Collimator

Motivation

- ISIS-II : 0.1% (1W/m) beam loss of 1.25MW with 1.2GeV.
- 0.42kW when 0.1% of beam loss at injection 400MeV.
    - Residual beam loss <<0.1% at JPARC due to foil scatterings.
- Except for sudden loss due to machine fails, loss of halo particles is an issue on high power machines.
- Halo formation (emittance growth):
    - Space charge
    - Residual gas interaction
    - Fail scattering
- In ISIS-II, even emittance growth is very small, a loss of single particle may cause huge impacts on the machine components.

What is the most efficient collimator system can be proposed for ISIS-II FFA ring?

Table1. Emittance growth par turn due to residual gas scattering at 1e-7 mmbar.

	FETS-FFA	ISIS-II
Energy (Inj, Ext) [MeV]	(3, 12)	(400, 1200)
$\bar{\beta}_{x,y}$ (Inj, Ext) [m]	(1.1, 1.2)	(4.0, 4.0)
$\Delta\epsilon_x$ (Inj, Ext) [$\pi\mu$m.μrad]	(27, 1.7)	(6e-2, 9.3e-3)
$\Delta\epsilon_y$ (Inj, Ext) [$\pi\mu$m.μrad]	(29, 1.8)	(6e-2, 9.3e-3)
θ_x (Inj, Ext) [μrad]	(6.9, 1.7)	(0.17, 6.8e-2)
θ_y (Inj, Ext) [μrad]	(6.9, 1.7)	(0.17, 6.8e-2)

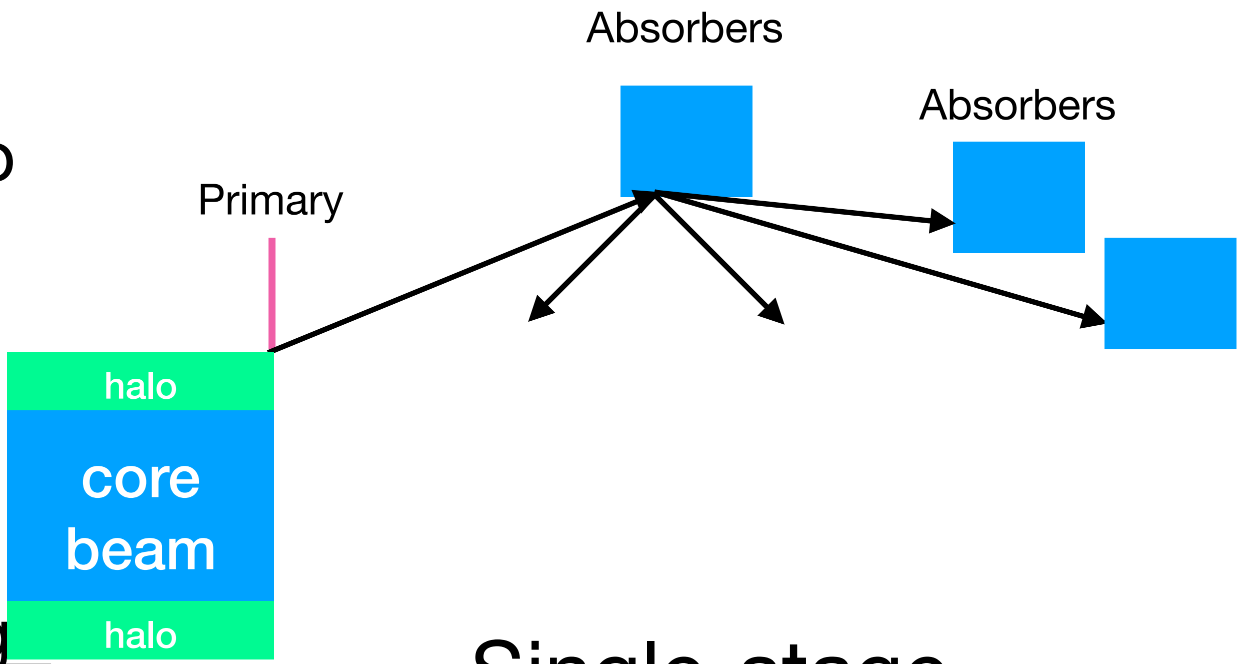
Table2. Emittance growth due to single event of scattering at the carbon foil. The foil thickness is 10×10^{-6}cm and 2×10^{-4}cm of carbon (2.0 g/cm^3) in 3 MeV and 400 MeV respectively.

	FETS-FFA	ISIS-II
Energy (Inj) [MeV]	3	400
$\beta_{x,y}$ at foil [m]	1.6	4
$\theta_{x,y}$ [μrad]	410	20
$\Delta\epsilon_{x,y}$ [πmm.mrad]	0.13	8e-4

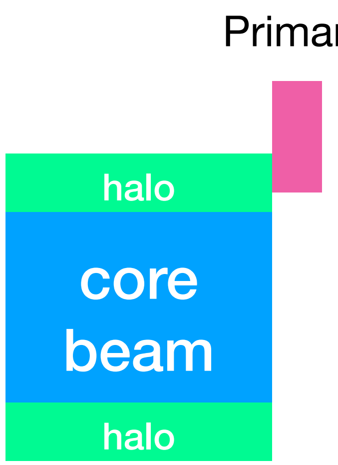
Motivation

- Multi-stage collimator system
  - Primary collimator: kick halo particles to give larger angles.
  - Secondary absorbers: capture particles scattered at primary collimator.
  - <u>Secondary particles are generated at absorbers, propagating and causing high residual dose-rate downstream of the ring</u>.
- Single-stage collimator system
  - 100% of beam loss due to halo particles are captured by primary collimator only.
  - Existing hFFA rings do not have collimators.

Multi-stage



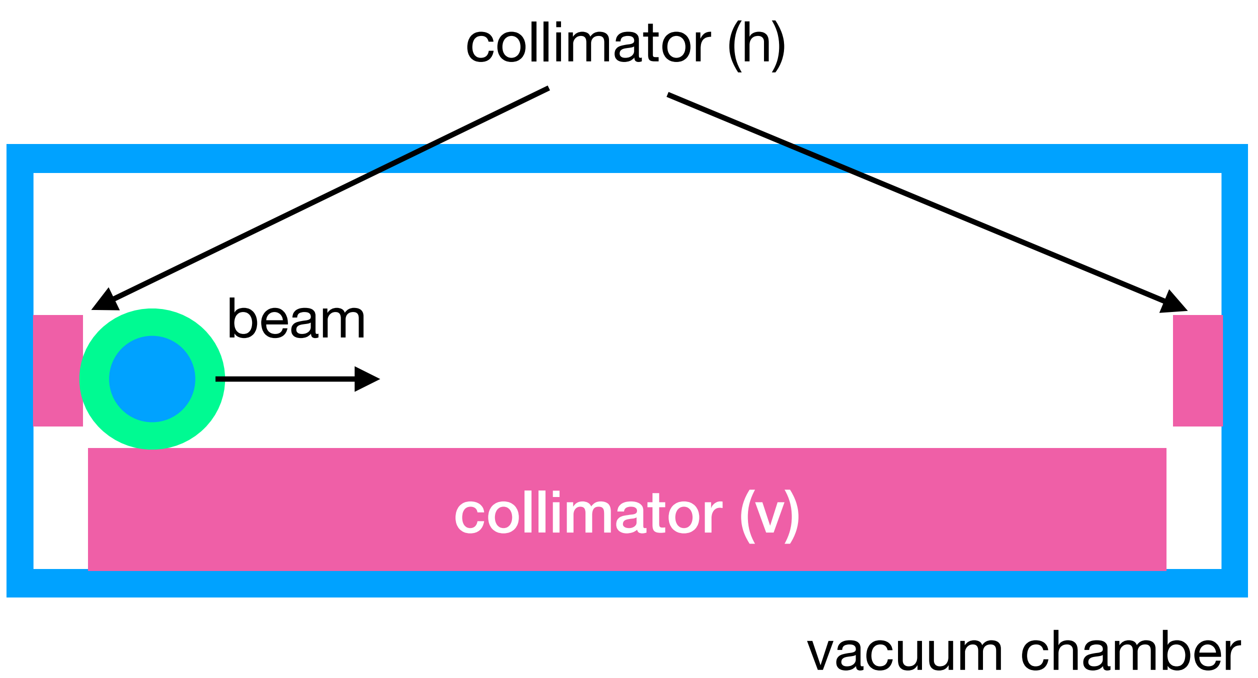
Single-stage



To evaluate and demonstrate single-stage collimation system in high power hFFA ring, the feasibility study has been performed in test ring: FETS-FFA.

Design Concept of single-stage collimator in FETS-FFA

- I-shape single-stage collimator system in horizontal and vertical.
  - Horizontal: localise beam loss at injection and extraction only.
  - Vertical: can be placed to capture beam halo through beam acceleration continuously.

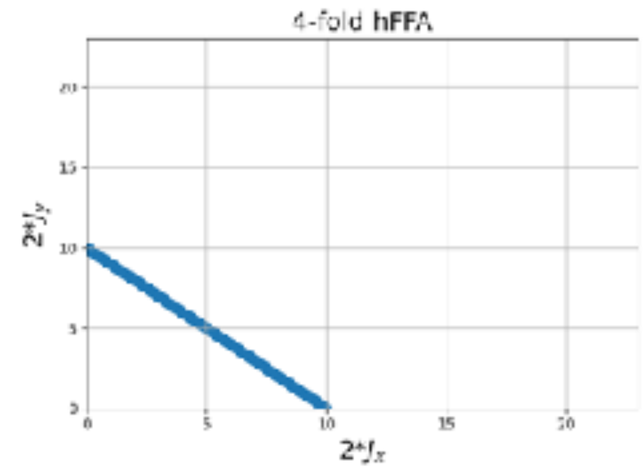


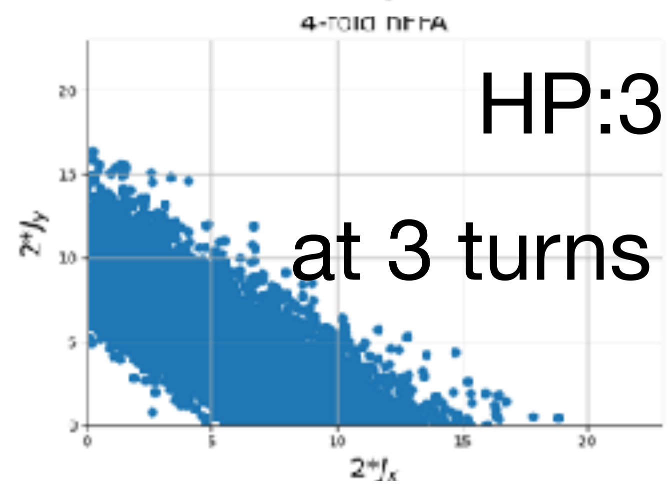
To evaluate efficiency and understand how the single-stage collimation system works, single particle tracking simulations were performed, focusing on injection periods.

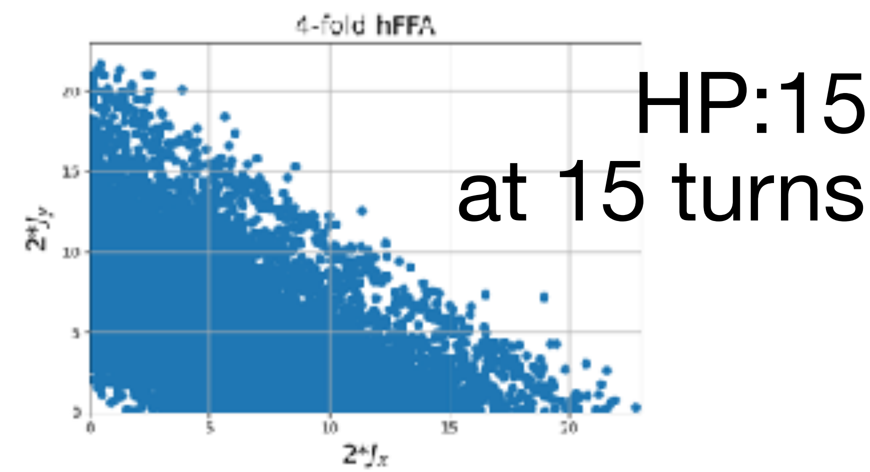
How fast particles reach 250π

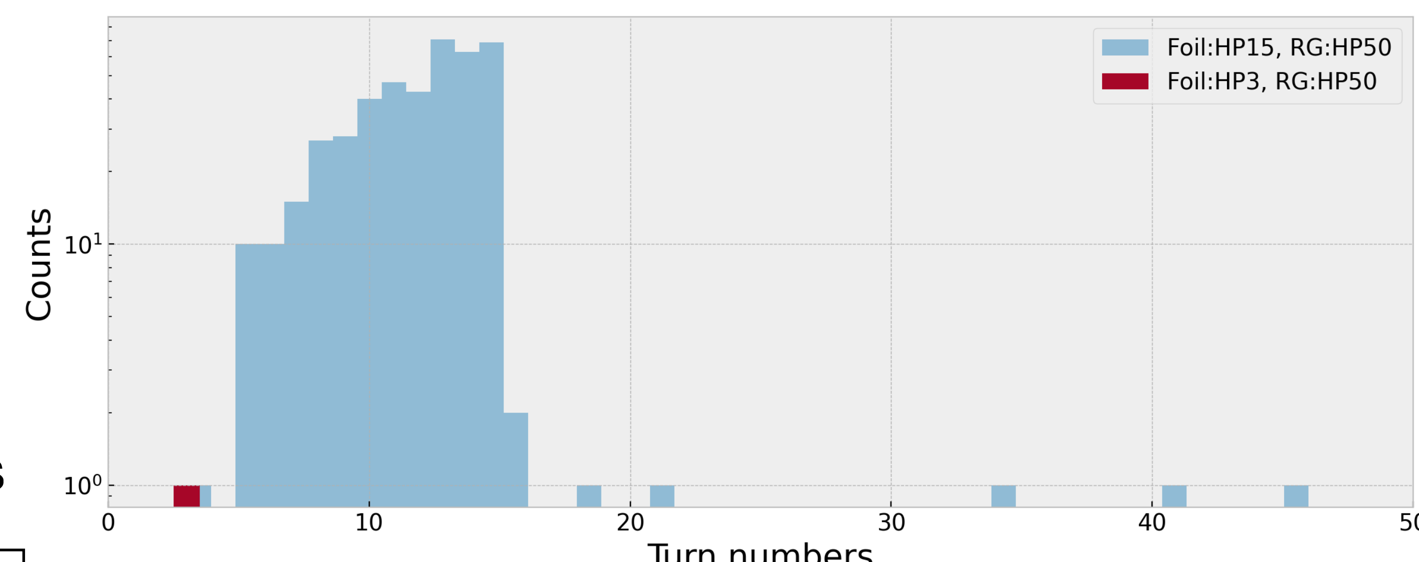
- Use a 1 turn transfer map of FD spiral FETS-FFA lattice.
- Kick angle
  - Residual gas :6.9 urad kick every turn.
  - Foil scattering: angle kicks randomly given by angle distribution computed by PHITS.
- KV distribution: 1x10^4 macro particles, 125 πmm.mrad at injection.
- Particles reaching 250 πmm.mrad (collimator acceptance) in total for 50 turns for different Hitting Probability (HP).
  - HP=3: 0.008% of initial particles reached 250π mm.mrad.
  - HP=15: 4.1% of injected particles reached 250π mm.mrad within 15turns

Collimators are required to localise a few % of beam loss due to foil scattering and residual gas scattering.





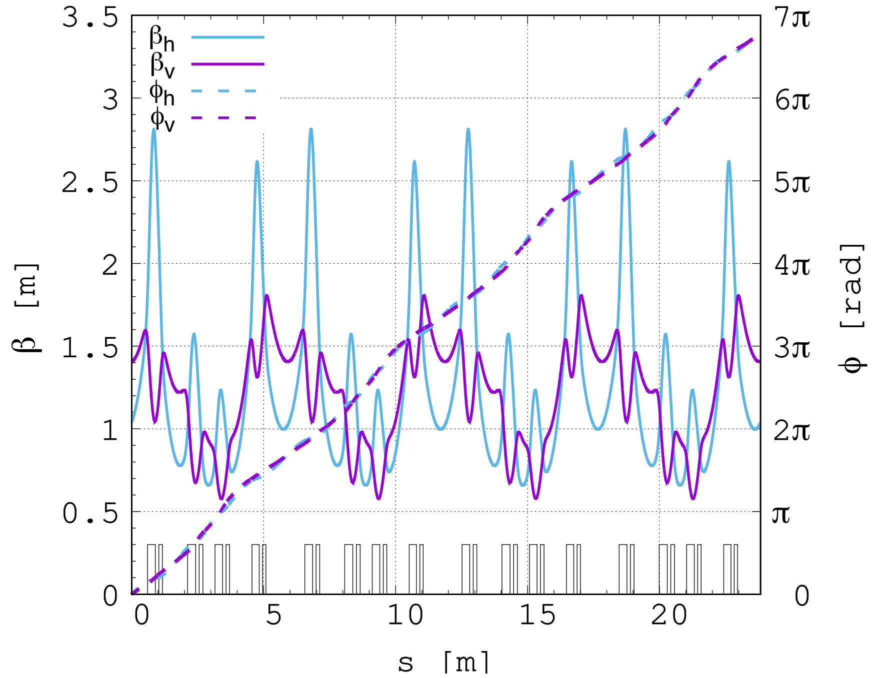




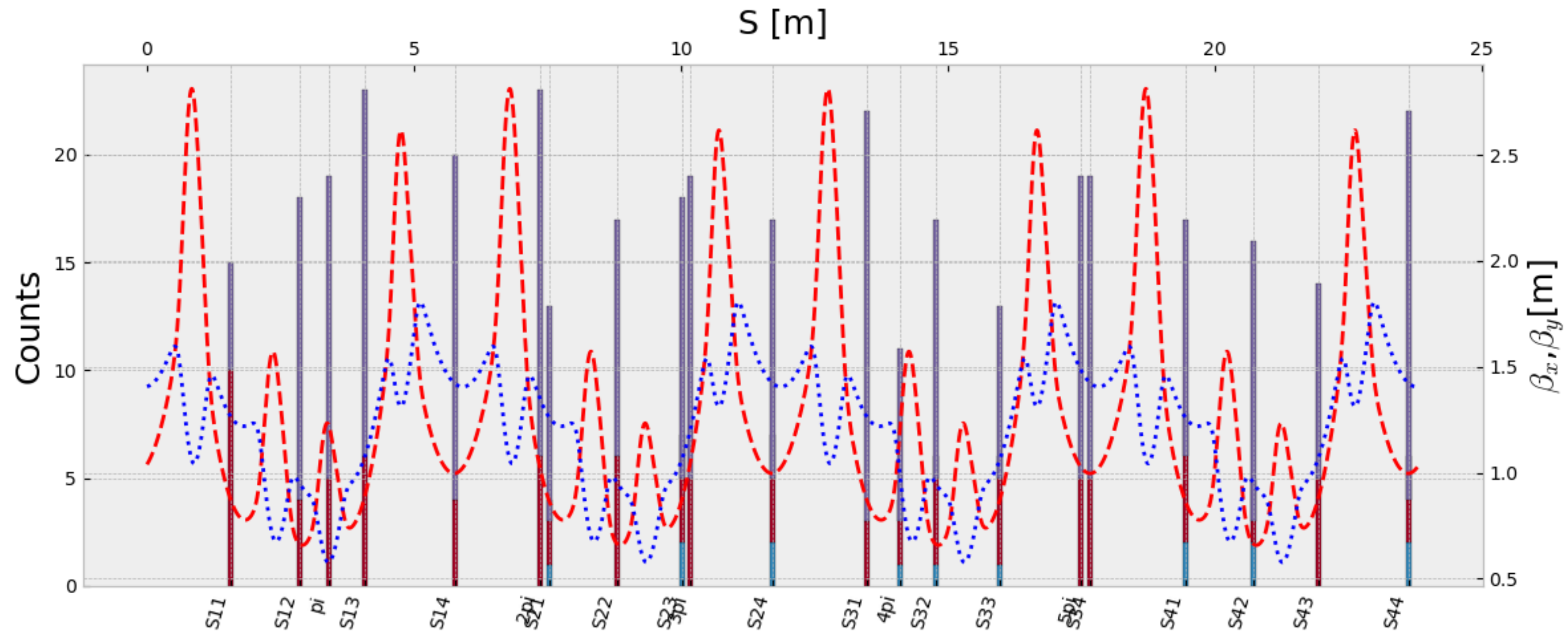
Turn numbers the particle reached 250πmm.mrad over 50turns when the beams hit the foil for first 3 and 15 turns, corresponding to the hitting probability of 3 and 15 respectively.

Optimum Location of Collimators

- 1 turn transfer map divided by each sector: Focusing magnet (F), Defocusing magnet (D) and Straight sections (S).
- Track initial particles starting from 125π mm.mrad over 50 turns.
    - Foil scattering for first 15 turns.
    - Residual gas scattering at every section for 50 turns.
- I-shape collimator in horizontal and vertical was installed at different straight section or nπ phase advance from the foil location.
- For different locations of collimators, particles lost at horizontal collimator in red, at vertical collimator in purple and at physical aperture in blue over 50 turns.



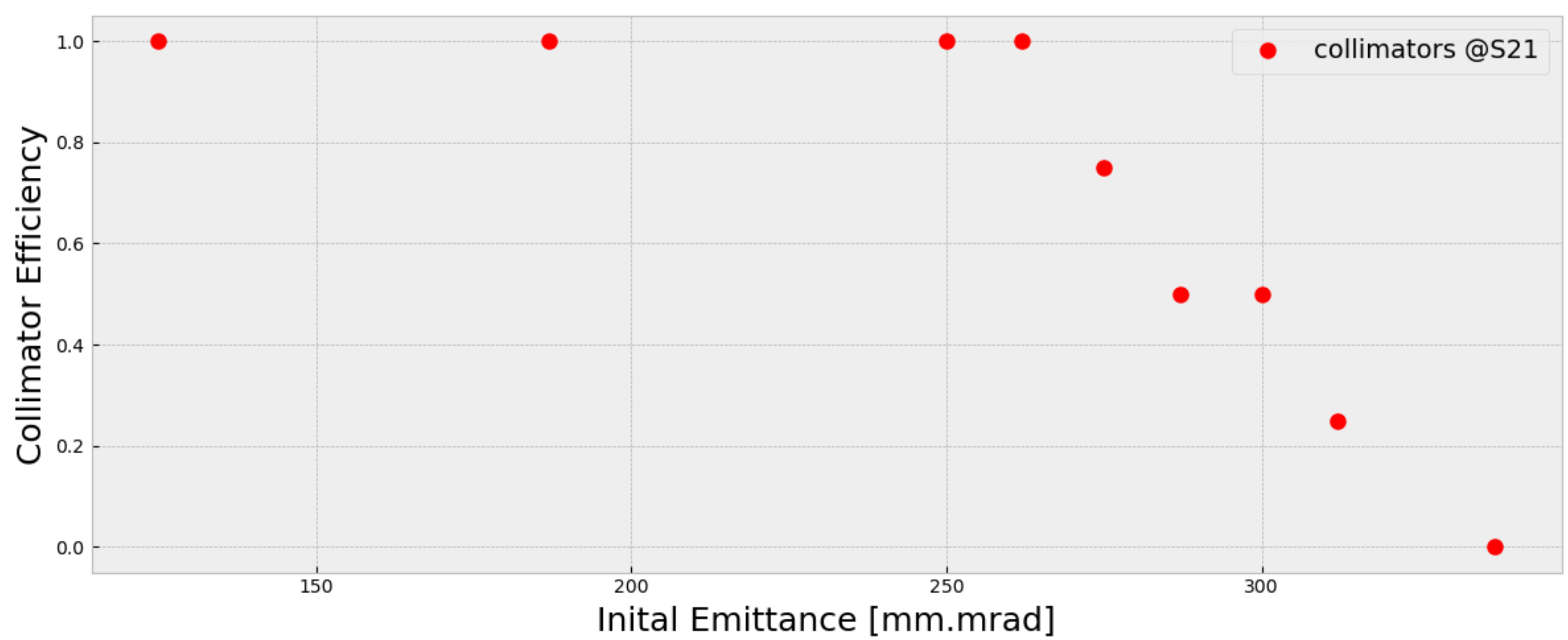
Collimators installed in any straight sections in the first supper period will capture halo particles before they lost at the downstream of the ring.



Collimator Efficiency

- Possible location of collimators should be the short straight section: *S12* where other large instruments will be hardly located.
- Track particles for different initial emittance from 125π mm.mrad to 350π mm.mrad over 50 turns.
    - Foil scattering for first 15 turns.
    - Residual gas scattering at every section for 50 turns.
- I-shape collimator in horizontal and vertical was installed at *S12.*
- Collimator efficiency defined by $E = \frac{N_{loss-col}}{N_{total}}$. N_{total}: total loss particles. $Nl_{loss-col}$: loss particles at collimator.

In order to keep collimator efficiency of 100%, the simulation results predicts the tolerance of collimator acceptance should be up to 5% of nominal (250πmm.mrad) at S12.



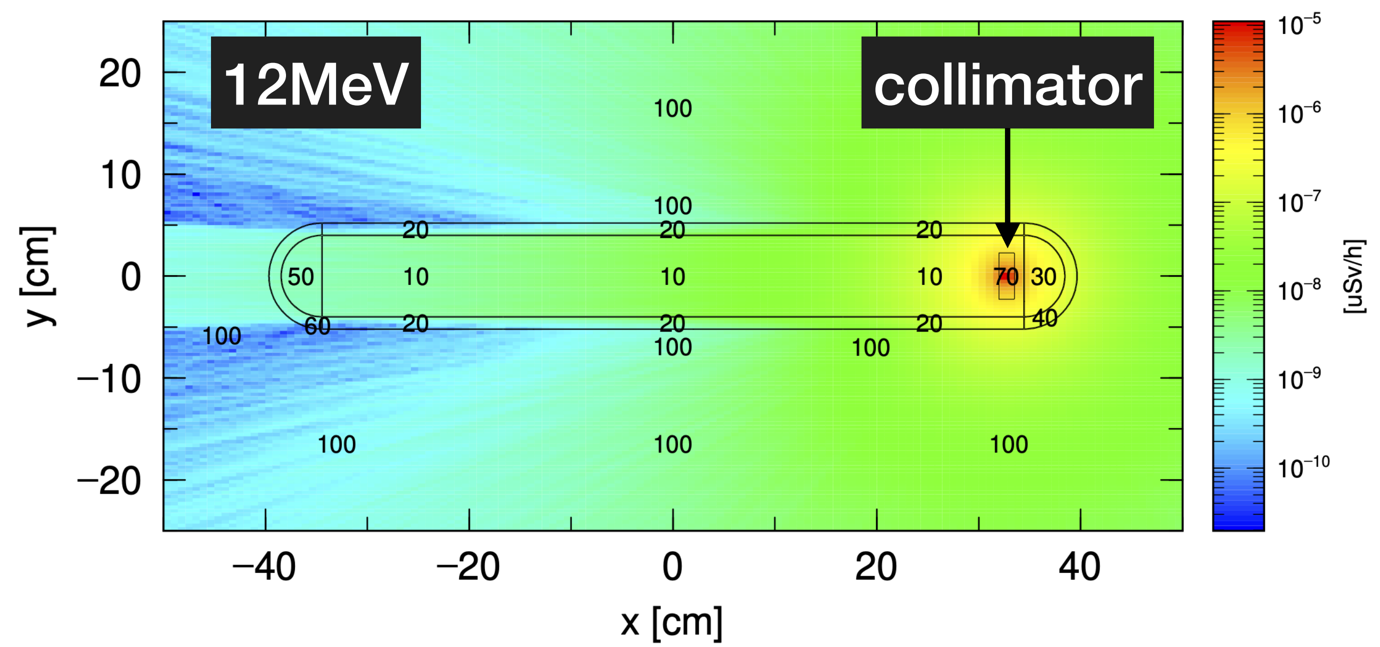
Radiation Impact on Collimator

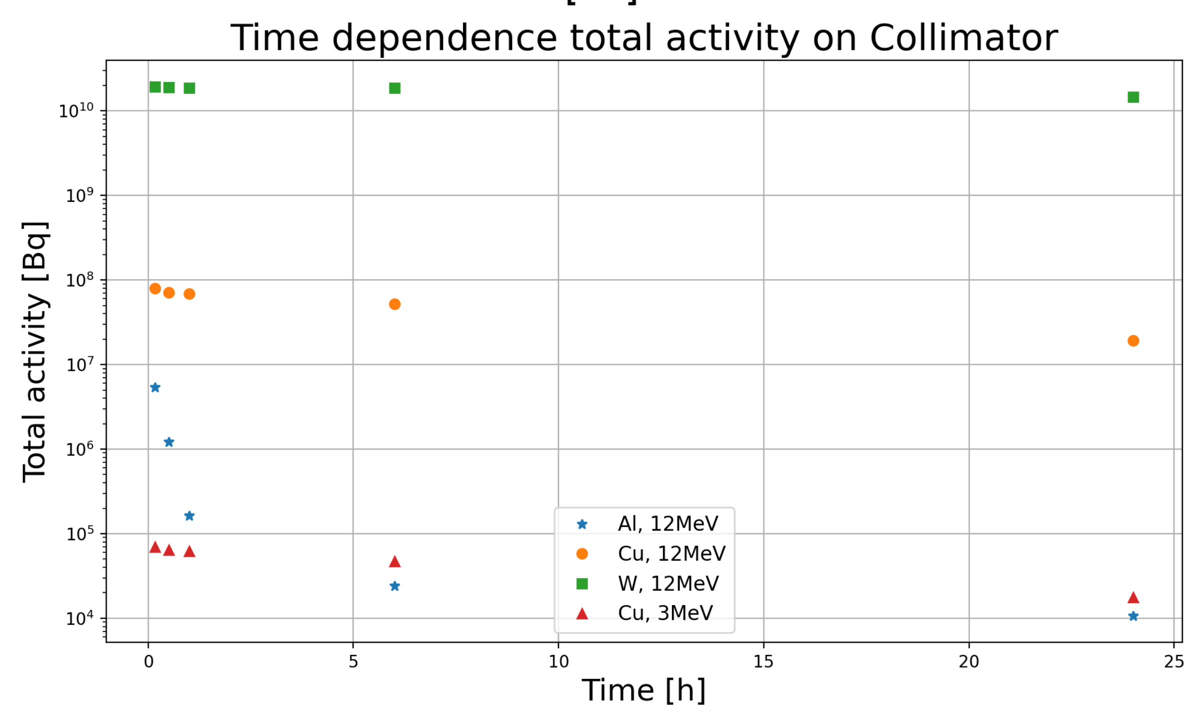
- Focus on horizontal collimator in the FETS-FFA
  - different materials
  - 46cm(H)x16cm(W) with 1cm thickness
- Radiation analysis done by PHITS.
  - 3MeV and 12MeV pencil protons hit collimator.
  - Prompt gamma rays around the collimator (middle figure: aluminium collimator when 12MeV protons hit the collimator).
  - Residual activity at collimators for different injection proton beam energies (bottom figure), assuming beam operation for 24 hours and cooling time for 24 hours.

Aluminium is suitable to for the FETS-FFA collimator that will generate less residual activities and decay quickly compared to other materials.

Table 3. Property of considered materials of FETS-FFA collimator.

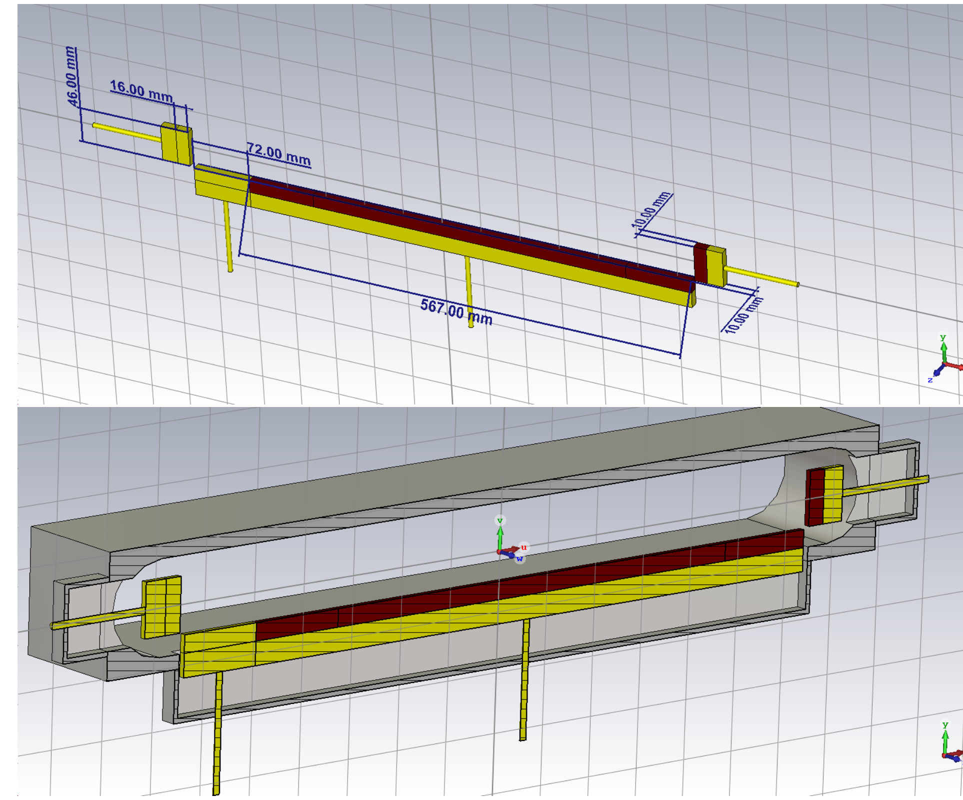
Material	Density [g/cm^3]	Melting Point [°C]	Thermal conductivity [W/m/K]	Proton Range [6] of 3/12 MeV [μm]	(p,n) reaction threshold
Aluminium	2.7	660	236	82/930	> 10 MeV [7]
Copper	8.96	1084	401	35/360	a few MeV [8]
Tungsten	19.3	3422	173	29/260	> 10 MeV [9]



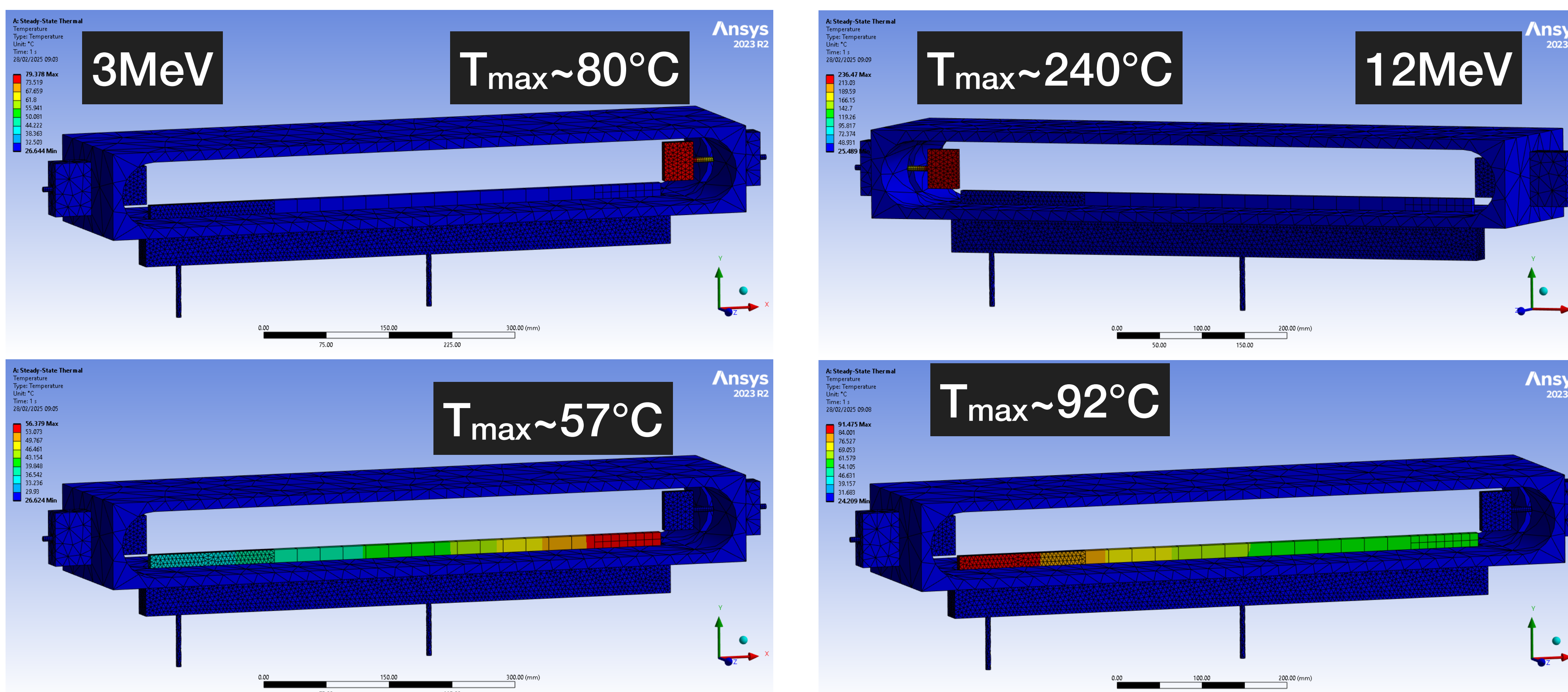


Thermal Analysis on Collimator

- Aluminium collimator in horizontal and vertical, supported by copper substrates under the collimator.
- Vertical collimator is separated in 2 blocks in horizontal aperture to control their positions for low energy and high energy regions.
- Heat source on the collimator made of aluminium.
  - 7 W for 3MeV (at injection)
  - 29 W for 12MeV (at extraction)



Aluminium with copper substrate will dissipate heats over the structure efficiently. Mechanical design study should be performed deeply in future.



Summary

- Single-stage collimator system has been proposed for FETS-FFA collimator.
  - Feasibility studies of the system were performed in the FETS-FFA test ring to investigate collimator efficiency to capture halo particles during injection period.
  - A few % of initial particles will reach the collimator acceptance due to foil scattering and residual gas scattering over injection period of 50 turns.
  - 100% of scattered halo particles could be captured by horizontal and vertical I-shape collimators in injection period, when they are installed in any straight sections in the first supper period.
  - When collimators were installed in S12 (shortest straight section) in the first super period, tolerable positioning error were 0.3 mm and 0.4 mm in horizontal and vertical physical position respectively.
- Radiation and thermal analysis suggested the 1cm of aluminium plate was suitable for the FETS-FFA collimators.
- Reliability and feasibility of single stage collimator system in ISIS-II FFA will be studied in future.