Rise time instability: Introduction

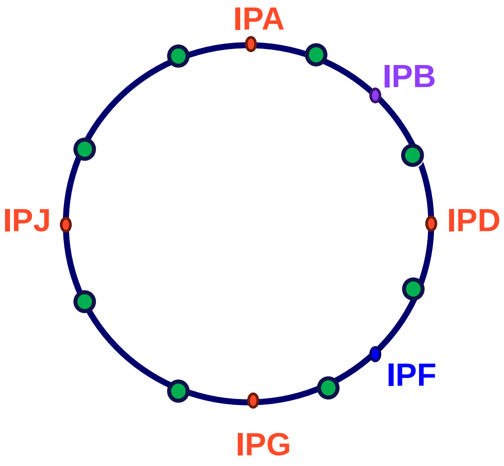
- The ring impedance can generate an instability that leads the **beam to be lost within few turns**.
- A feedback system is under development to dump the beam in case of rising instability.
- However, **feedback failures might happen and need to be investigated**.
- Effects on machine and detectors need to be understood to avoid damage and backgrounds.
- Collimation system must protect the machine/detectors also in this scenario.
- If not, both collimation and feedback systems must be improved.

Simulation setup

- Performed with **Xsuite-BDSIM** simulation tool.
- Building on the **state-of-the-art FCC-ee optics**.
- Fast instability introduced as **8 exciter placed along the ring** (one per arc, shown as green points).
- Kicks (H/V) are **equally distributed in phase advances across 90° and 180°** (smooth change in amplitude within 1 turn).
- The exciter **strengths change with time** as:

$$k = \frac{A_0}{\sigma_{x,y}} \cos\left(2\,\pi\, Q_{x,y}\, t\right) e^{\frac{t}{\tau}}$$, where $\boldsymbol{\tau}$ is the **rise time.**

- Resulting in **betatron oscillations exponentially growing with time**.



Simulation parameters:

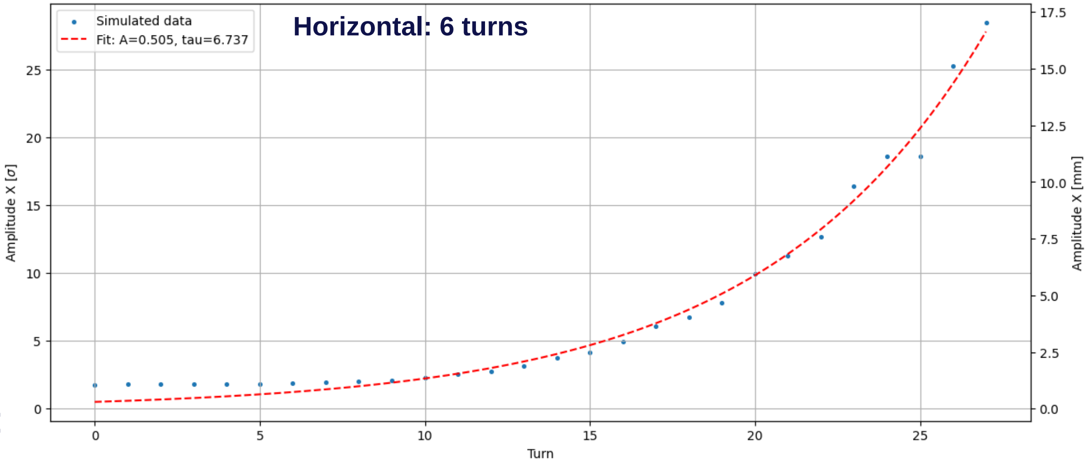
- $\mathbf{5 \times 10^5}$ **45.6 GeV electrons**.
- **SR** (mean model), **RF** cavities, magnet **tapering.**
- detailed **aperture model**, **halo and tertiary collimators**, **SR collimator**, wiggler.

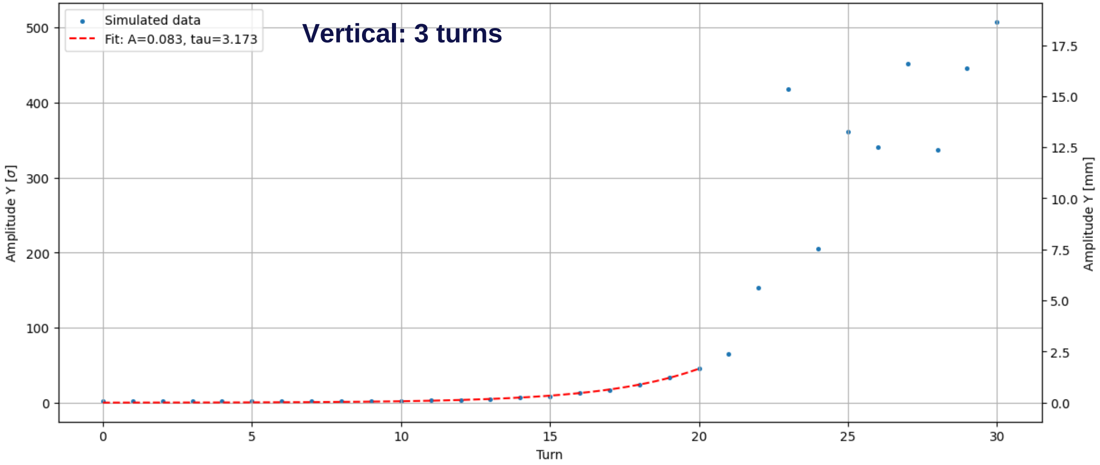
Case studies

- Since the instability can start at any point, it is relevant to **explore the phase dependence**.
- Exciters shifted along the ring to have **four different phase advances between the first exciter and the primary collimator**.
- **16 different cases** have been investigated:

	$3\ turns$	$6\ turns$
Horizontal	$\Delta\mu_0 = 0°, 30°, 60°, 90°$	$\Delta\mu_0 = 0°, 30°, 60°, 90°$
Vertical	$\Delta\mu_0 = 0°, 30°, 60°, 90°$	$\Delta\mu_0 = 0°, 30°, 60°, 90°$

$$\boxed{A_x[\sigma] = \frac{\sqrt{2\,J_x\beta_x}}{\sigma_x}}$$

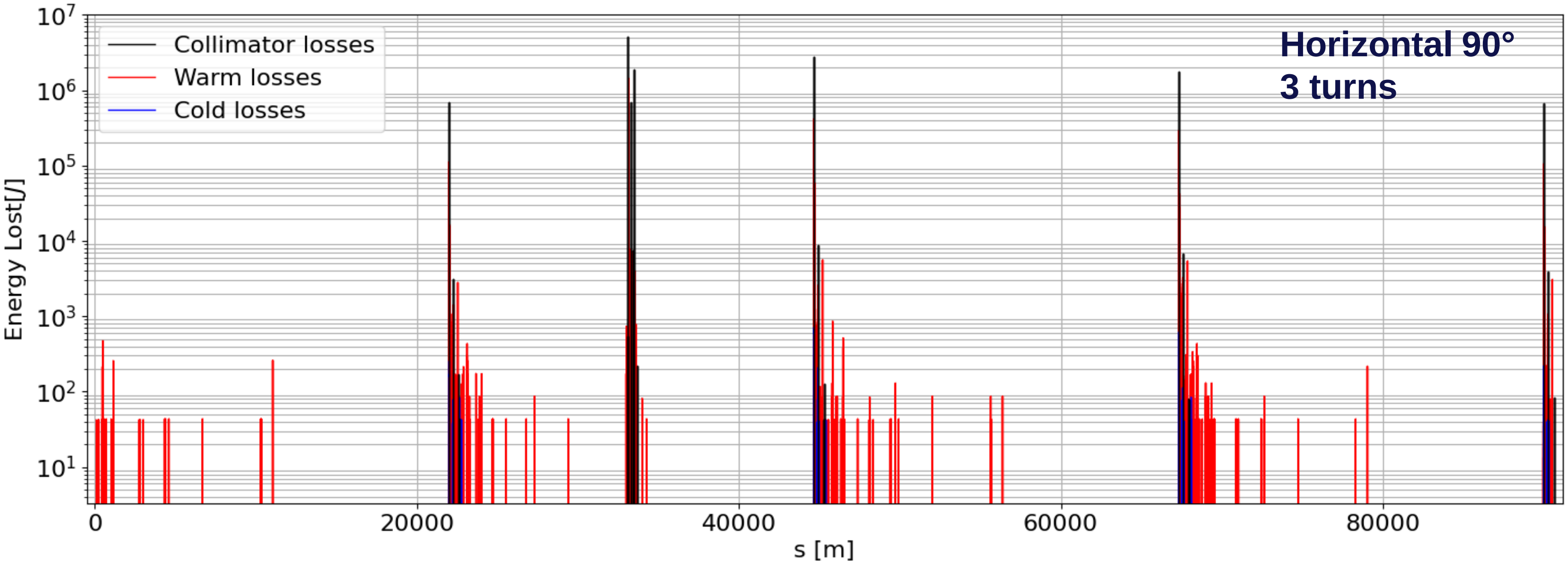

Horizontal: 6 turns


Vertical: 3 turns

Preliminary results

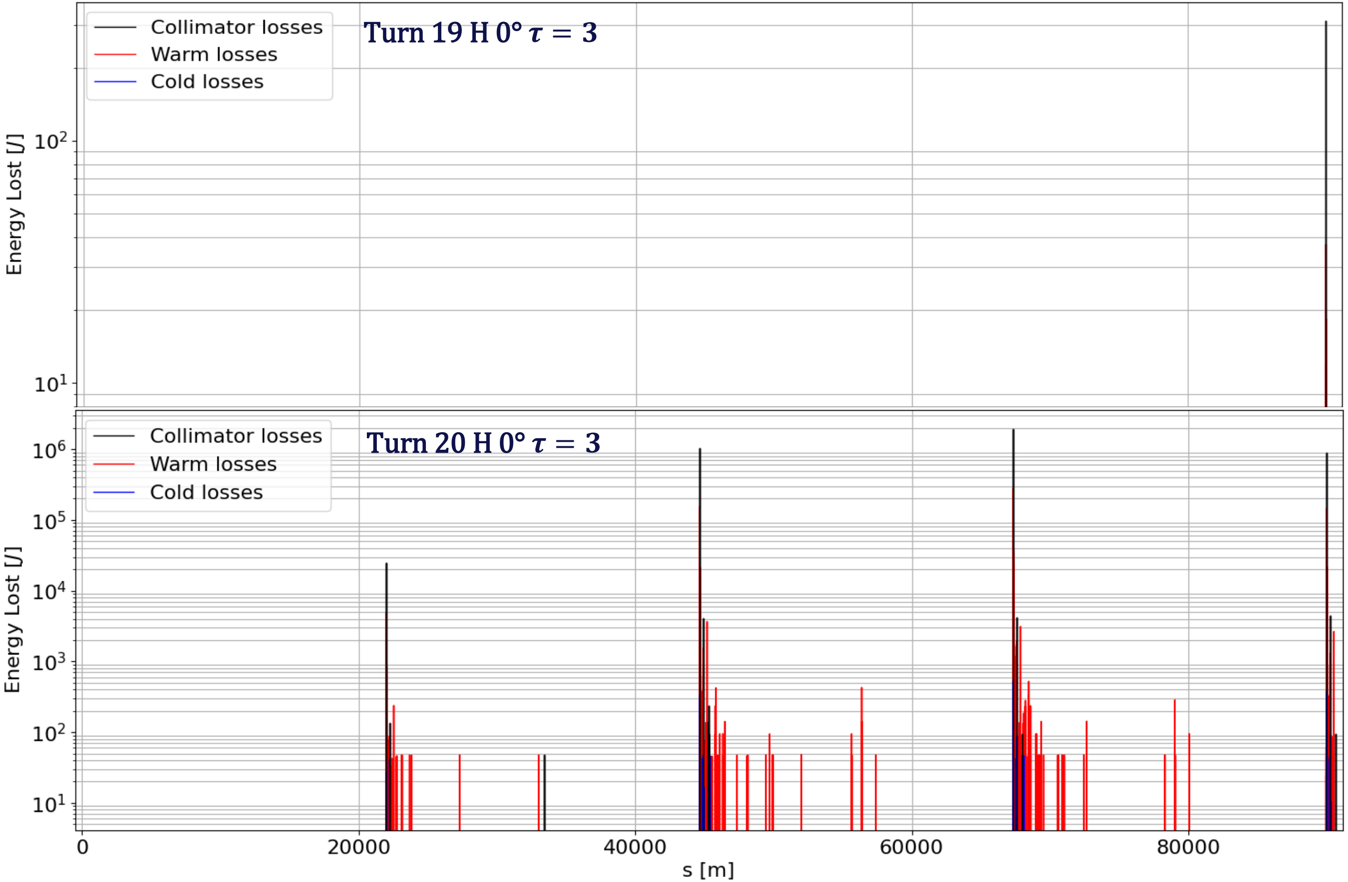
Lossmaps at each turn have been generated to study the **time distribution of the losses**:

- Entire beam is lost in few turns.
- Most of the configuration presents a **turn where up to $\sim 50\%$ of the beam is lost.**
- **Order of MJ lost across collimators and apertures in one turn.**
- The energy lost in first turns might be detected to damp the beam before damages.



Horizontal 90°
3 turns

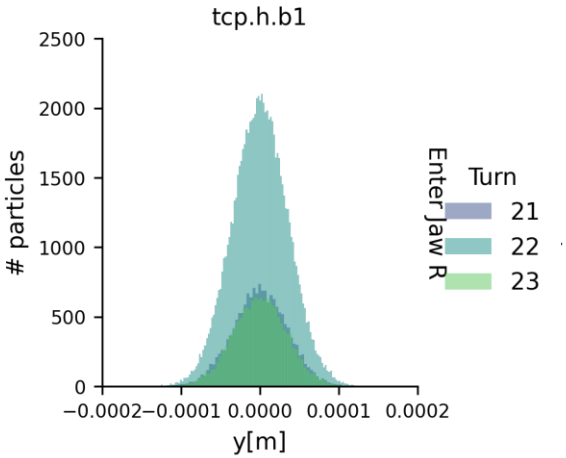
Horizontal instability: worst case

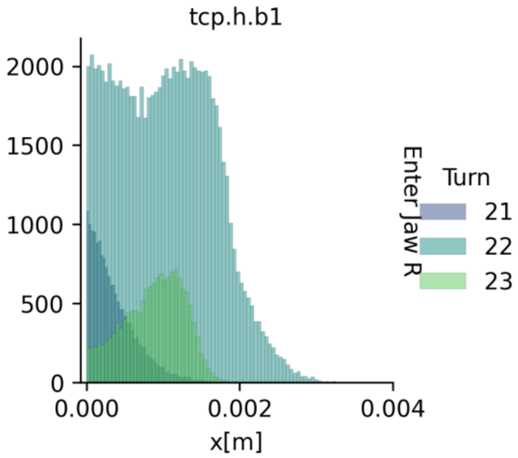


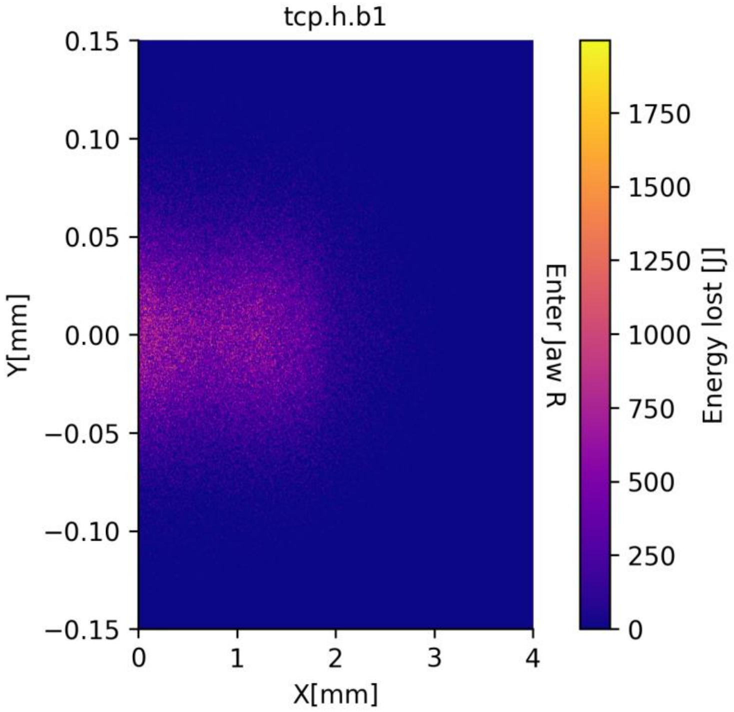
- Entire beam lost within $\sim 5(7)$ turns for $\tau = 3(6)$.
- **From turn 19 ($E_{lost} \sim 400\ J$) to turn 20 ($E_{lost} > 5\ MJ$).**
- Losses in the aperture coming from secondary particles or scattered primaries.
- Significant losses close to the IPs, more than in the collimator insertion.

Horizontal instability: collimator impacts

Considering the configuration $\boldsymbol{\mu = 0° \, \tau = 3}$:





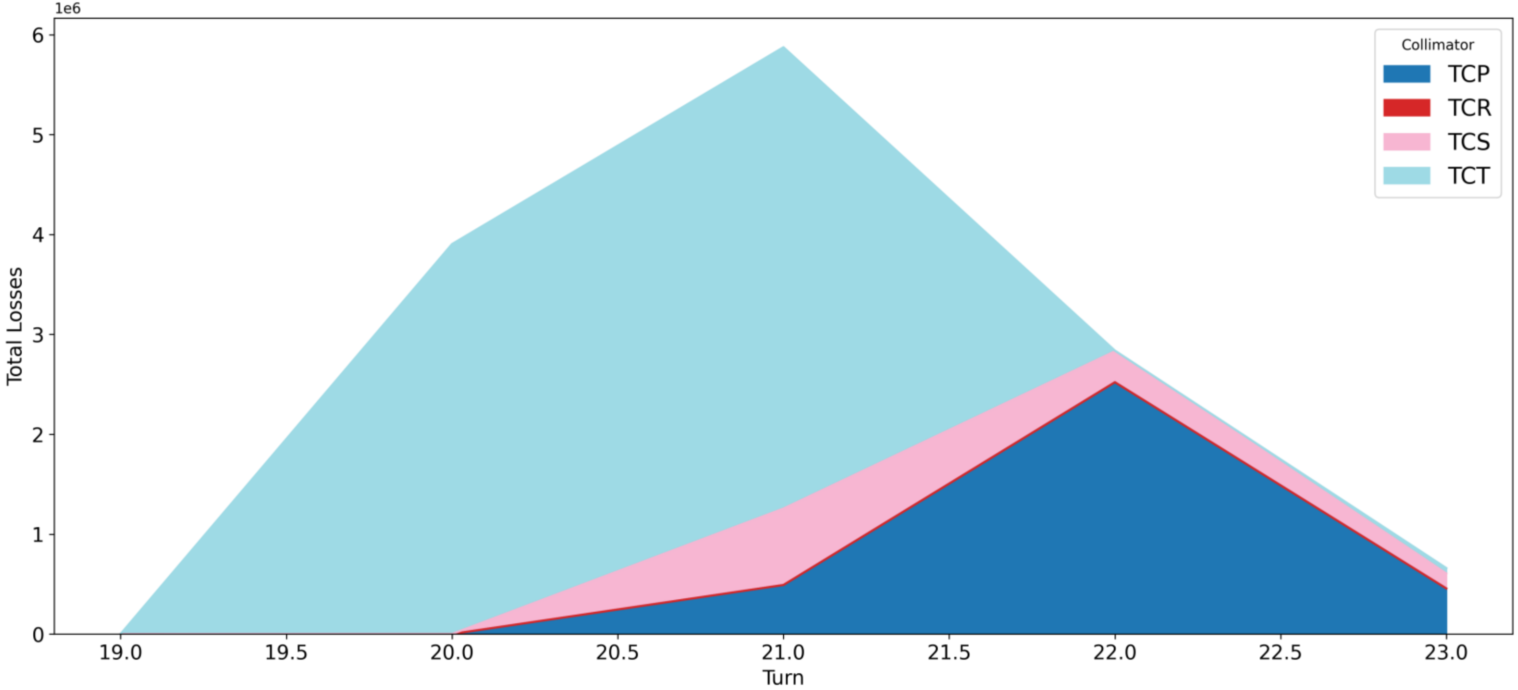


Note: Axes are with respect to the collimator system

Horizontal instability: losses across collimators

Considering the configuration $\mu = 0° \; \tau = 3$:

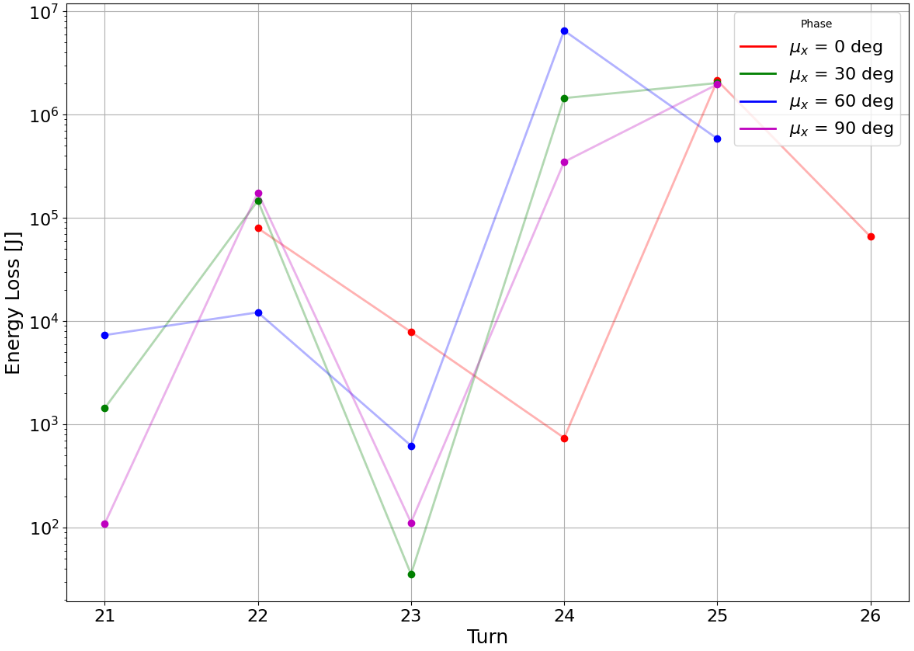
- Significant losses in the tertiary collimators, efficiently protecting SR collimators.



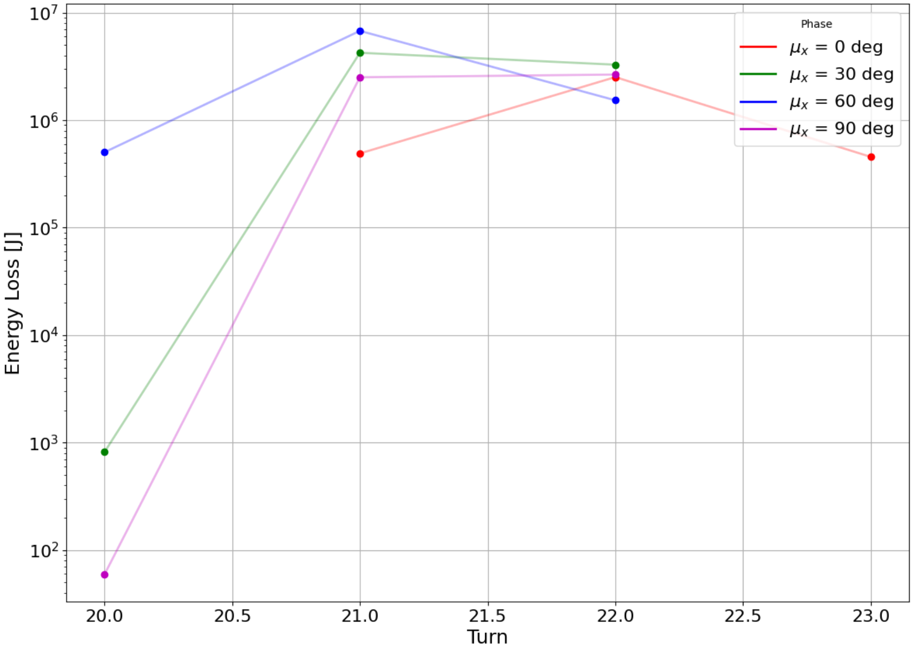
Losses at the primary collimators: horizontal

To compare the various cases is useful to look at the losses in the primary wrt time:

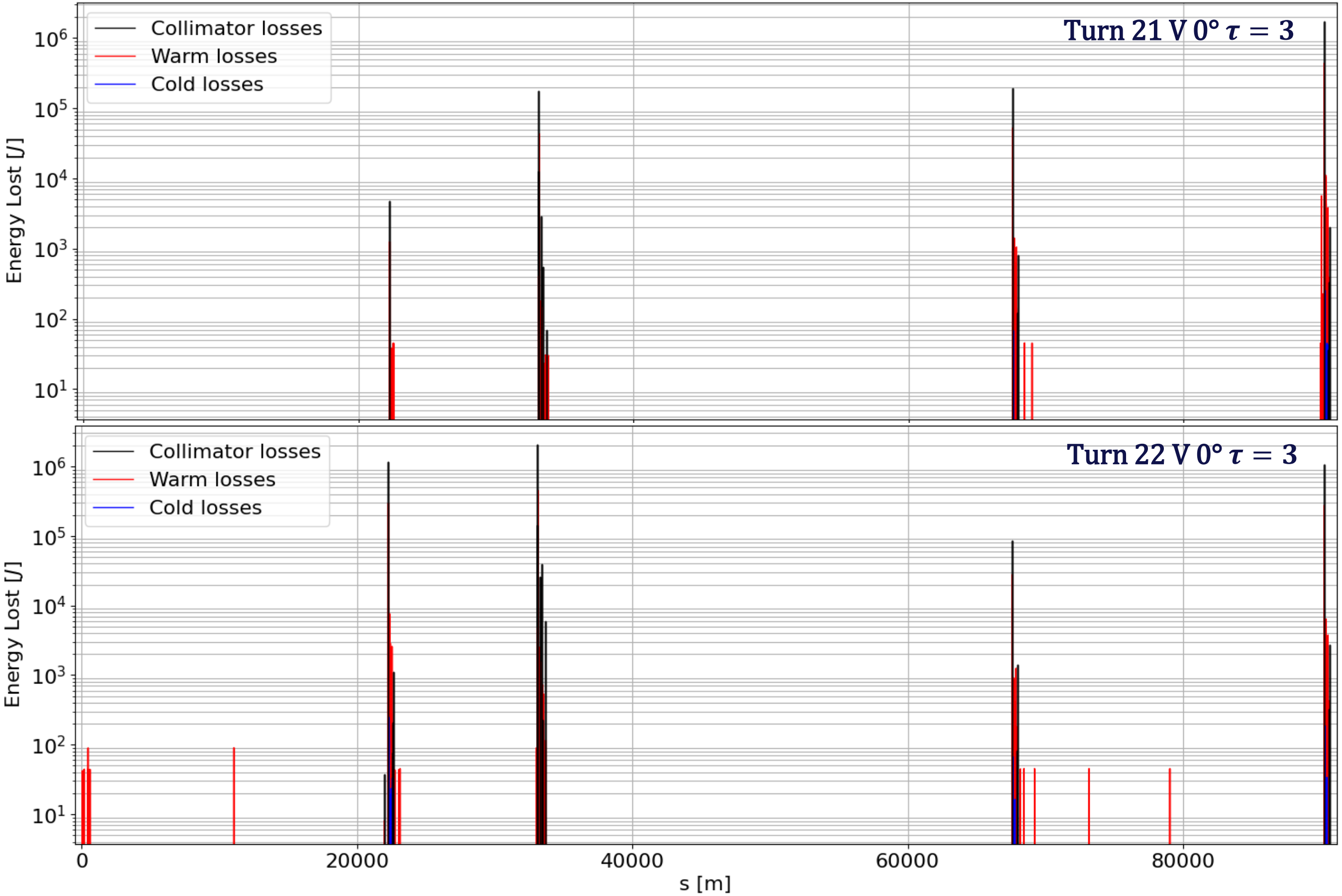
$\tau = 6$



$\tau = 3$



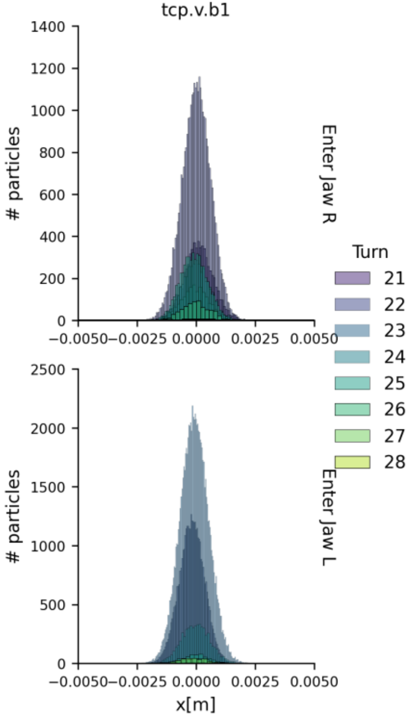
Vertical instability: worst case

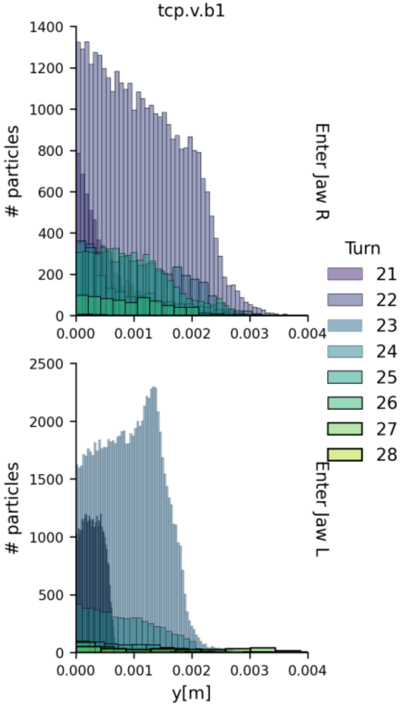


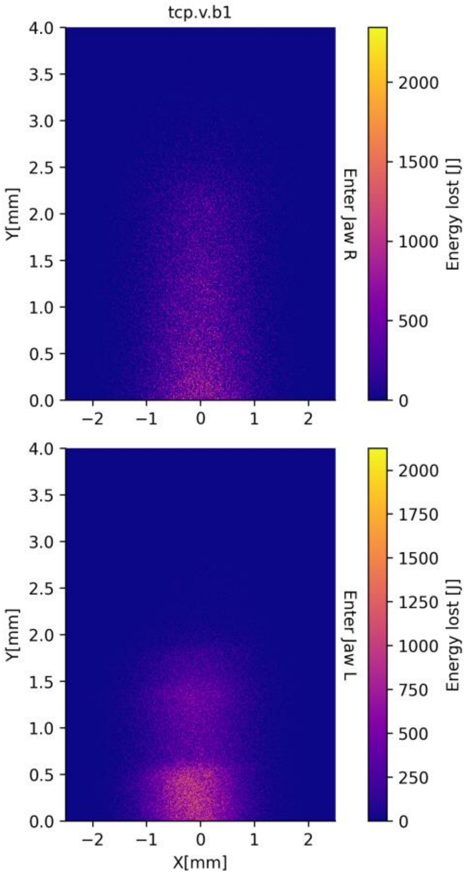
- Entire beam lost within $\sim 9(14)$ turns for $\tau = 3(6)$.
- **First loss at turn 21 ($E_{lost} \sim 3\ MJ$) then turn 20 ($E_{lost} \sim 5\ MJ$).**
- Less losses in the aperture compared to the horizontal case.
- Losses are more spread across the turns.

Vertical instability: collimator impacts

Considering the configuration $\boldsymbol{\mu} = 0^\circ \ \boldsymbol{\tau} = 3$:





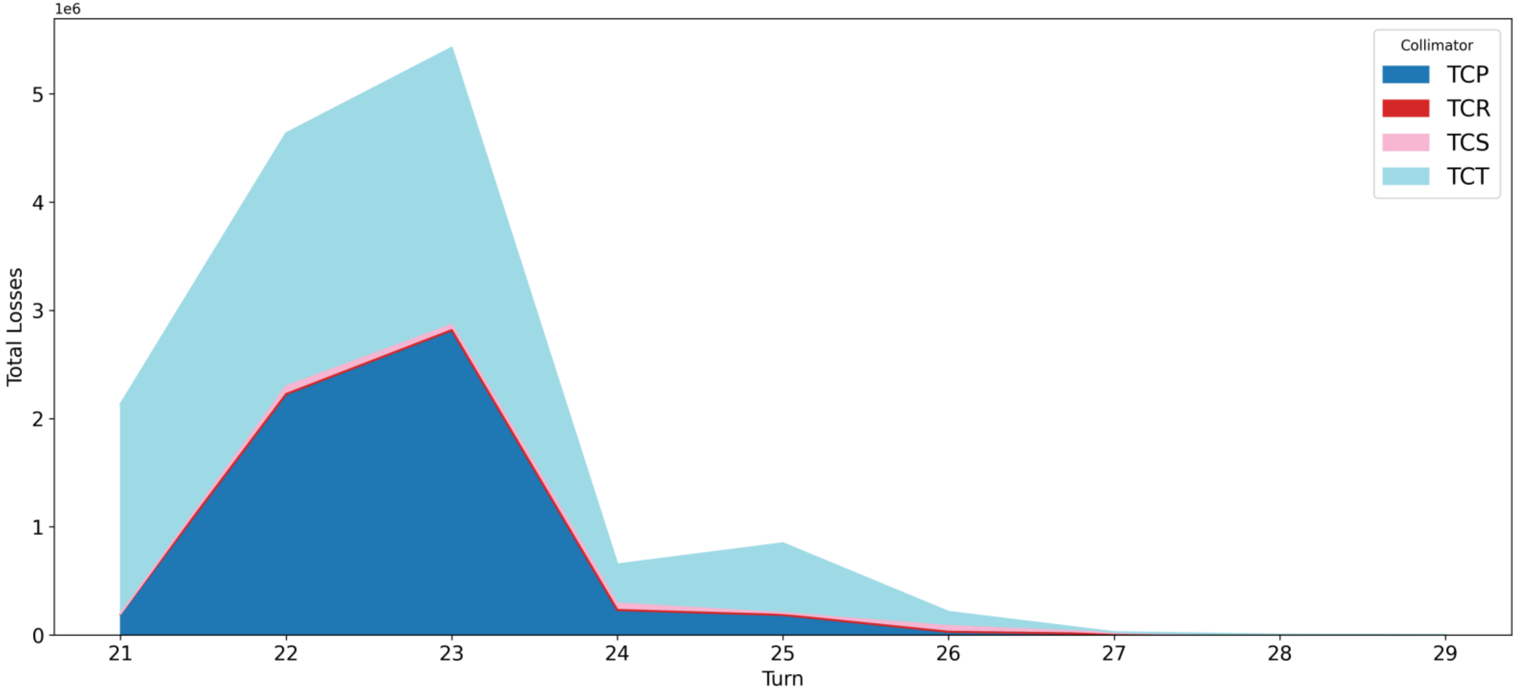


Note: Axes are wrt to the collimator system

Vertical instability: losses across collimators

Considering the configuration $\mu = 0° \; \tau = 3$:

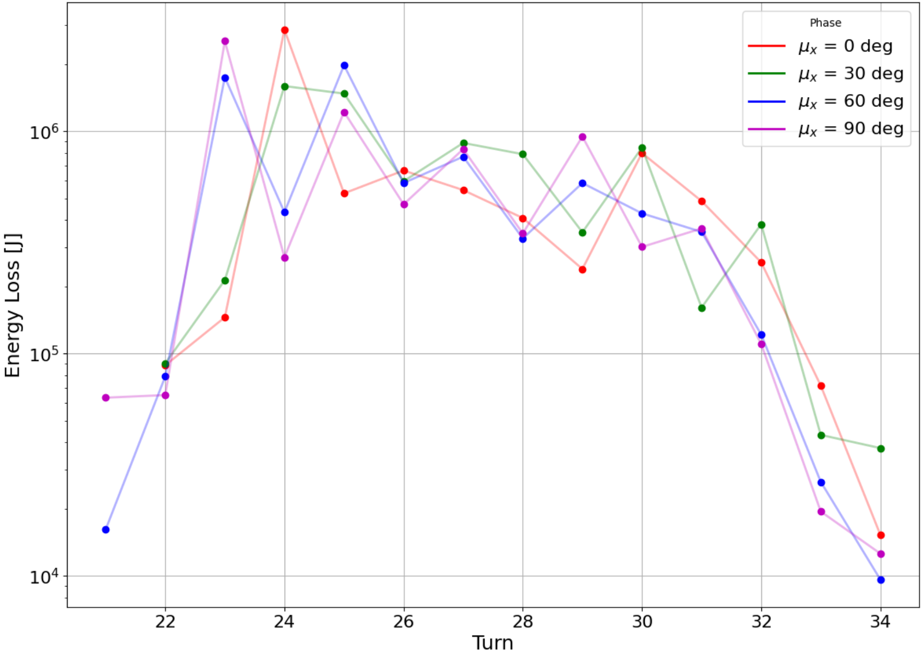
- Significant losses in the tertiary collimators, efficiently protecting SR collimators



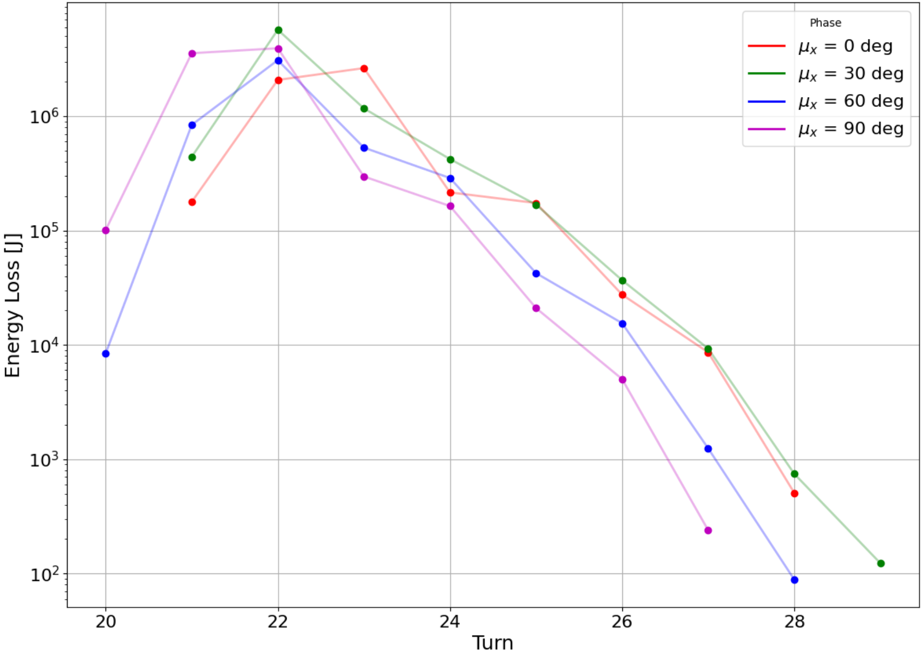
Losses at the primary collimators: vertical

To compare the various cases is useful to look at the losses in the primary collimator wrt time:

$\tau = 6$



$\tau = 3$



Conclusions

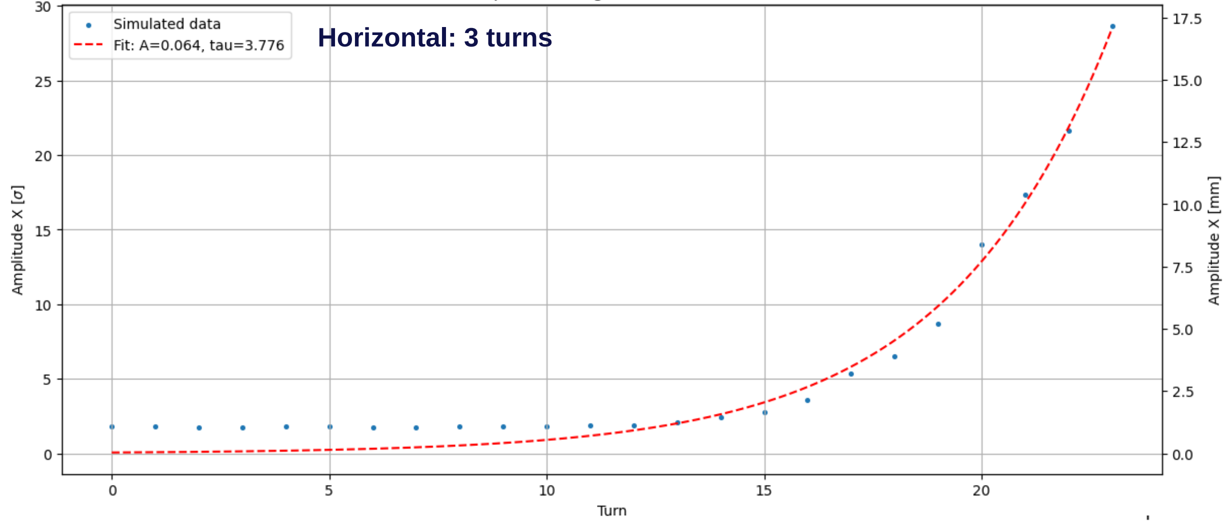
The **fast instability could be dangerous** if the feedback system fails.

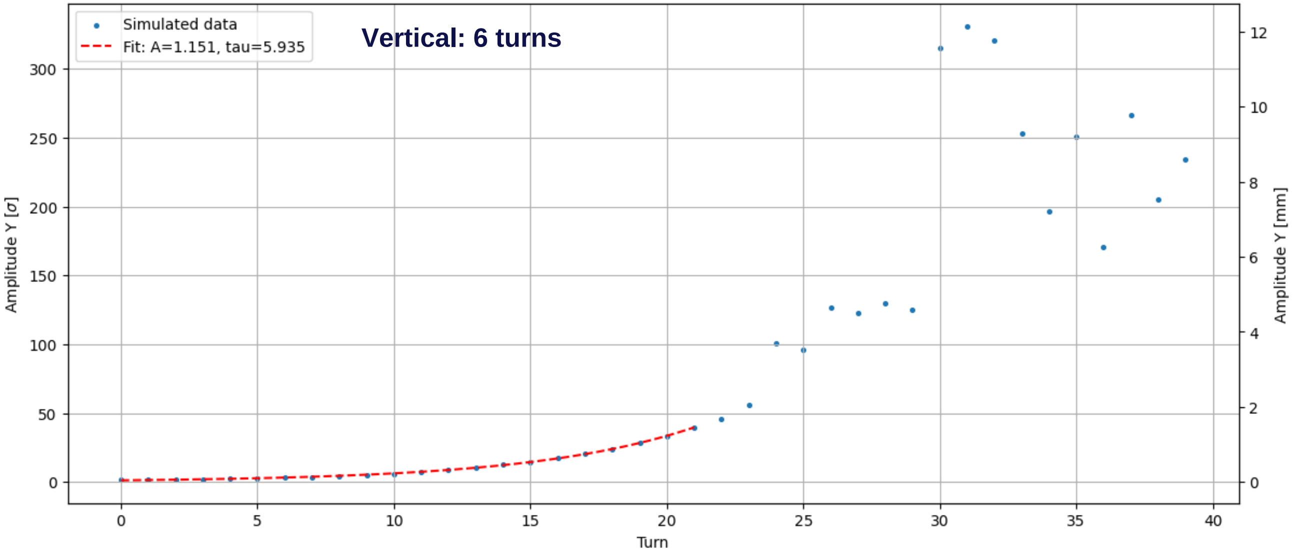
- This instability can cause damage both at the machine and detectors, as well as increasing backgrounds.
- **Chances of damaging collimators/detectors**. The beam is lost within few turns, almost 50% of beam energy lost in one turn.
- The effect depends also on the phase advance.
- High losses nearby experiments, shower calculation in the detector region is needed.

Thank you
for your attention.

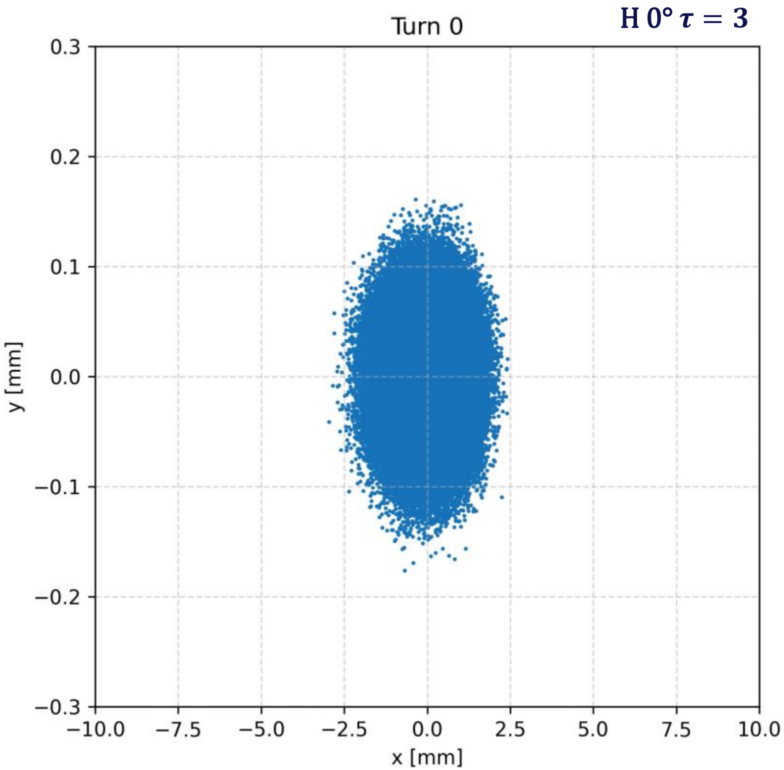
Backup

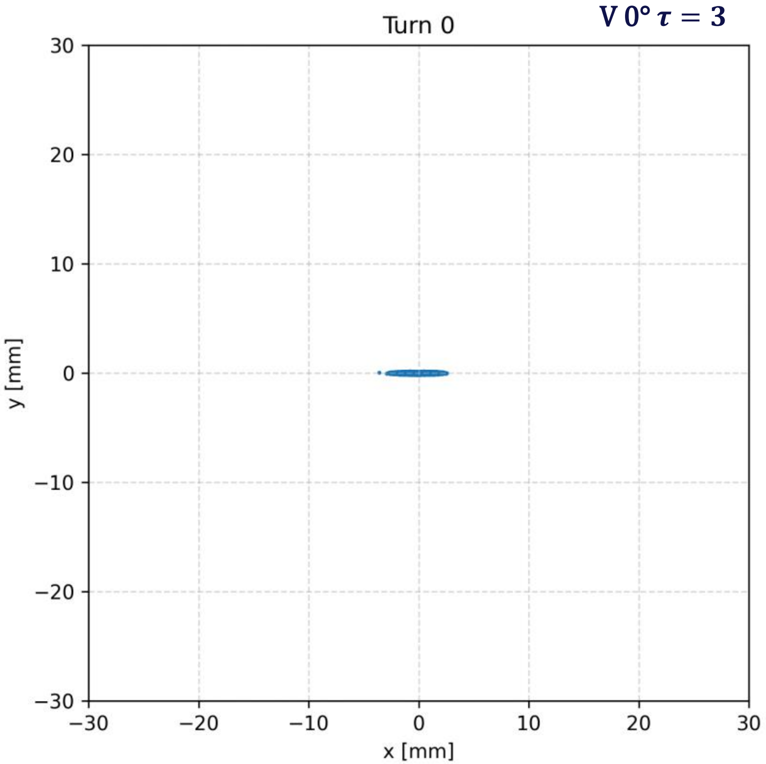
At primary collimator.


Horizontal: 3 turns


Vertical: 6 turns

Transverse beam position over turns


H 0° $\boldsymbol{\tau = 3}$


V 0° $\boldsymbol{\tau = 3}$

- The broad distribution are reasonable if we look at the oscillation during the looses turn
- This animation does not include scattering in the collimators, so the distribution would be even more spread.

Fast instability: Introduction

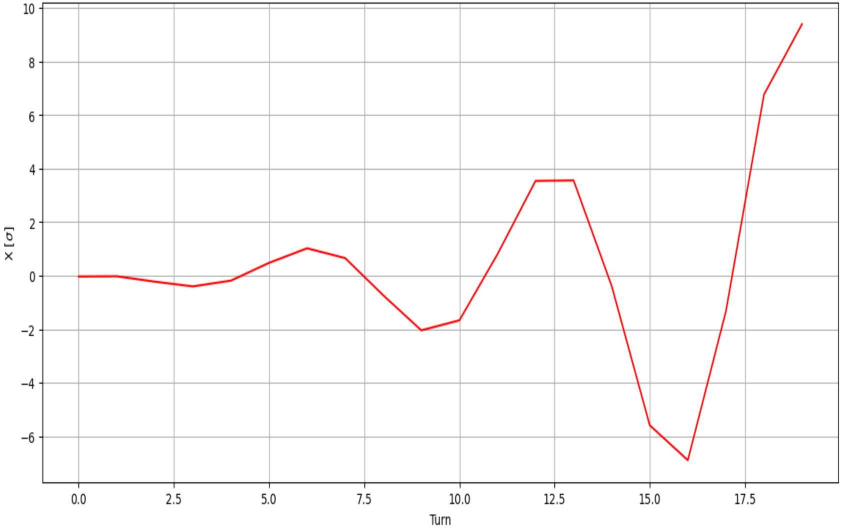
Assuming the beam as a single particle of charge $N_b e$ (no coupling) under the influence of an external force(wake fields/impedance) and neglecting the longitudinal motion.

A complex tune shift is generated due to the impedance of the ring $\Delta\omega = U - jV$:

- The betatron motion is influenced by such impedance.
- The real part of the impedance define growth/damping rate of the betatron oscillation.
- The **instability rise-time** is given by:

$$\tau_{x,y} = \frac{1}{V_{x,y}} = \frac{4\,\pi Q_{x,y}(\frac{E_t}{e})}{I\ c\ \times\{-Re[Z_{x,y}(\omega)]\}}$$

- **If $\tau > 0$ → betatron oscillations grow exponentially.**



For more detalies X. Buffat.