Conceptual Design of FFA for Super Heavy Element Production using ERIT

2023.9.14 y.ishi KURNS

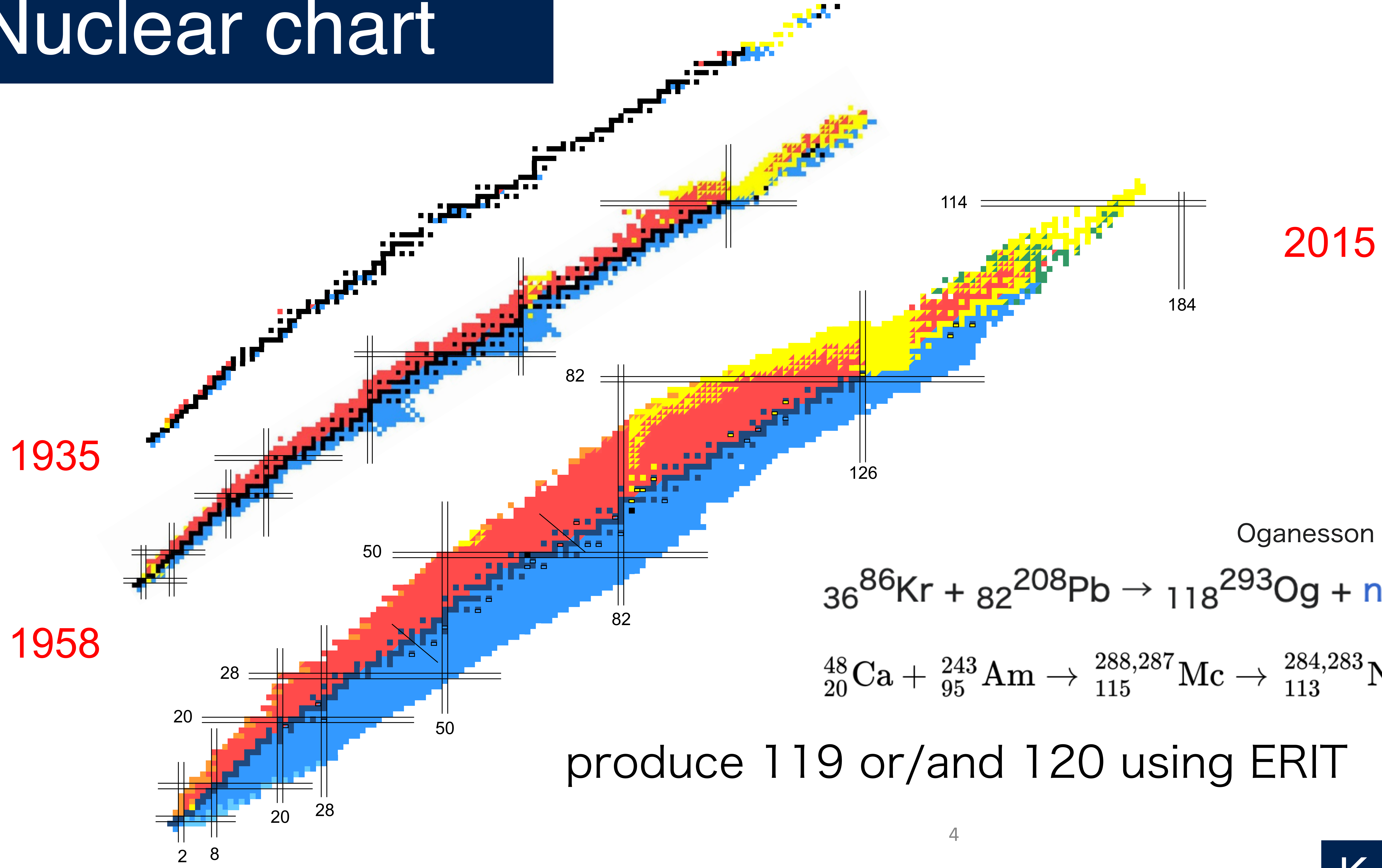
Outline

1. Introduction
2. Super heavy element
3. Possibility of ERIT for SHE production
   - Validity of the ERIT scheme for SHE ring
   - Stability of the beams with different charge state
4. Summary

Introduction

1. It has been 14 years since the main ring started operation.
2. Machine operation has been stopped since March 2023.
3. Some users desire the beam from KURNS FFA, but No concrete plans for operation are in place.
4. The utilization plan of the entire facility and the future reuse of the FFAs are under consideration.
5. One of the main option is modification of the main ring to an ERIT ring for producing the super heavy element.

Nuclear chart



Oganesson

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

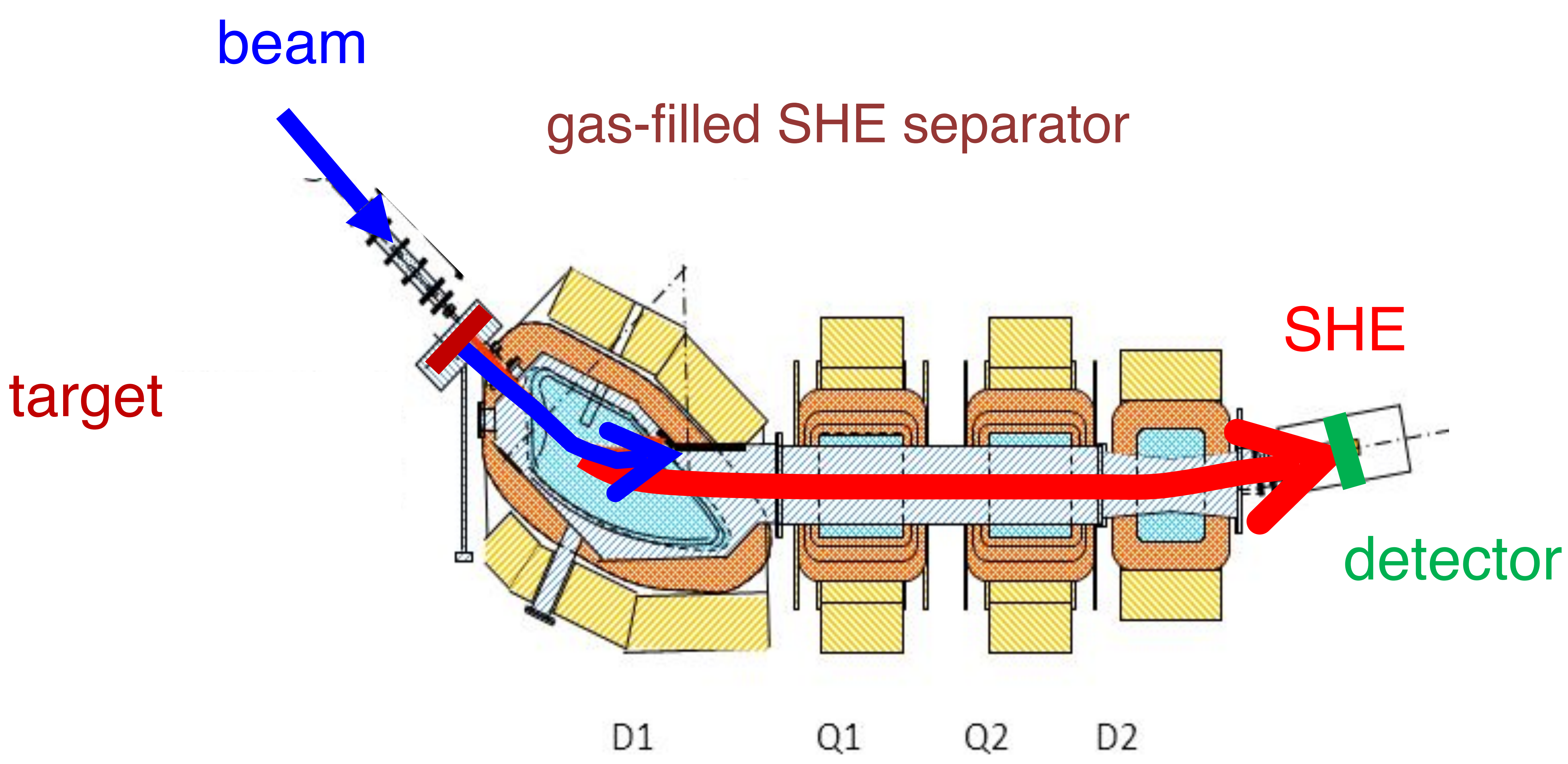
$^{48}_{20}Ca + ^{243}_{95}Am \rightarrow ^{288,287}_{115}Mc \rightarrow ^{284,283}_{113}Nh$

produce 119 or/and 120 using ERIT

K. Nishio

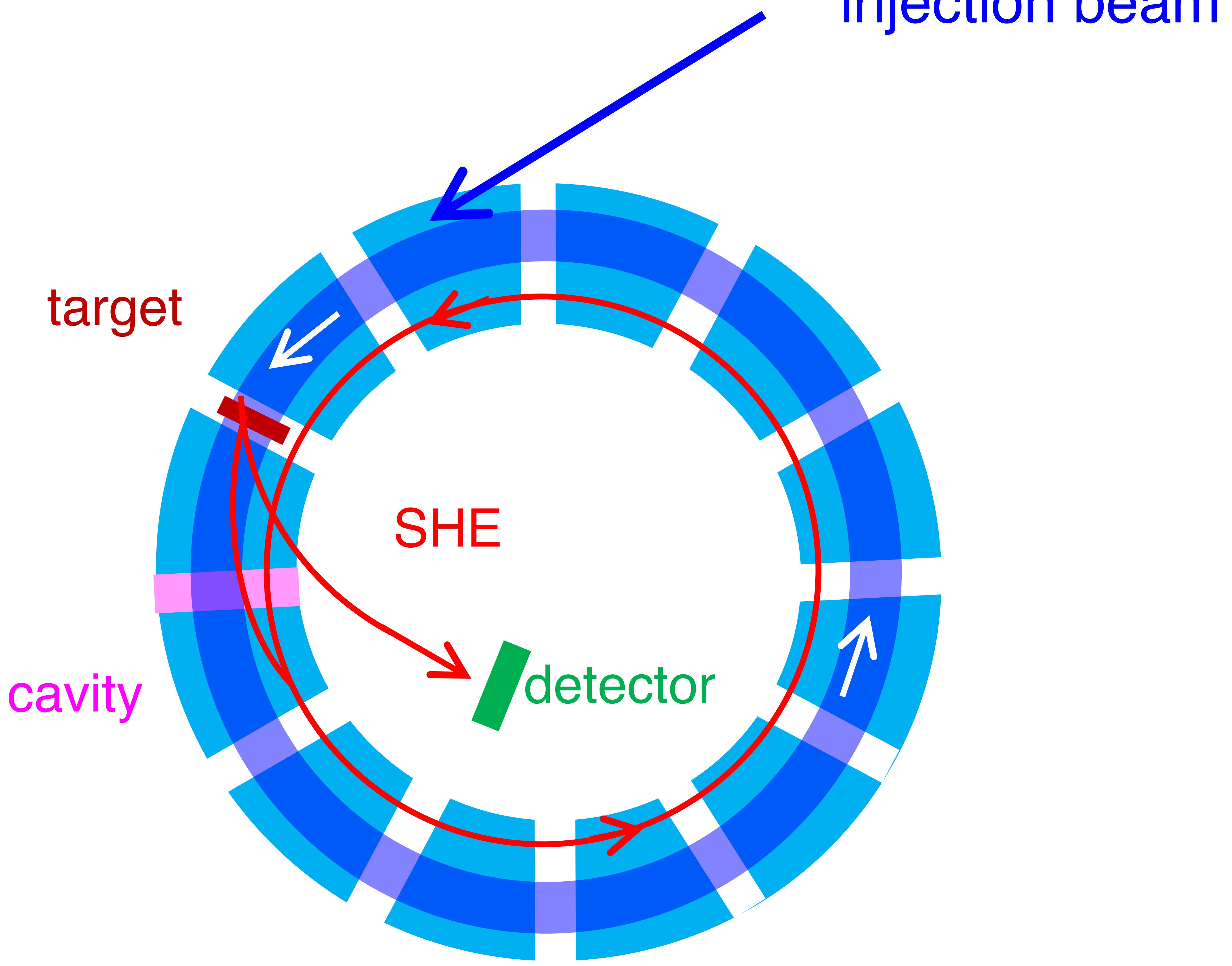
ERIT_SHE

conventional method



SHE: Super Heavy Element

new scheme



K. Nishio

Beam species, target for SHE

test run

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

real run

$$^{50}_{22}Ti + {}^{249}_{97}Bk \rightarrow {}^{299}_{119}Xx$$

$$^{50}_{22}Ti + {}^{249}_{98}Cf \rightarrow {}^{299}_{120}Xx$$

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

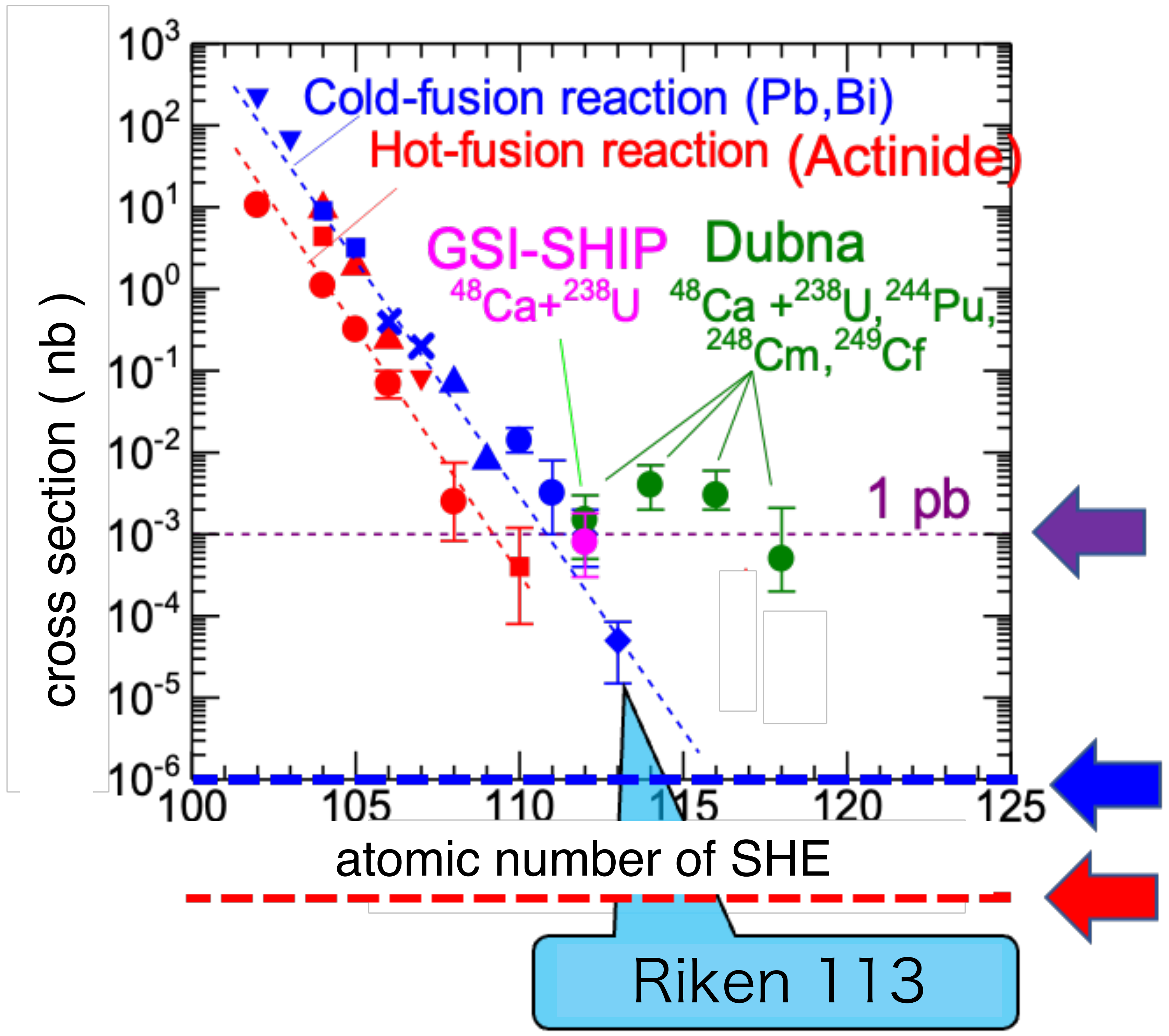
$$^{54}_{24}Cr + {}^{243}_{95}Am \rightarrow {}_{119}Xx$$

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

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

ERIT_SHE

target	beam	
	Z=119	Z=120
^{248}Cm(Z=96) 3.4x10^5 y	^{51}V (23)	^{54}Cr (24)
^{249}Bk (Z=97) 327 d	^{50}Ti (22)	^{51}V (23)
^{249}Cf (Z=98) 351 y	^{45}Sc (21)	^{50}Ti (22)



assume ERIT can accumulate 1000 turns

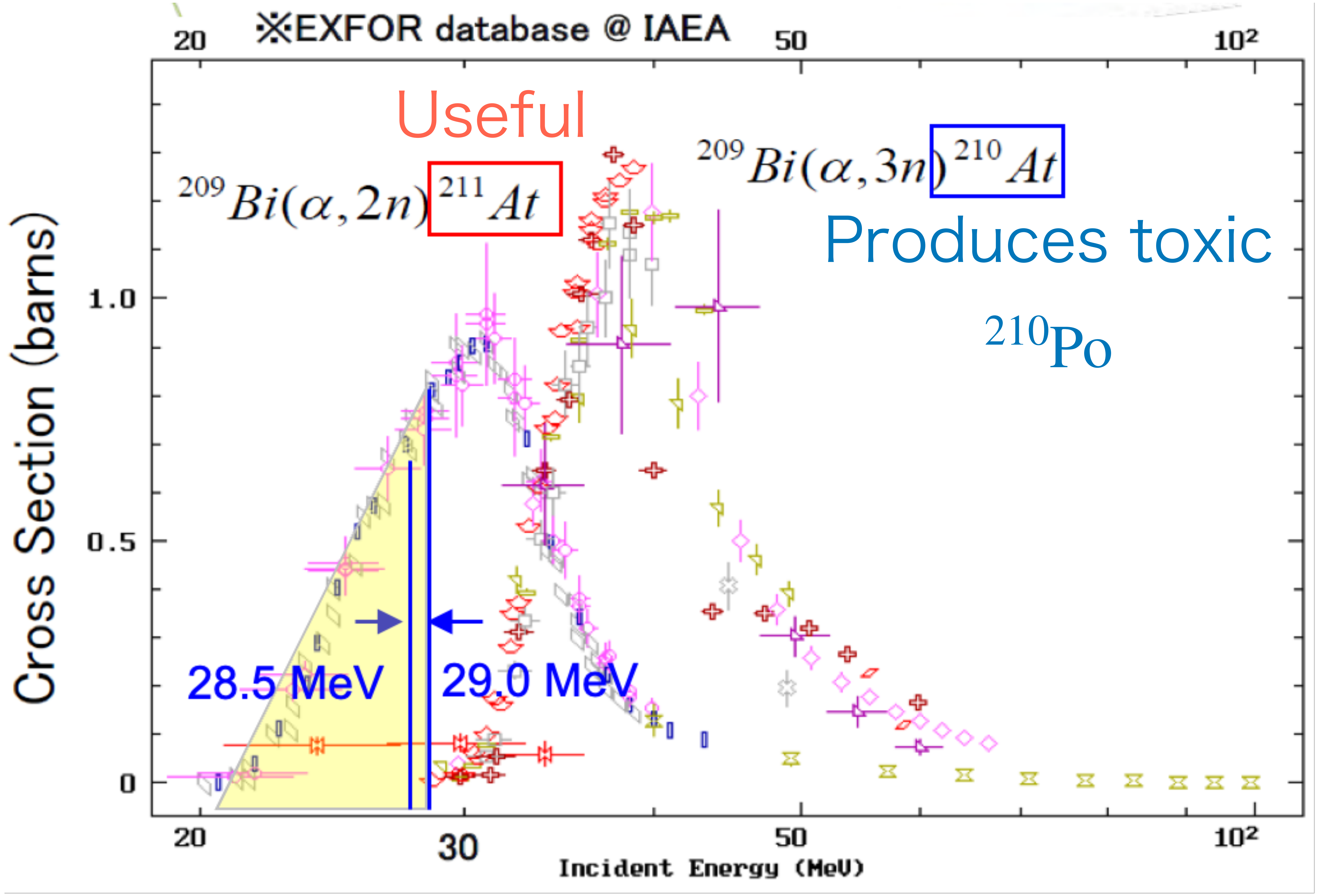
1 pb one event per week using existing method

1 fb one event per 10 years using existing method

0.1 fb one event per month using ERIT

$^{4}He + ^{209}Bi \rightarrow ^{211}At$

^{211}At can be produced using ^{4}He beam energies of 21 MeV to 29 MeV (^{209}Bi target 80 μm).
If the energy is higher than 29 MeV, the toxic ^{210}Po is produced and cannot be used.
The lifetime of ^{211}At is 7.2 hours and is produced after about 5 hours of irradiation.



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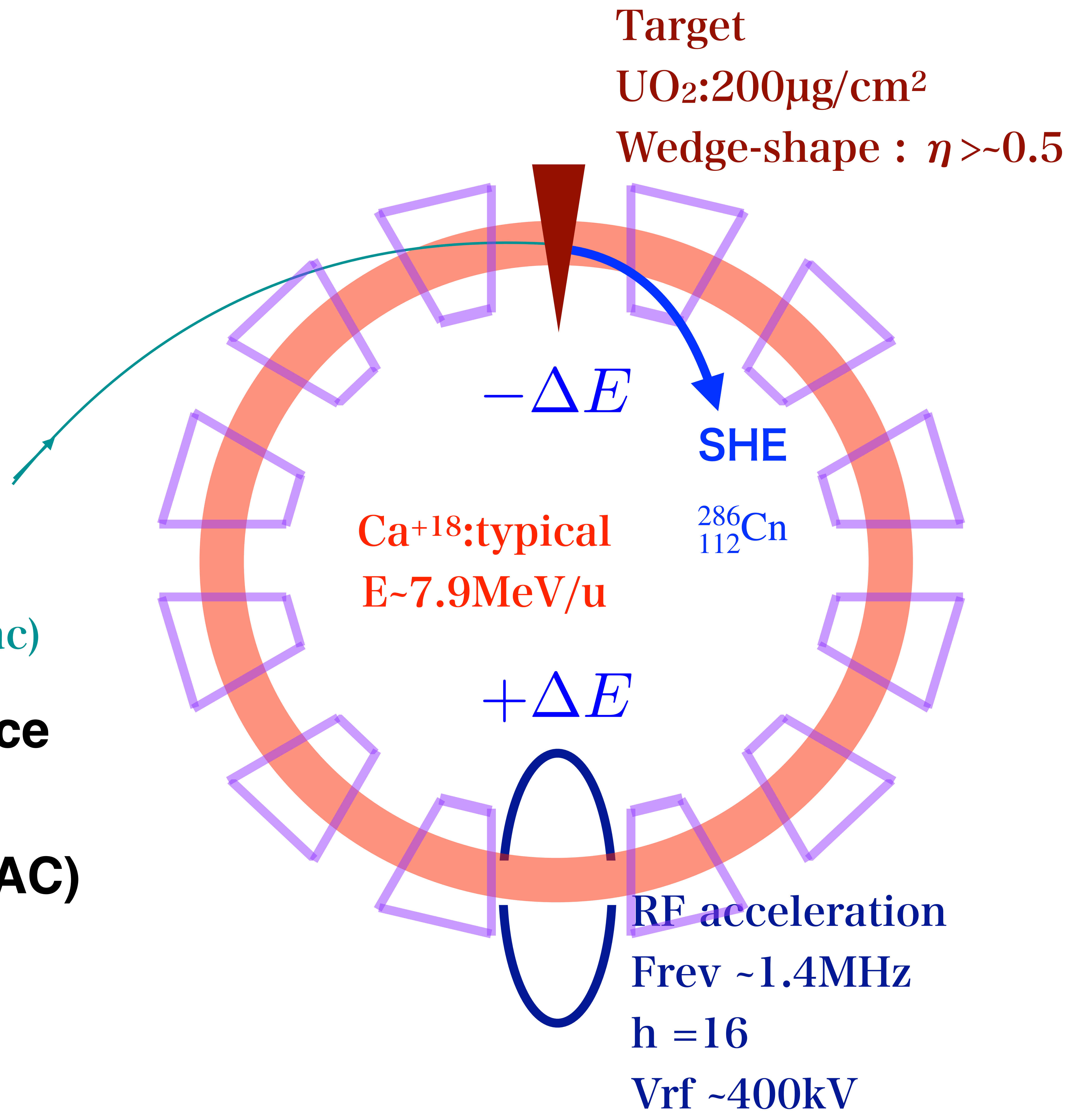
ERIT_SHE scheme



Ca^{+10}
7.9MeV/u
(from Linac)

Ion source
RFQ
DTL(LINAC)

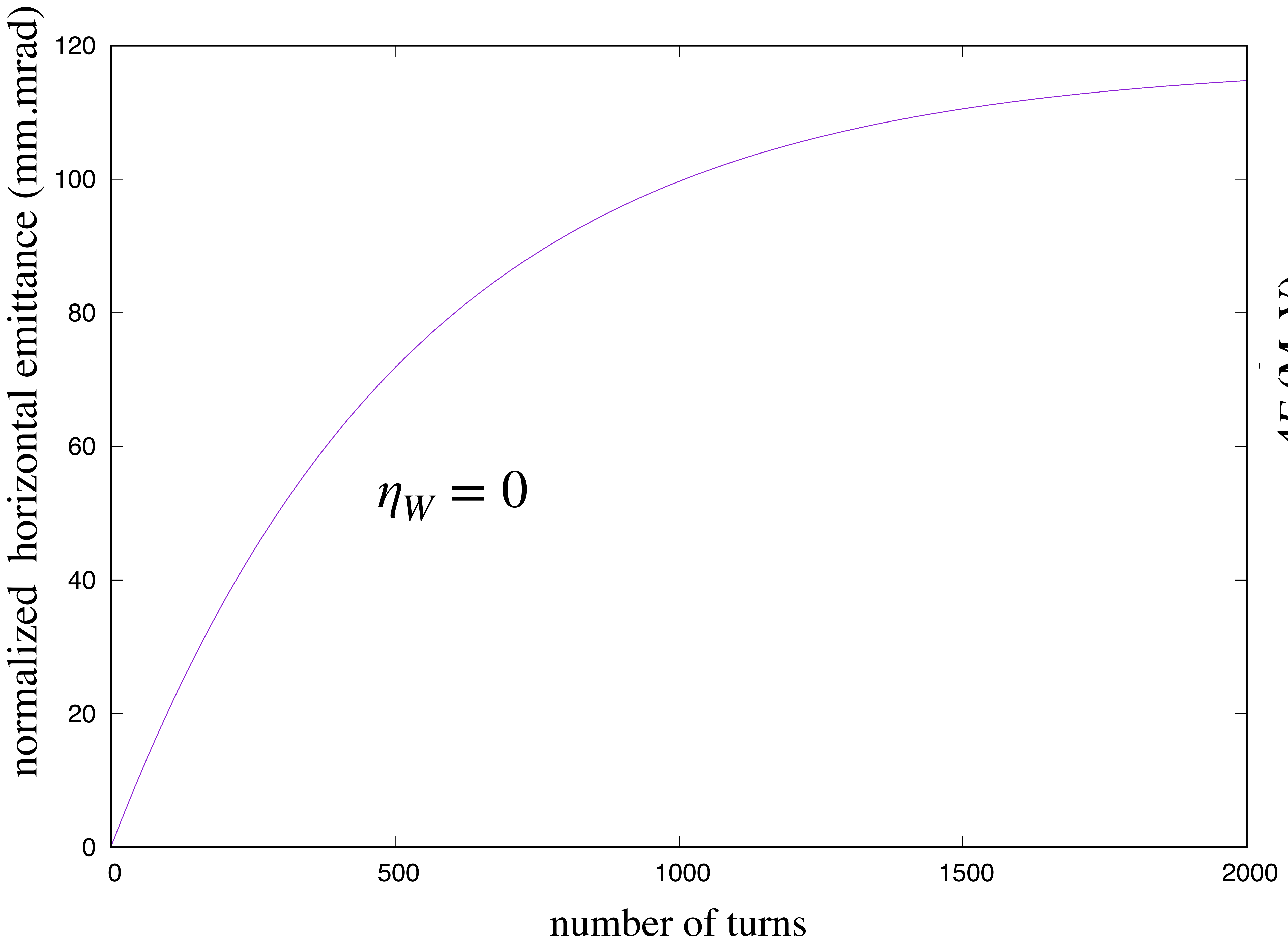
Injection current : 1 pμA (6.25E12 pps)

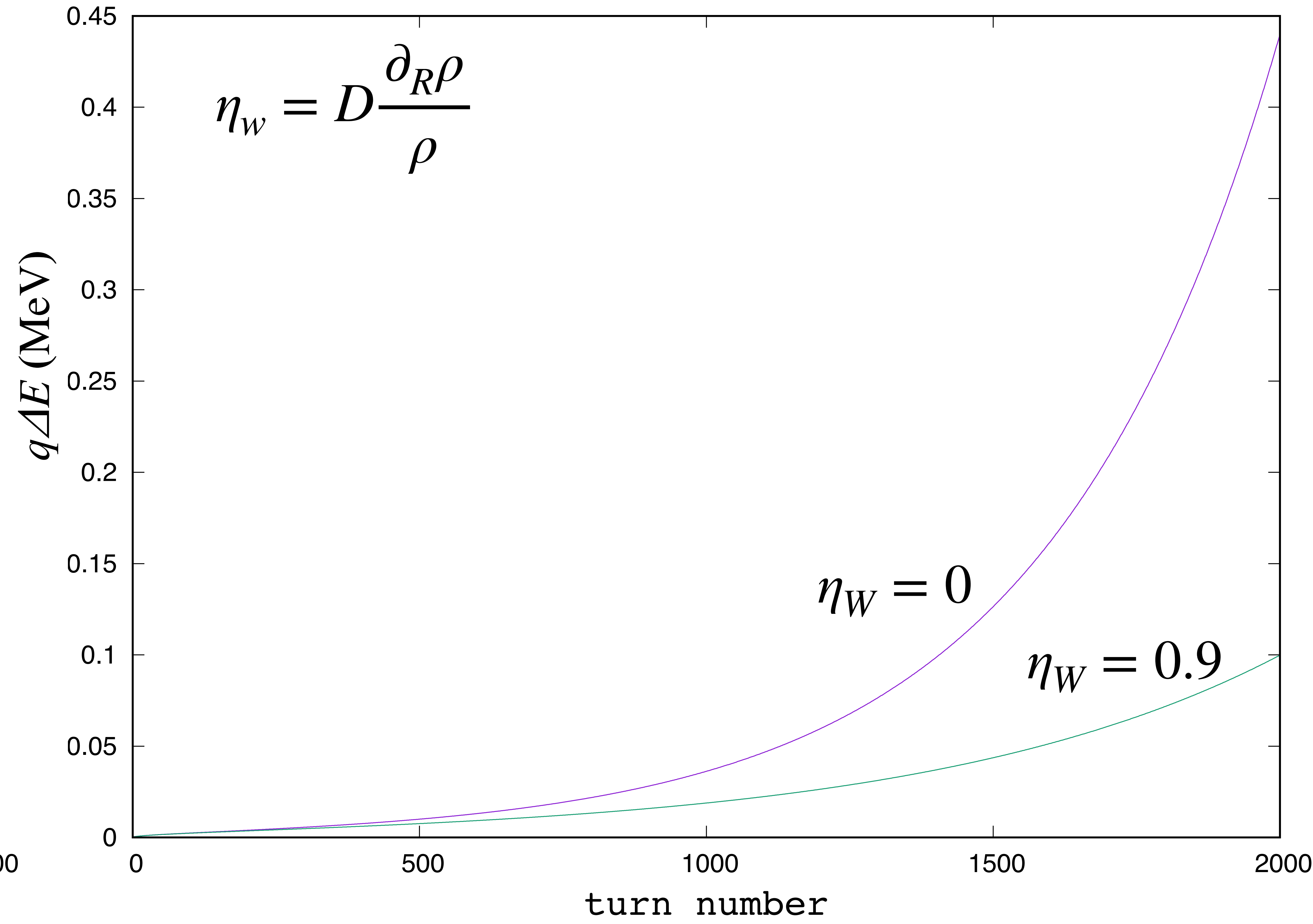
assumption :
- **1000 turn survival**
- **target thickness 200μg/cm2**
- **detection efficiency 10%**

Can detect 1 SHE in every 38 days

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

Growth of transverse emittance and energy spread





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Summary of ERIT simulation

- Transverse emittance tends to constant value after 2000 turns due to the ionization beam cooling. →$\varepsilon_{N=}$115 mm.mrad
- As the beam cooling does not affect in longitudinal direction, energy spread increases. After 1000 turns→$<\sigma_E>$~50*q keV
- Using wedge target, transverse-longitudinal coupling suppress the energy spread increase. η=0.9→ ε_N~350[mm.mrad], $<\sigma_E>$~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）

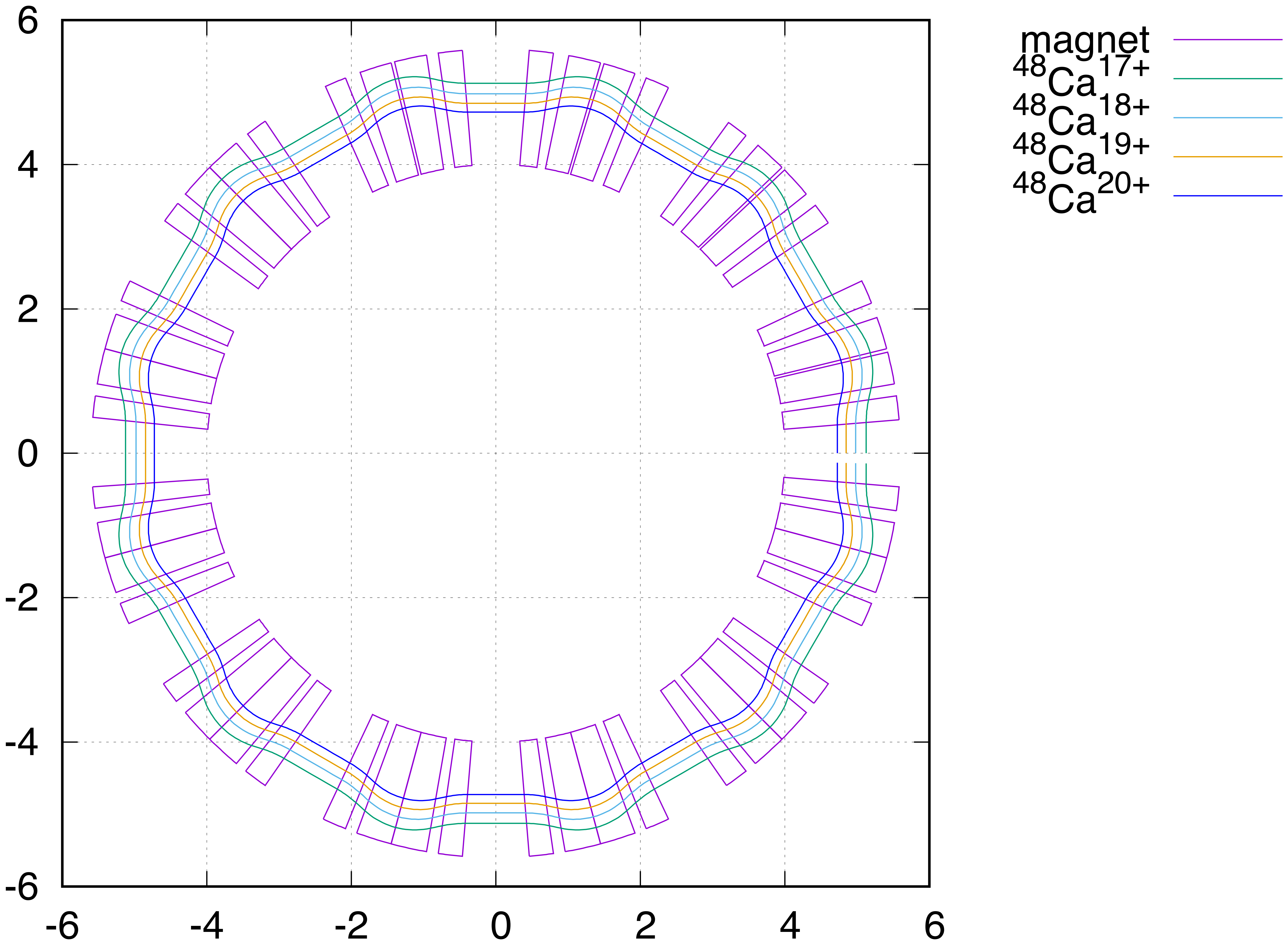
Y. MORI

closed orbit of different charge state(static)

- 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

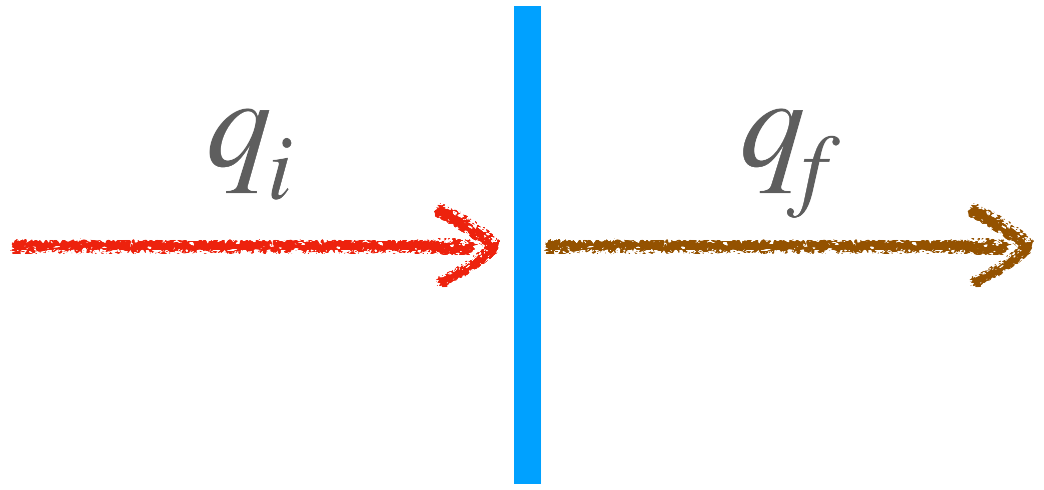


From the ring, beams with different charges appear to have different momenta.

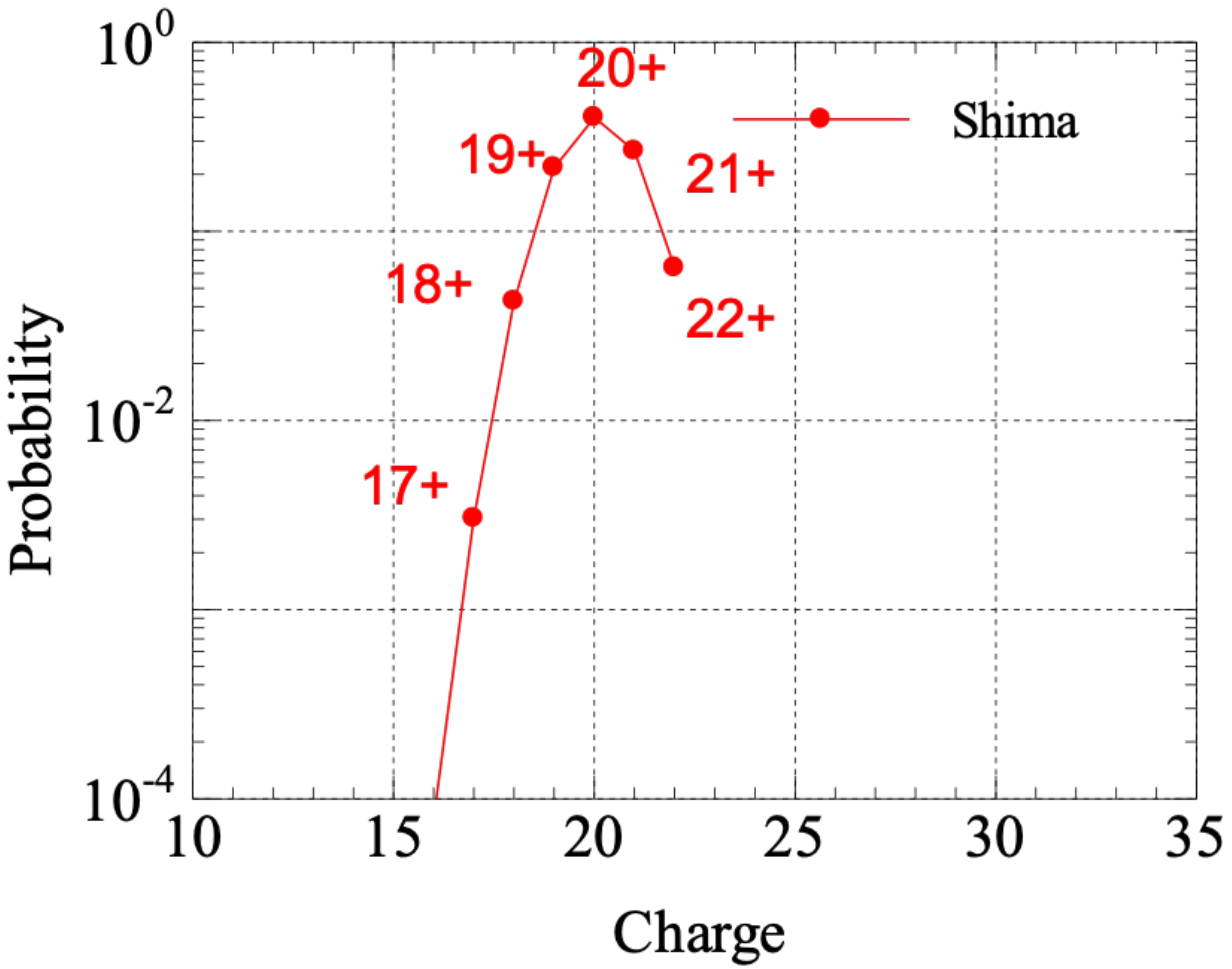
charge state distribution

- Initial charge state q_i will be changed into the state q_f passing thru the production target.
- Final charge state q_f is determined statistically by the probability distribution regardless the initial state q_i.

production target



Ti50＋Cm248: Elab=275MeV = 5.5 MeV/u



amplitude change due to charge state transition

- **Suppose the case of charge changing e.g. +20 → +22 → +19**

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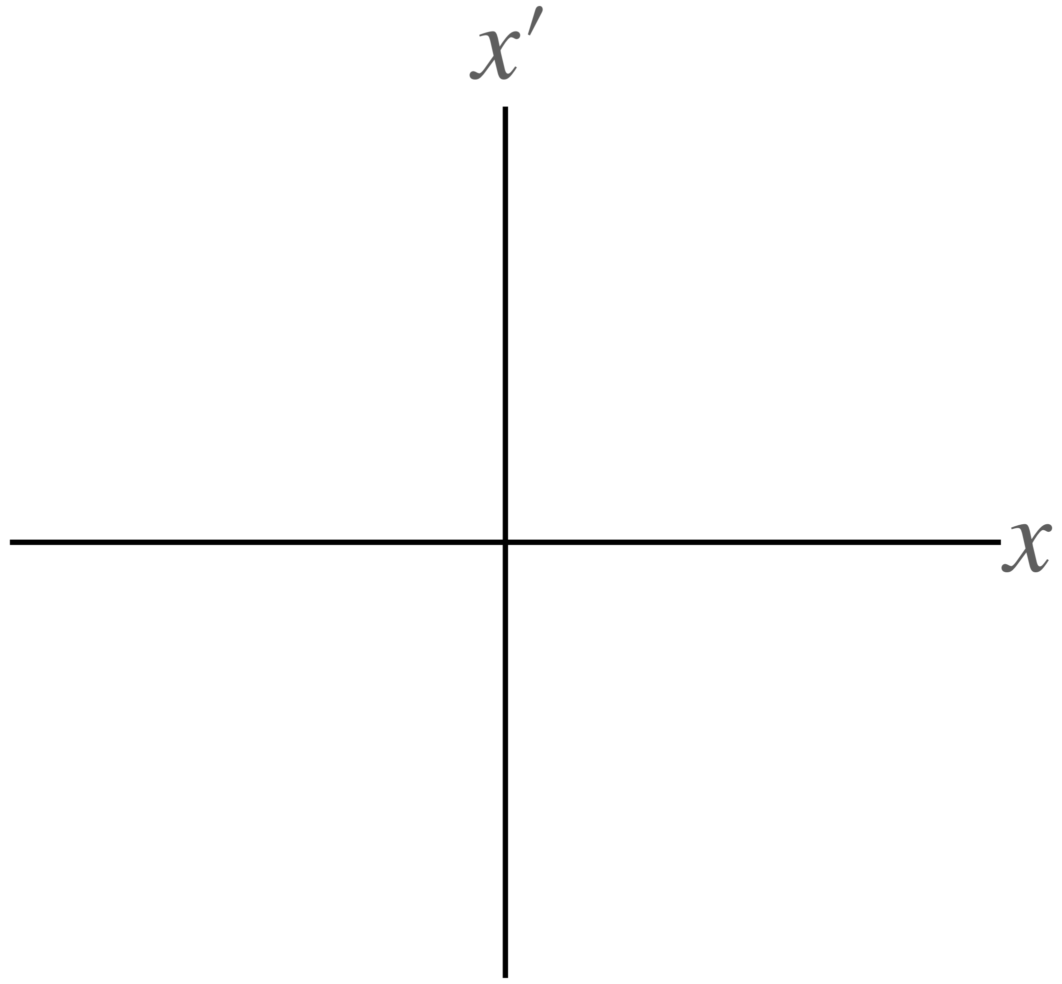

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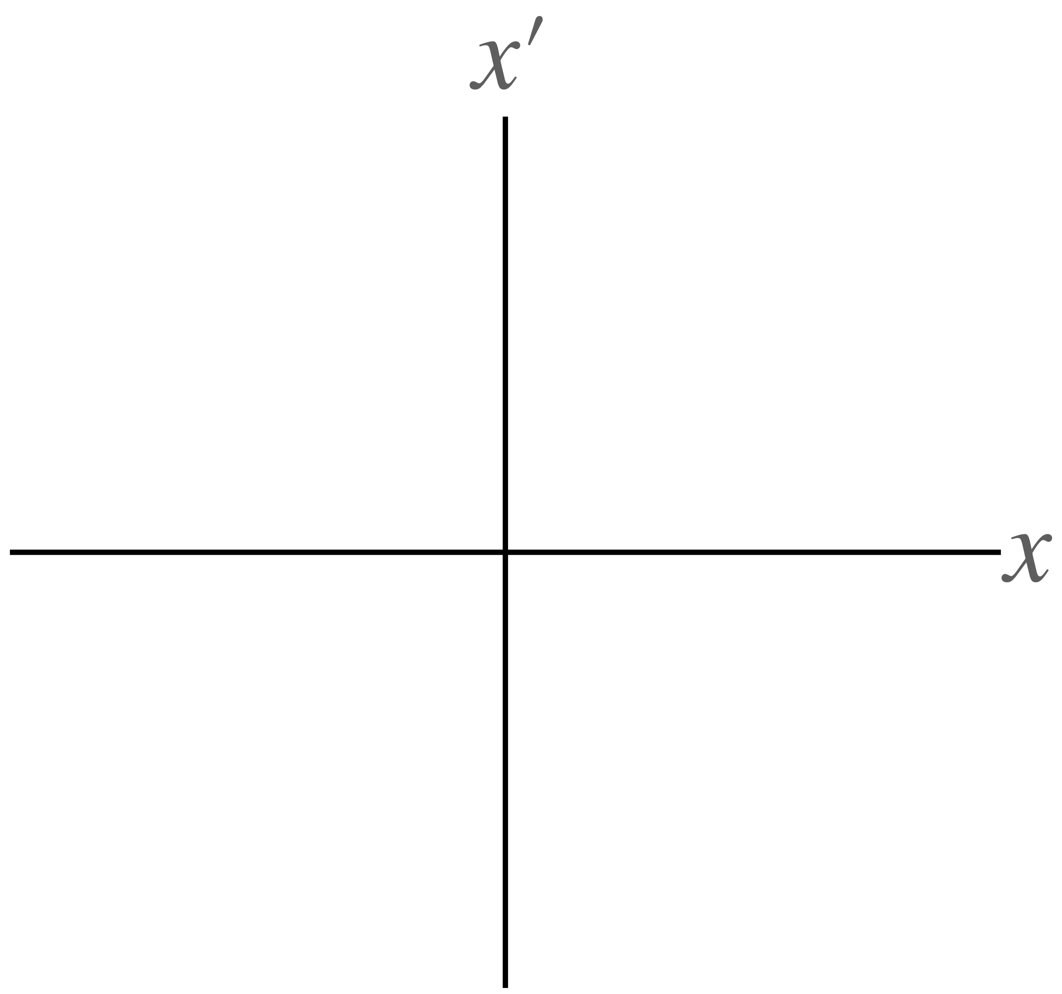

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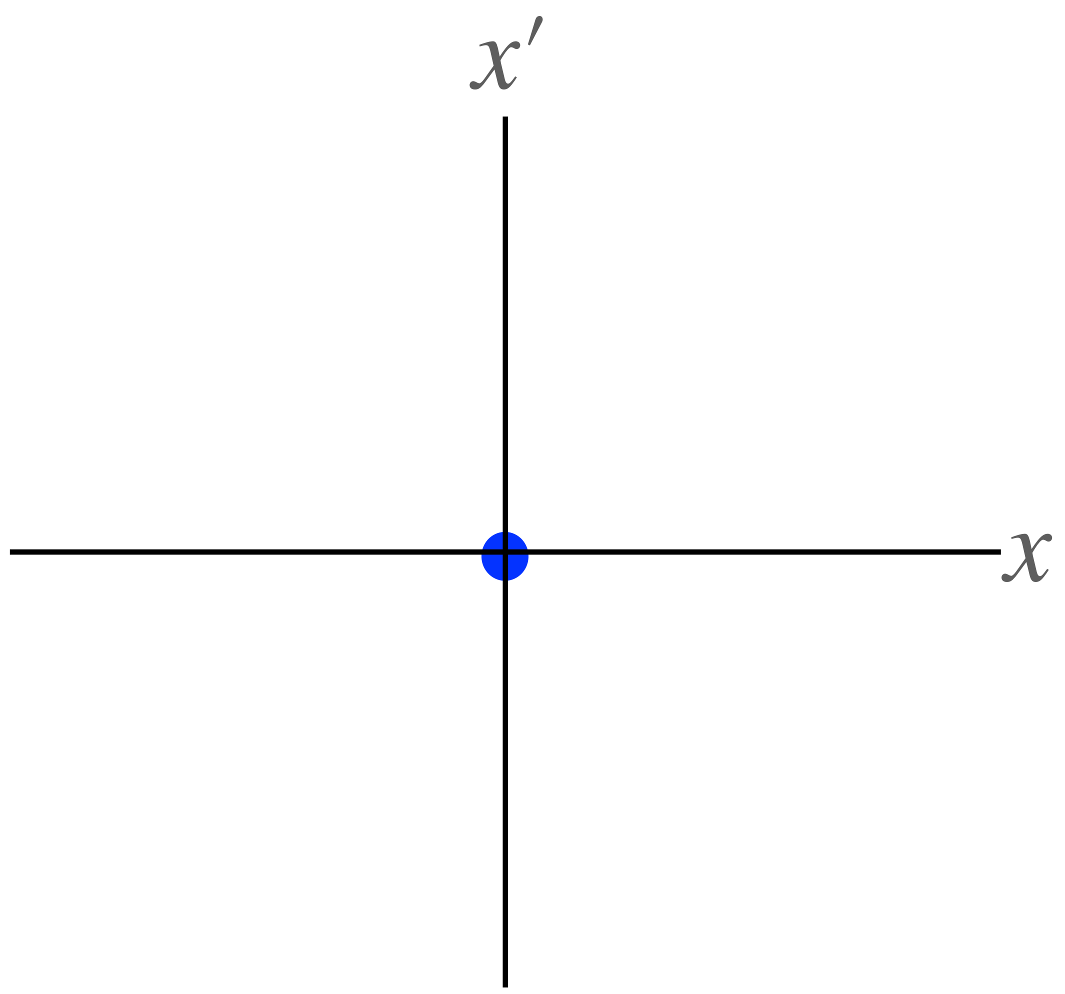

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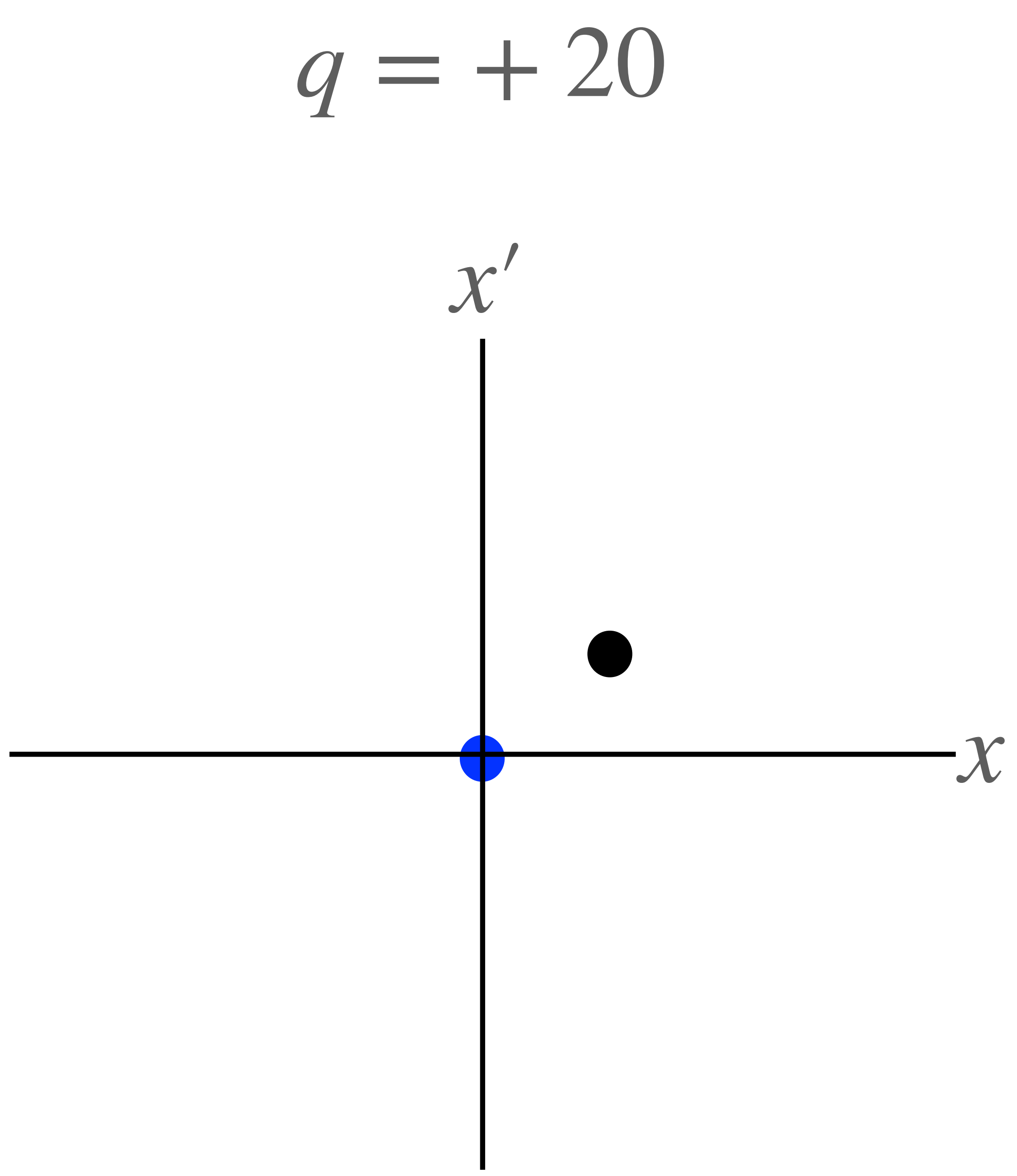

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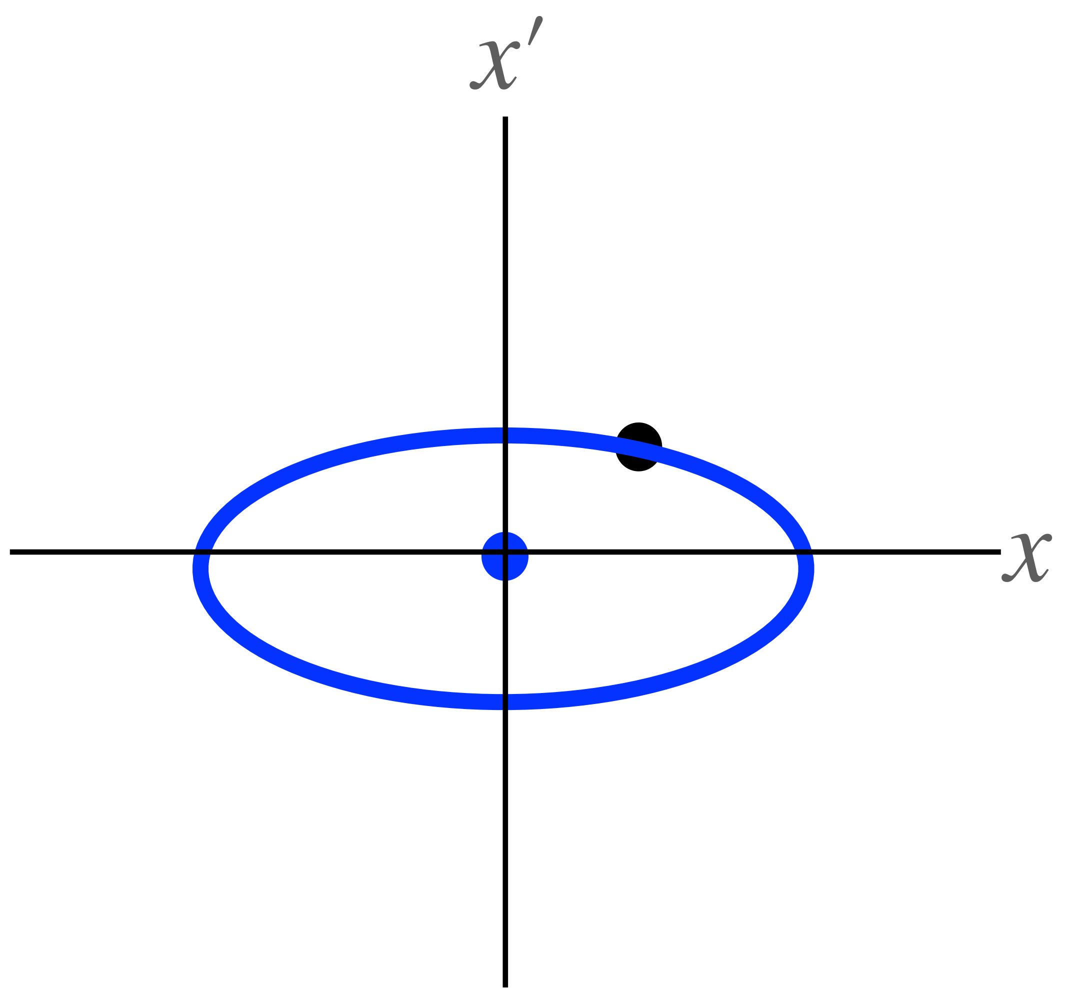

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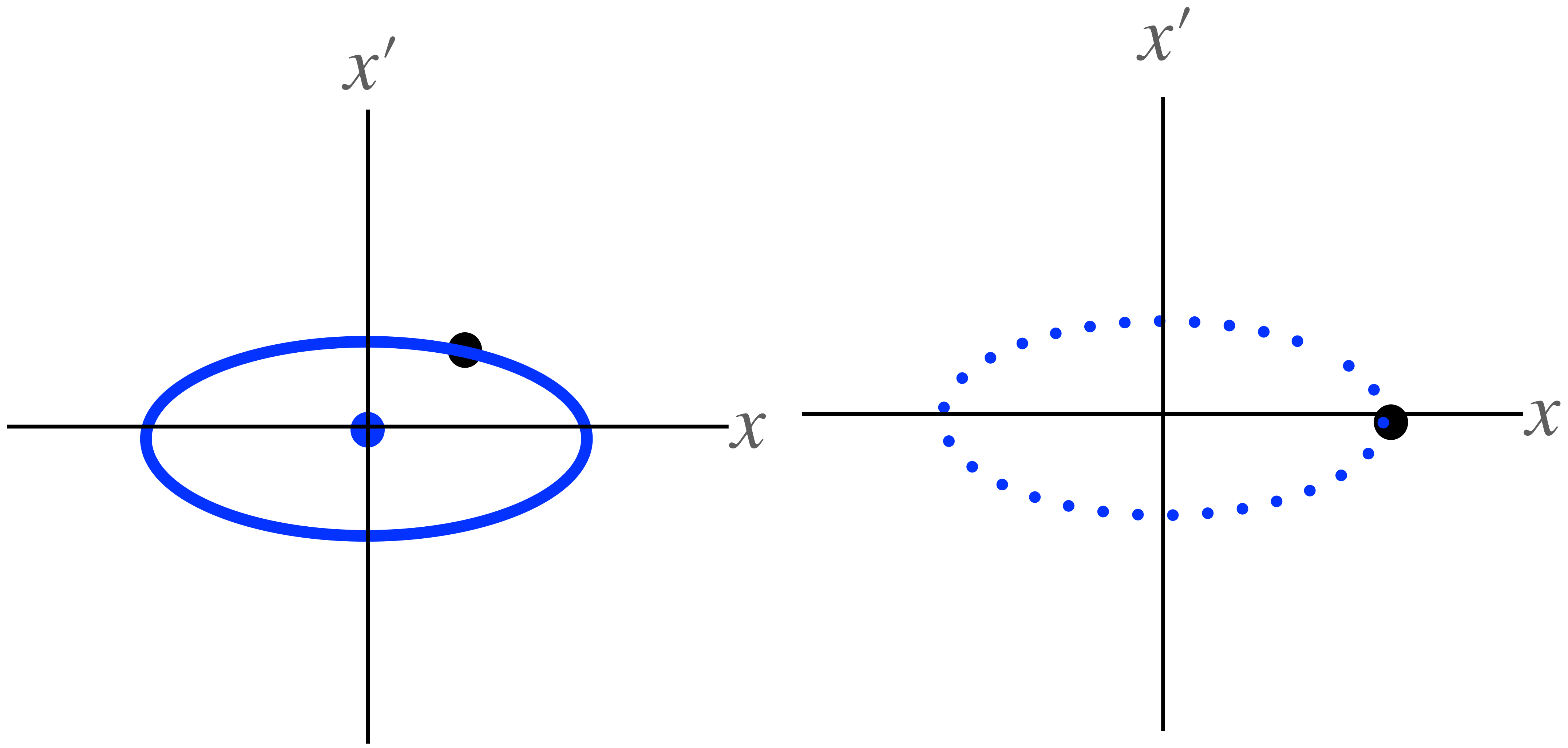

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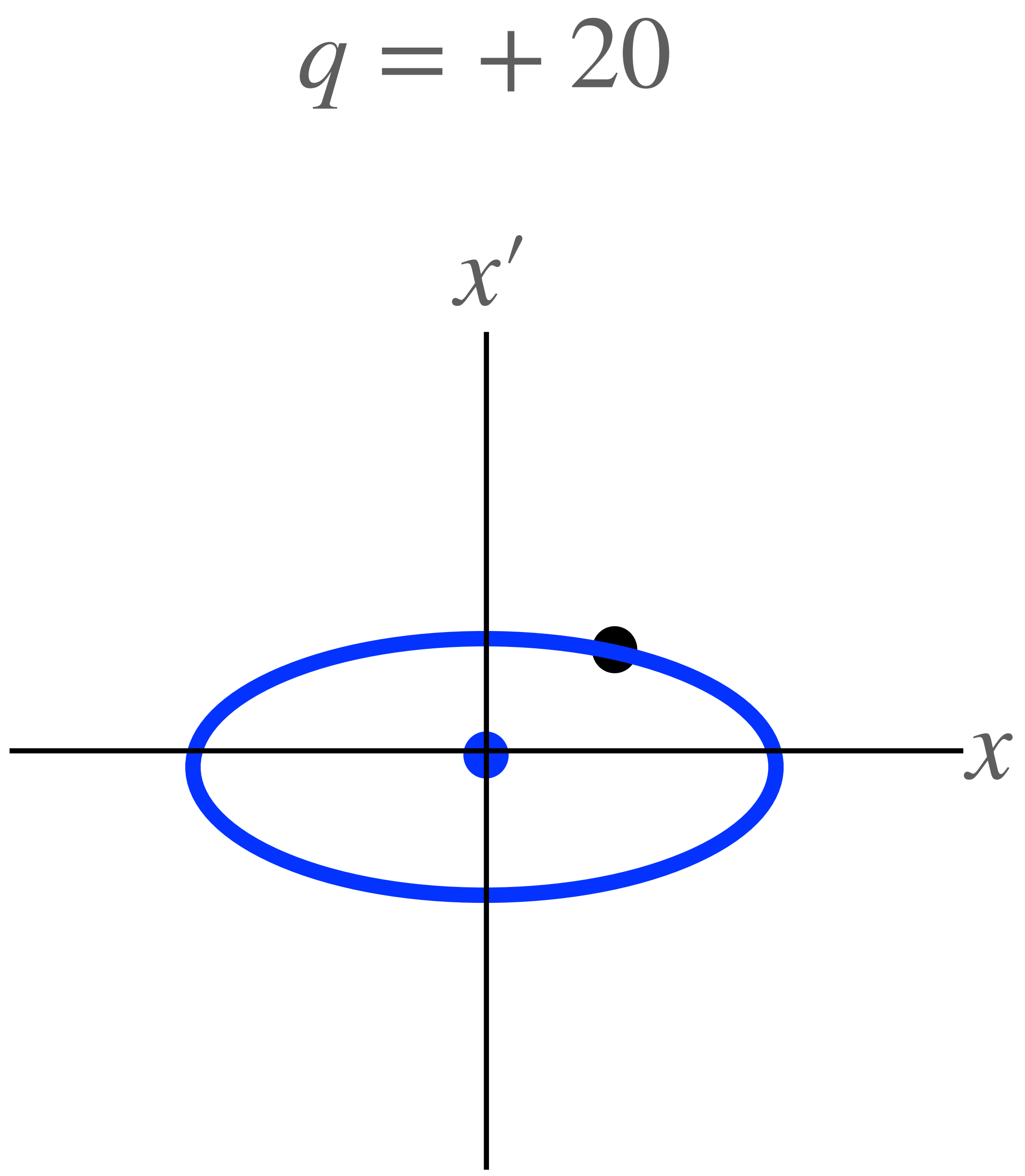

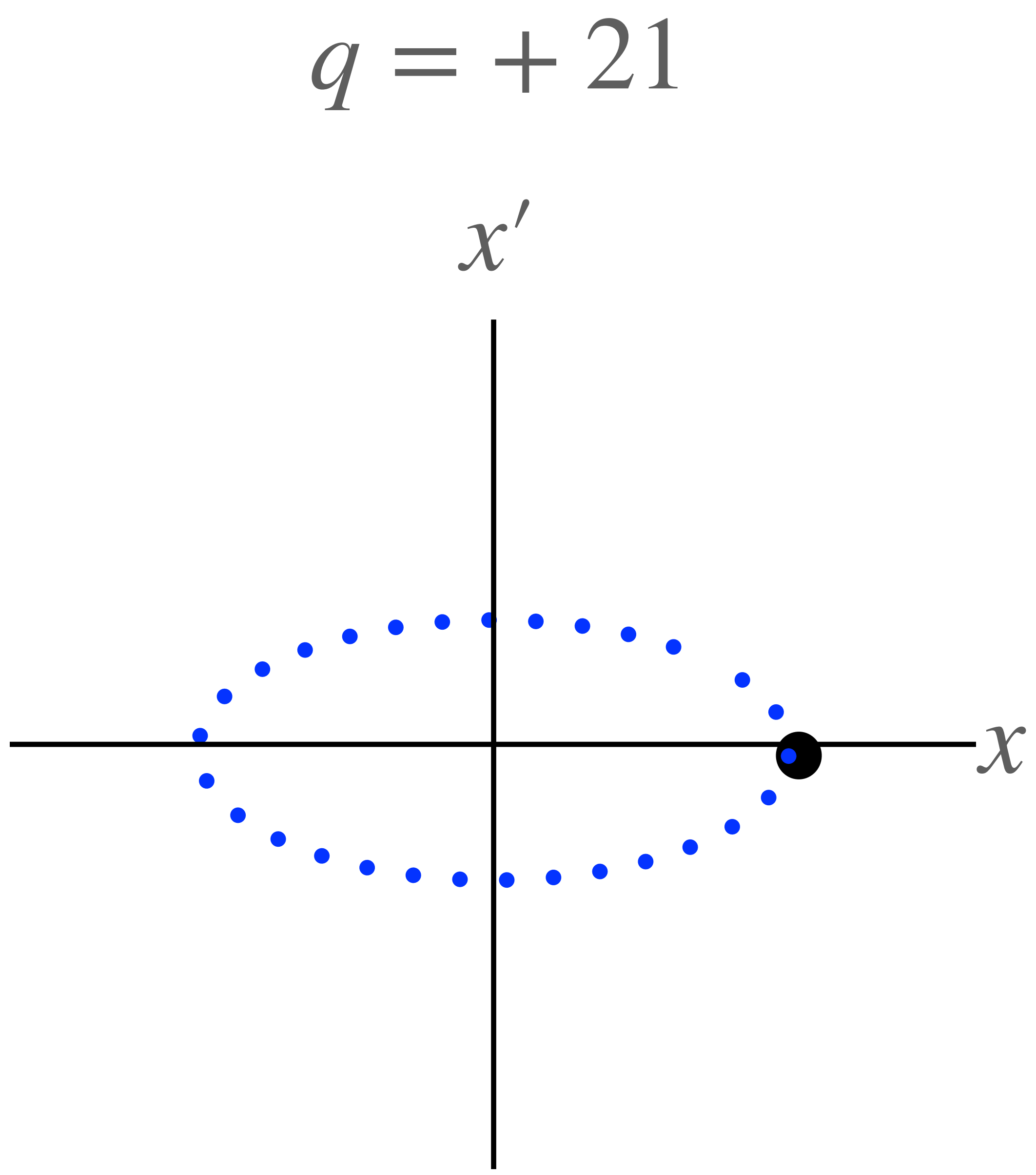

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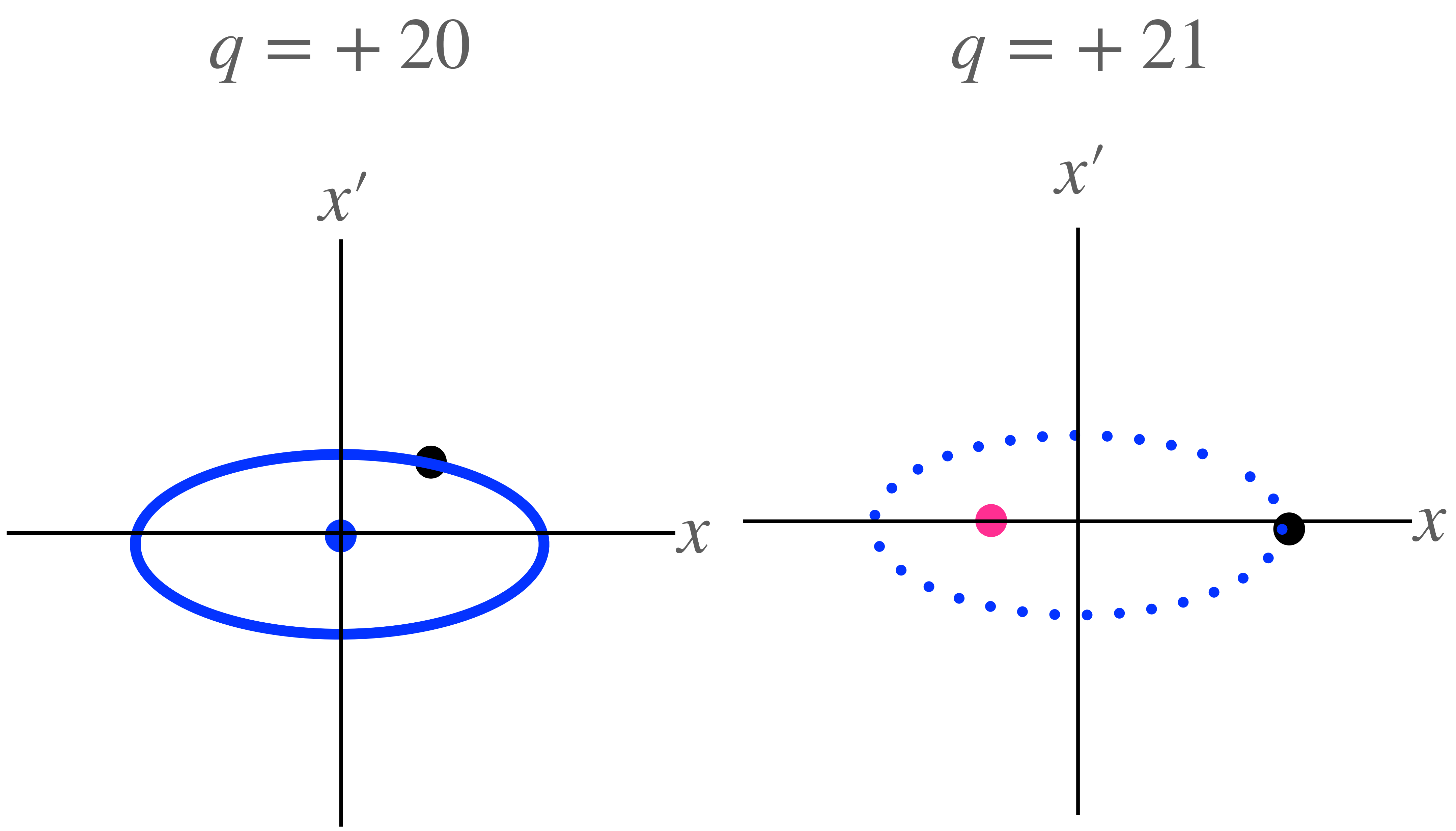

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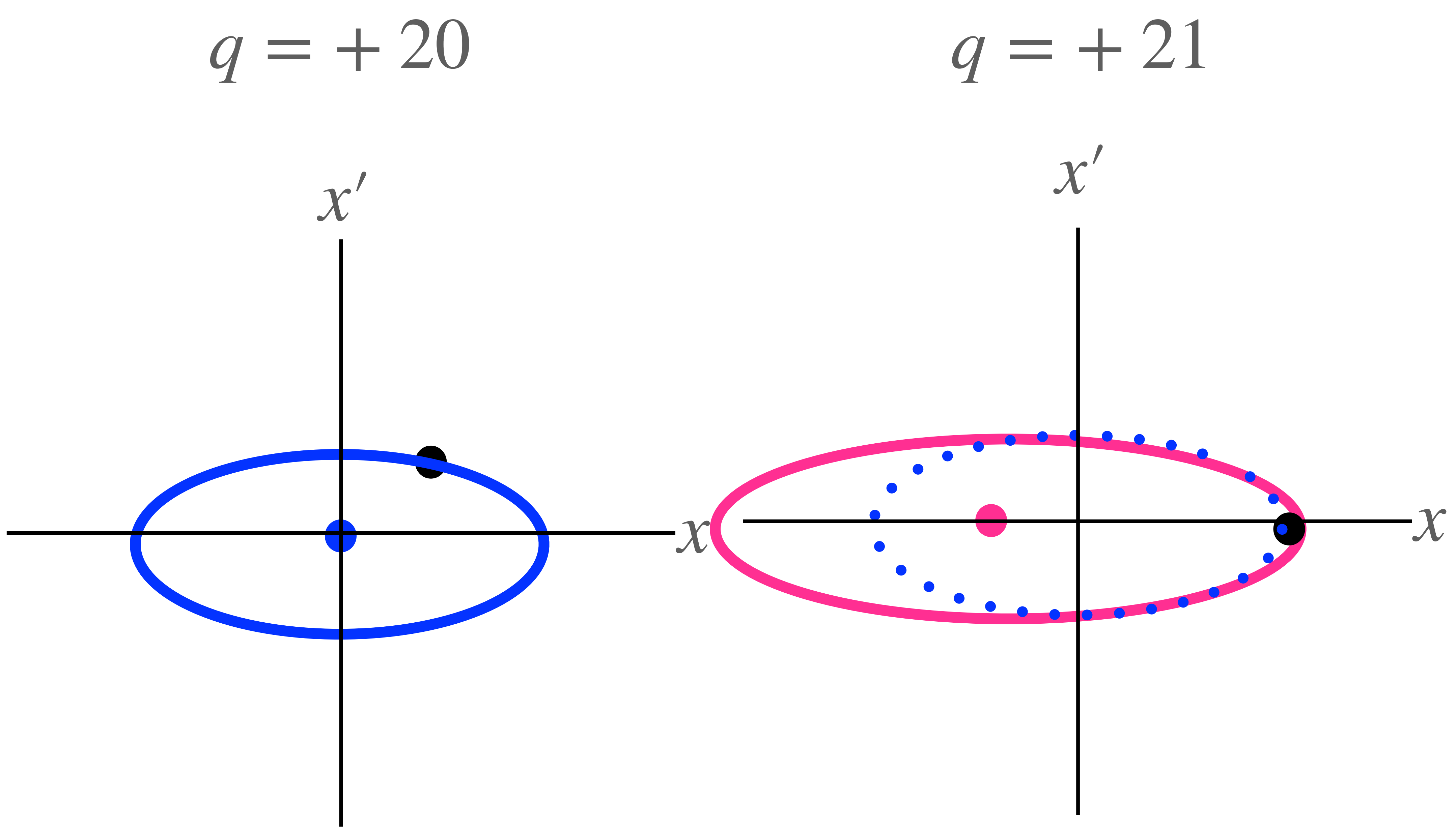

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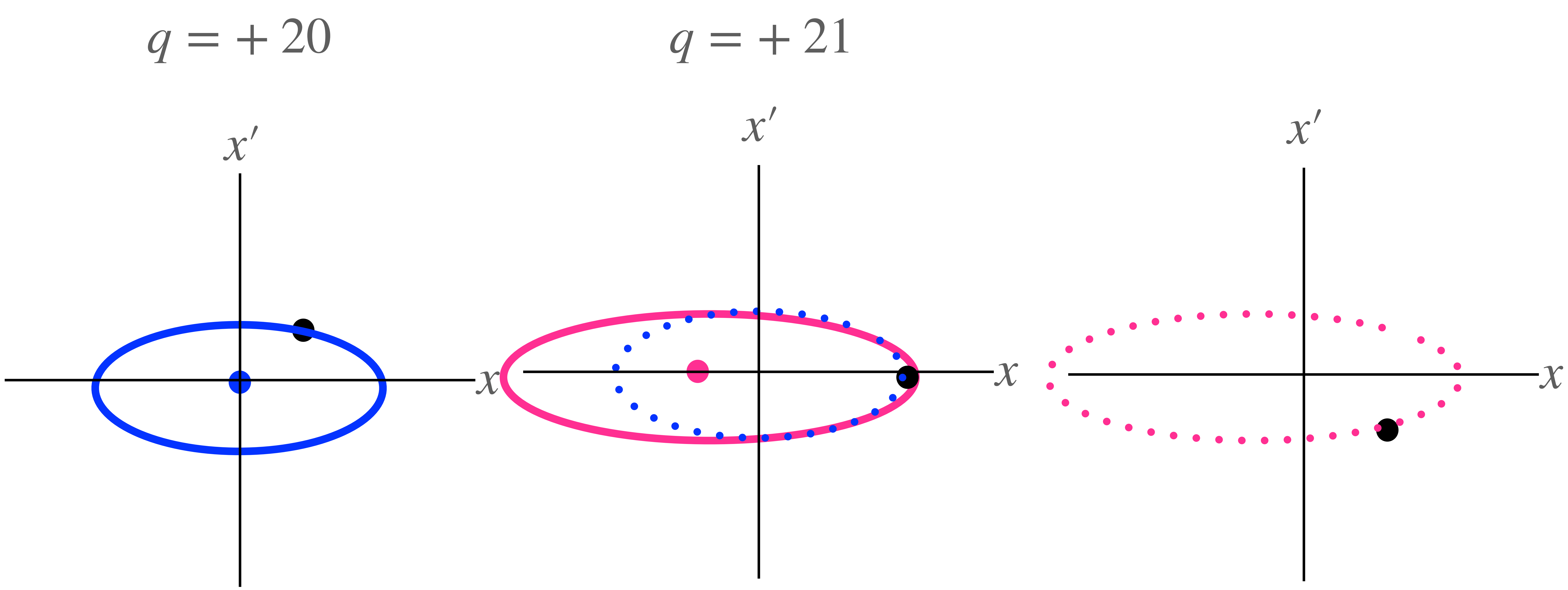

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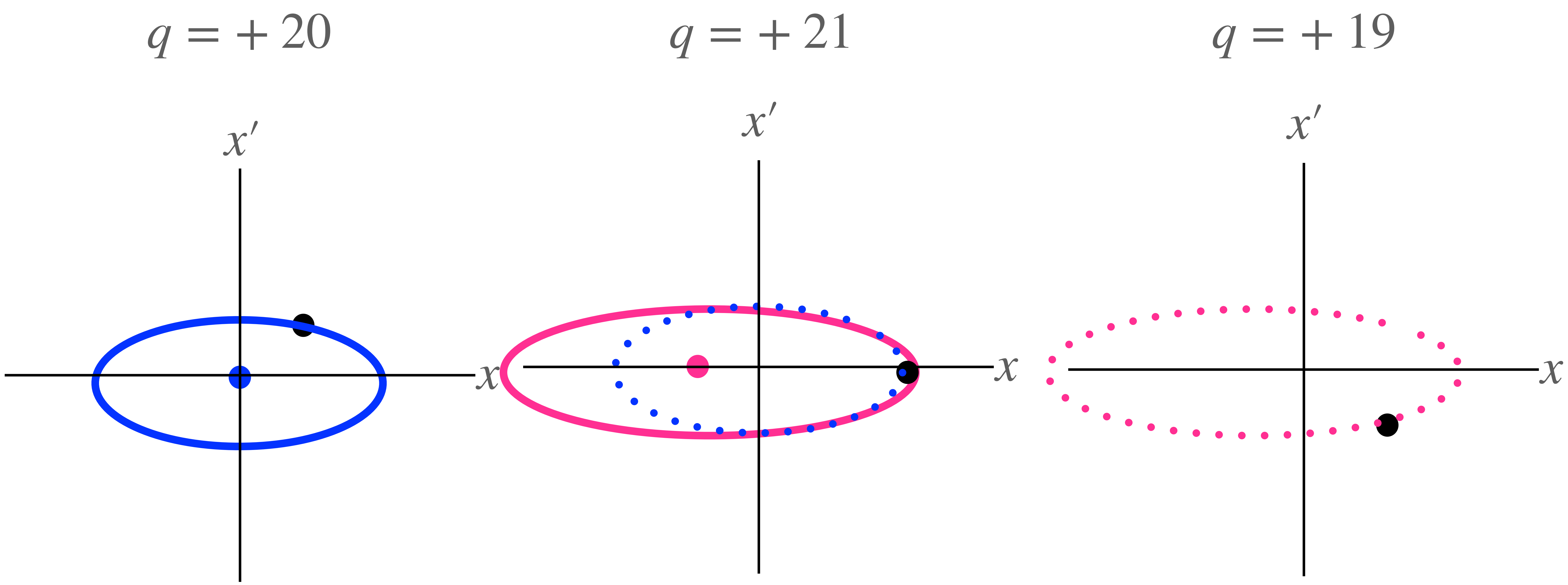

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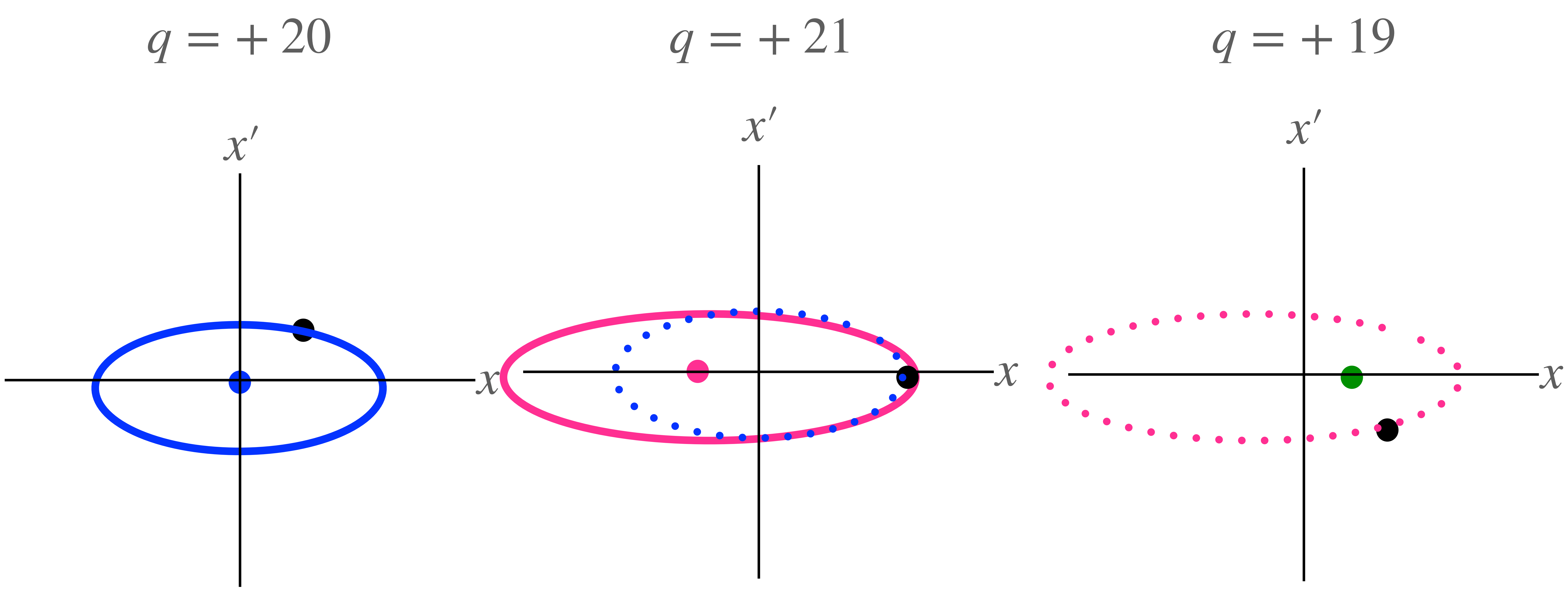

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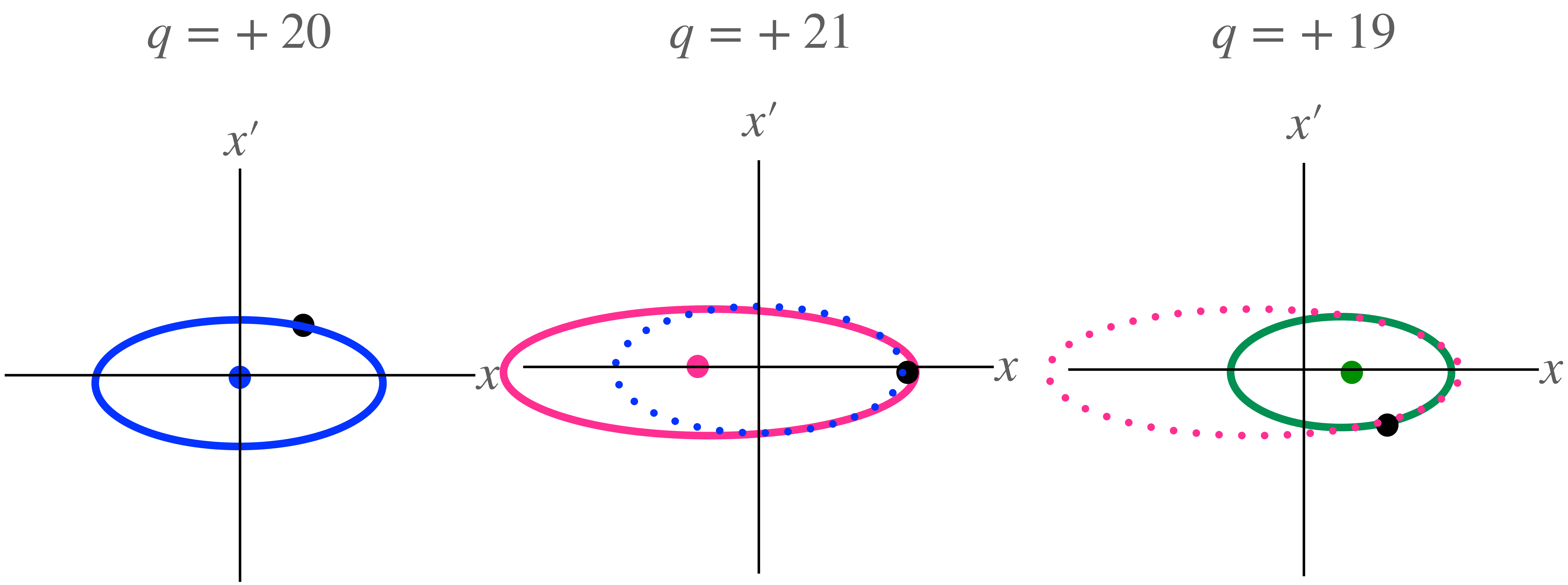

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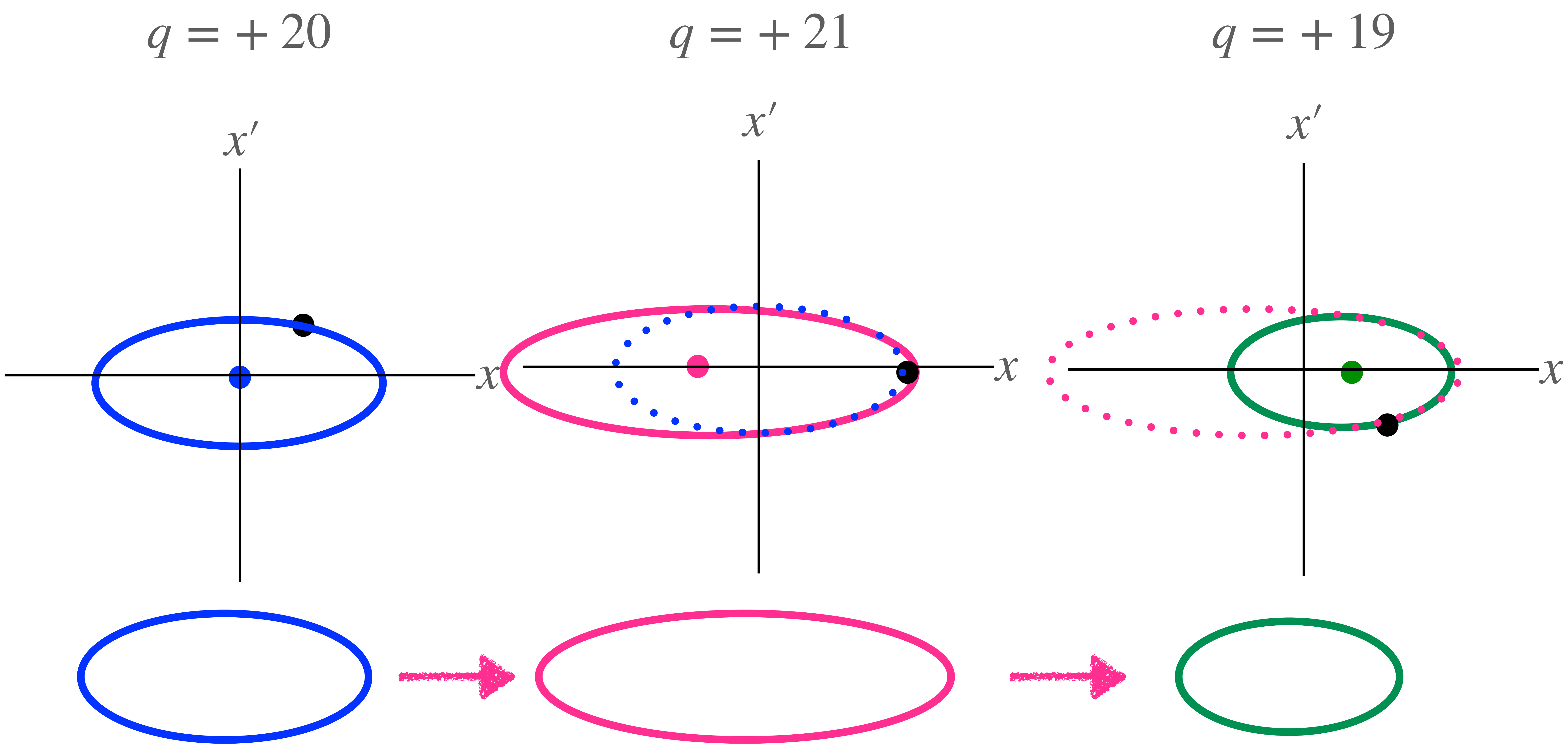

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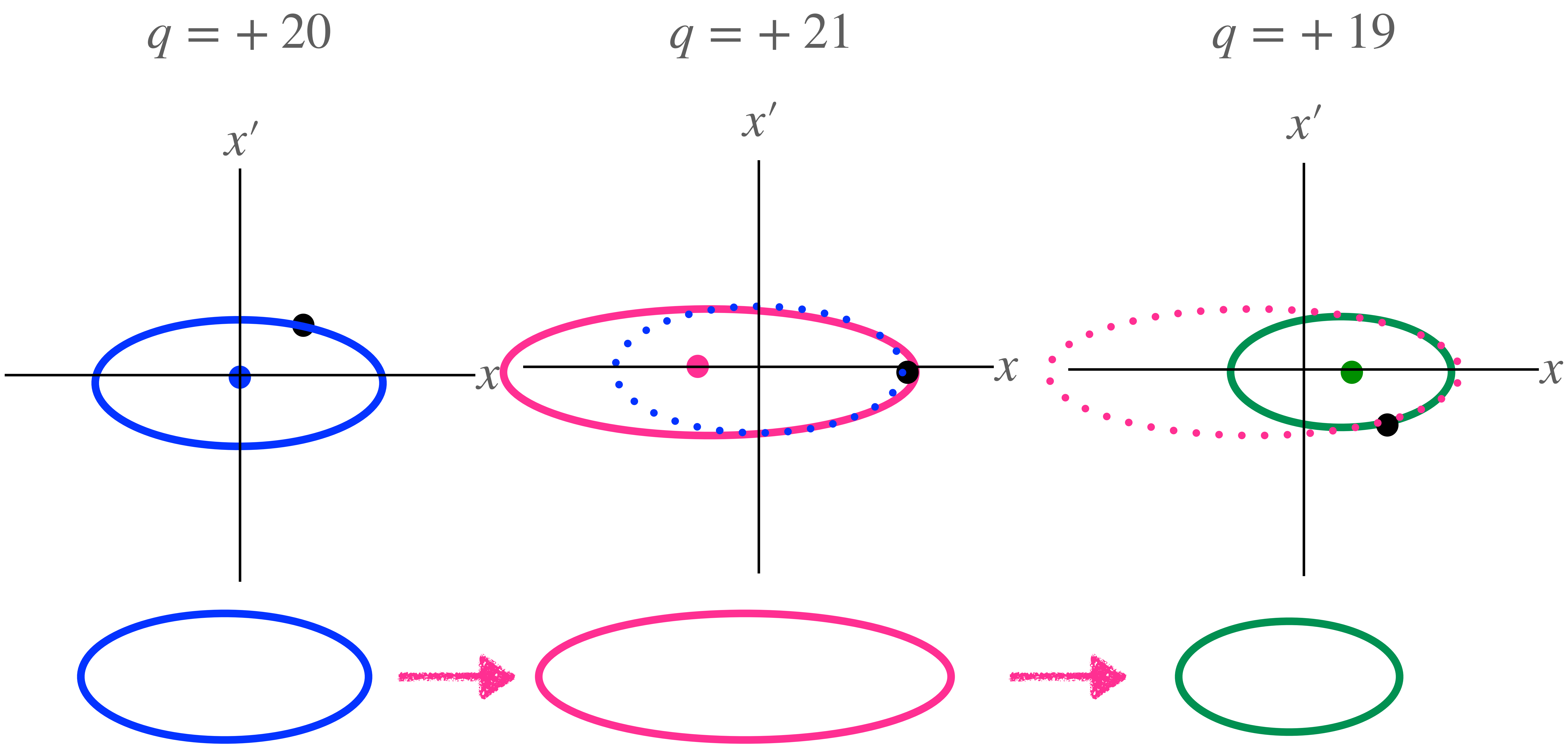

- **betatron amplitudes change turn by turn**

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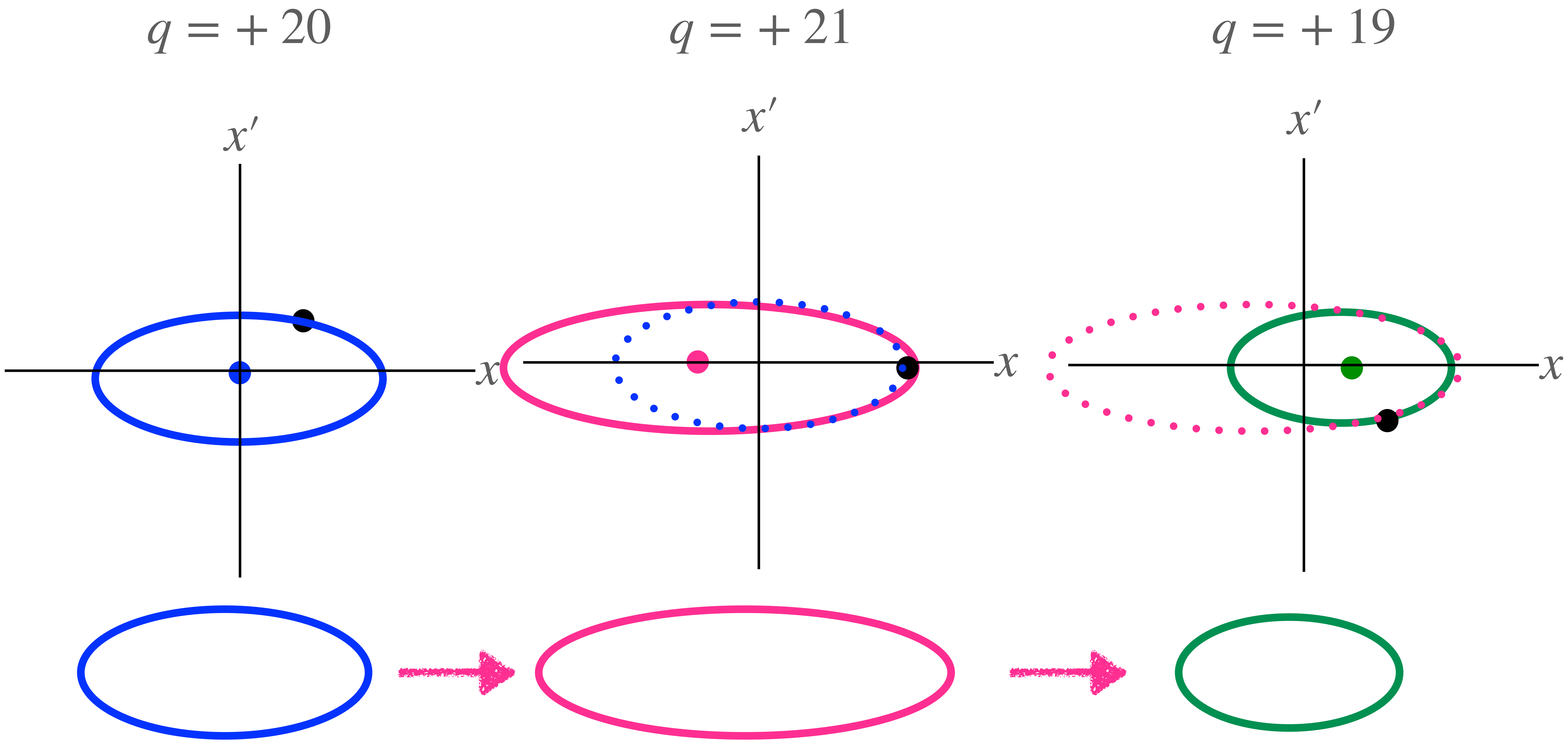

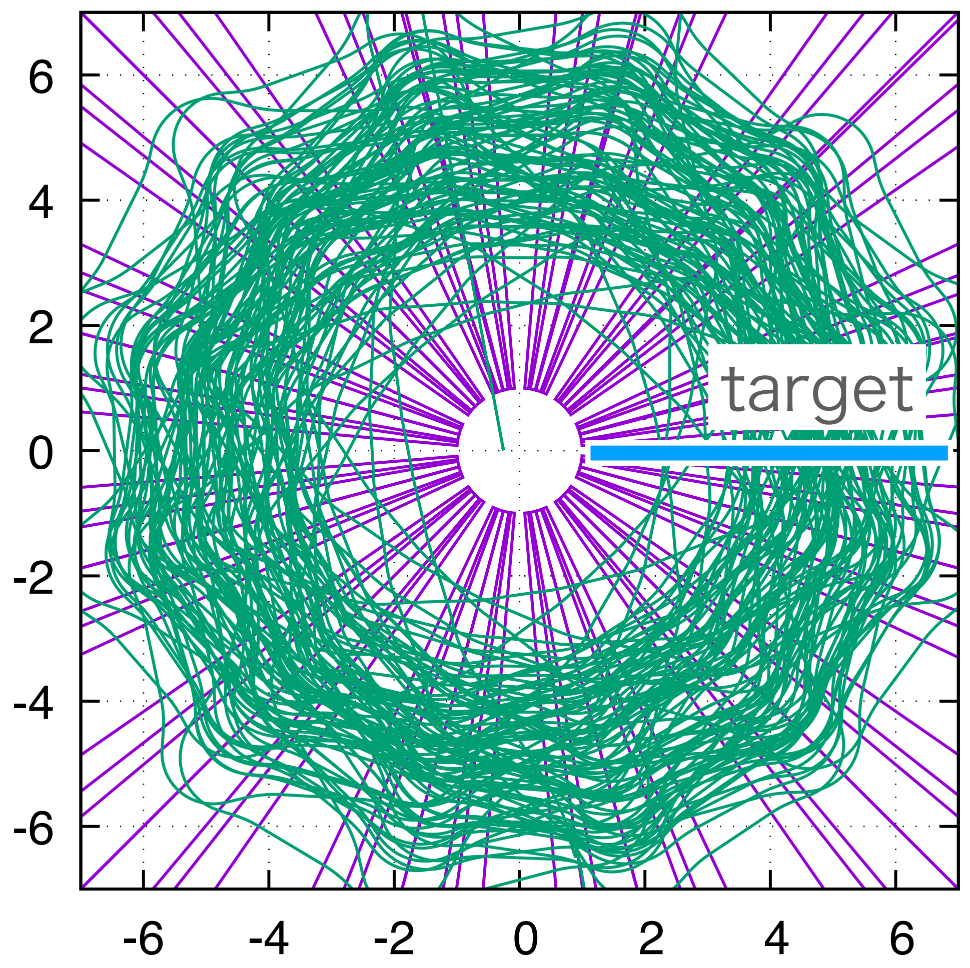

- **betatron amplitudes change turn by turn**

increase the k value

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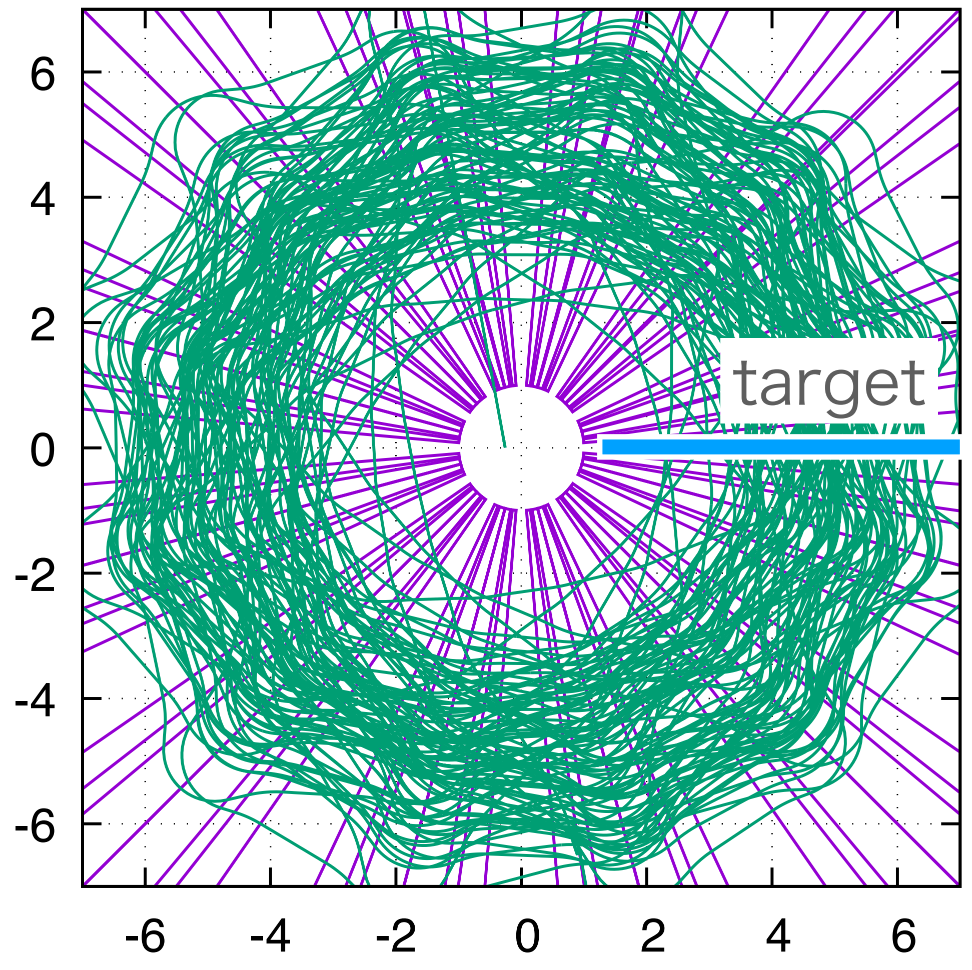

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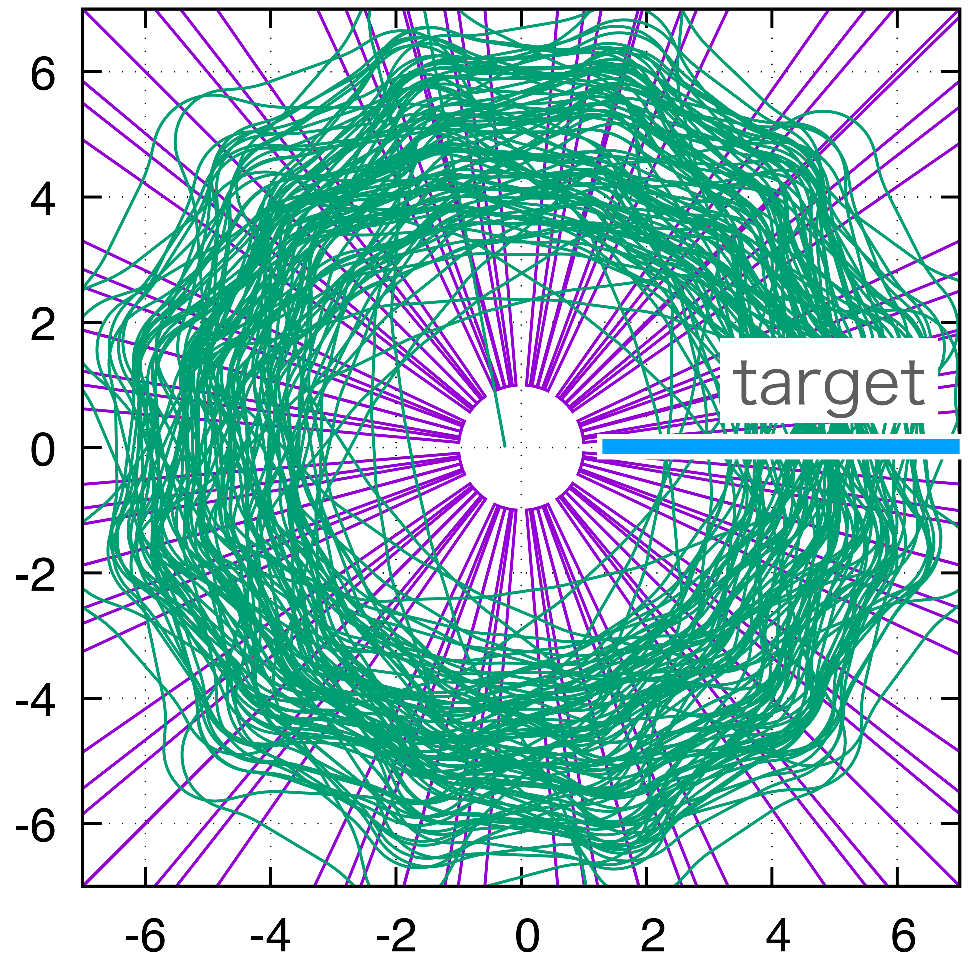

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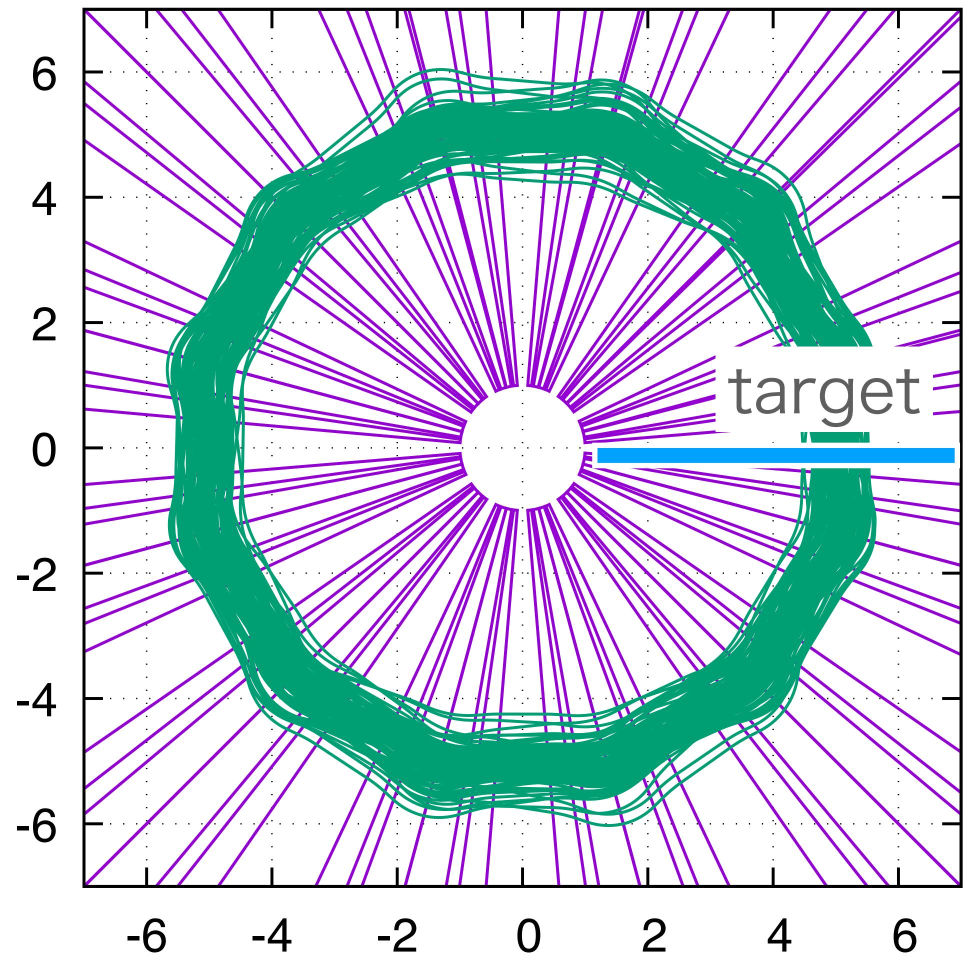

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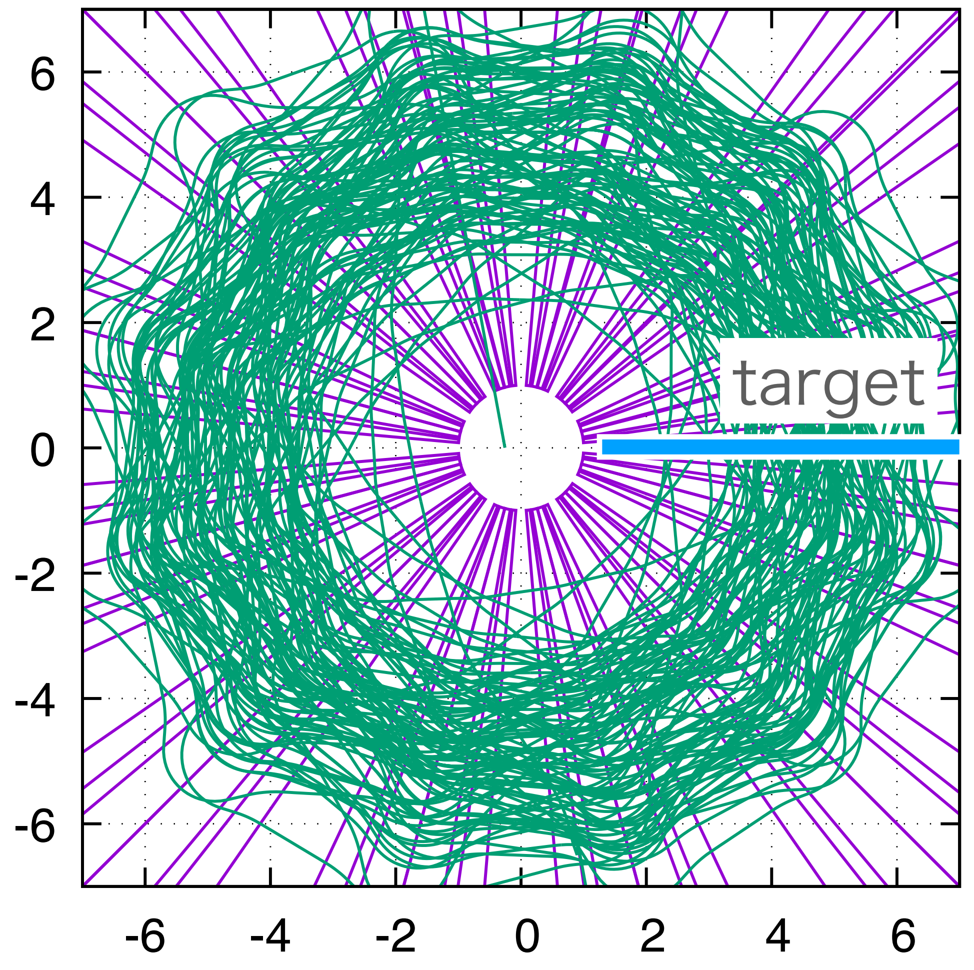

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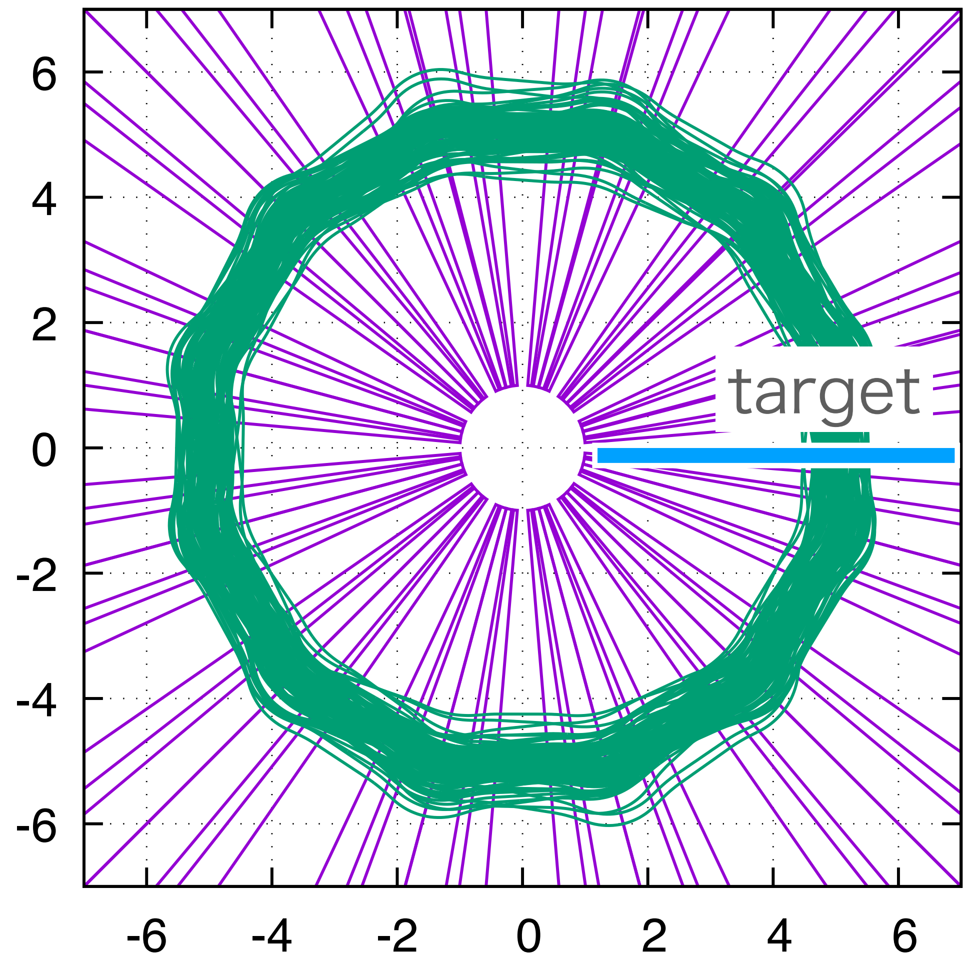

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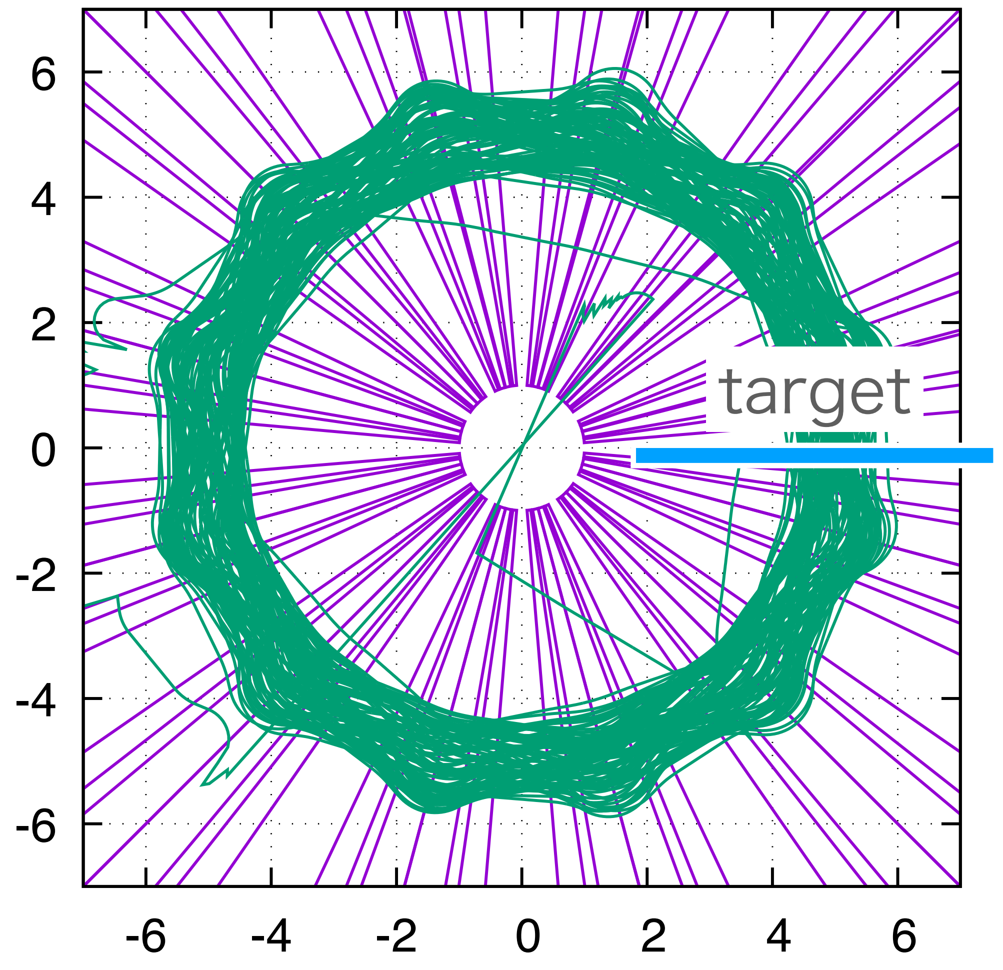

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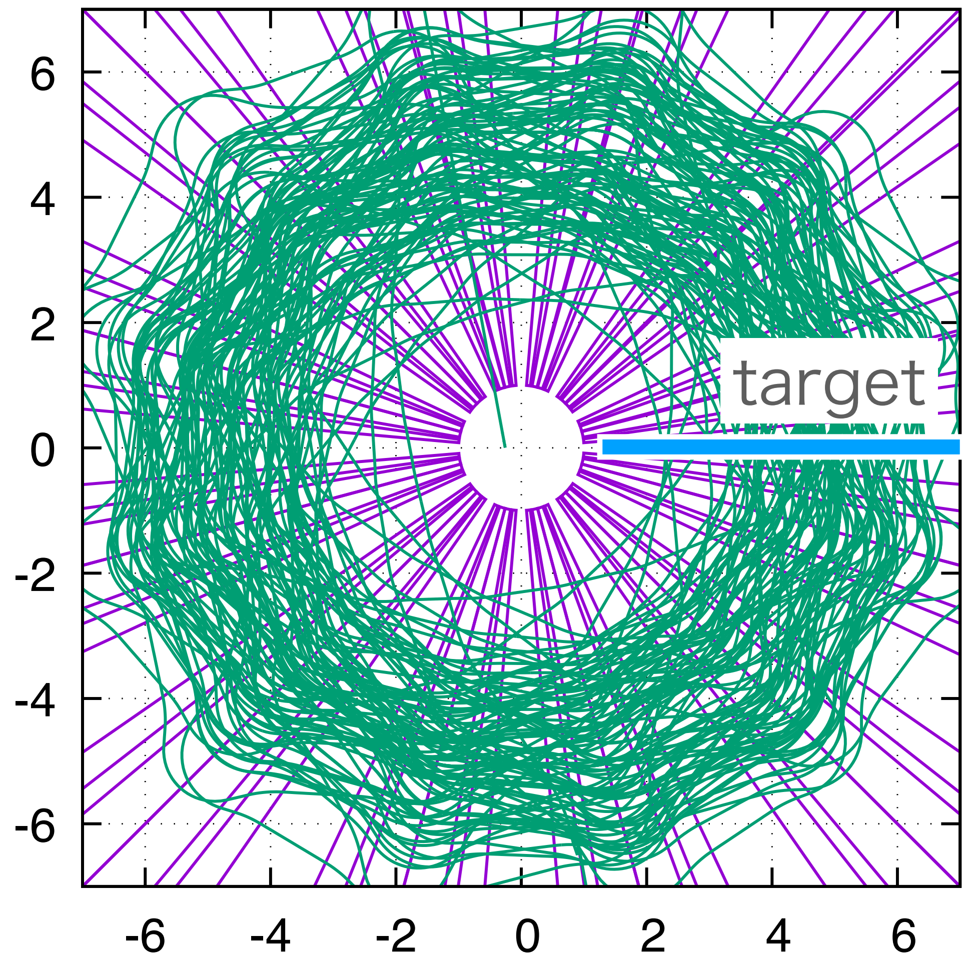

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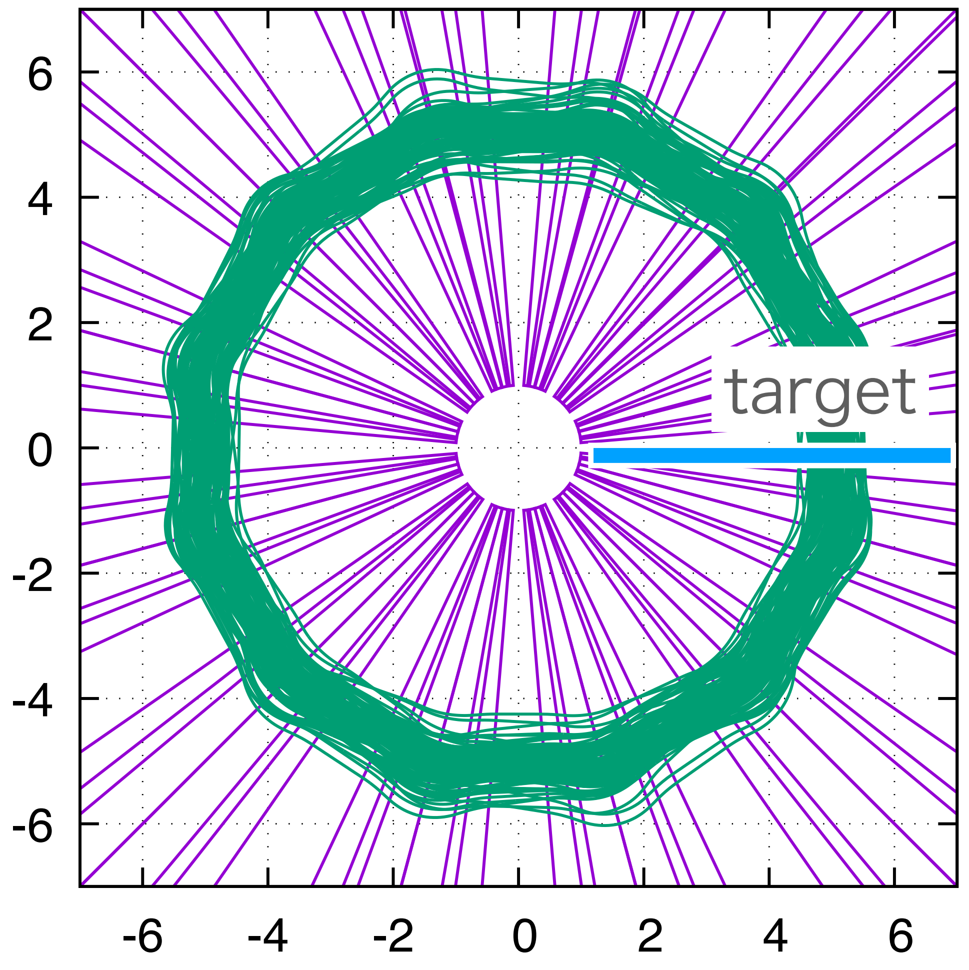

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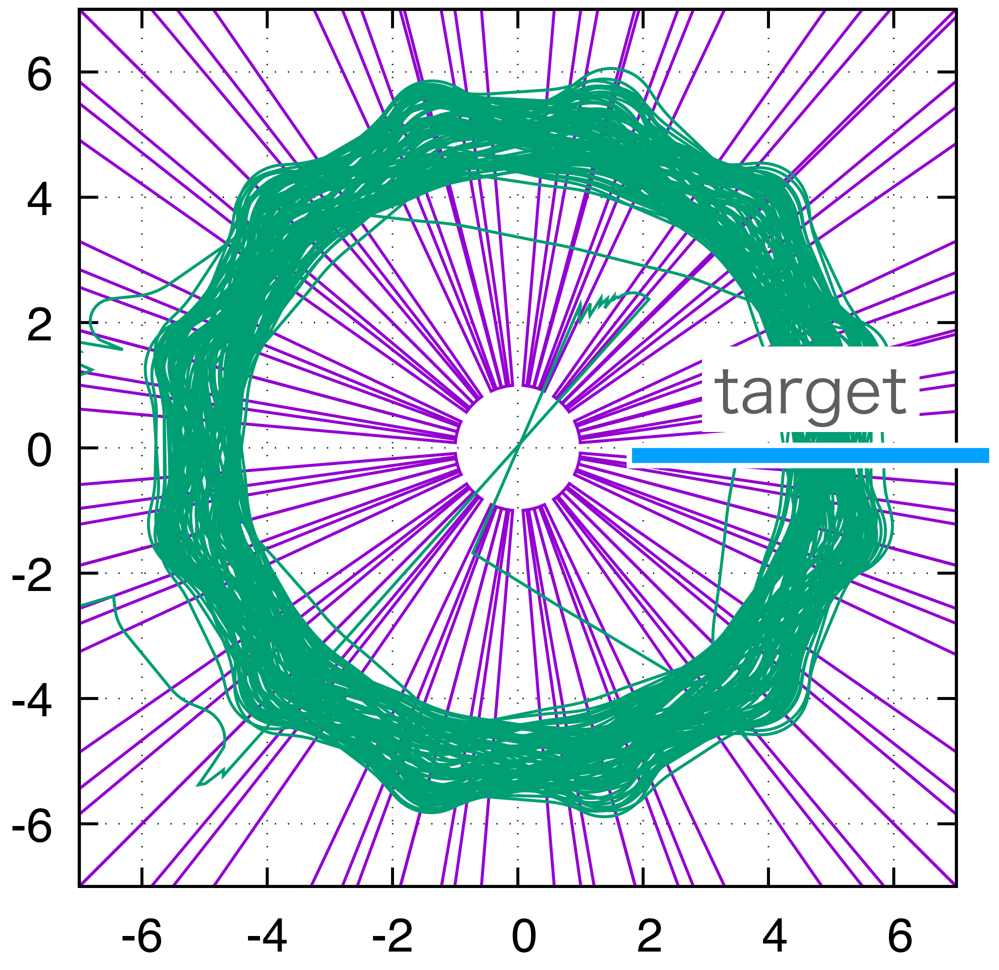

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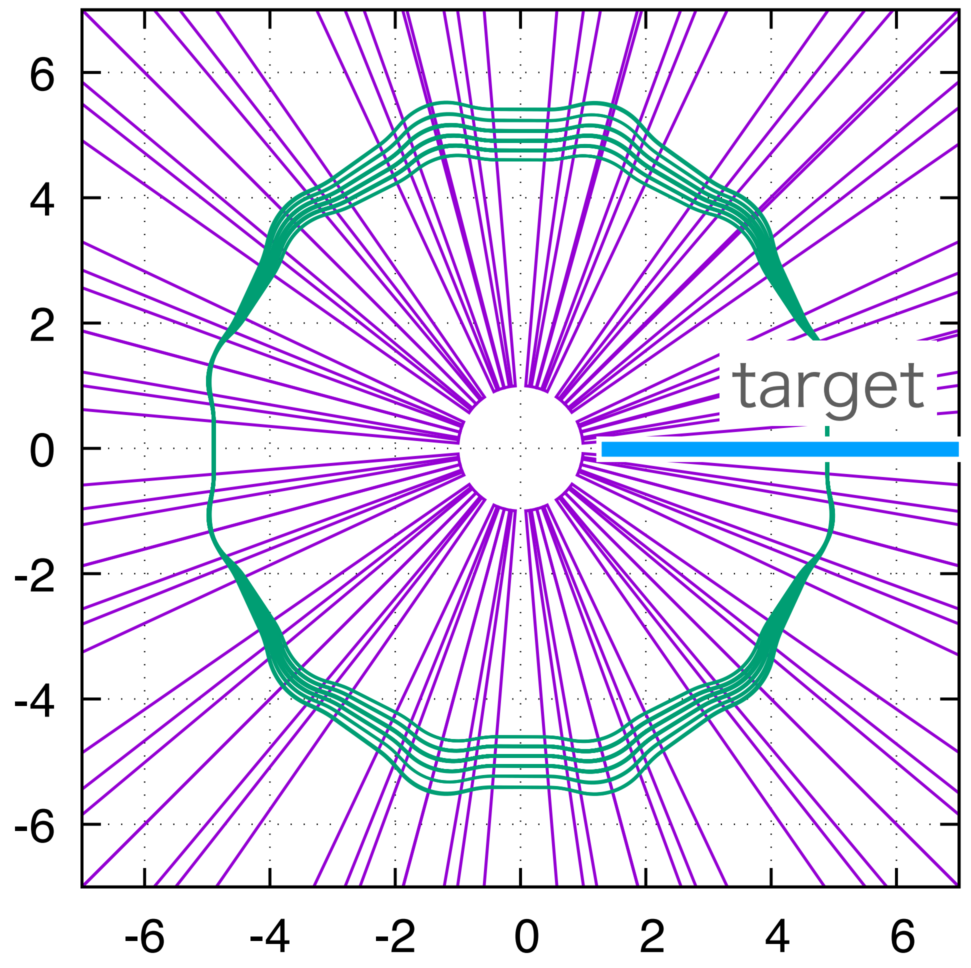

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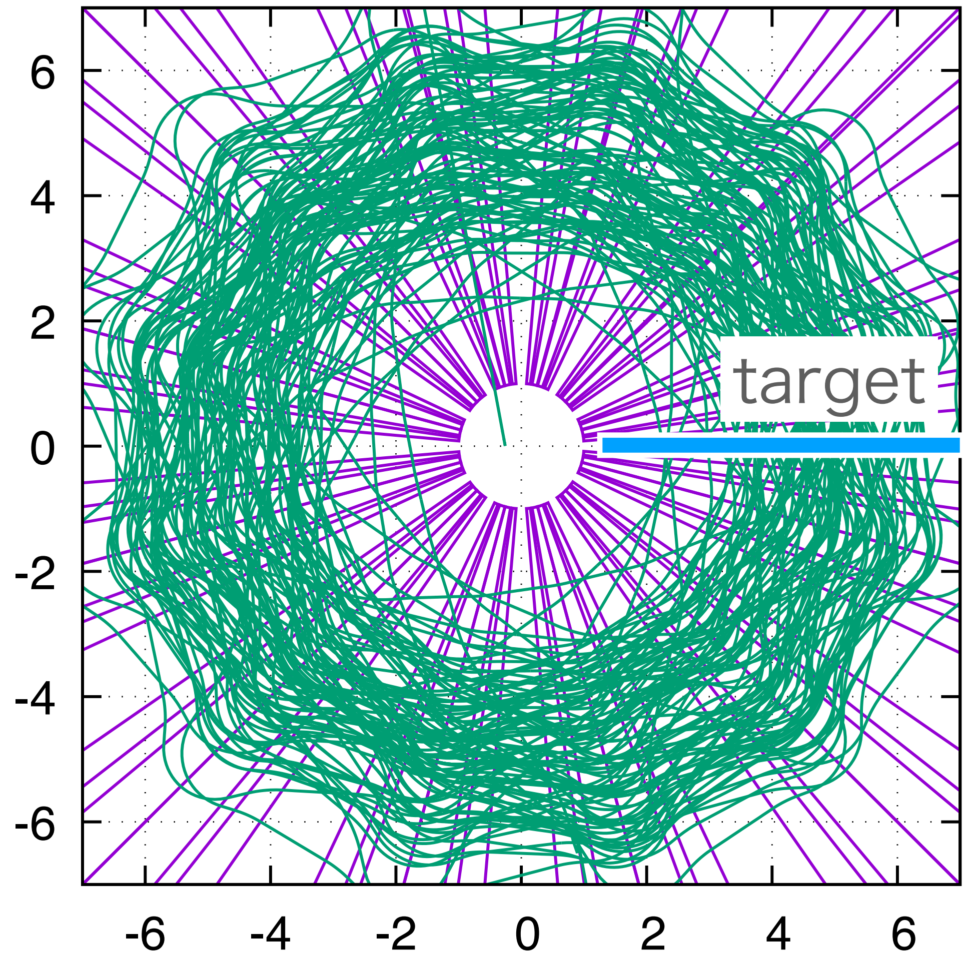

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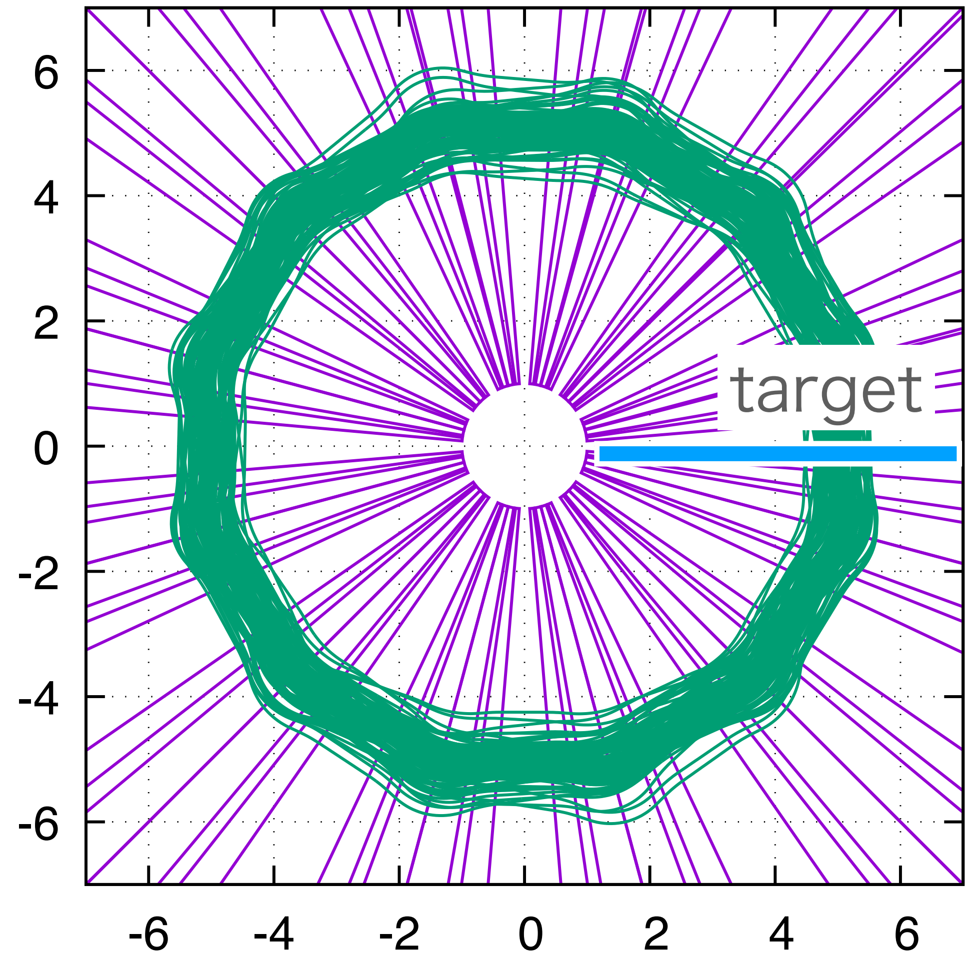

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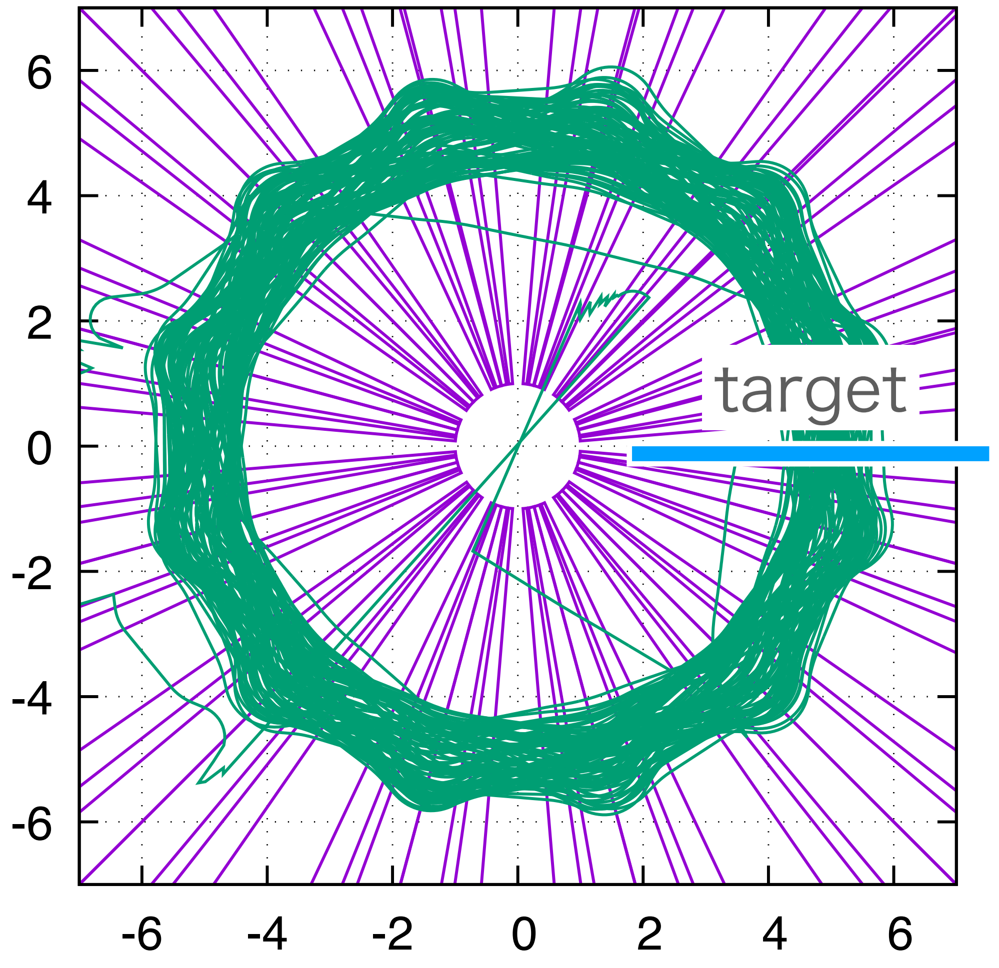

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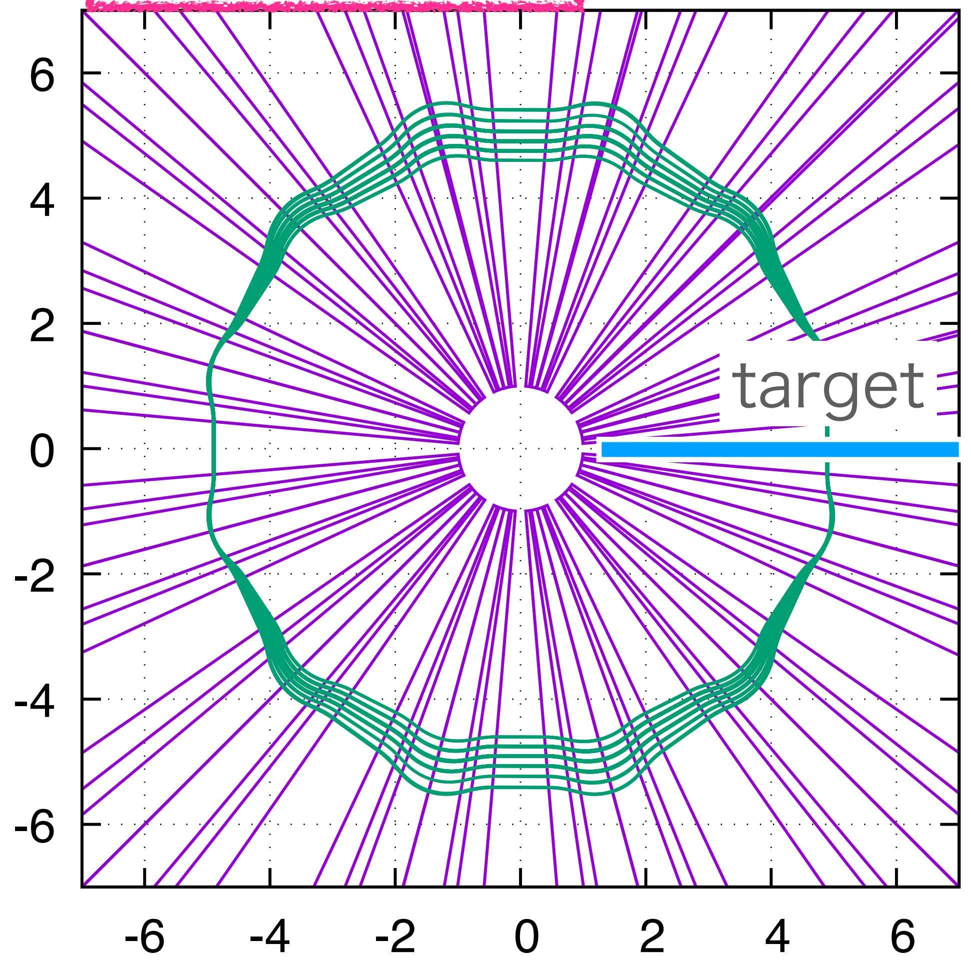

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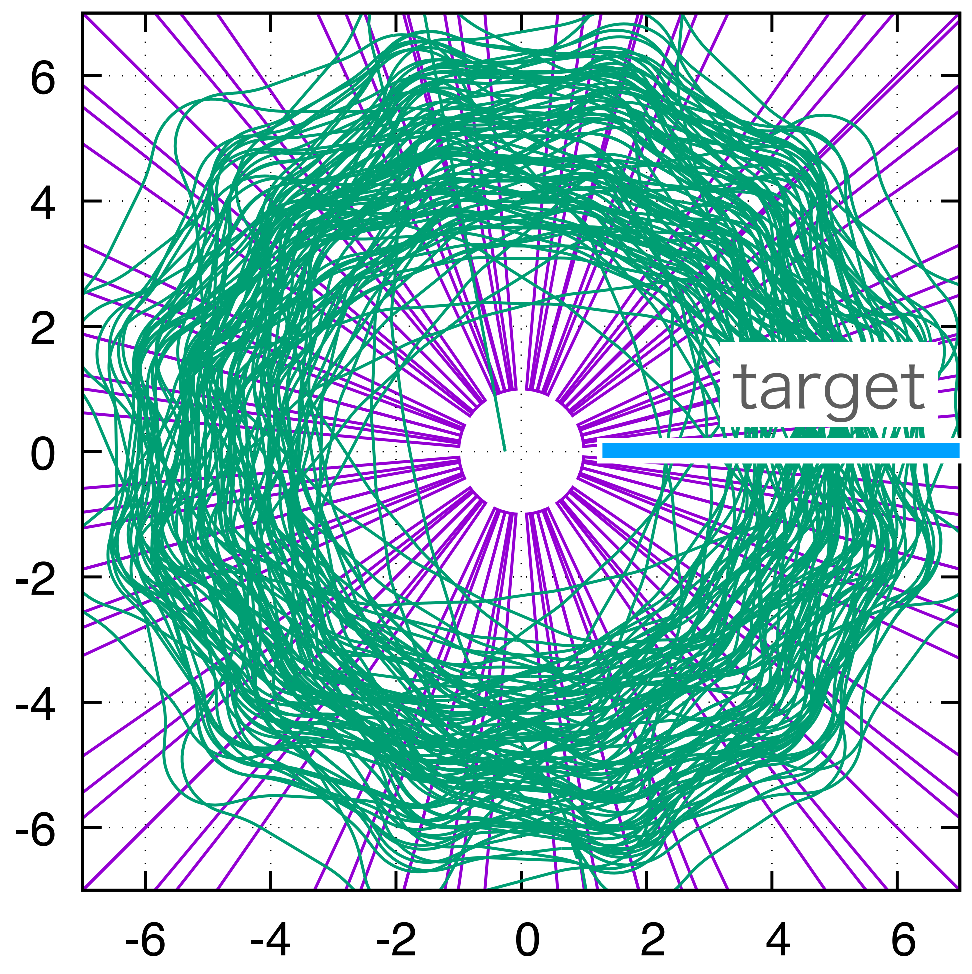

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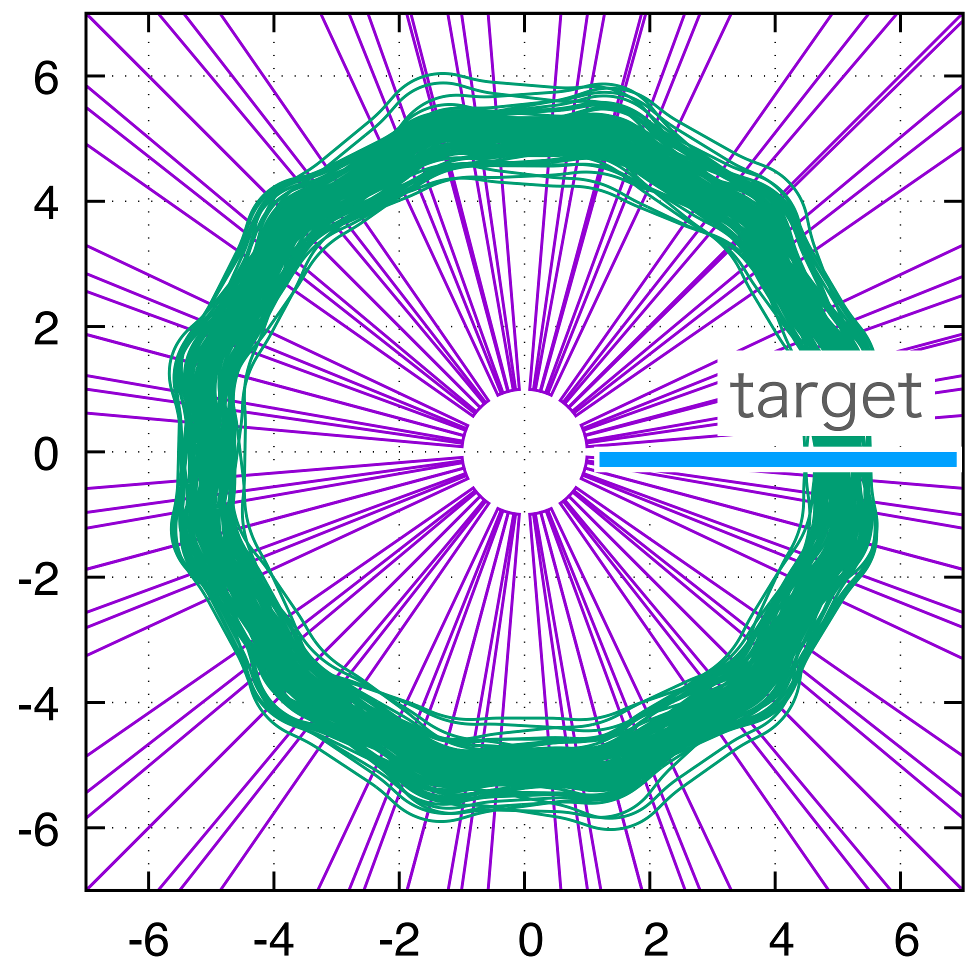

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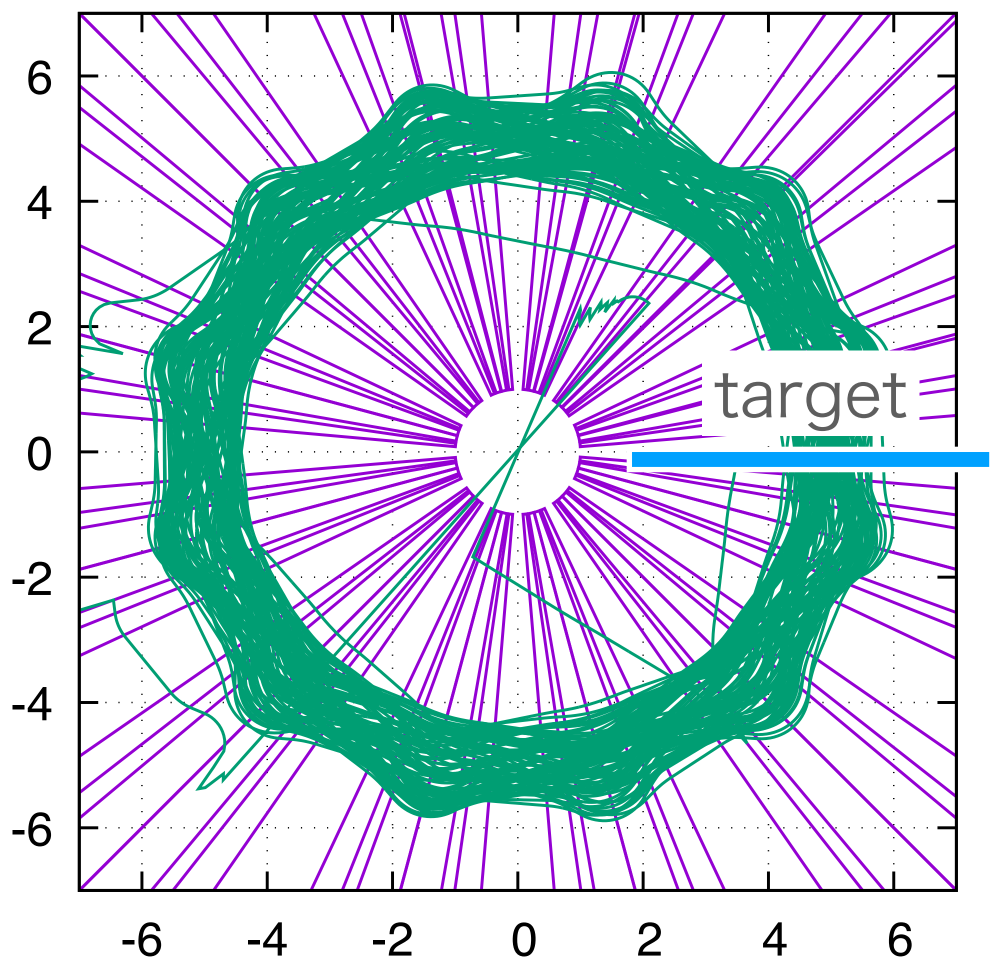

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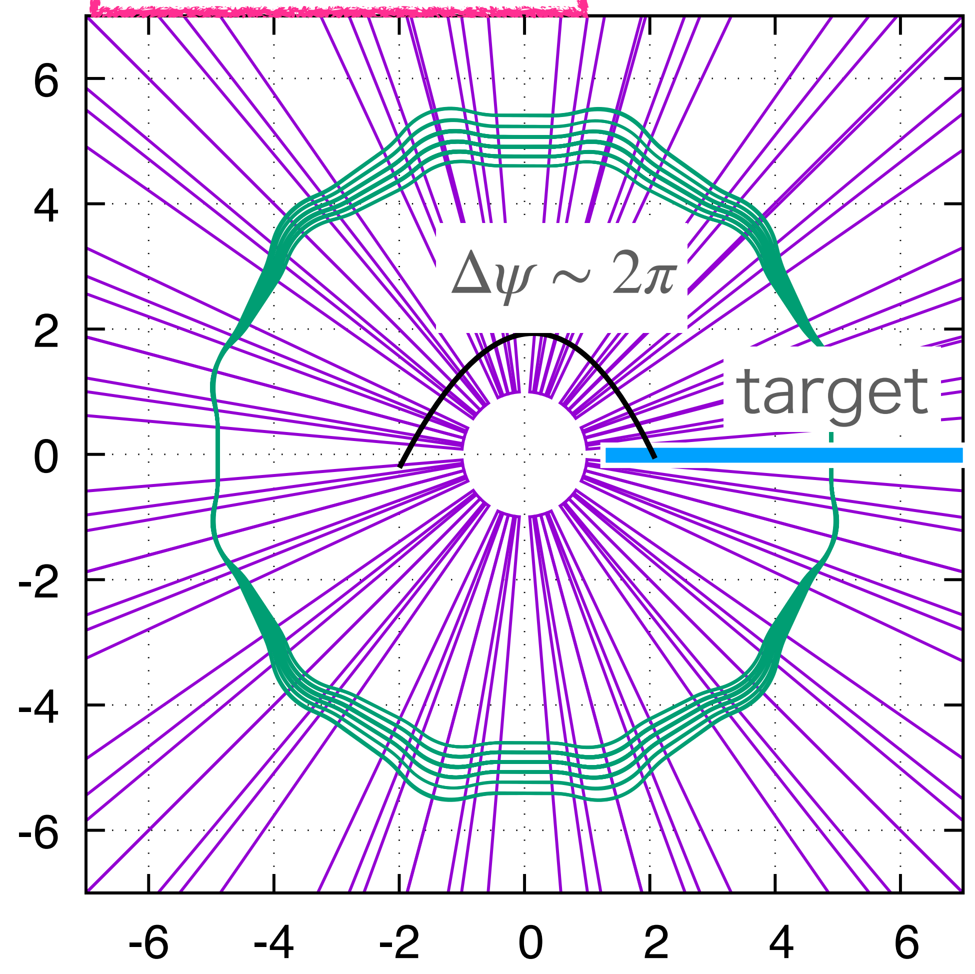

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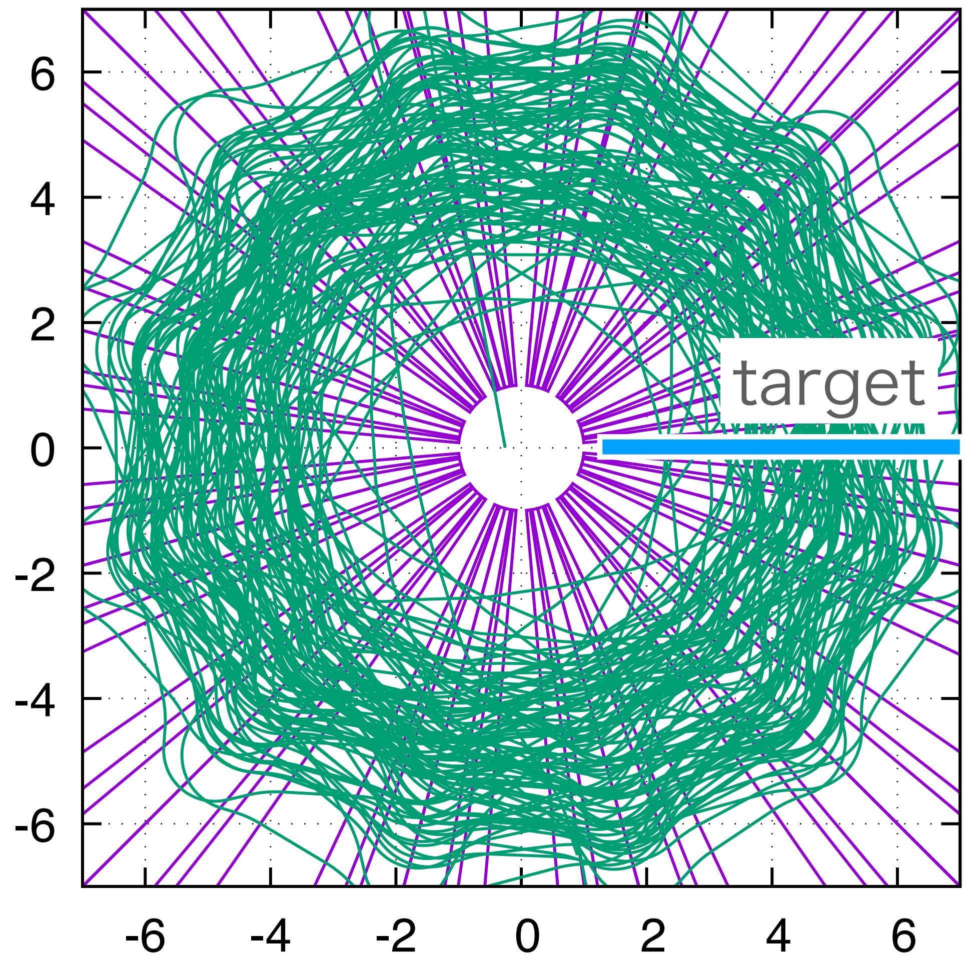

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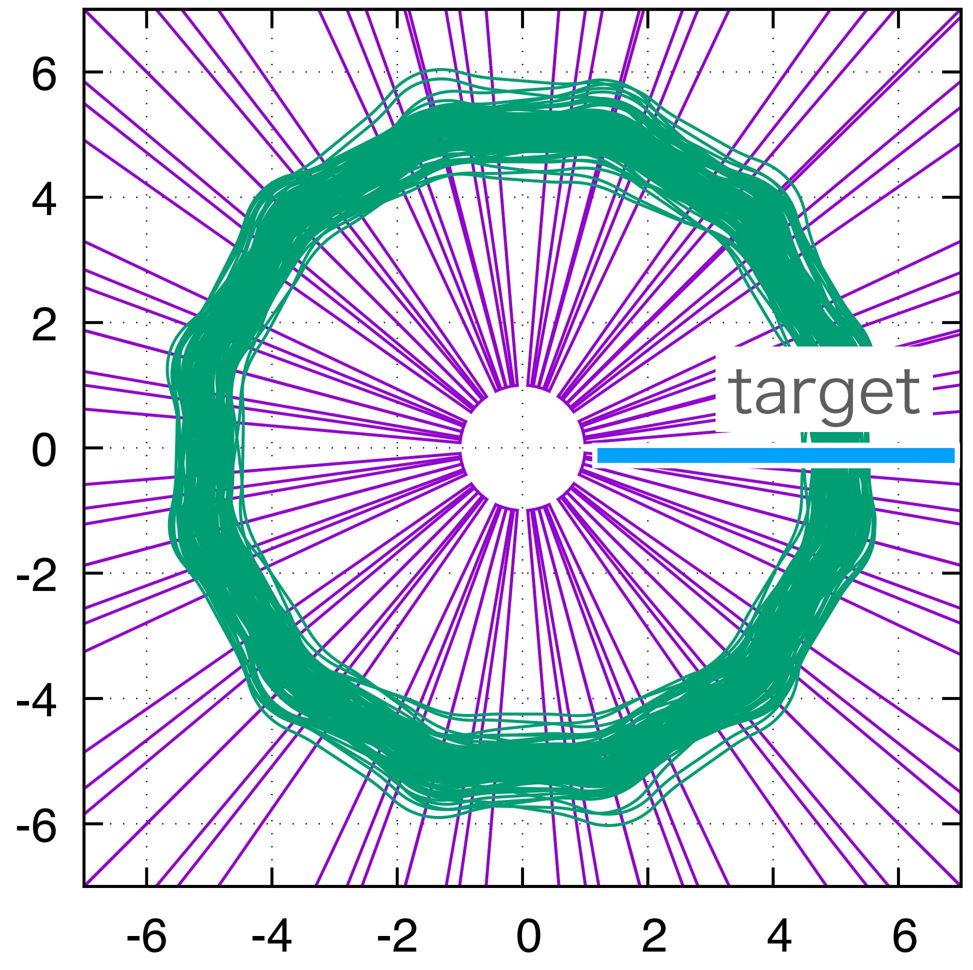

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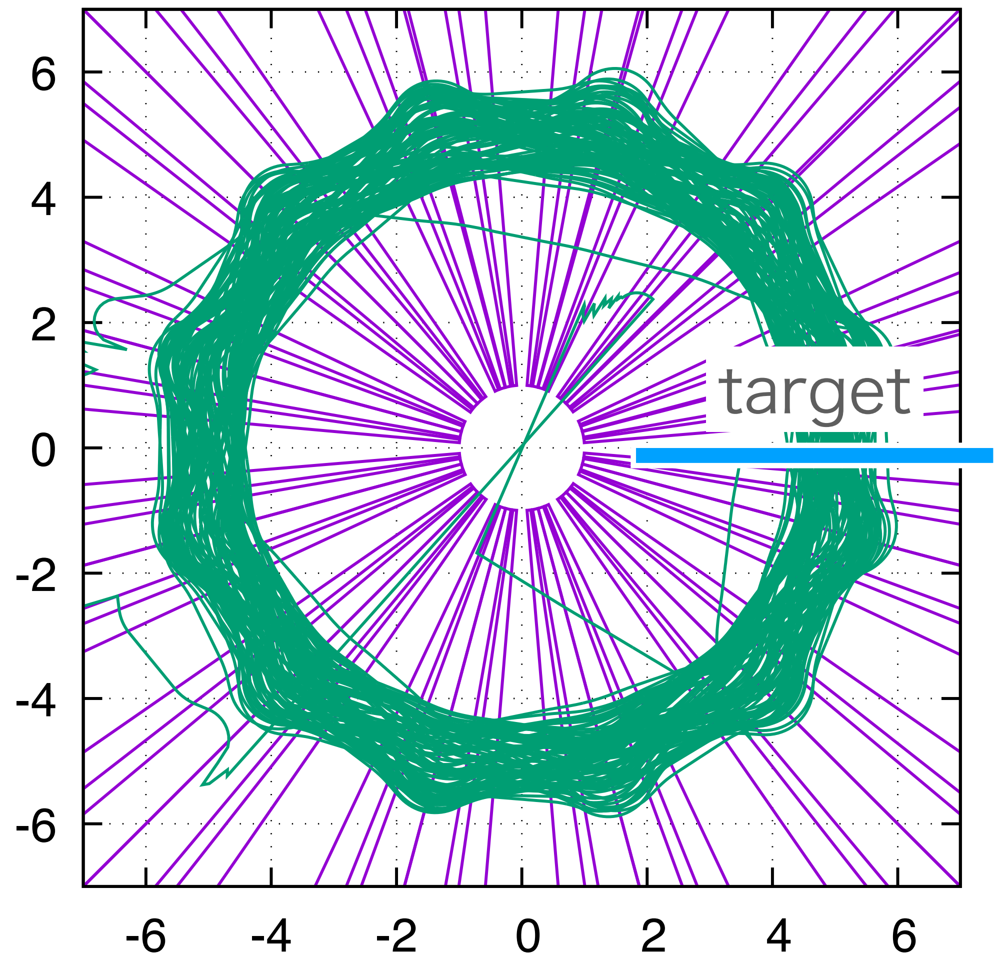

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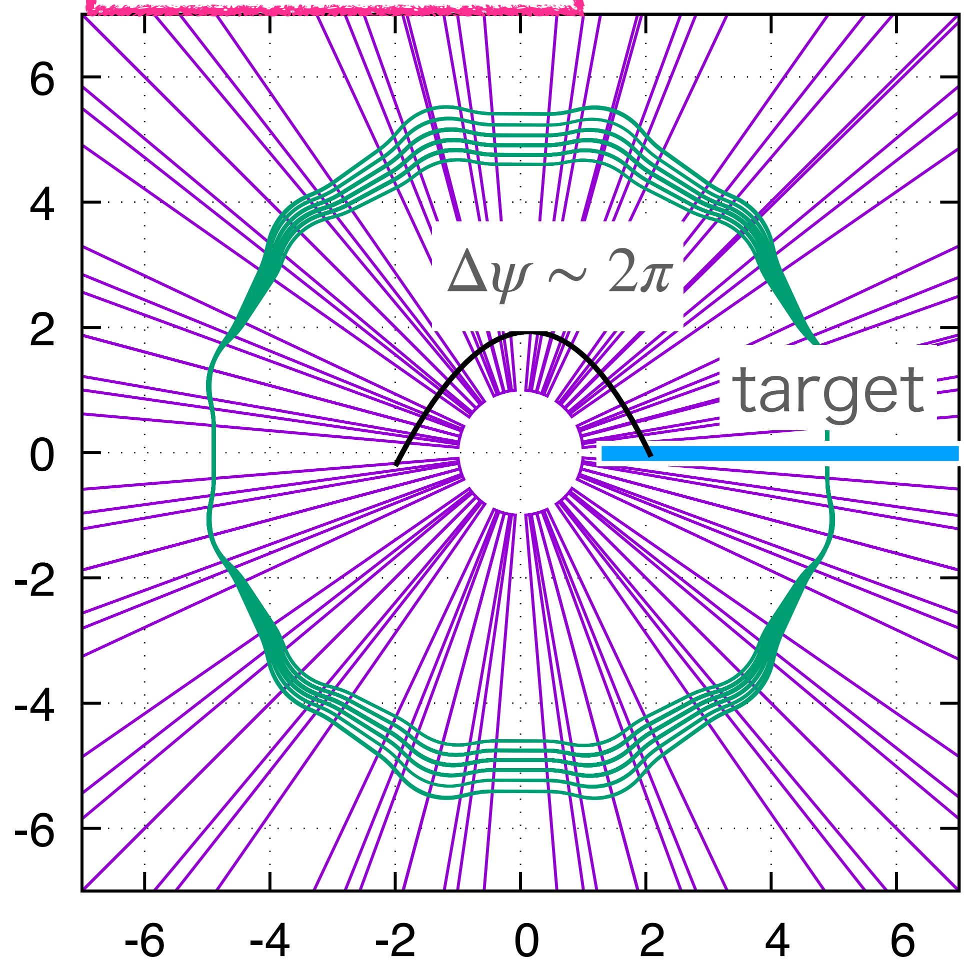

$D_x \sim 0$

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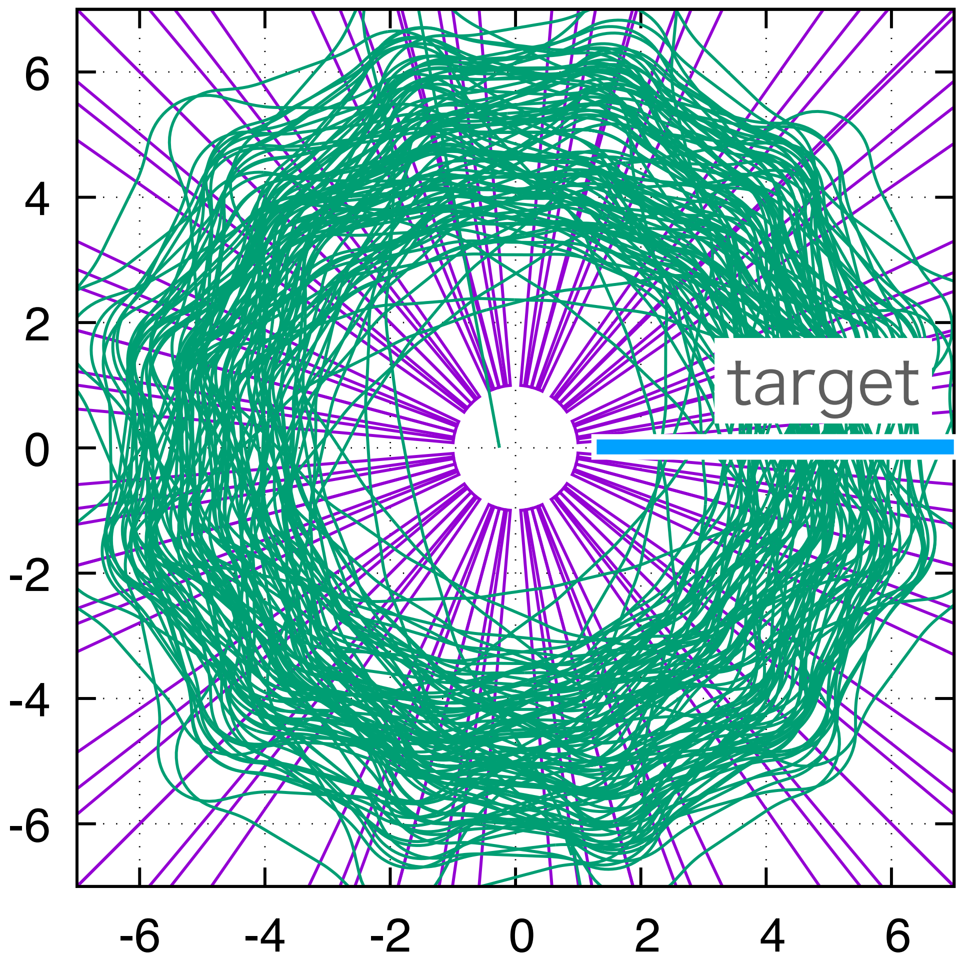

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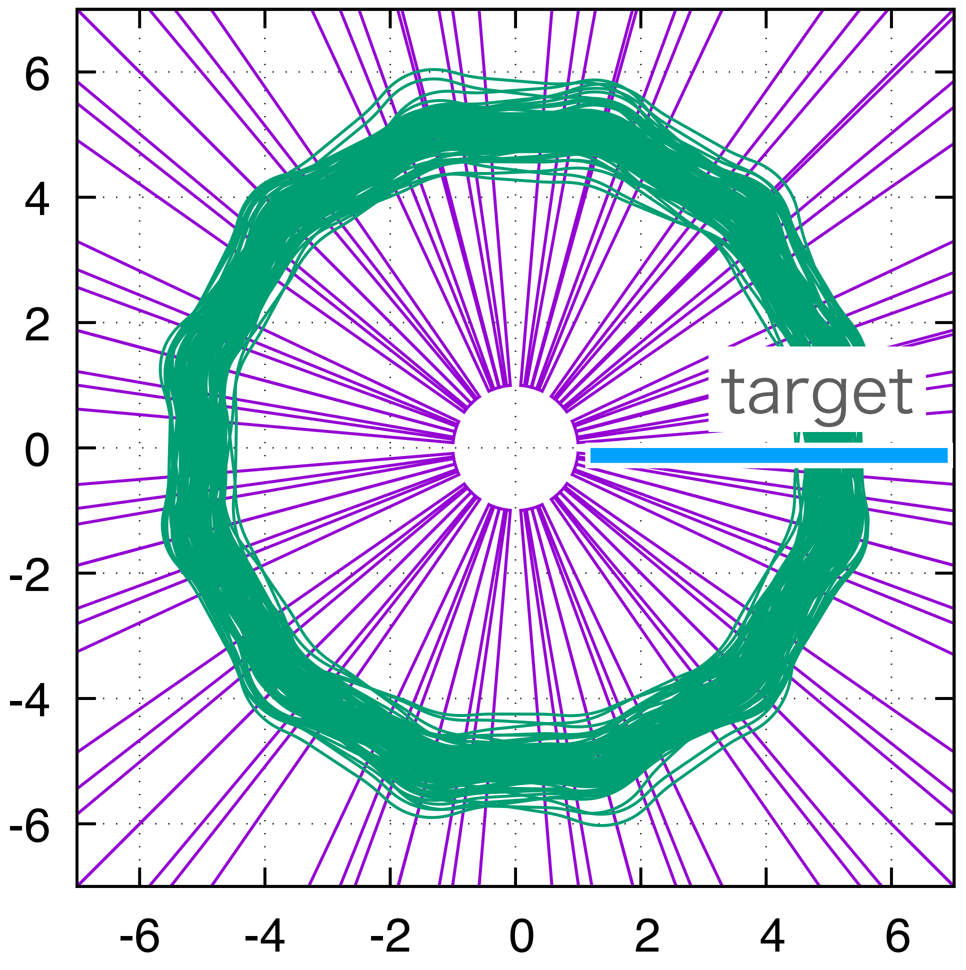
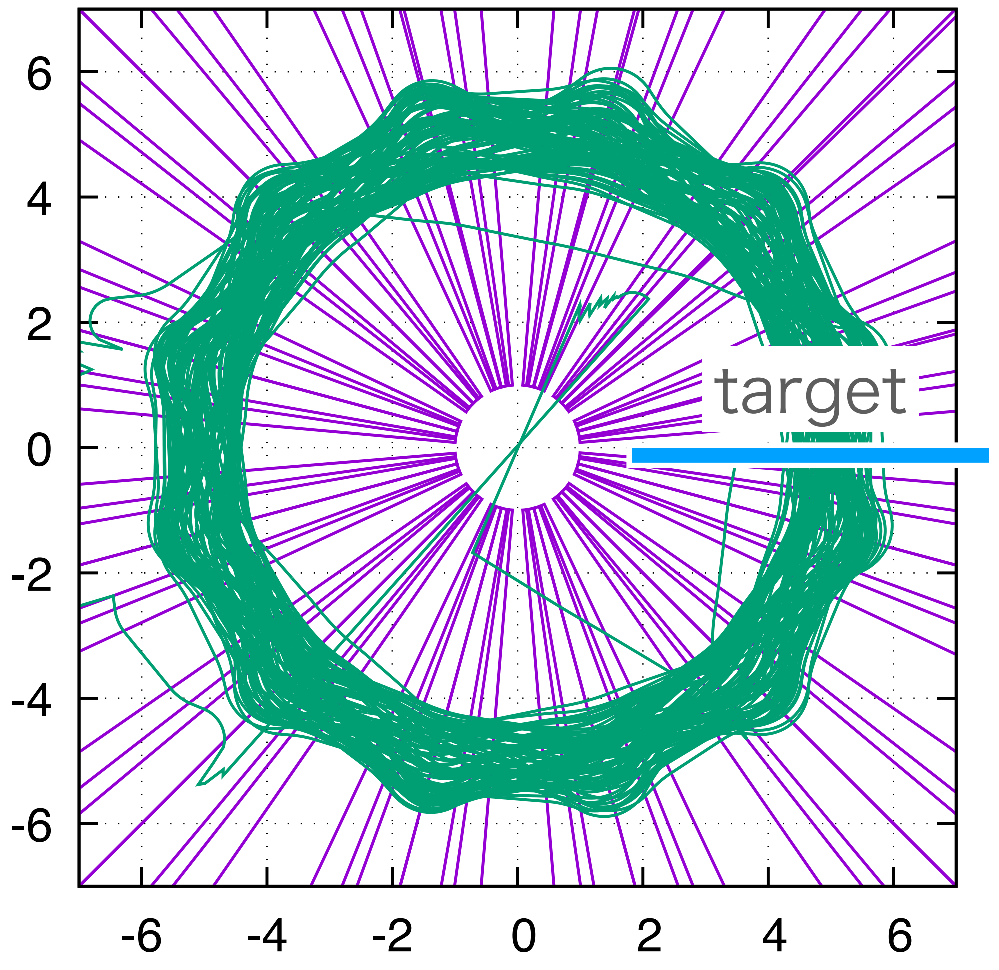
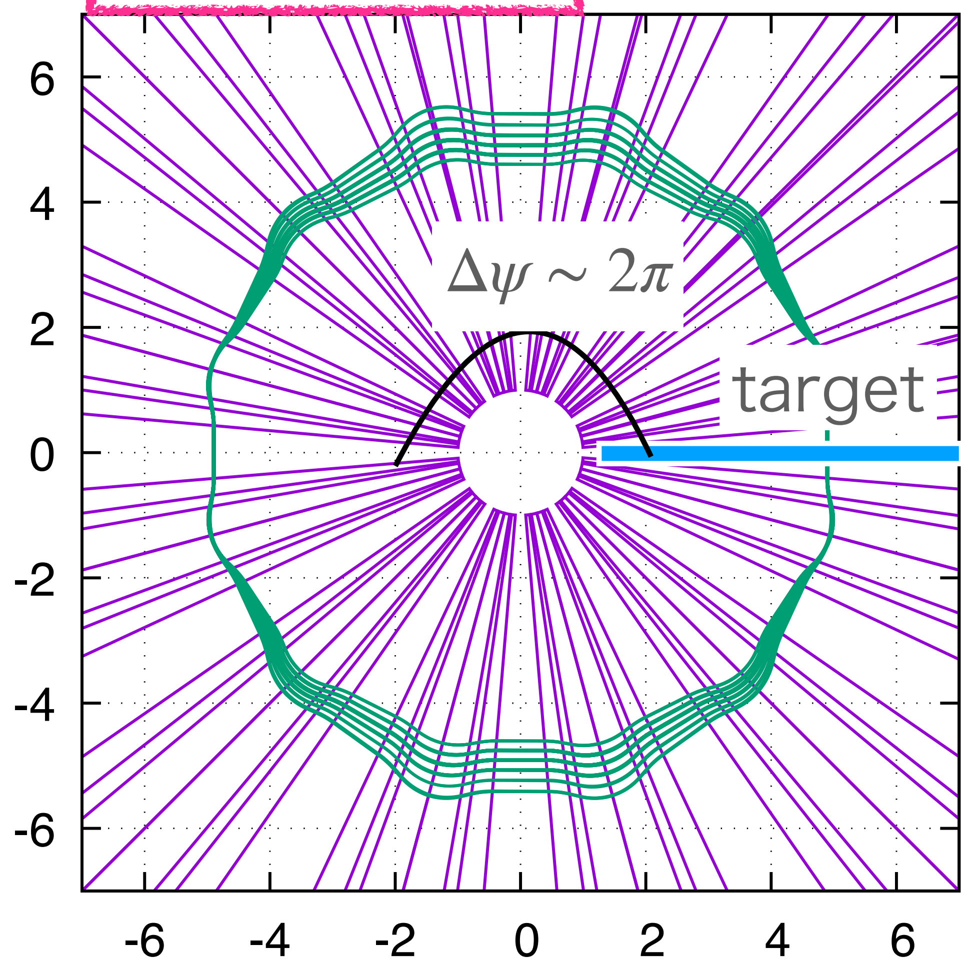


$k = 4.1, \ \nu_x = 2.52, \ \nu_y = 1.62$

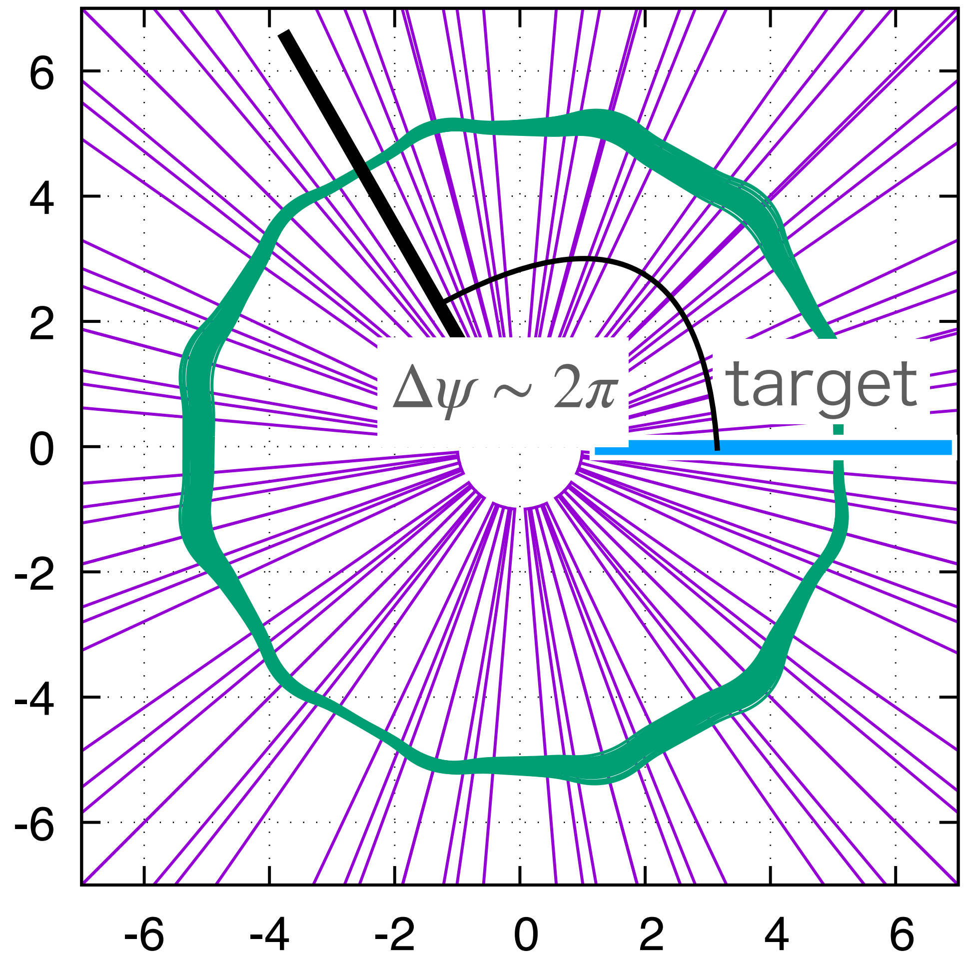


$k = 2.14, \ \nu_x = 1.998, \ \nu_y = 3.090$



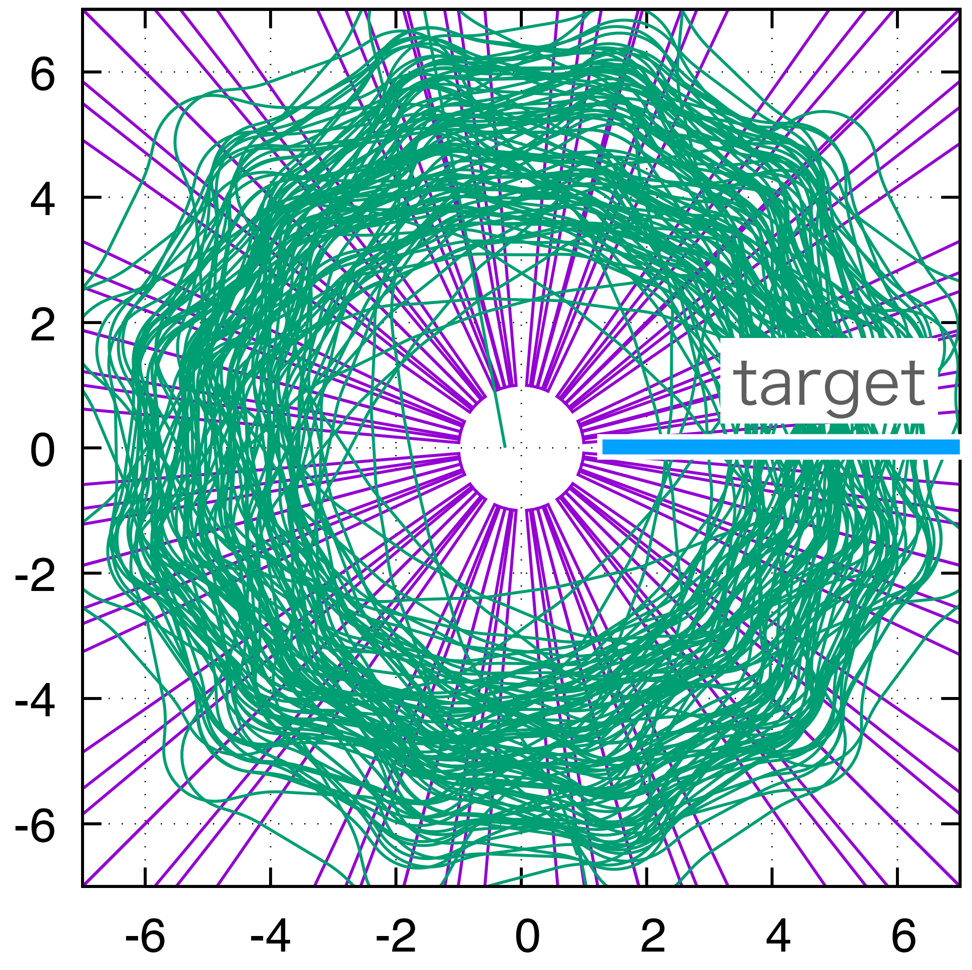
$D_x \sim 0$

$k = 5.57, \ \nu_x = 2.956, \ \nu_y = 1.245$

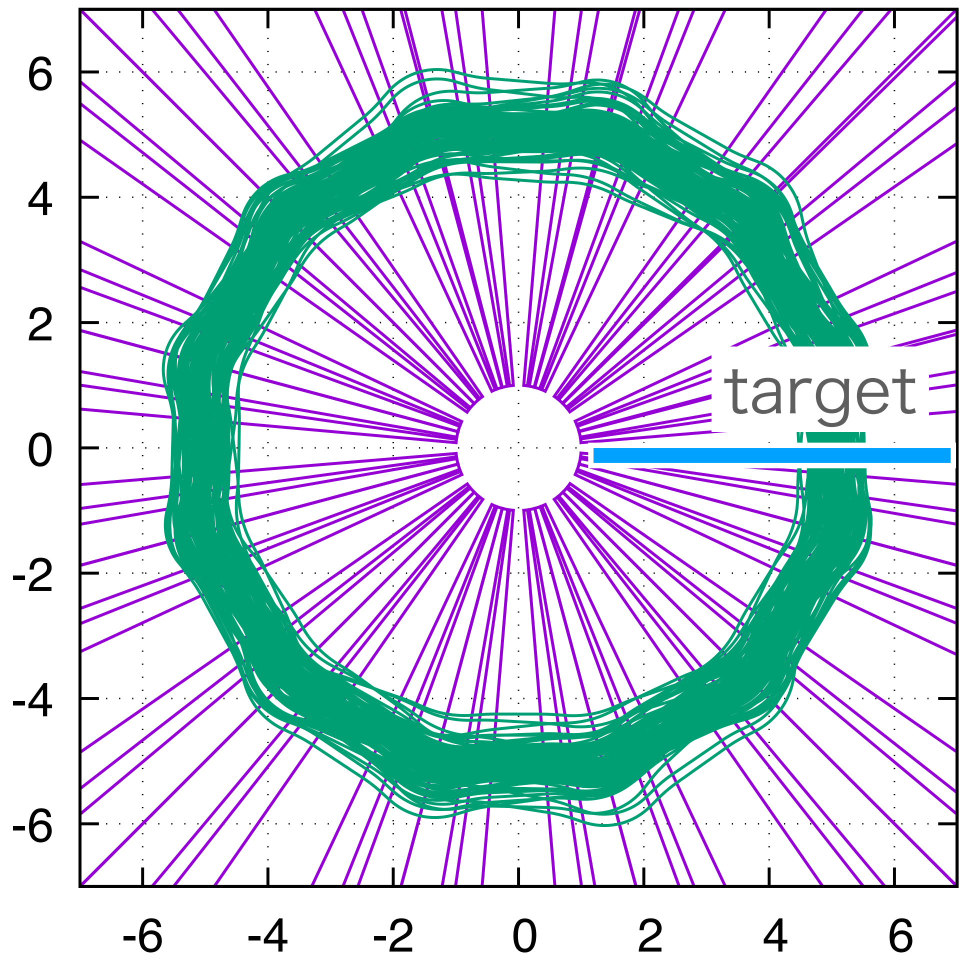


increase the k value

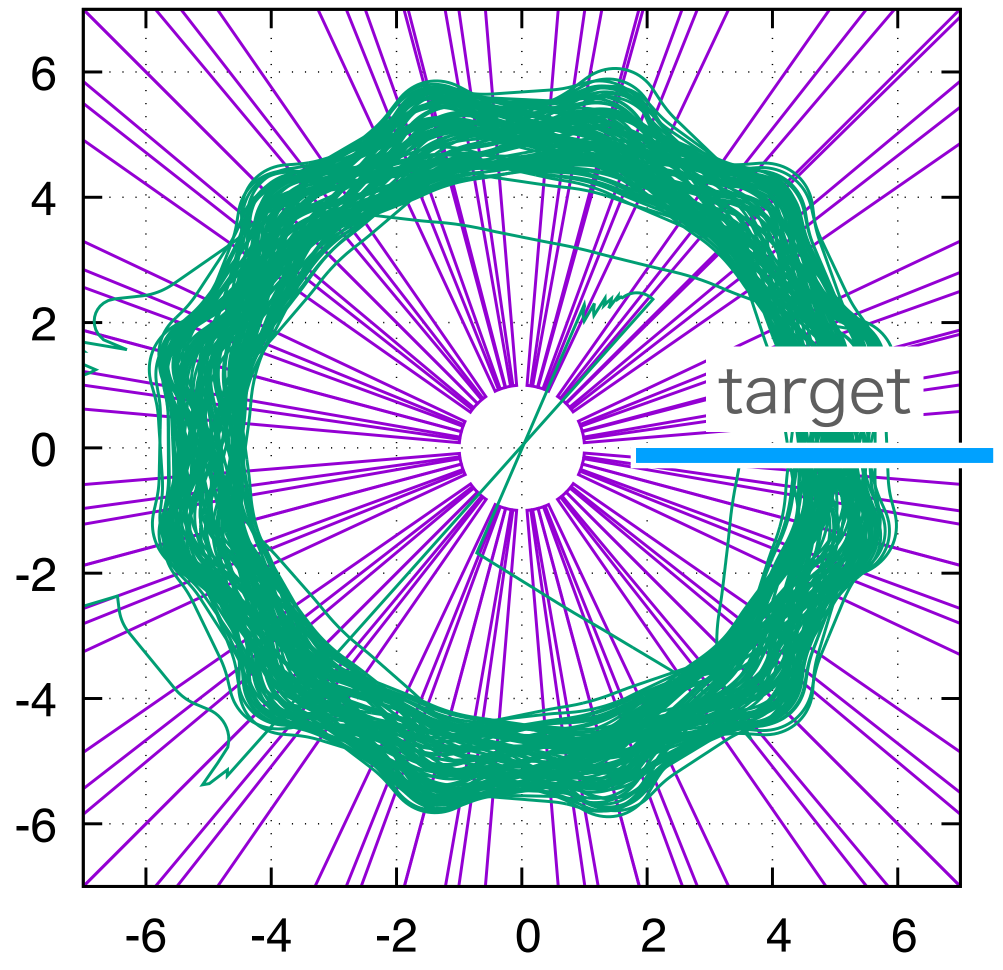
$k = 1.1,\ \ \nu_x = 1.53,\ \ \nu_y = 2.27$



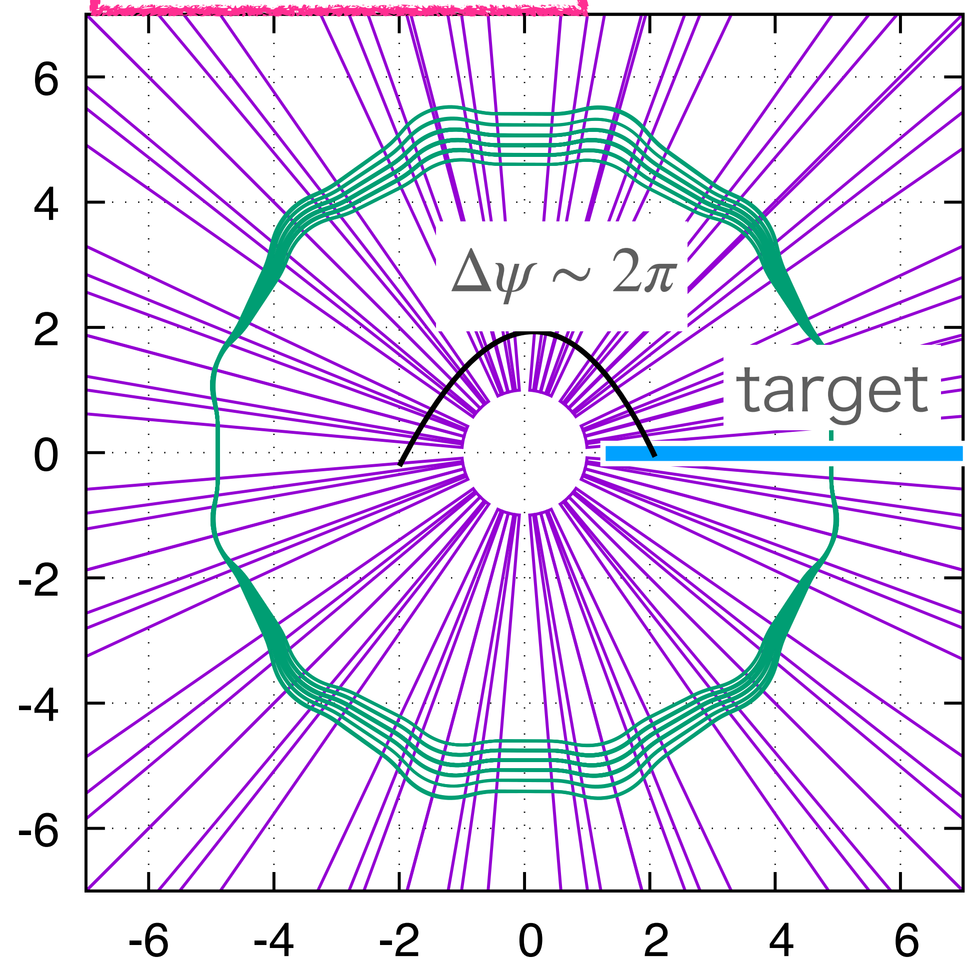
$k = 2.1,\ \ \nu_x = 1.89,\ \ \nu_y = 2.07$



$k = 4.1,\ \ \nu_x = 2.52,\ \ \nu_y = 1.62$



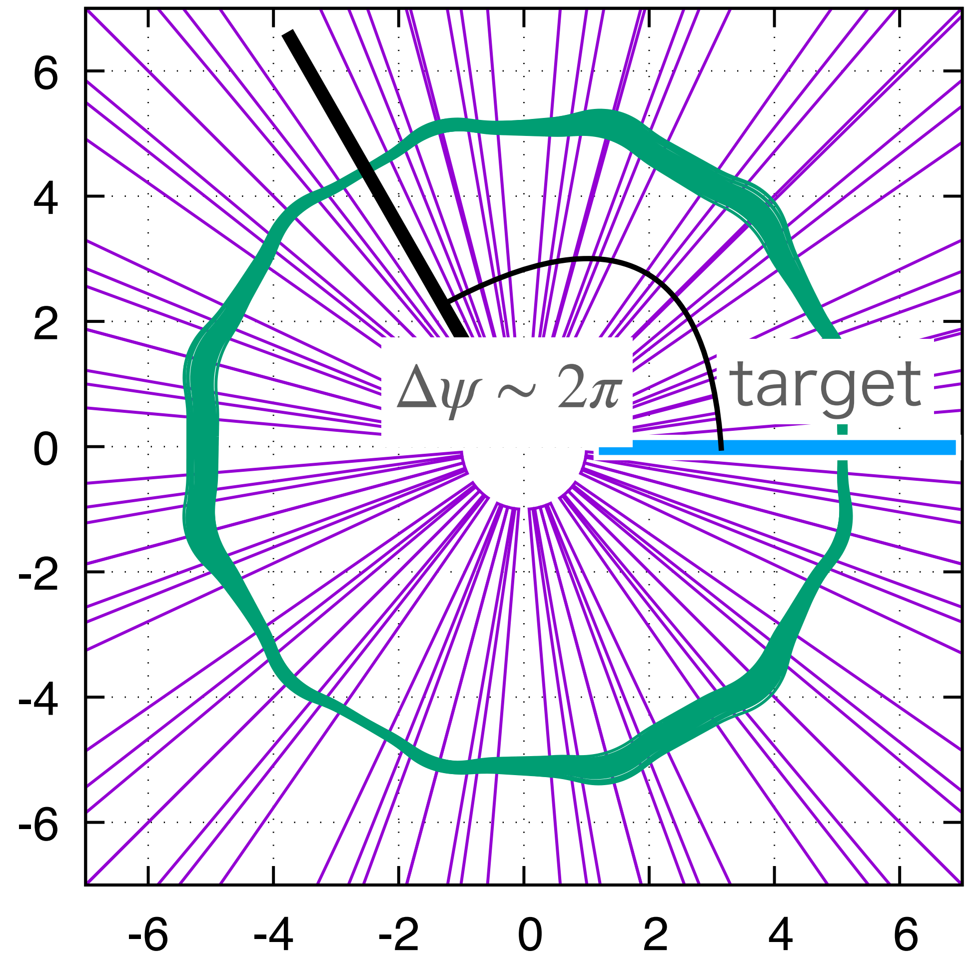
$k = 2.14,\ \ \nu_x = 1.998,\ \ \nu_y = 3.090$



$D_x \sim 0$

$D'_x \sim 0$ at the target

$k = 5.57,\ \ \nu_x = 2.956,\ \ \nu_y = 1.245$



in ordinary synchrotron lattice

- Betatron amplitude variations caused by COD fluctuation due to the charge state variation can be suppressed by making dispersion suppressed sections and locating the target in that section as well as FFA lattice with an integer horizontal tune.
- Betatron amplitude change caused by ellipse fluctuation i.e. tune fluctuation coming from the higher order chromaticity, which doesn’t exist in “scaling” FFA rings.

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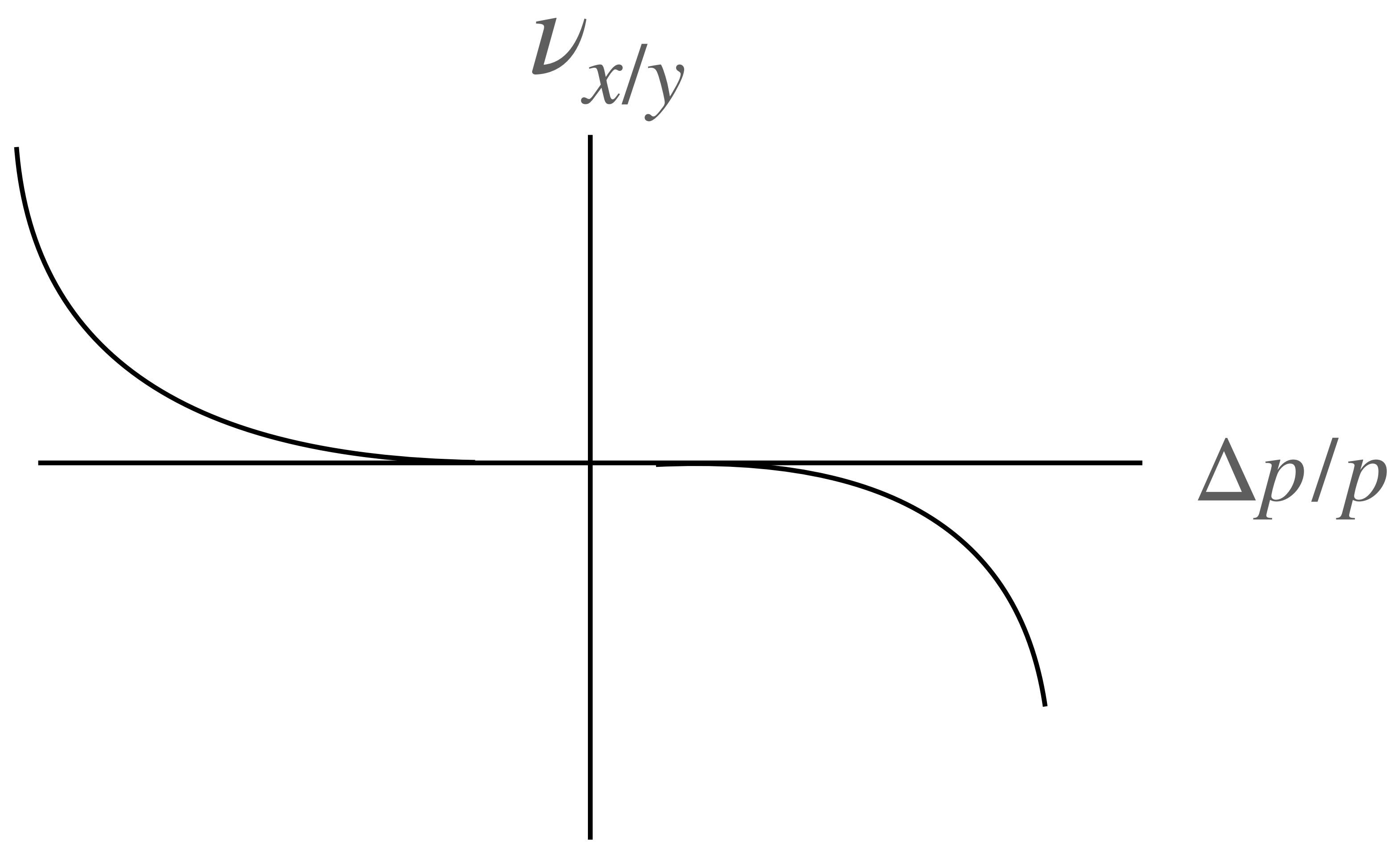

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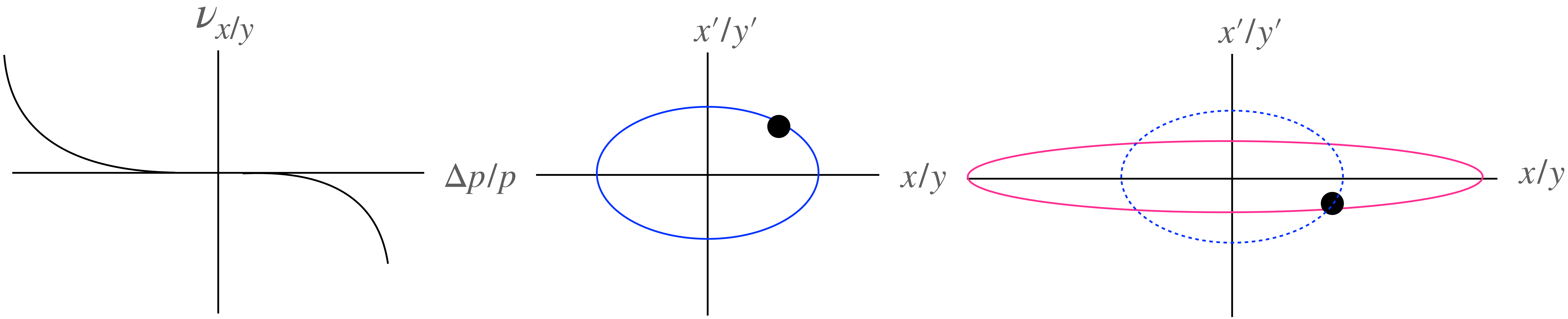

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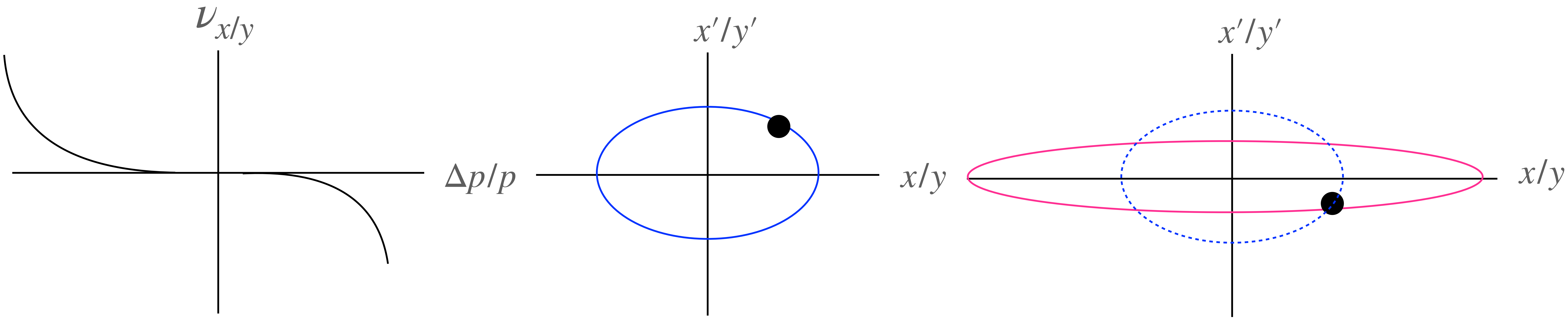

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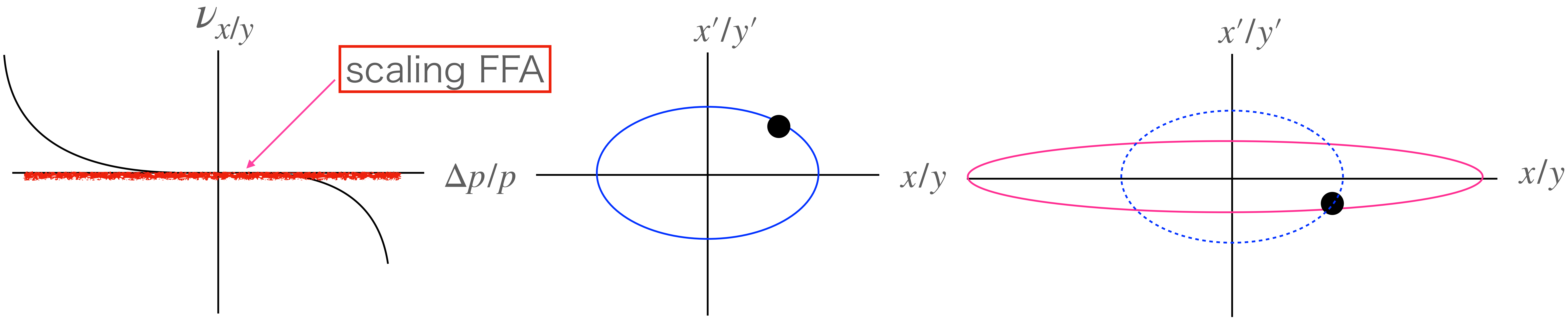

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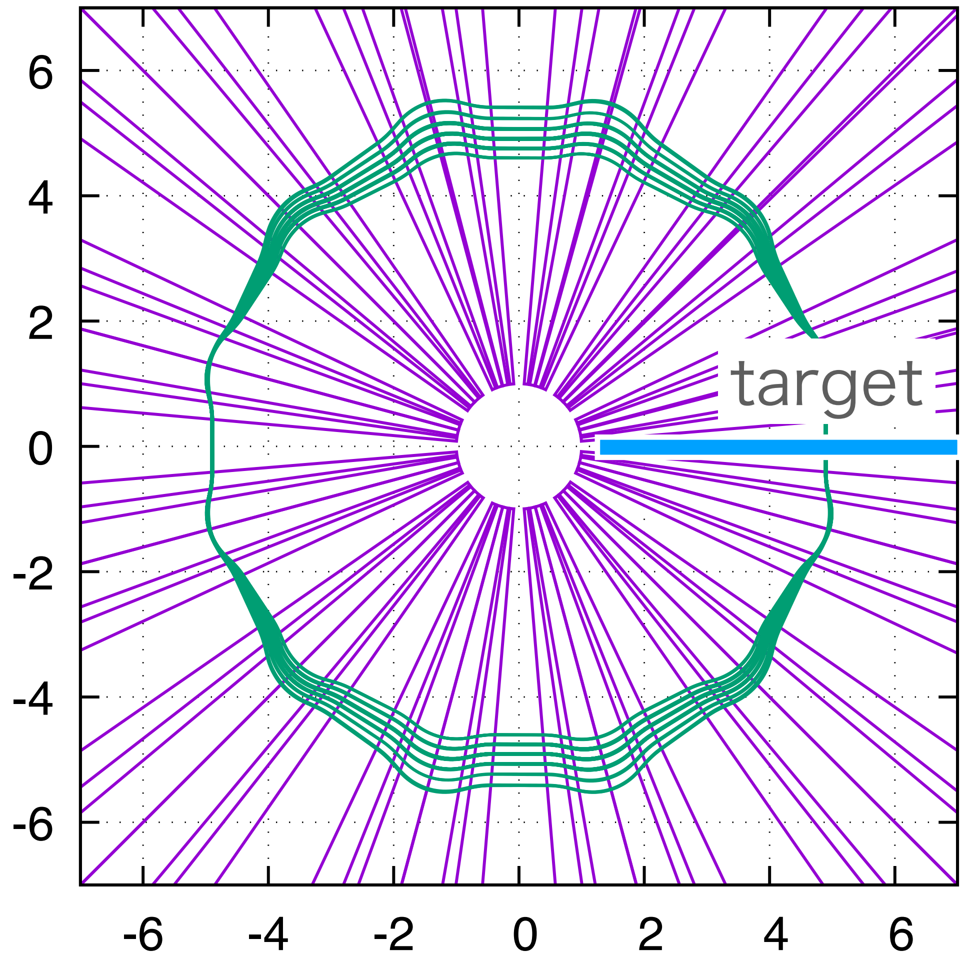
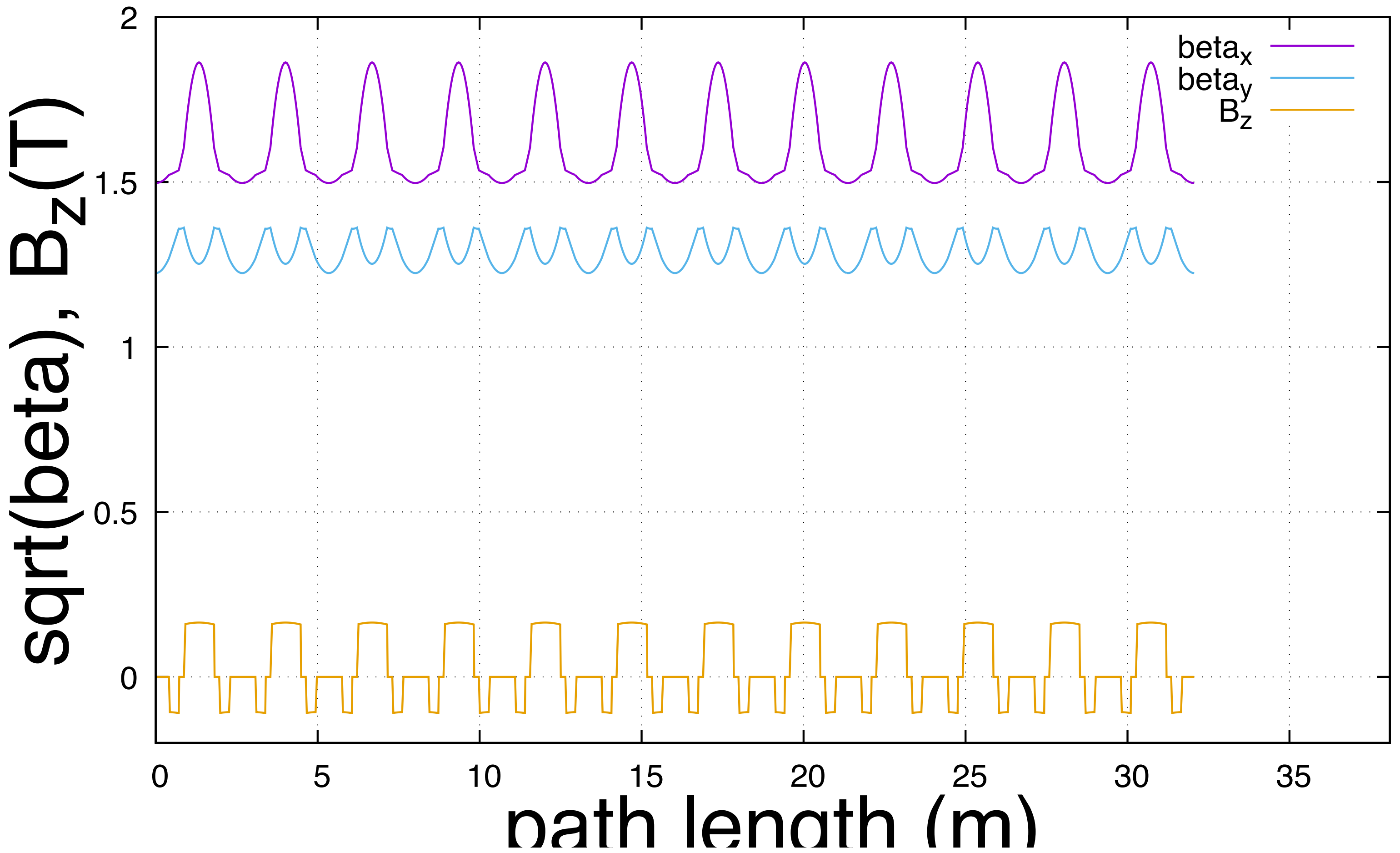
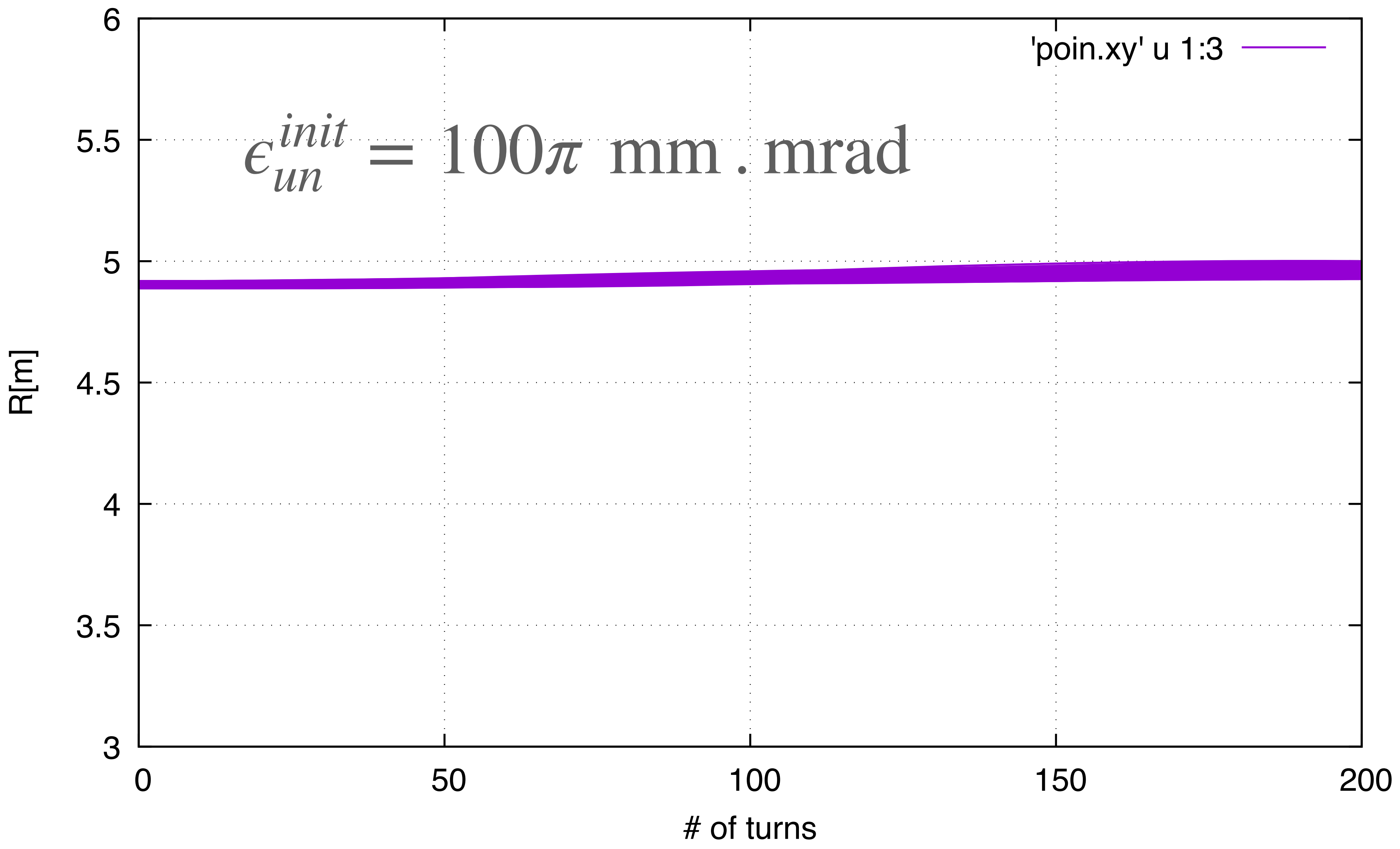
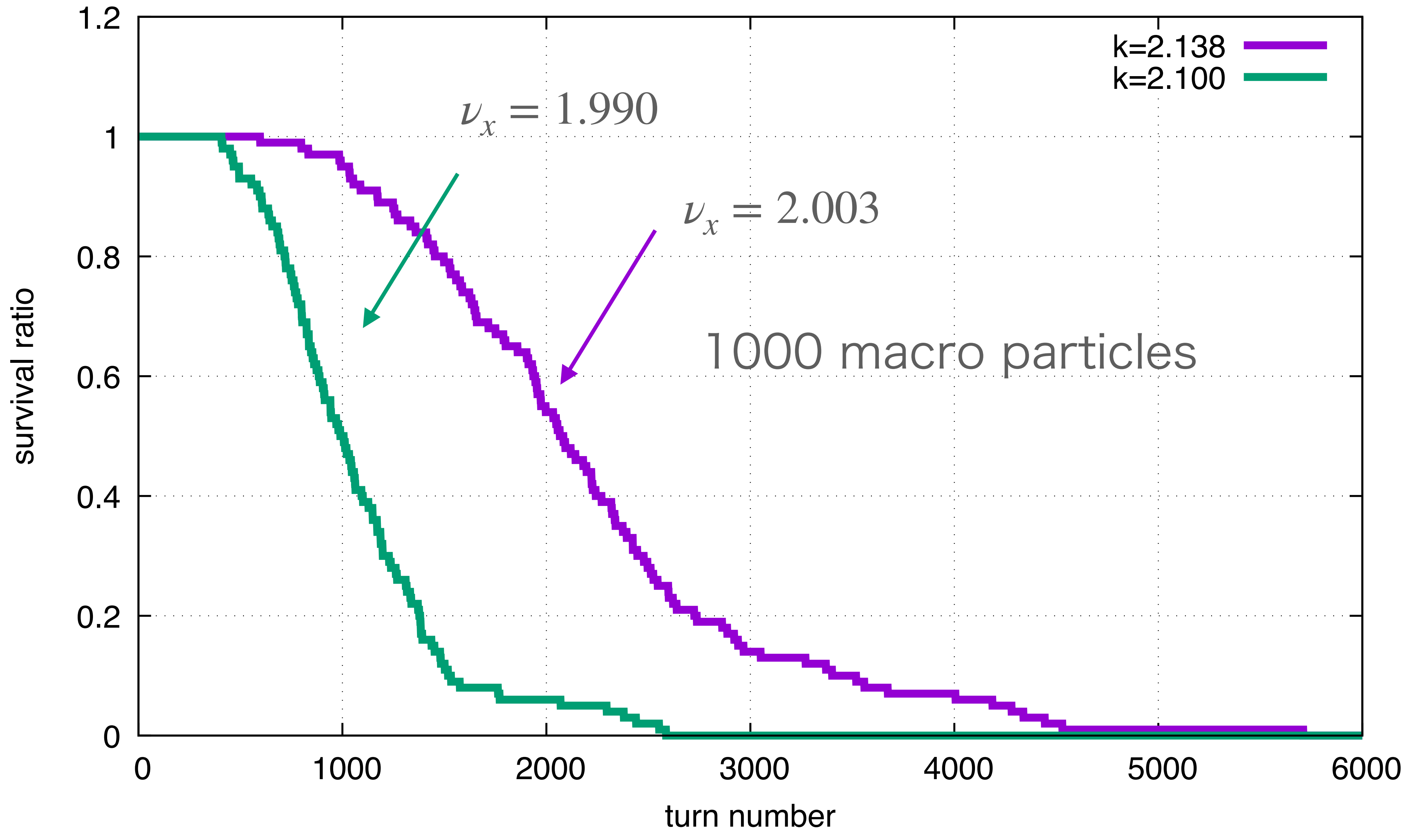
multi particle tracking

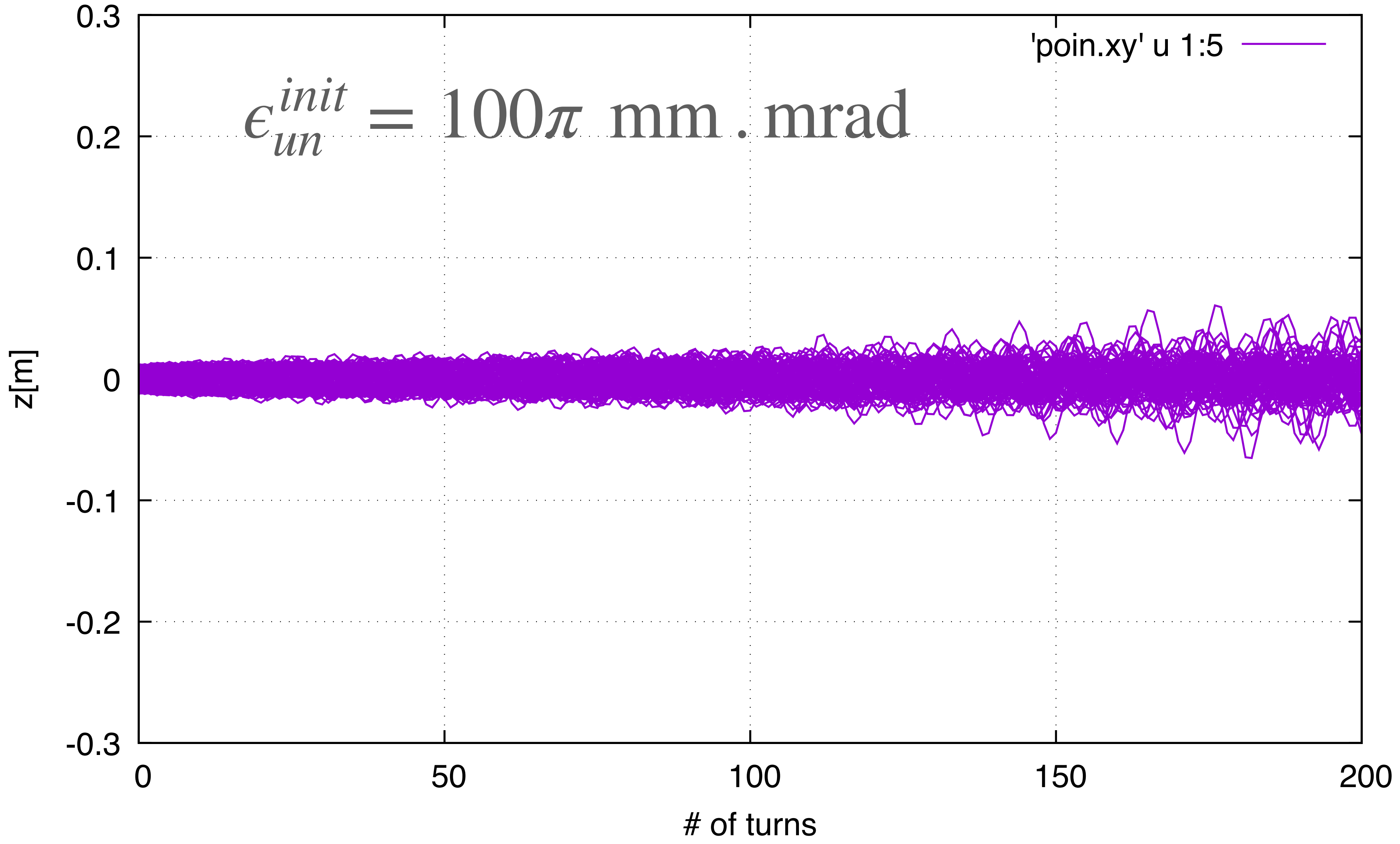
$k = 2.14, \quad \nu_x = 1.998, \quad \nu_y = 3.090$



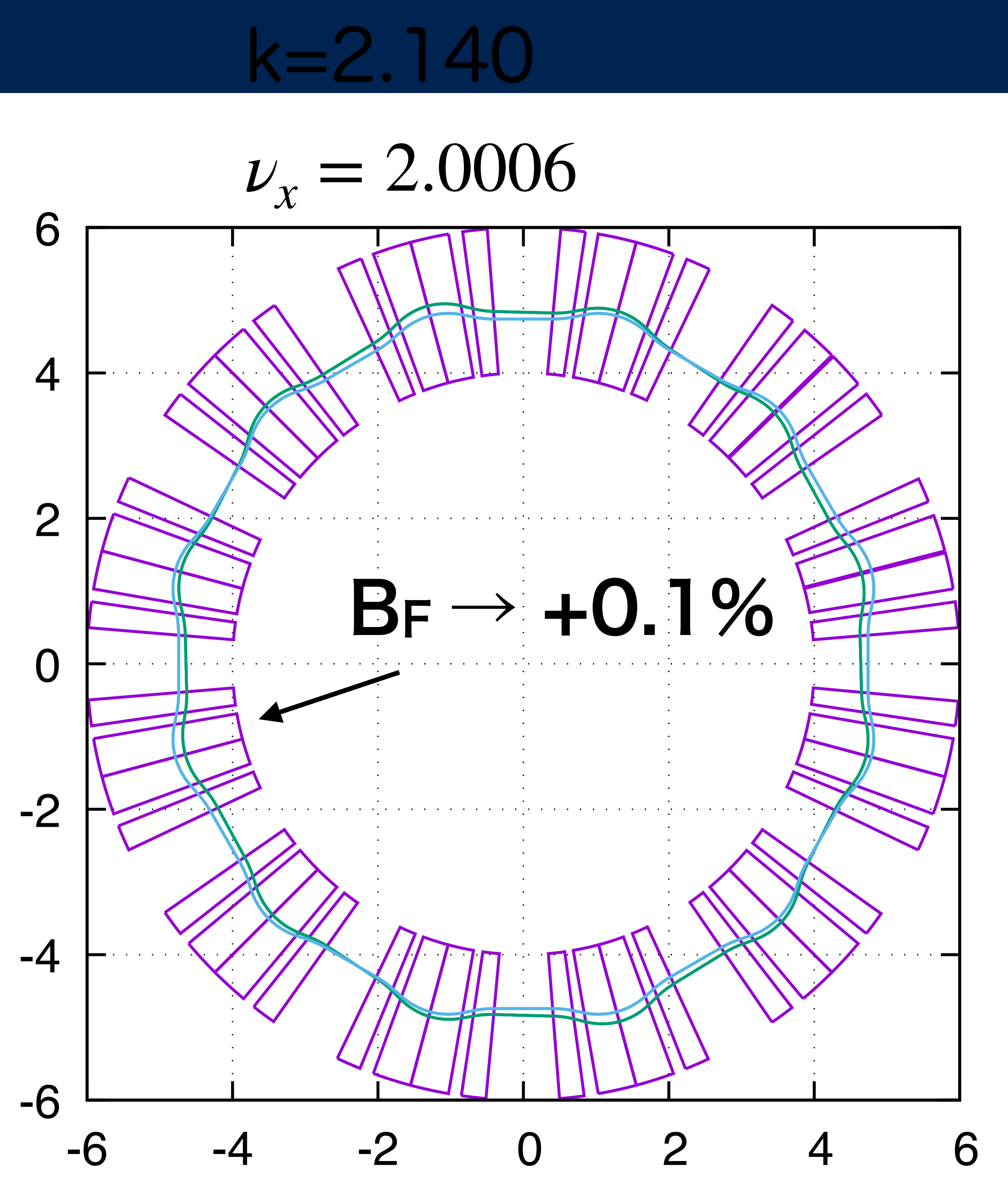


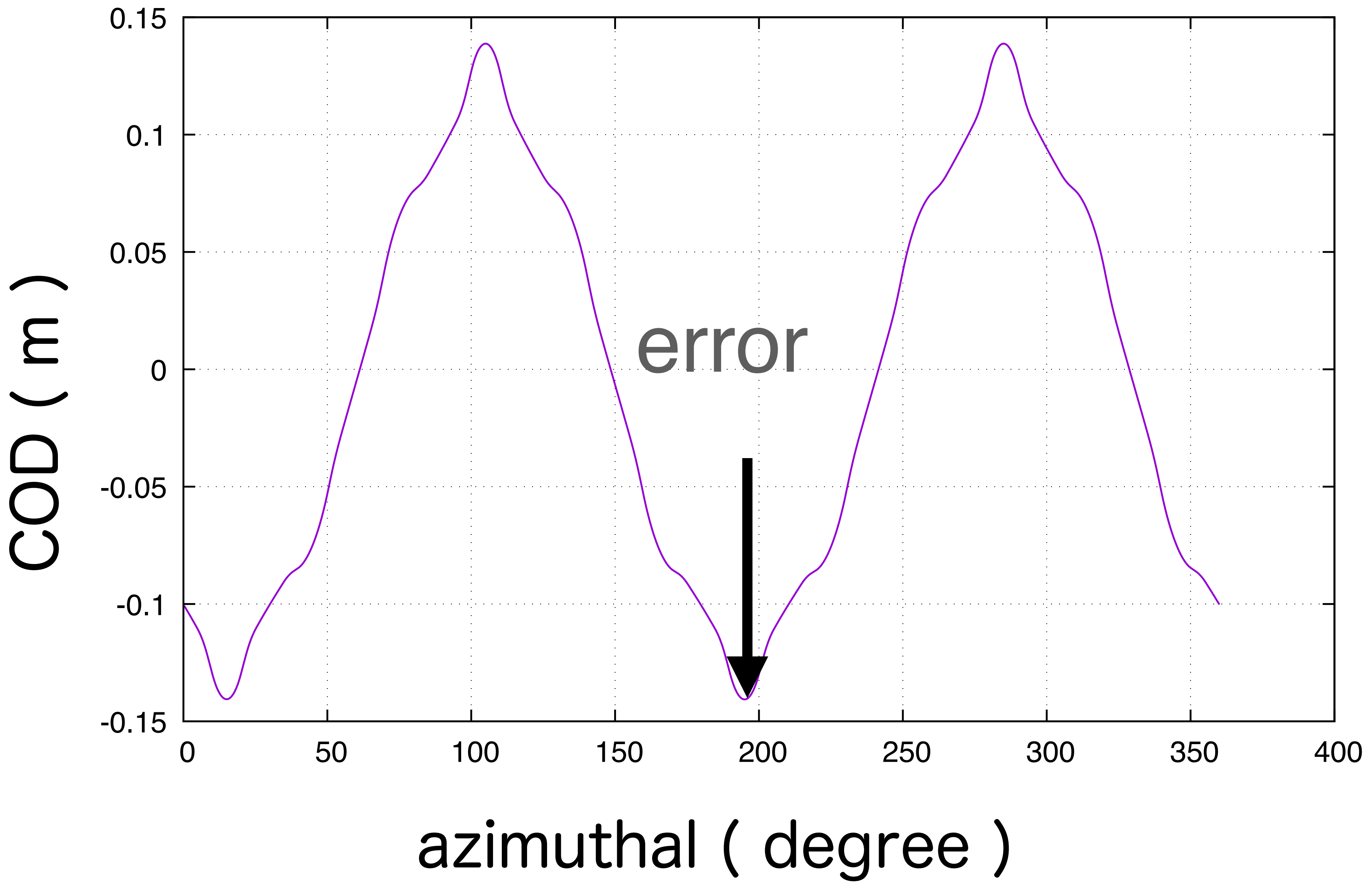


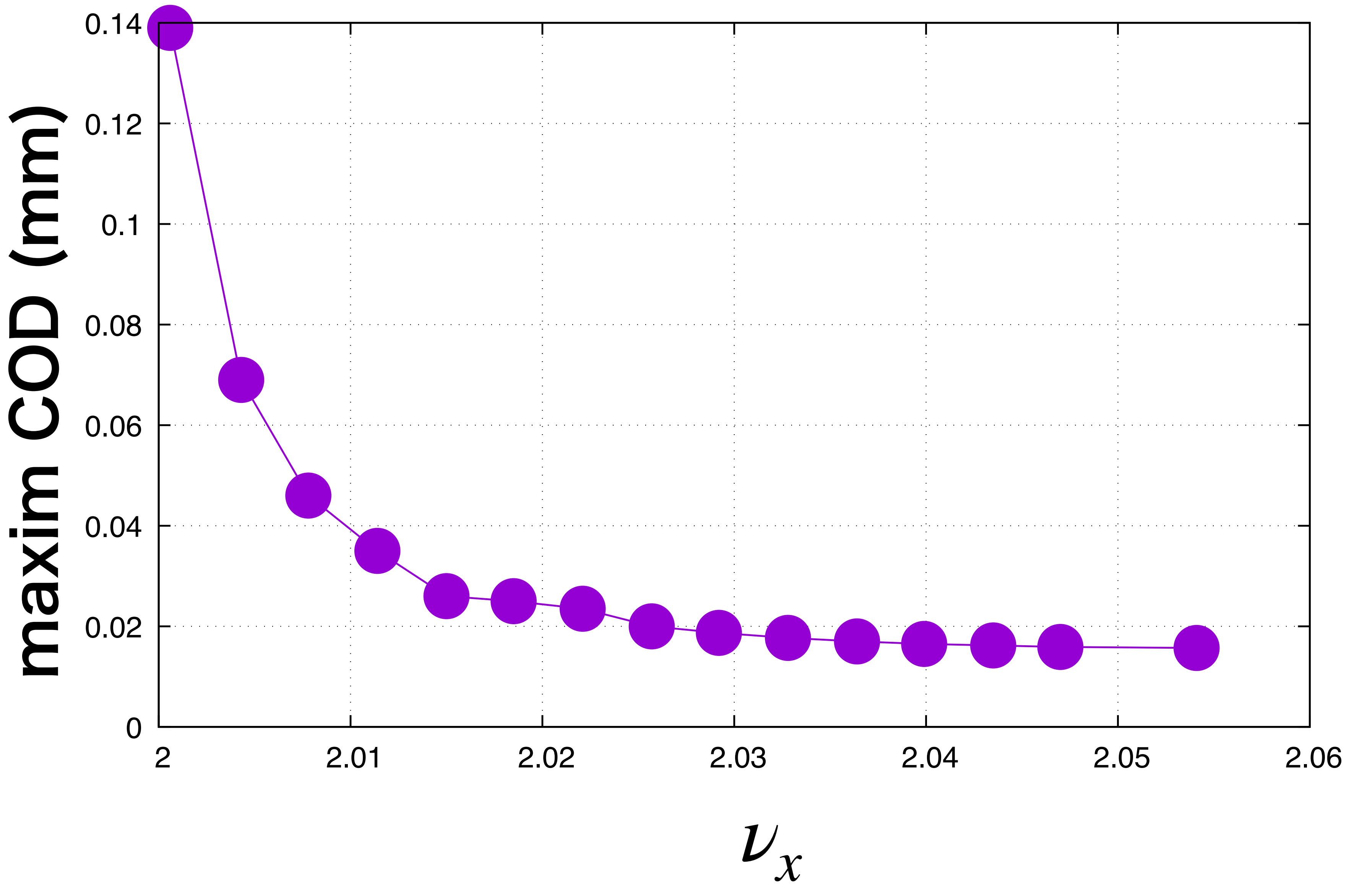


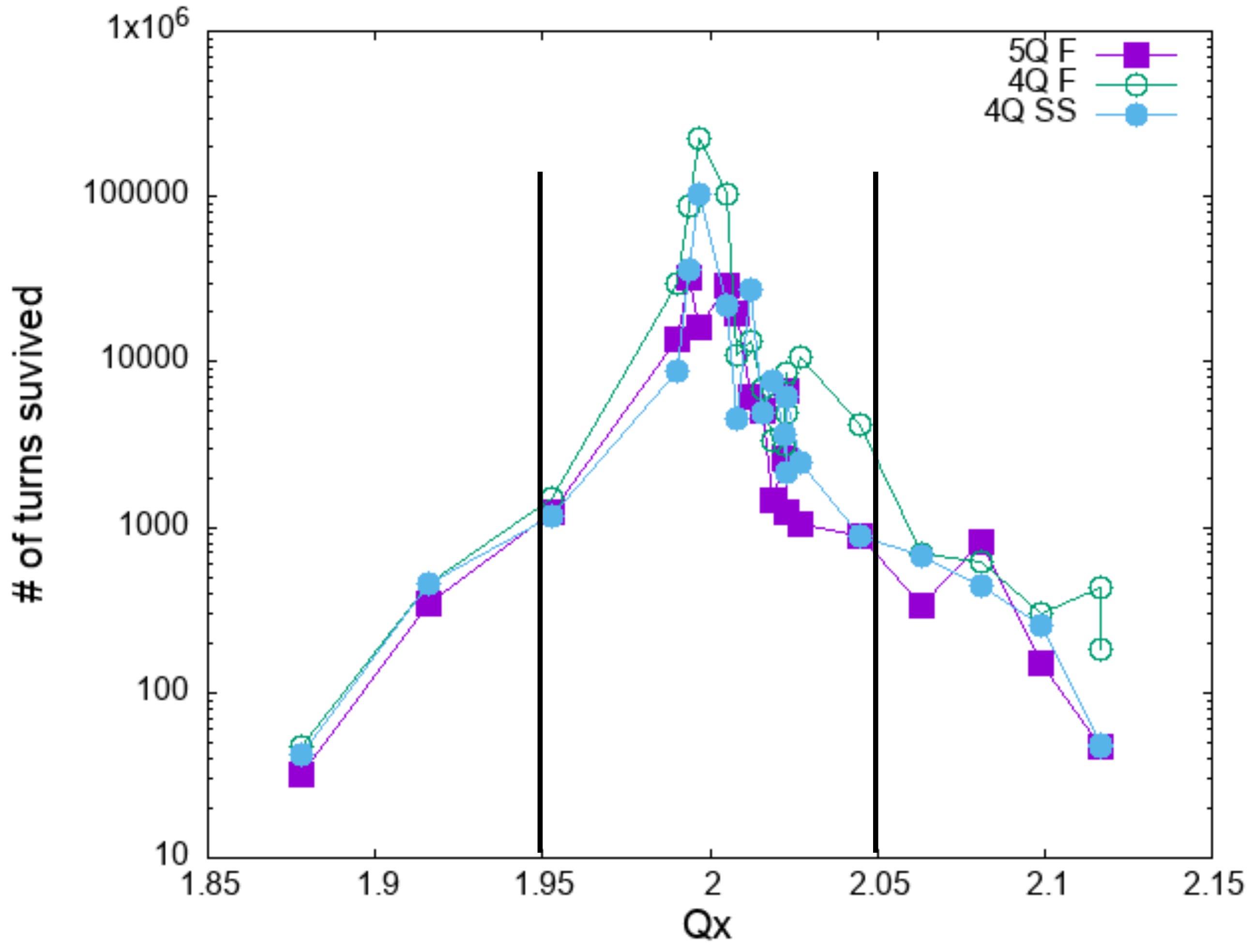


error sensitivity near $\nu_x = 2$



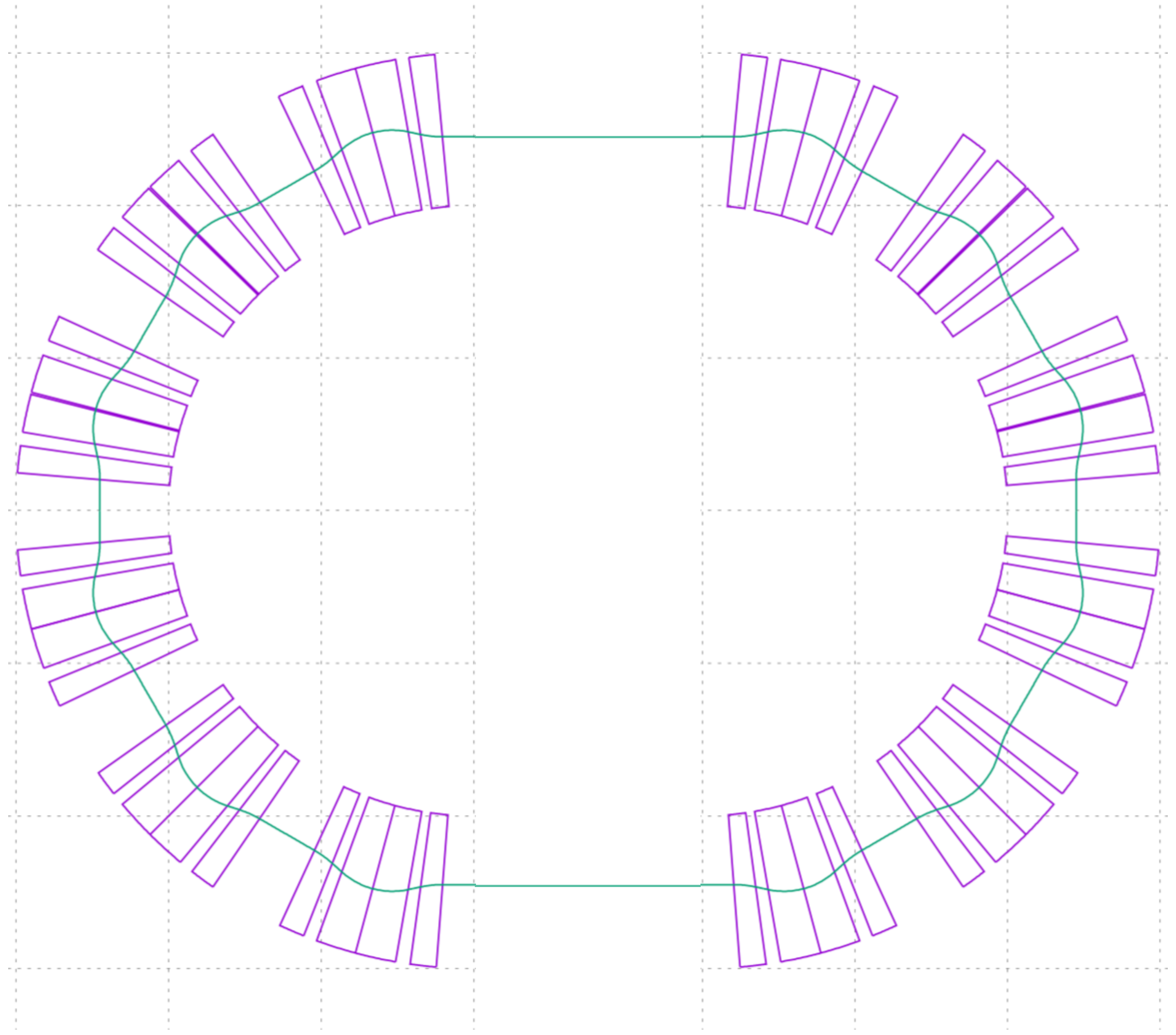






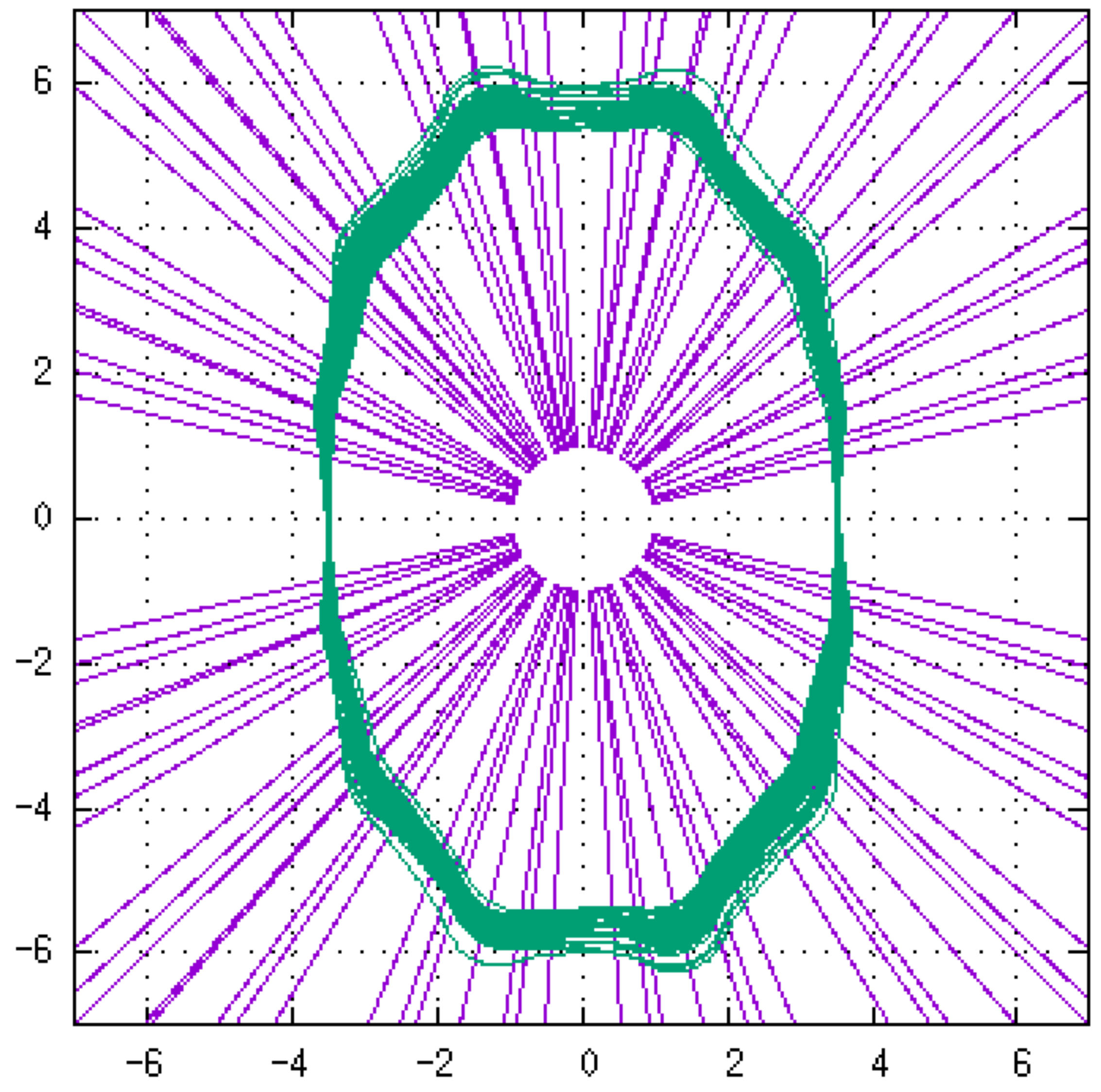
setting the ν_x at least 0.05 away from the $\nu_x = 2$, beam survives ~1000 turns.

ERIT with long straight



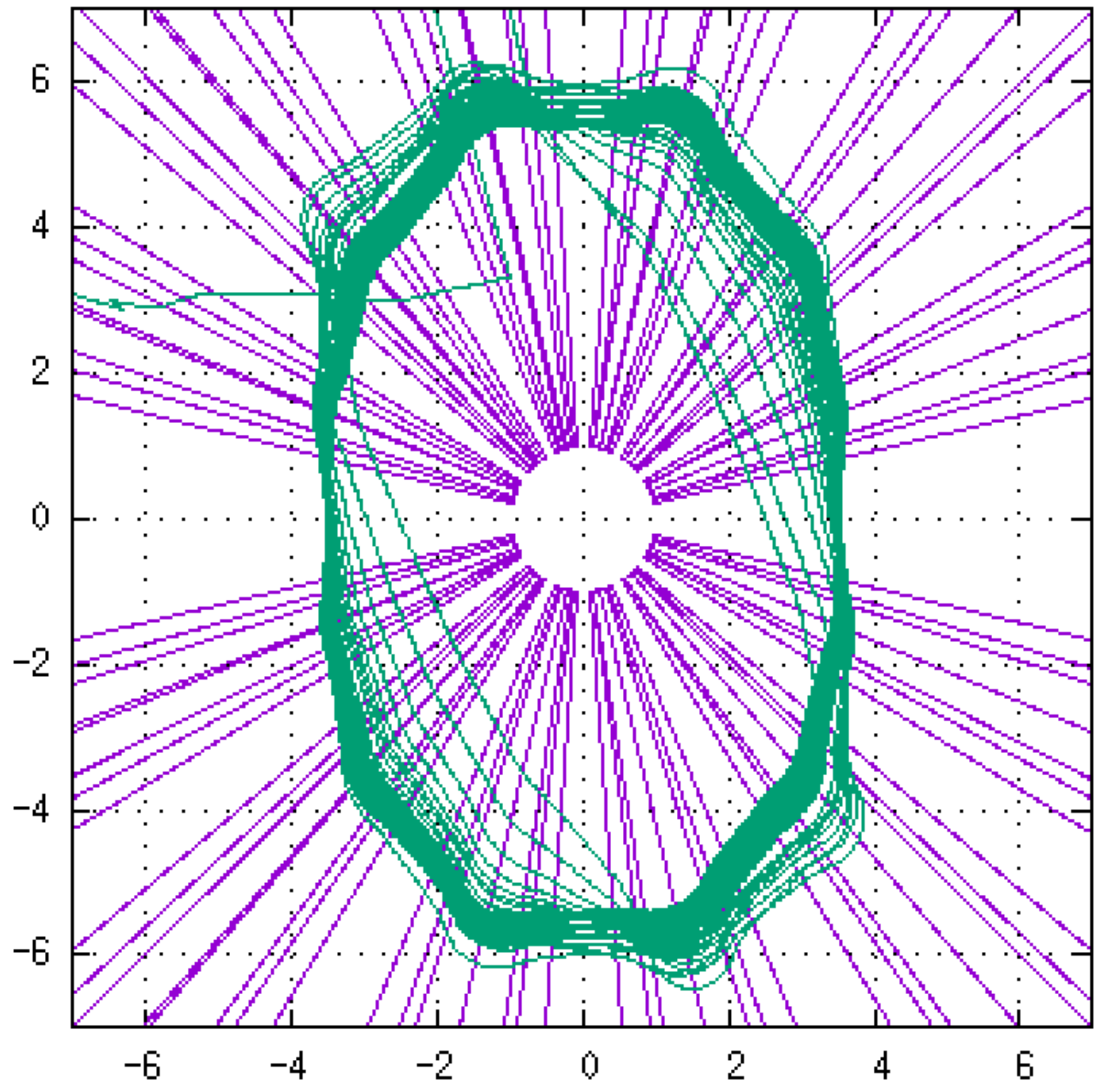
race track configuration violates the scaling law which is essential for multi-charge ERIT

$\nu_x = 1.95$



insertion of the wedge drift section fulfills the scaling law

$\nu_x = 1.96$



the approach to the resonance

$$1\nu_x = 2$$

makes closed orbit unstable

Summary

1. ERIT for producing superheavy element as one of the plans for reuse of the main ring is under consideration.
2. Multi charge state beams can circulate in the ring with the target located at the pseudo dispersion free section.
3. Operating ERIT near $\nu_x = 2.05$ (1.95) can accumulate multi-charged beams.
4. Zero chromaticity is essential for multi-charge state ERIT.
5. Use the Lagrangian insertion?

backup 1

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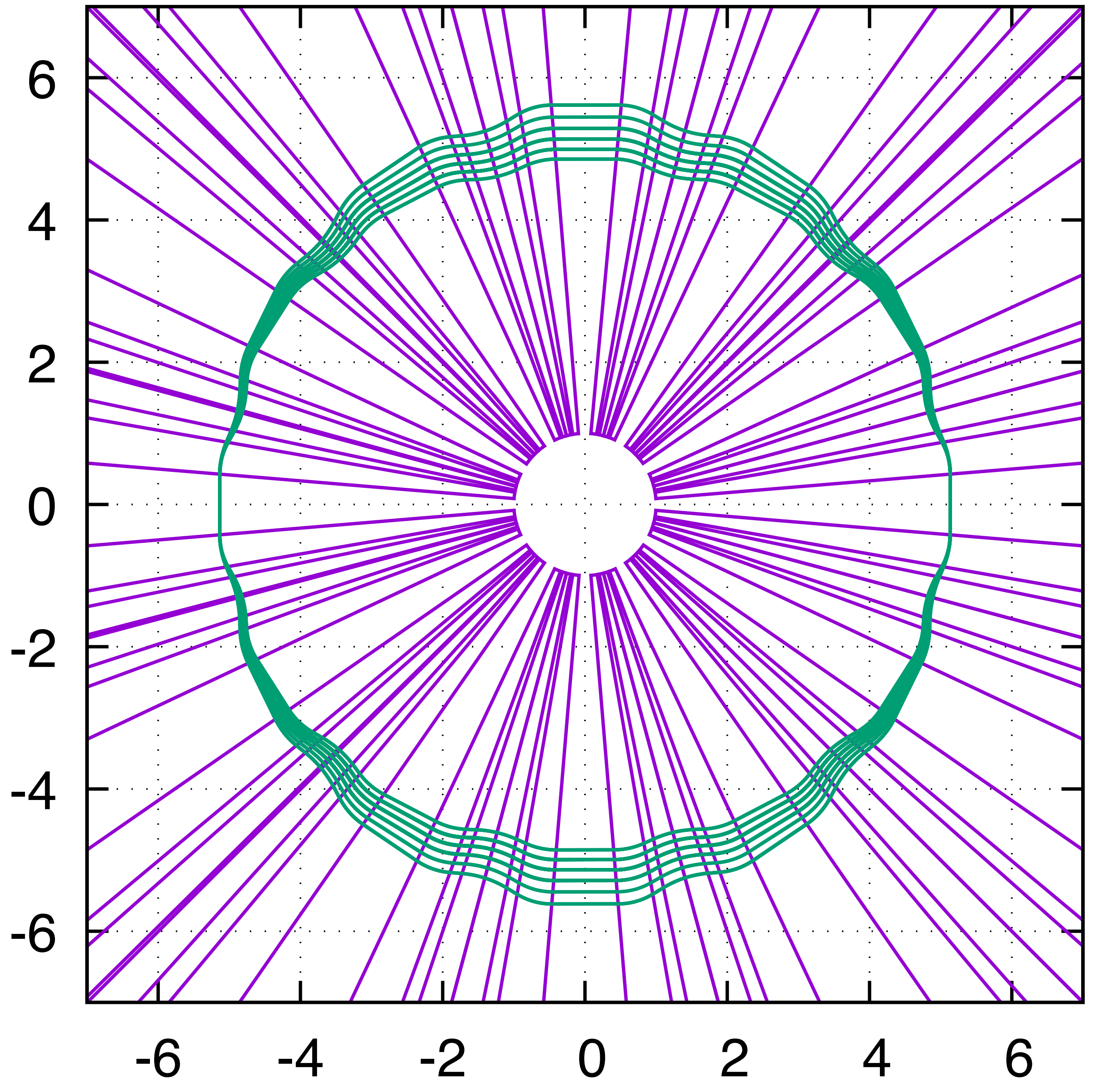
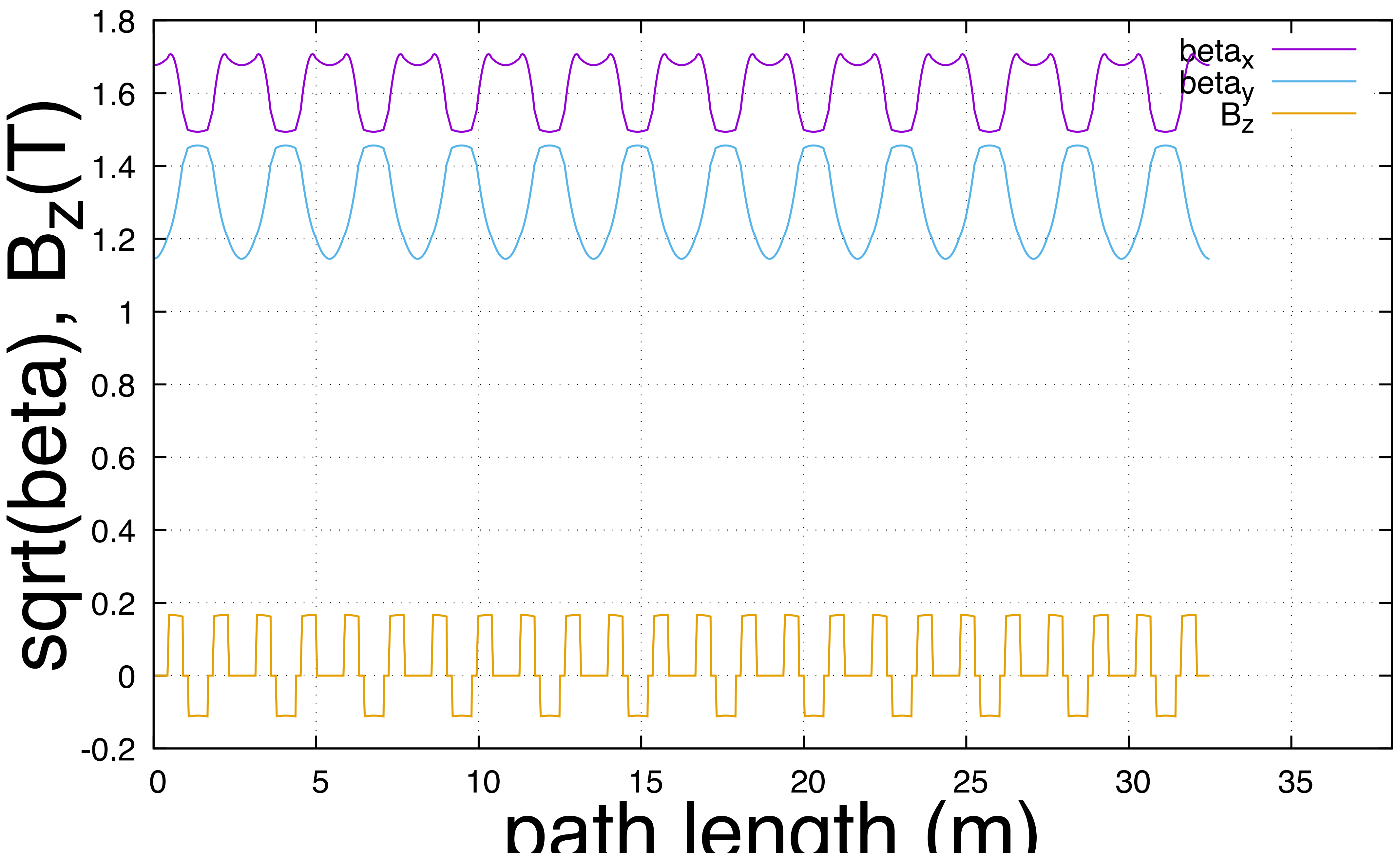
```

FDF



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dmag      dmag      3.43d0    1.200000  5.2000    2.500     10        0.        1.
ss        drift     1.7d0     0.000000  1.0       0.0       10        0.        0.
fmag      fmag      5.12d0    -1.7000   5.2000    2.500     10        1.        1.
ls        drift     4.75d0    0.000000  1.0       0.0       10        0.        0.
//
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