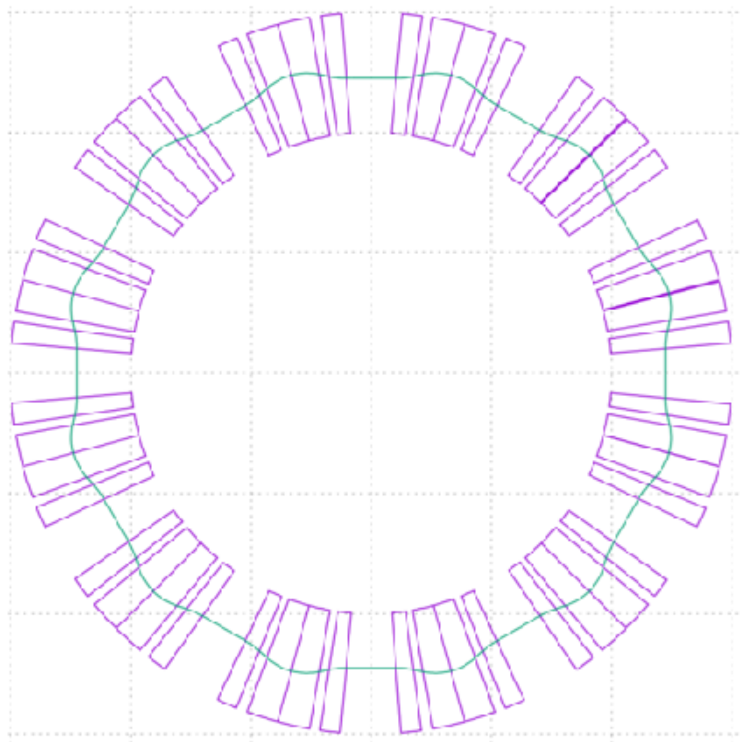

beta$_x$
beta$_y$
sqrt(beta), B_z(T)
path length (m)
r0 = 0.490000000748401E+01
e_kine = 122.23373 MeV
νx = 1.56079
νy = 3.42090

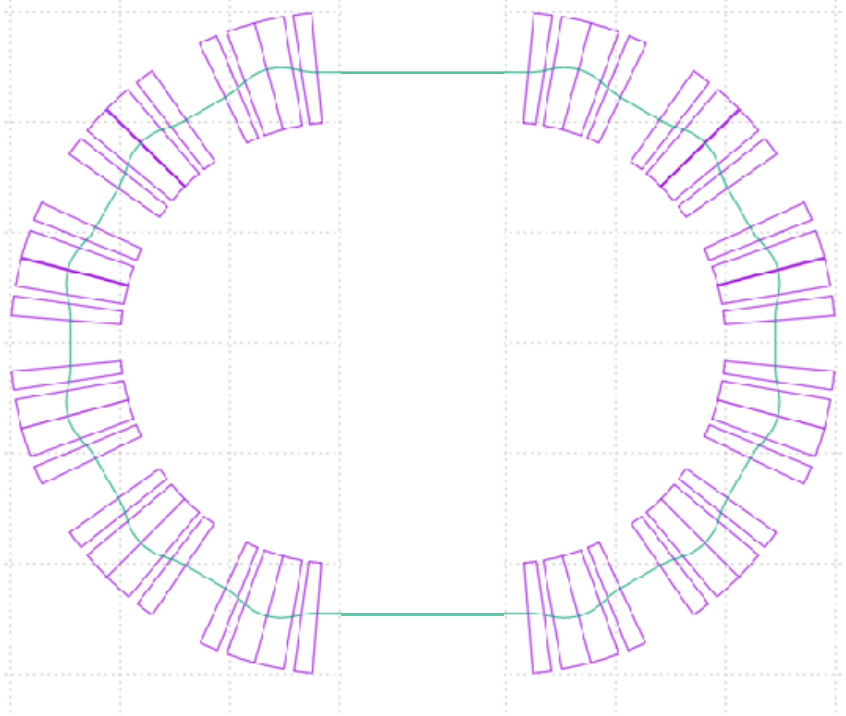

beta$_x$
beta$_y$
sqrt(beta), B_z(T)
path length (m)
r0 = 0.490000000748401E+01
e_kine = 122.23373 MeV
νx = 1.73633
νy = 3.86523




LL = 3.0 m

long drift





	w/o long drift				w/ long drift		
z/A	18/48	19/48	20/48		18/48	19/48	20/48
ν_x	1.561	1.561	1.561		1.731	1.736	1.749
$\Delta\nu_x$	0	0	0		-0.005	0	0.013
ν_y	3.421	3.421	3.421		3.842	3.865	3.890
$\Delta\nu_v$	0	0	0		-0.023	0	0.025
R_0 (m)	5.035	4.900	4.776		5.035	4.900	4.776
C (m)	32.985	32.099	31.287		38.253	38.099	37.287
$\Delta C/C$	2.76%	0	-2.53%		2.33%	0	-2.13%

schedule

2023
2024
2025
2026
2027
2028
designing / engineering
production
installation
commissioning

Summary

1. It has been 12 years since the main ring started operation.
2. Proton beams from the main ring will be available until March 2023.
3. The utilization plan of the entire facility and the future reuse of the FFAs are under consideration.
4. One of the option of remodeling the main ring for pion production i.e. PiPER ring has been designed.
5. The other option for producing the super heavy element is under consideration.