BEAM LOSSES FROM FAST INSTABILITY

WORK IN PROGRESS

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Fast instability Introduction

- The ring impedance can generate an instability that leads the **beam to oscillate coherently with an exponentially growing amplitude, potentially losing the beam within few turns**.

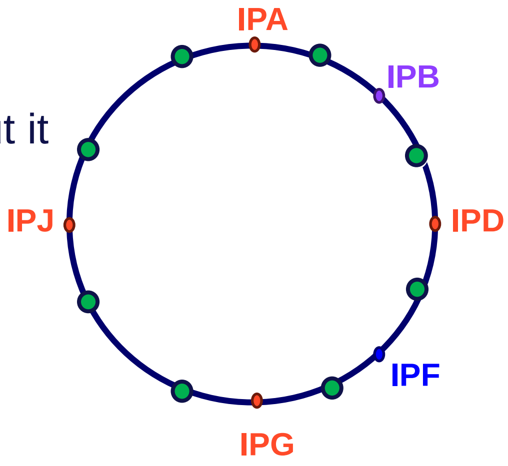
- A feedback system is under development to damp the instability. However, **feedback failures might happen and need to be investigated**.

- Effects on machine and detectors need to be understood to avoid damage.

- Collimation system must protect the machine/detectors also in this scenario and shouldn’t be damaged by it.

- If not, both collimation and feedback systems must be improved or the beam must be dumped before any damage occurs.

Simulation setup



- **Impedance model and intrabeam interactions not simulated**, but it is under studying within the collective effects group.
- Fast instability modeled by **8 exciters, giving dipole kicks, placed along the ring** (one per arc, shown as green points).
- Exciters are synchronized such that the 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:

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

- Resulting in **betatron oscillations exponentially growing with time**.
- Performed with **Xsuite-BDSIM** simulation tool, as for the other collimation studies with combined tracking and scattering routines.
- Beam loss distributions along the ring are produced as outputs.

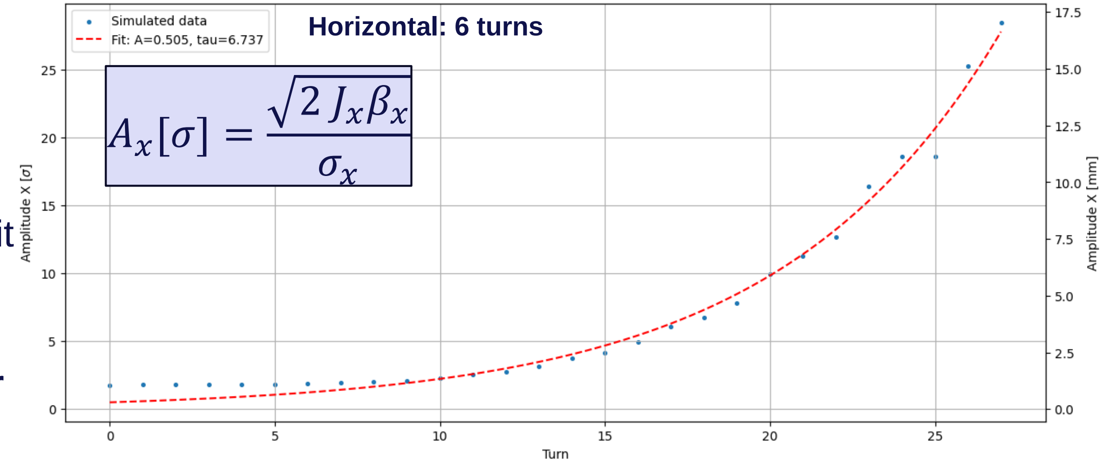
Simulation parameters:

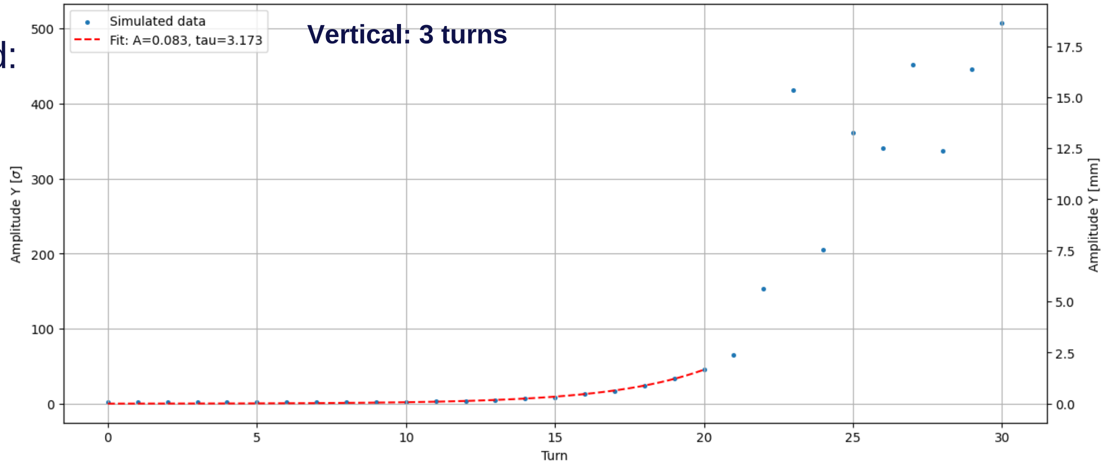
- 5×10^5 **45.6 GeV electrons (Z-mode)**.
- **SR** (mean model), **RF** cavities, magnet **tapering.**
- detailed **aperture model**, **halo and tertiary collimators**, **SR collimator**, wiggler.

Case studies

- Fit of the amplitude growth to the average centroid of the beam.
- 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:

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

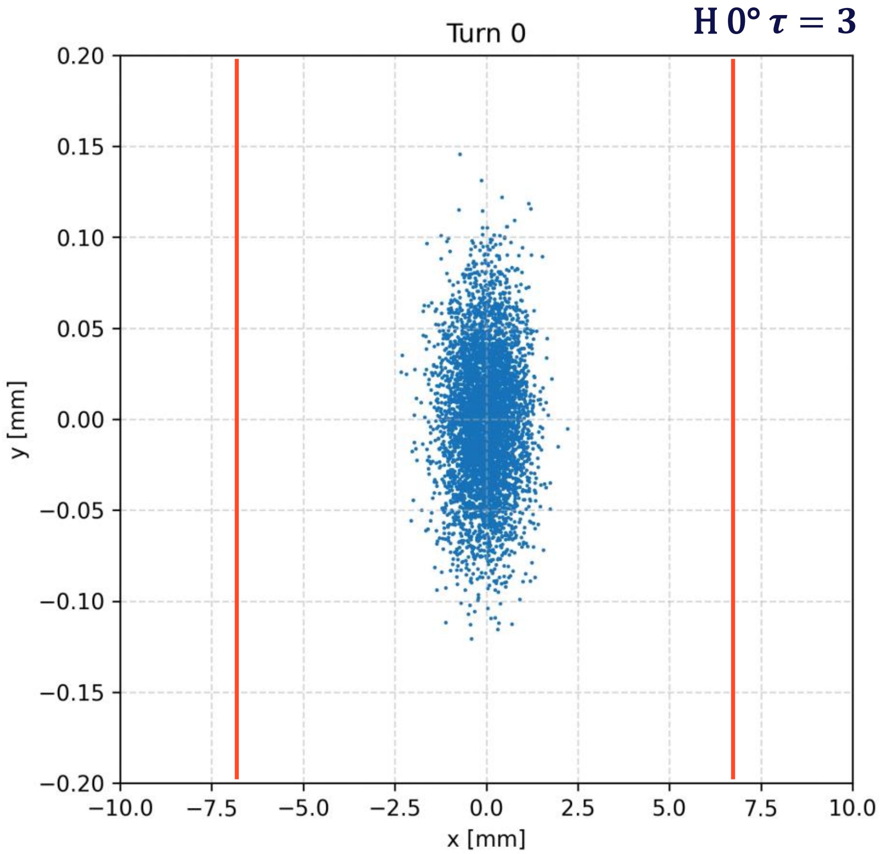




HORIZONTAL INSTABILITY CHARACTERISTICS

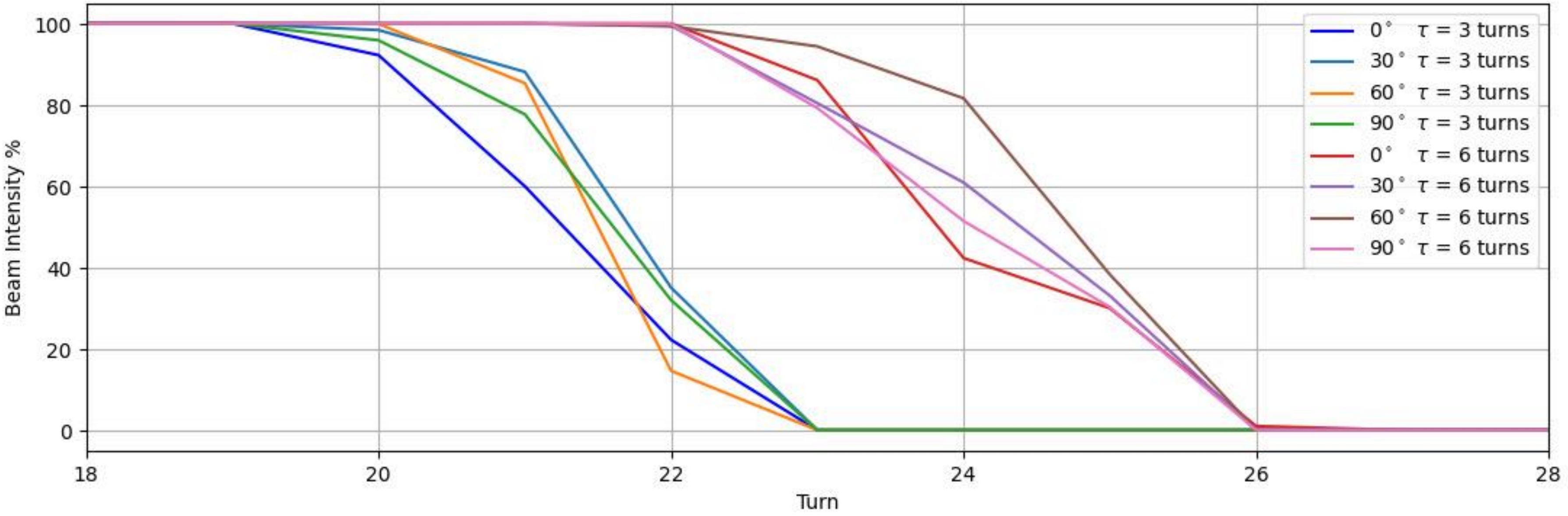
Transverse beam position at primary collimator

- The beam oscillates coherently in the horizontal plane until collimator apertures are reached.

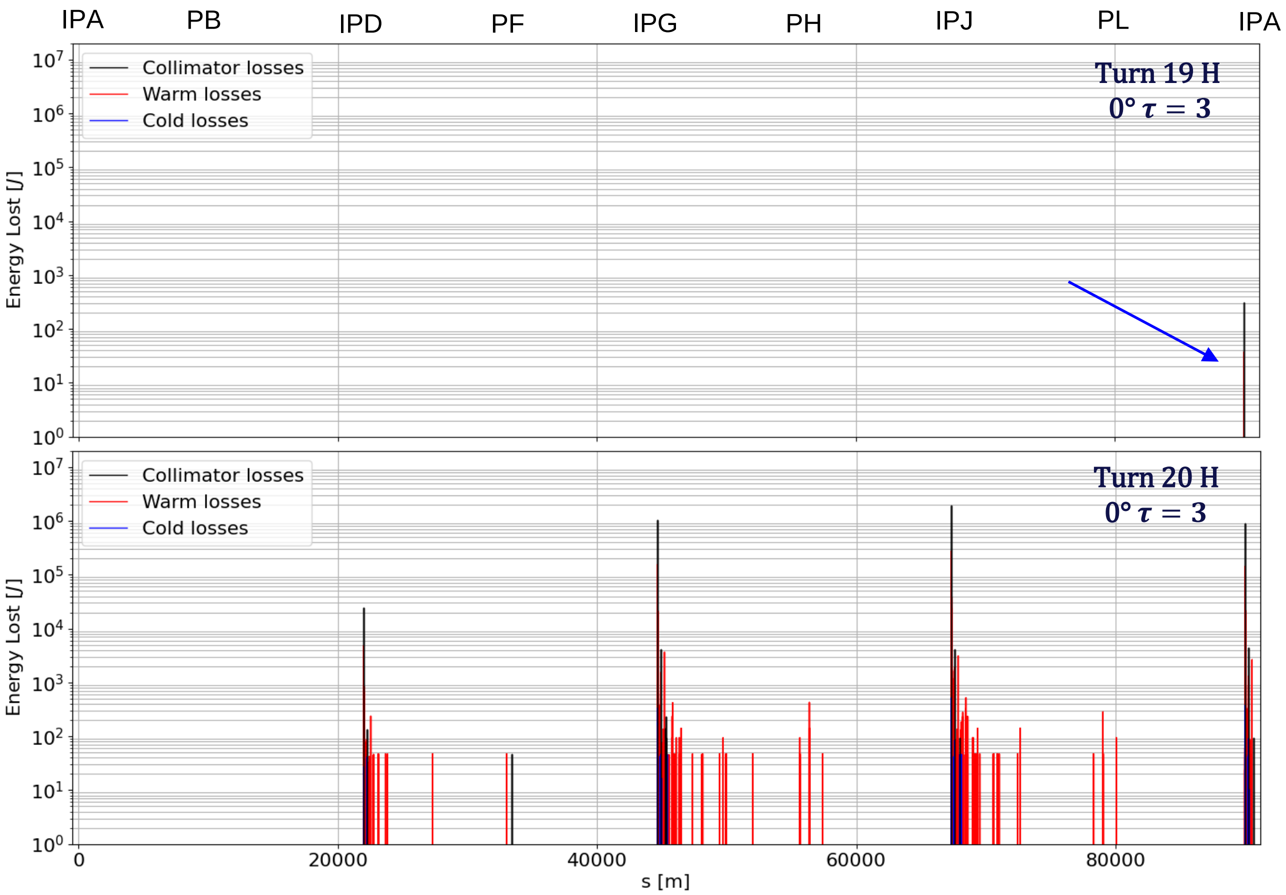


Beam intensity

- **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 dump the beam before damages.

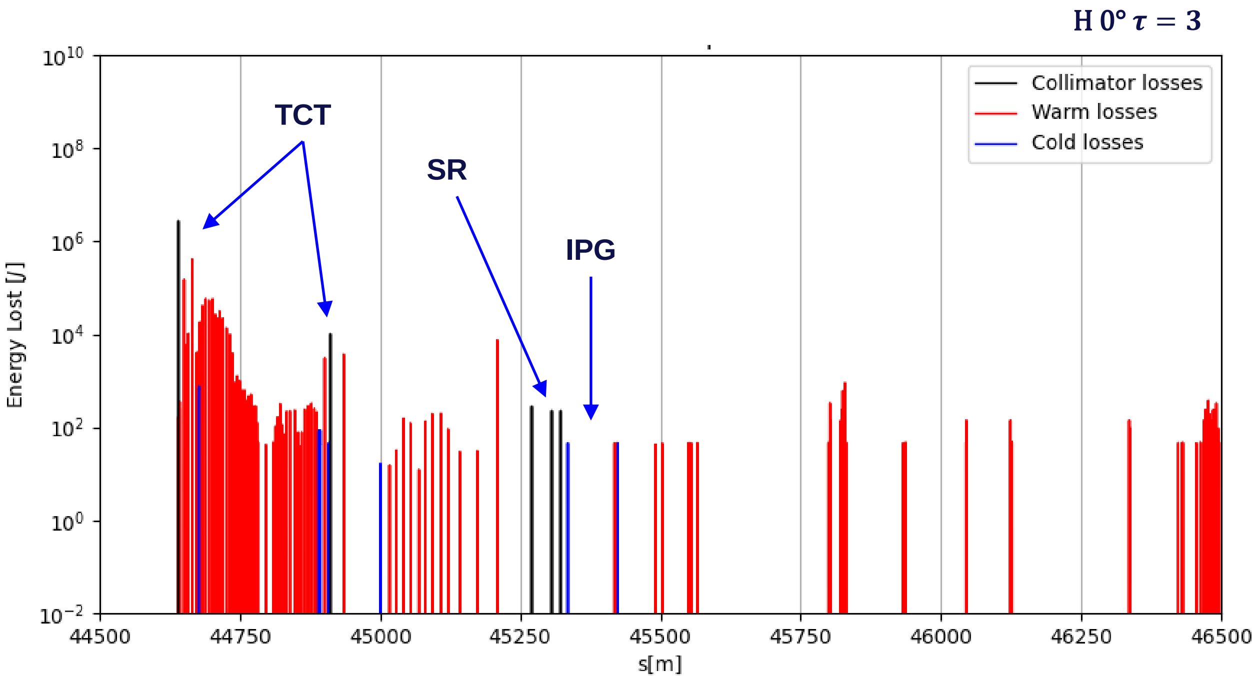


Lossmaps: worst case



- Primary particles on tertiary collimator → current collimation system in PF cannot intercept this fast losses.
- Could be a problem for other type of losses with similar timing characteristics.
- **From turn 19 ($E_{lost} \sim 400\ J$) to turn 20 ($E_{lost} > 5\ MJ$).**
- Losses in the aperture ($\sim 25\%$ of total losses) coming from secondary particles or scattered primaries.

Lossmaps: Interaction region (IPG)

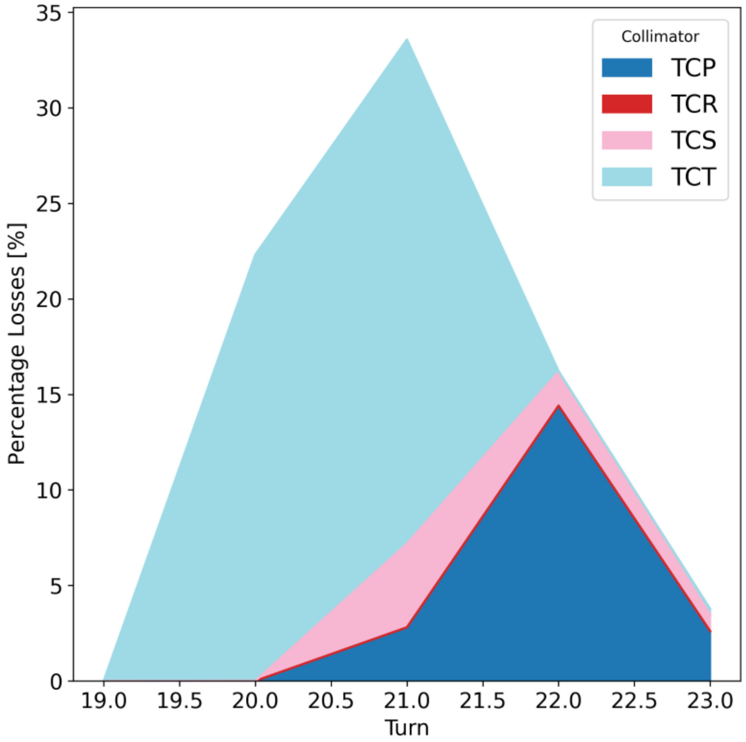


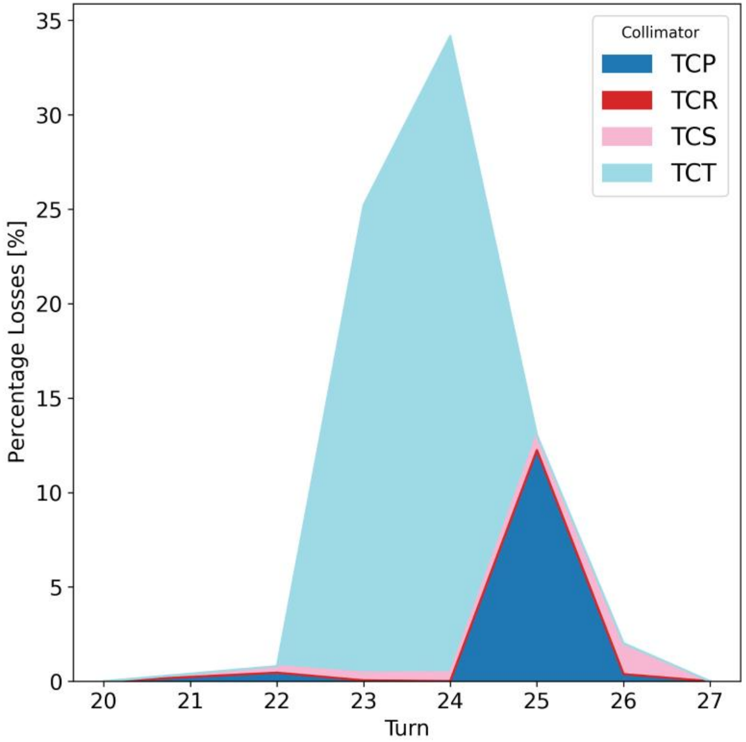
- **Significant losses close to the IPs**, even more than in the collimator insertion.
- Possible solution:
  - Shower absorber after tertiary collimator to protect detectors.

Losses across collimators

- Total loss on same type of collimator shows:
  - Primary collimators not always absorb most of the energy lost → primaries on tertiary collimators.
  - SR collimators are efficiently protected by the TCTs → shower absorber nearby IPs.

H 0° $\tau = 3$



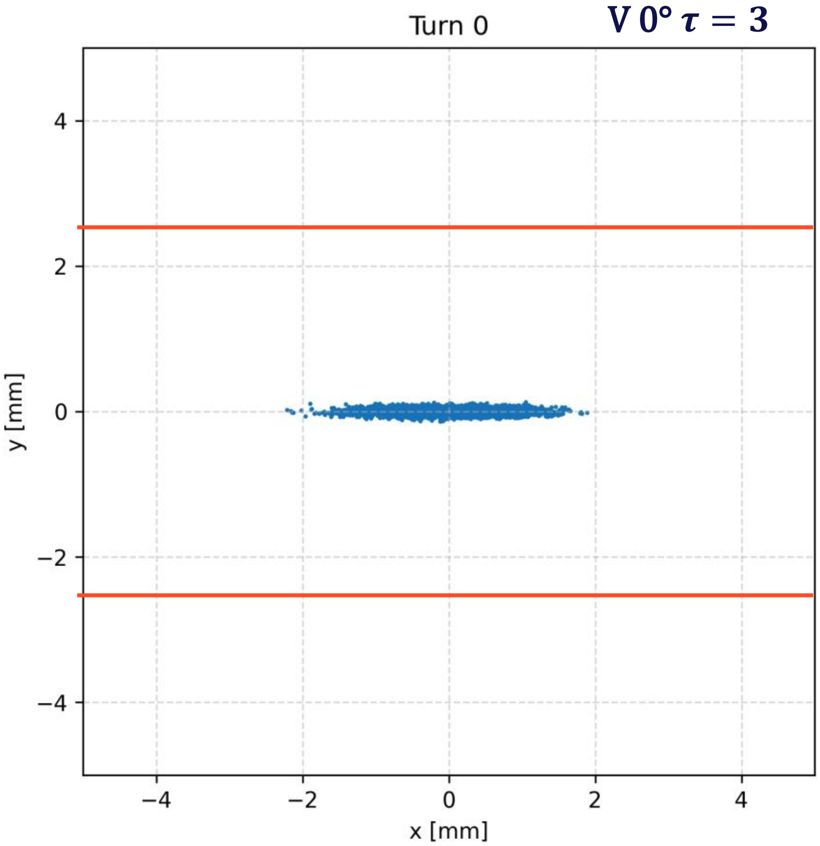


H 60° $\tau = 6$

VERTICAL INSTABILITY CHARACTERISTICS

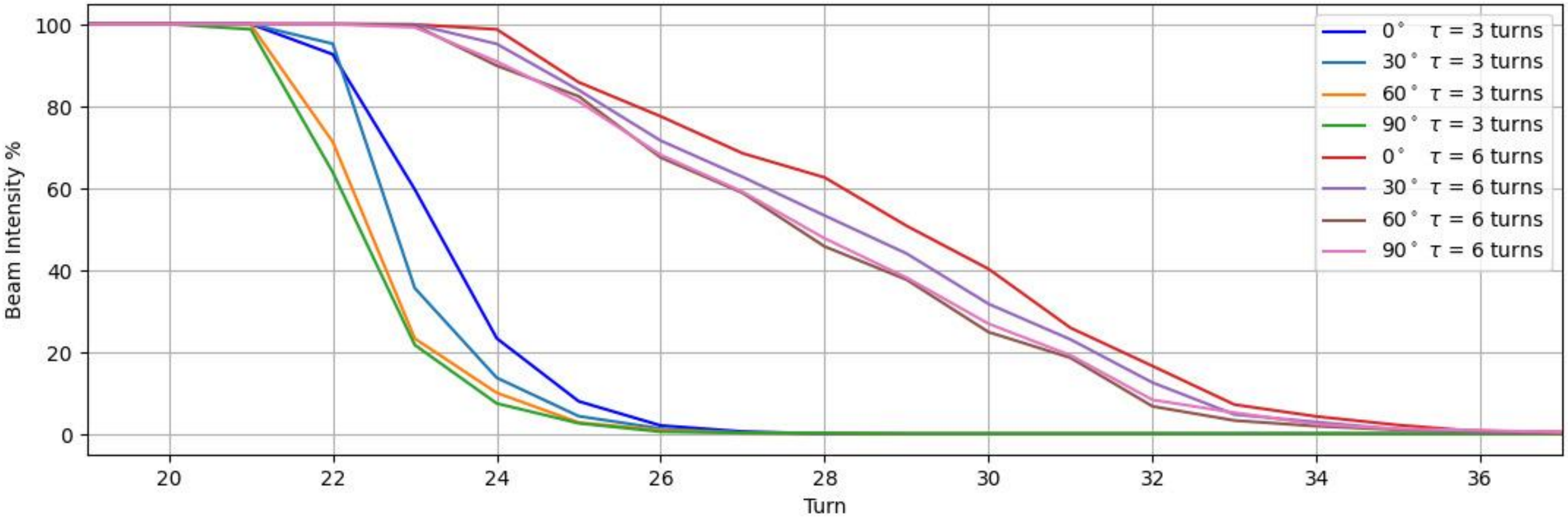
Transverse beam position at primary collimator

- The beam oscillate coherently along the vertical axis for many turns **until the dynamic aperture is reached → beam distribution blows up**.
- Ongoing studies to tighten the vertical collimator's apertures up to the DA ($< 30\ \sigma$).
- First hit in the collimators at turn 21, after the blow up.

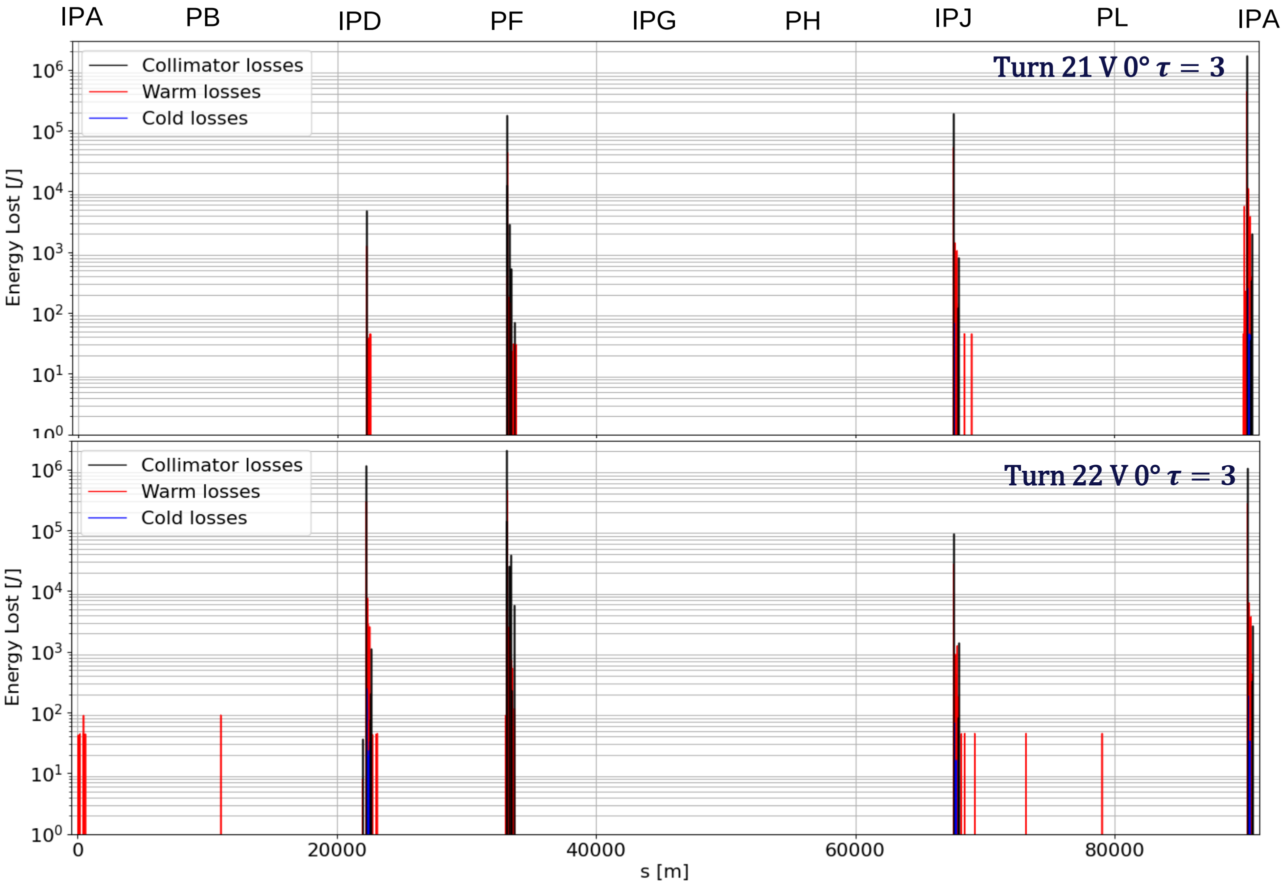


Beam intensity

- **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.**
- Losses are more spread in time due to the beam blow up.



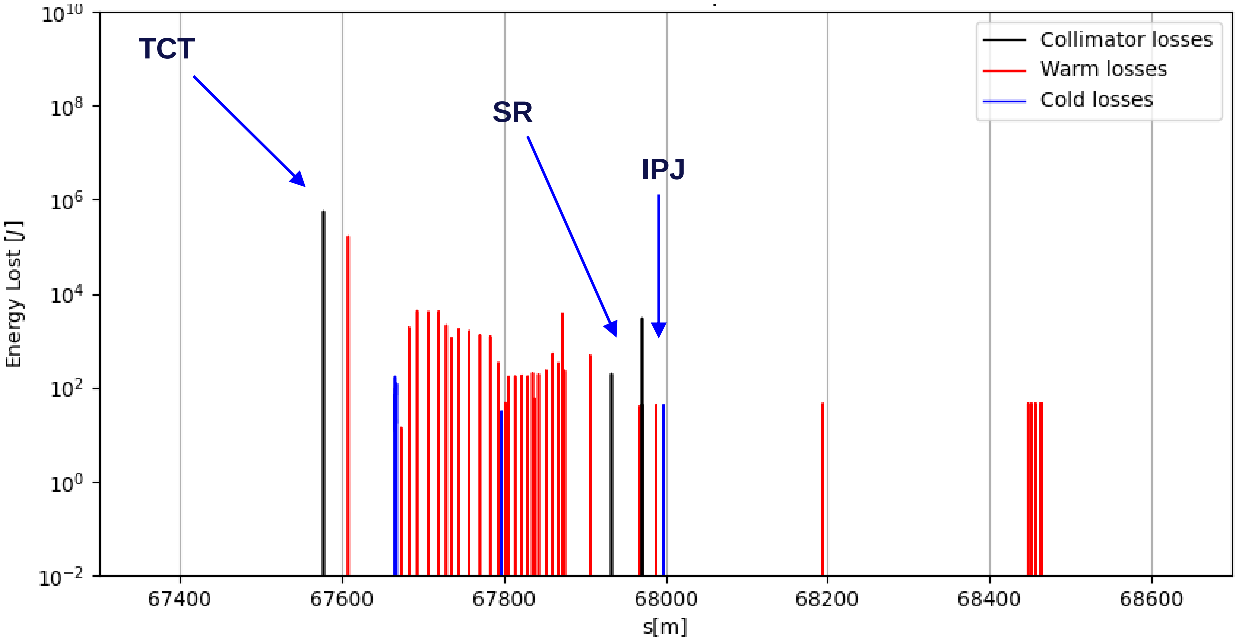
Lossmaps: worst case



- Entire beam lost within $\sim 9(14)$ turns for $\tau = 3(6)$.
- **First loss at turn 21 ($E_{lost} \sim 3\ MJ$) then turn 22 ($E_{lost} \sim\ 5\ MJ$).**
- Less losses in the aperture compared to the horizontal case($\sim 20\%$).

Lossmaps: Interaction region (IPJ)

$\mathbf{V\ 0°\ \tau = 3}$

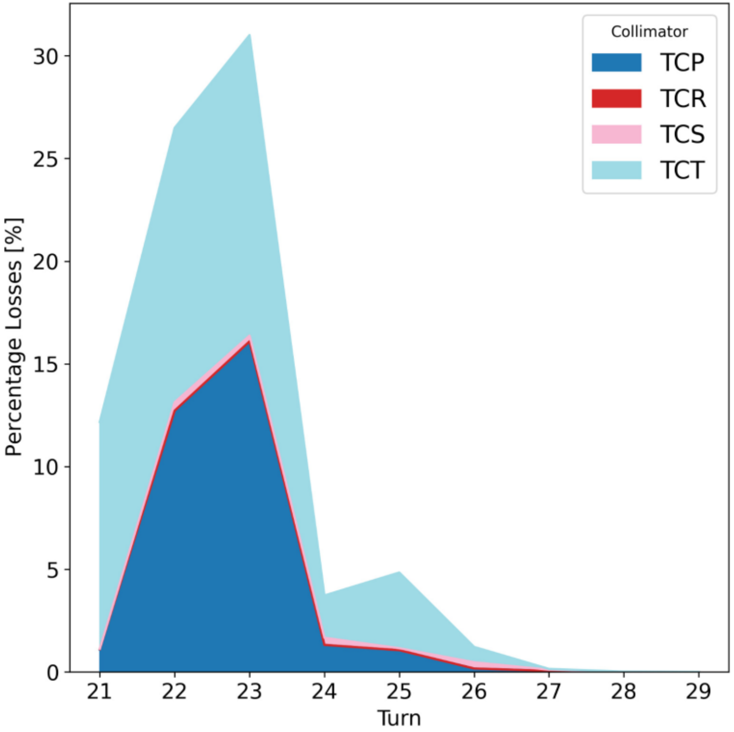


- Primary particles on tertiary collimator **($E_{lost} \sim 1\ MJ$).**
- Solutions:
  - Shower absorber after tertiary collimator to protect detectors.
  - Tightening of vertical collimators apertures (**ongoing studies**).

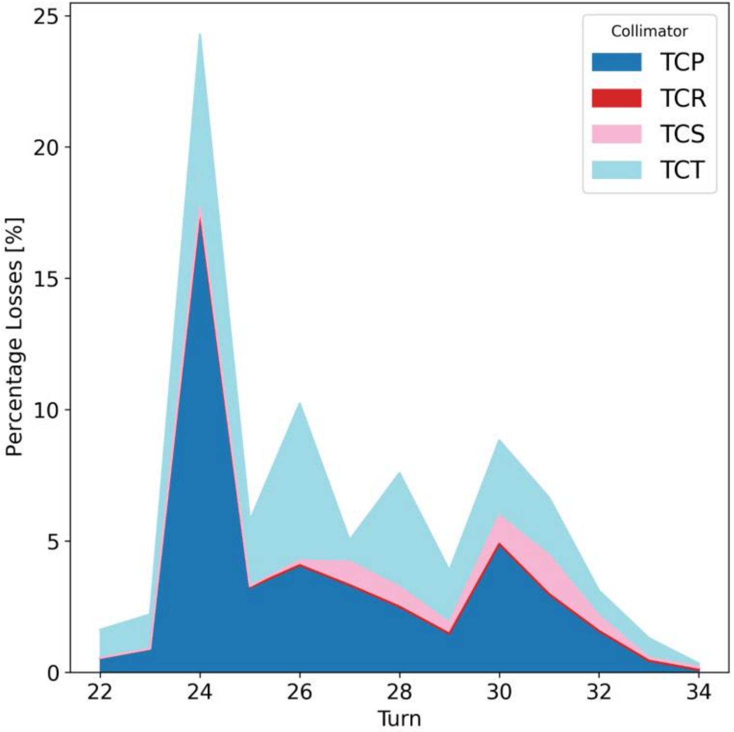
Losses across collimators

- Total loss on same type of collimators shows the same characteristic of the horizontal case:
  - Primary collimators not always absorb most of the energy lost → primaries on tertiary collimators.
  - Significant losses in the tertiary collimators, efficiently protecting SR collimators.

V 0° $\tau = 3$

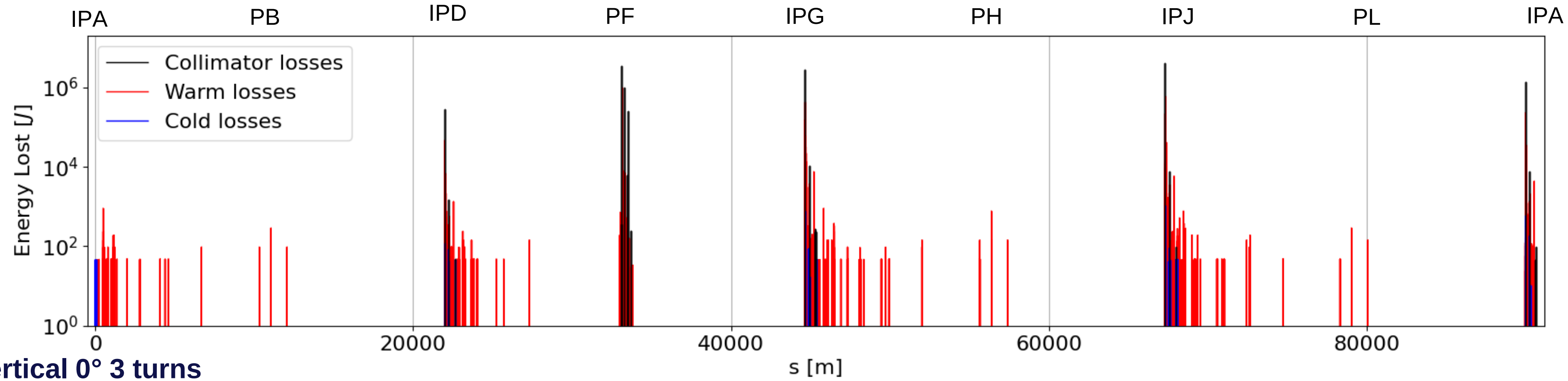


V 0° $\tau = 6$

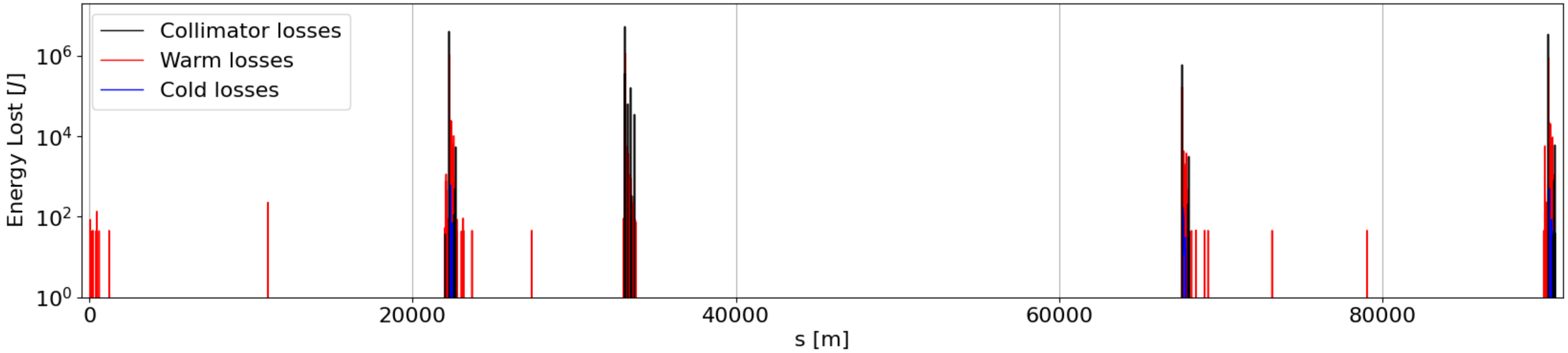


Integrated lossmaps over all turns H vs V

Horizontal 0° 3 turns



Vertical 0° 3 turns



Conclusions

- **Fast instability modeled by synchronized kicks placed along the ring with raising strength**:
  - Reproduced exponential growth of betatron oscillation amplitudes.
  - Studied beam loss distributions around the ring and across multiple turns.

- **THIS IS A WORK IN PROGRESS**, affected by collimation optics updates and impedance modeling as well as potential tightening of the vertical collimator cut.

- The **fast instability could be dangerous** if the feedback system fails.
  - Full beam potentially lost within few turns.
  - Almost 50% of beam energy lost in one turn, losses of order of MJ in the collimator can be expected.
  - The effects depend also on the phase advance.
  - High losses in tertiary collimators hence nearby experiments.

- This instability could potentially cause damage both at the machine and detectors → further investigation is needed.

Next steps

- **Energy deposition studies** → impact distributions on collimators jaws provided to the FLUKA team.

- High losses nearby experiments, **shower calculation in the detector regions** are needed.

- **Mitigating potential damage**: the machine needs to be design such that this instability doesn't occur:
  - redundancy in damper system,
  - Interlocks,
  - reduced impedance,
  - high chromaticity,
  - …

Thank you
for your attention!

Backup

Fast instability: Introduction

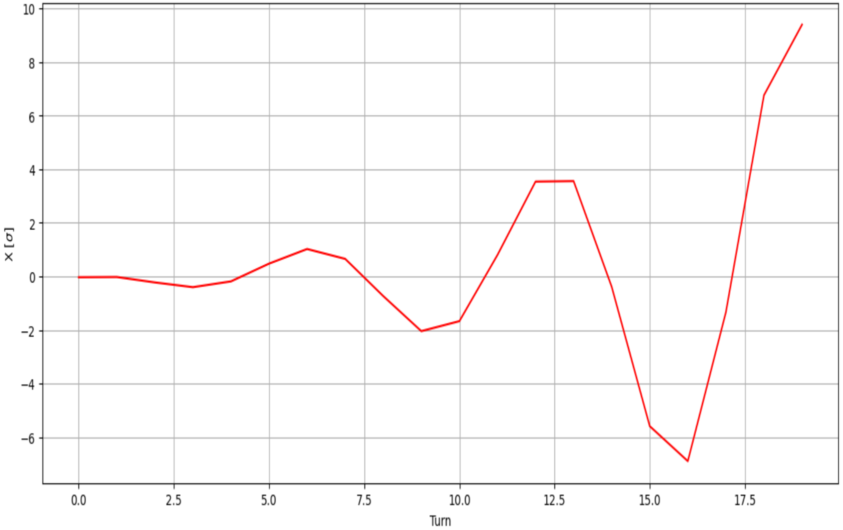
Assuming the beam as a single particle of charge $N_b e$ (no coupling) under the influence of an external force(wake fields/impedance) and neglecting the longitudinal motion.

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:

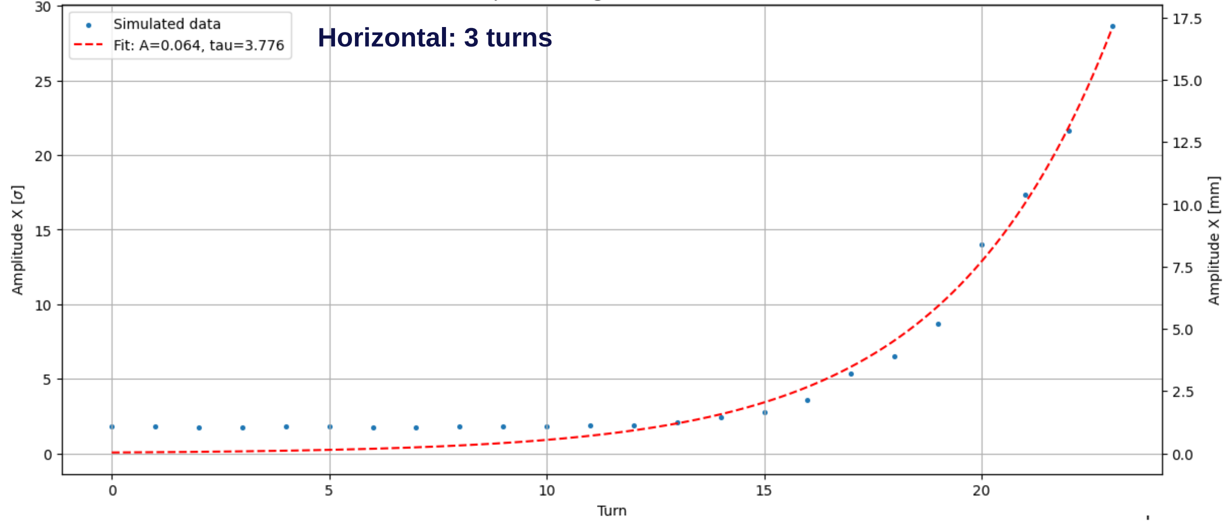
$$\tau_{x,y} = \frac{1}{V_{x,y}} = \frac{4\,\pi Q_{x,y}(\frac{E_t}{e})}{I\ c\ \times\{-Re[Z_{x,y}(\omega)]\}}$$

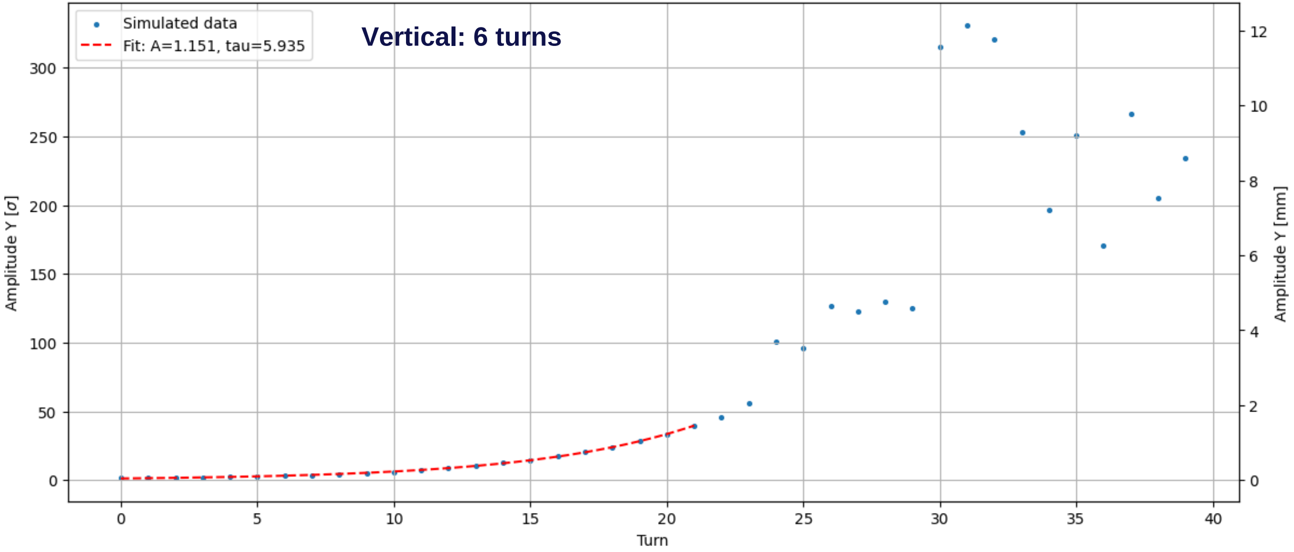
- **If $\tau > 0$ → betatron oscillations grow exponentially.**



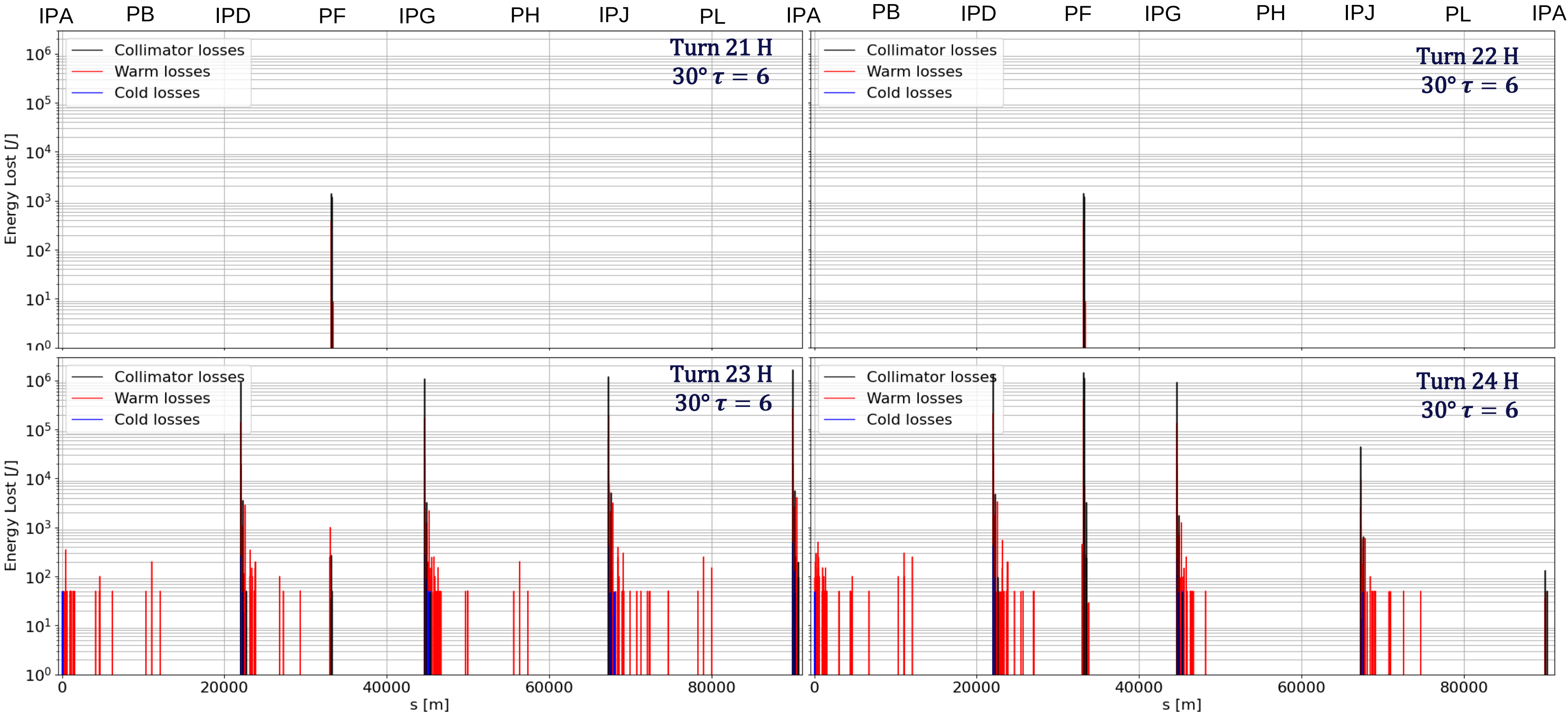
For more detalies X. Buffat.

At primary collimator.



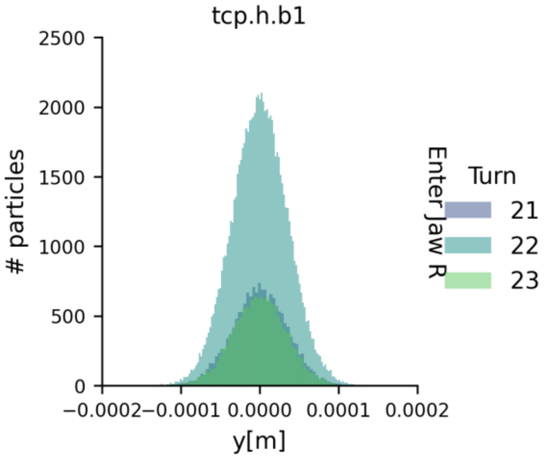


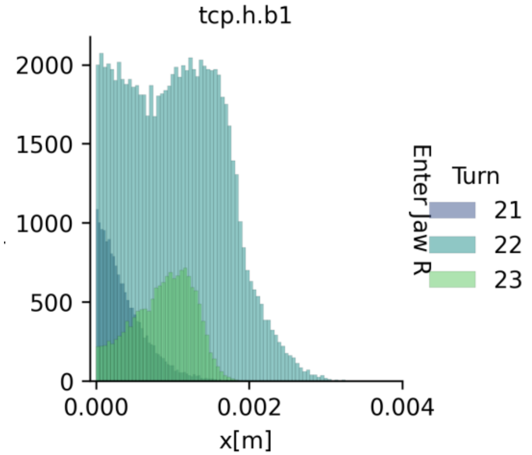
Lossmaps: Time distribution (H)

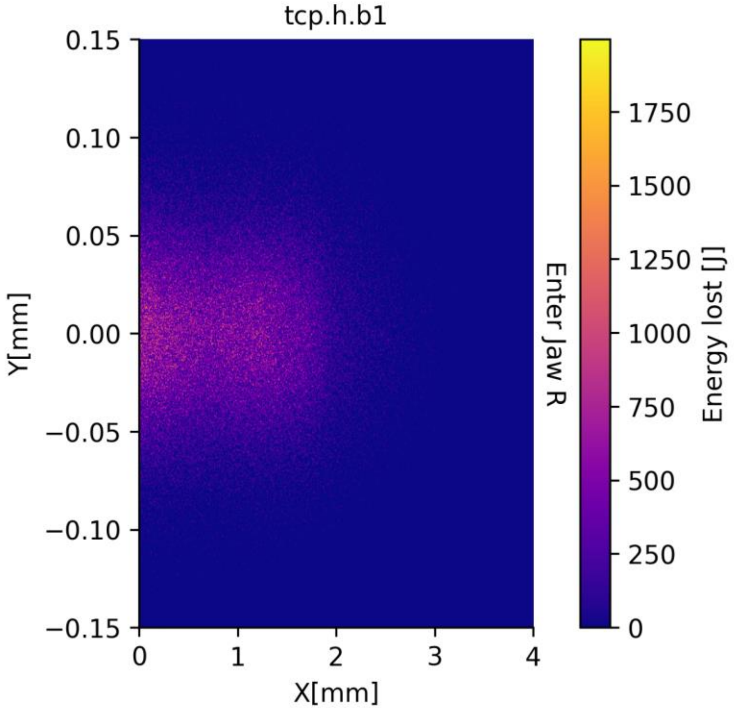


Collimator impact distributions (H)

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







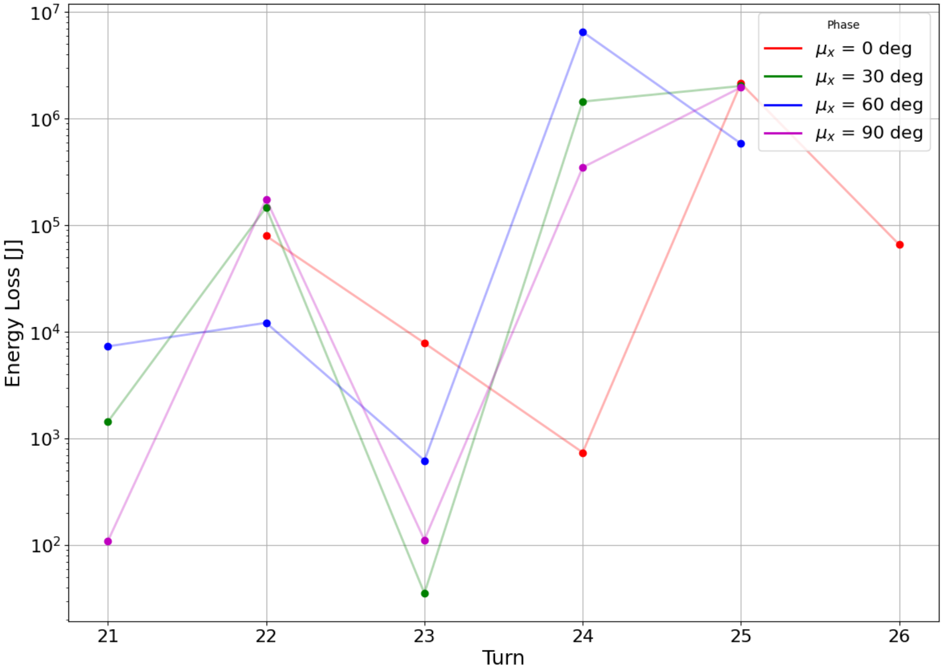
Impact distributions have been provided to the FLUKA team for energy deposition studies.

Note: Axes are with respect to the collimator system.

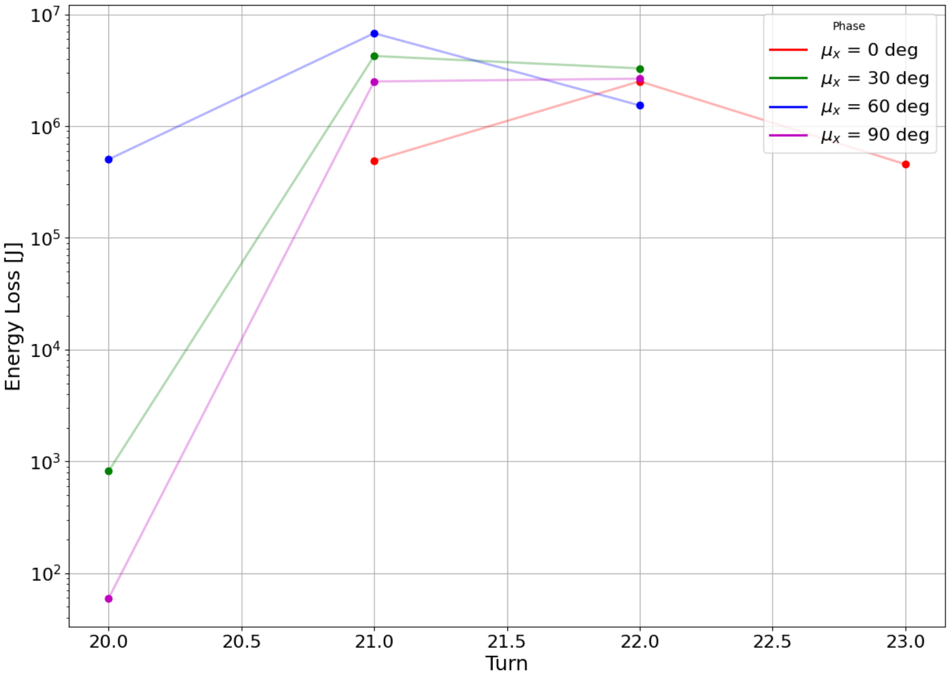
Losses at the primary collimator (tcp.h.b1)

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

$\tau = 6$



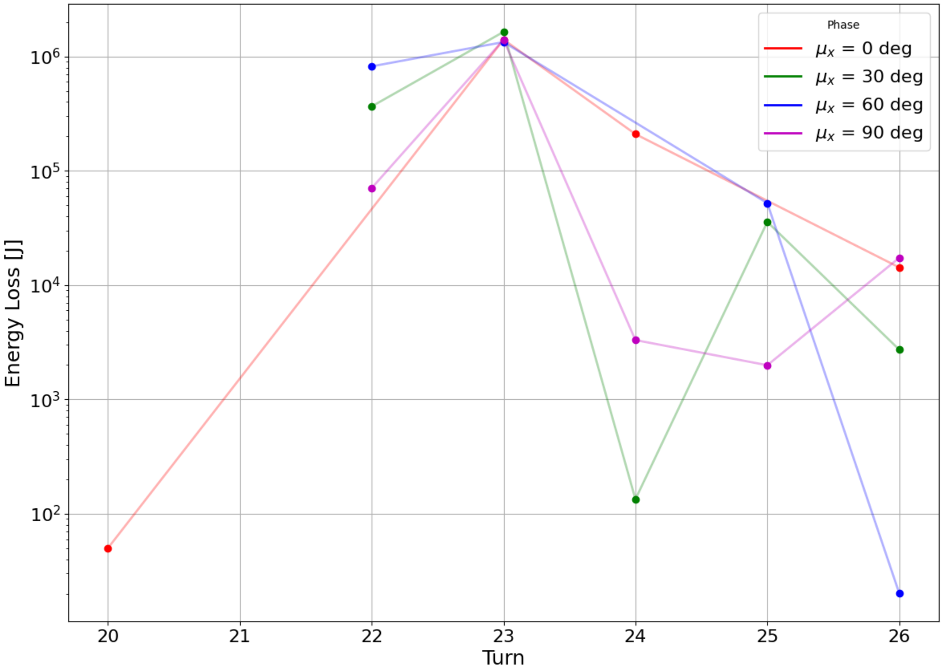
$\tau = 3$



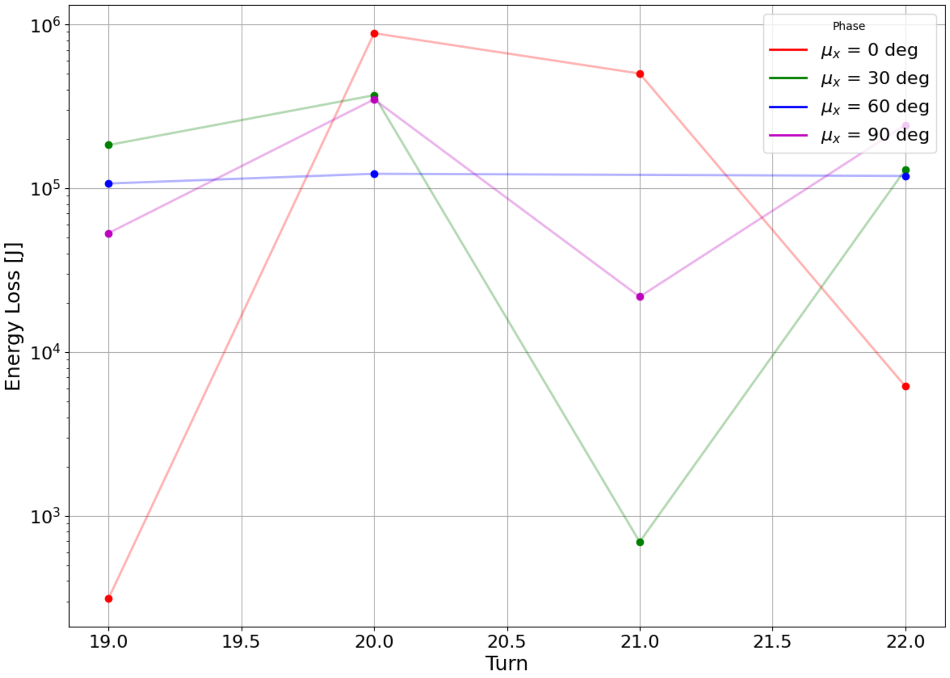
Losses at the tertiary collimator (tct.h.1.b1)

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

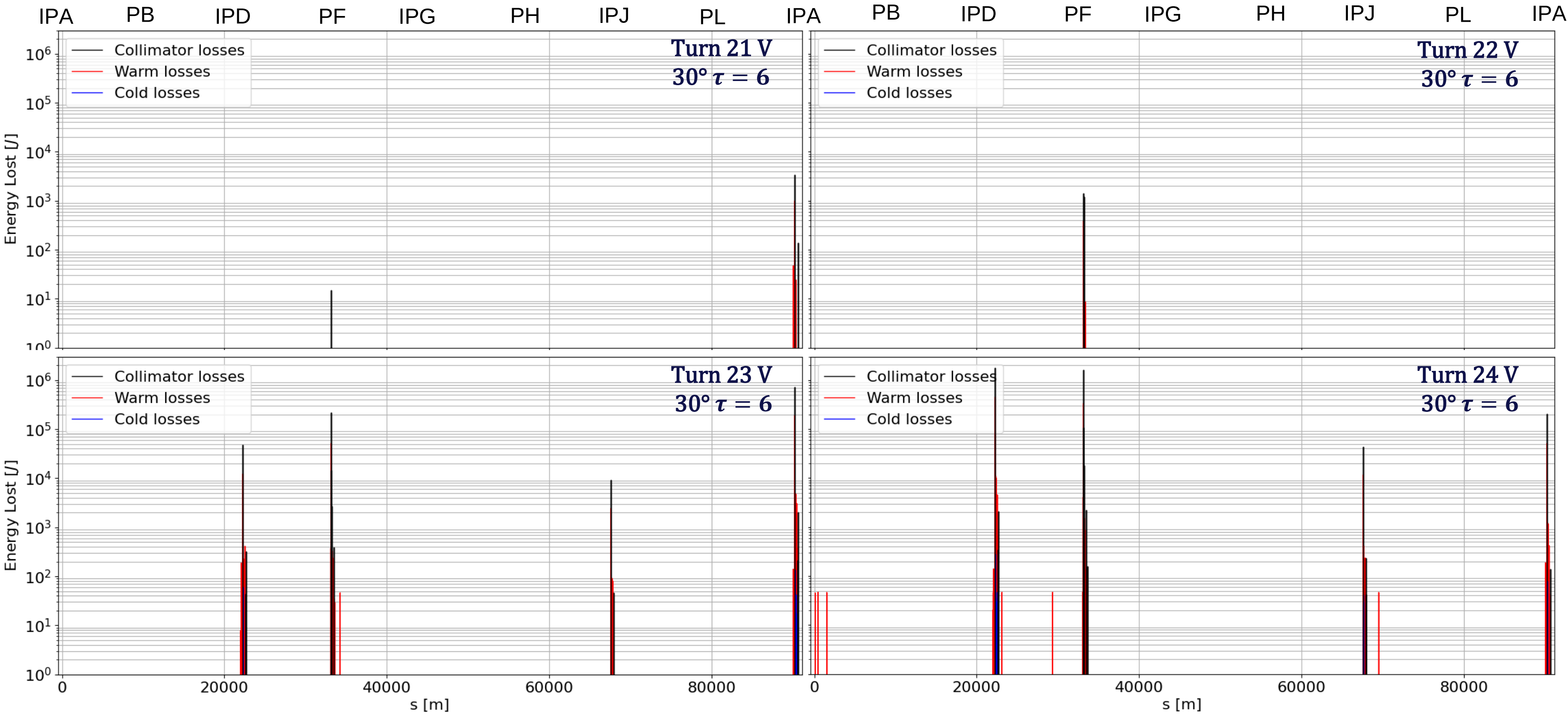
$\tau = 6$



$\tau = 3$

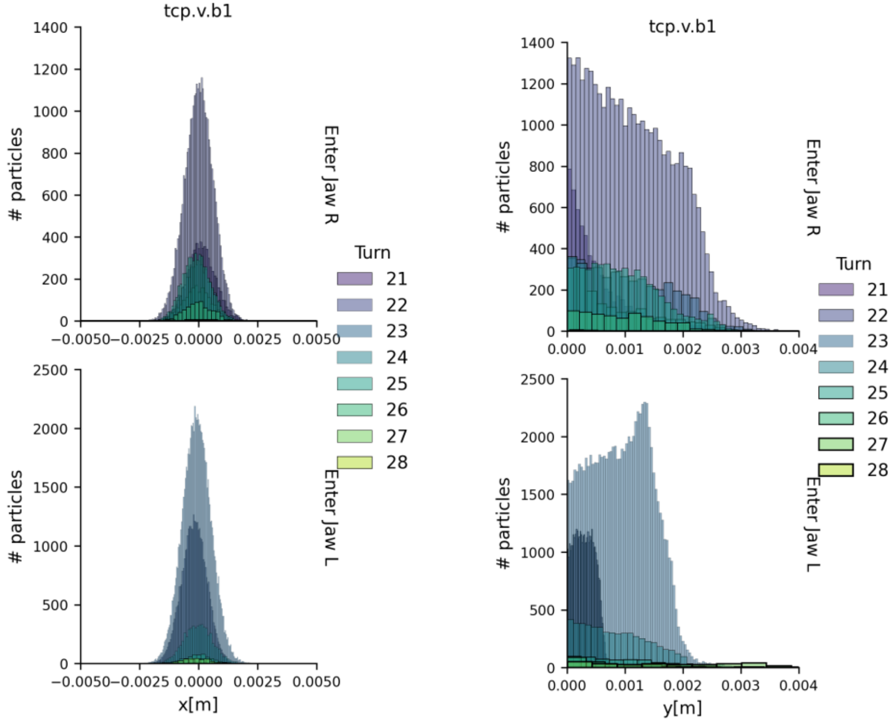


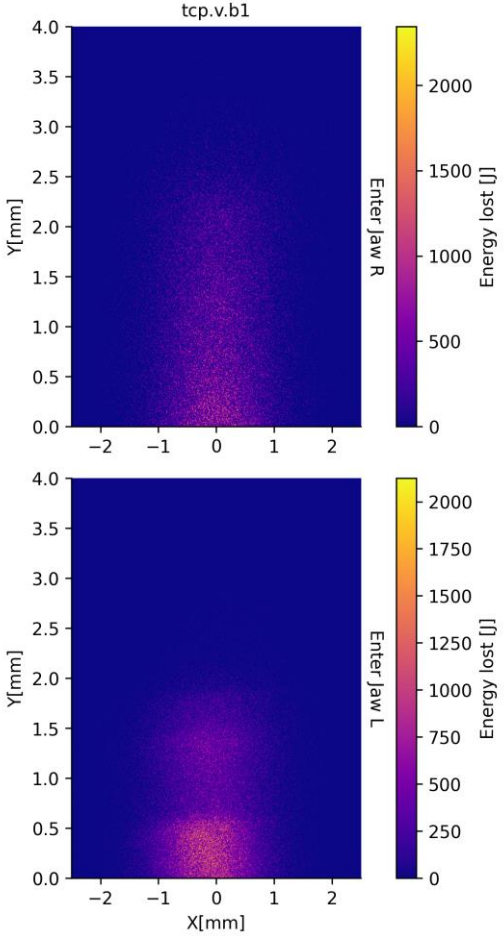
Lossmaps: Time distribution (V)



Collimator impact distributions (V)

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



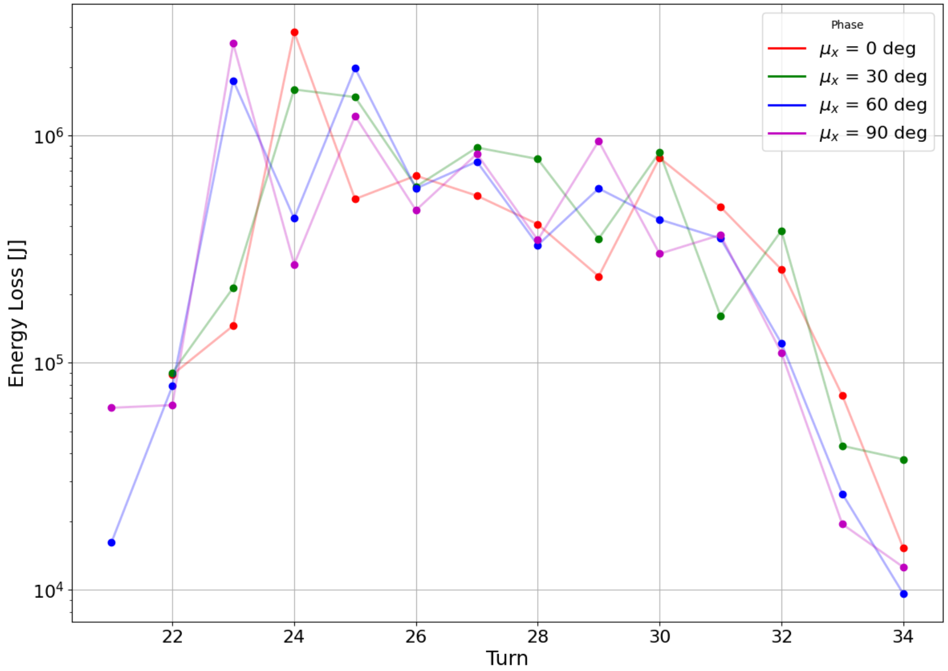


Impact distributions have been provided to the FLUKA team for energy deposition studies.

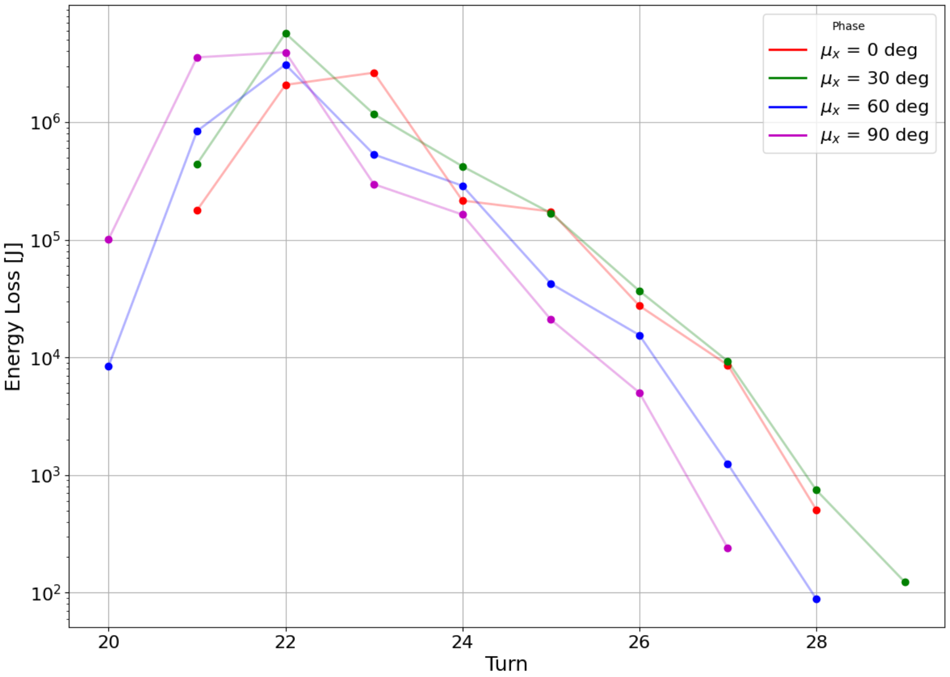
Losses at the primary collimator (tcp.v.b1)

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

$\tau = 6$



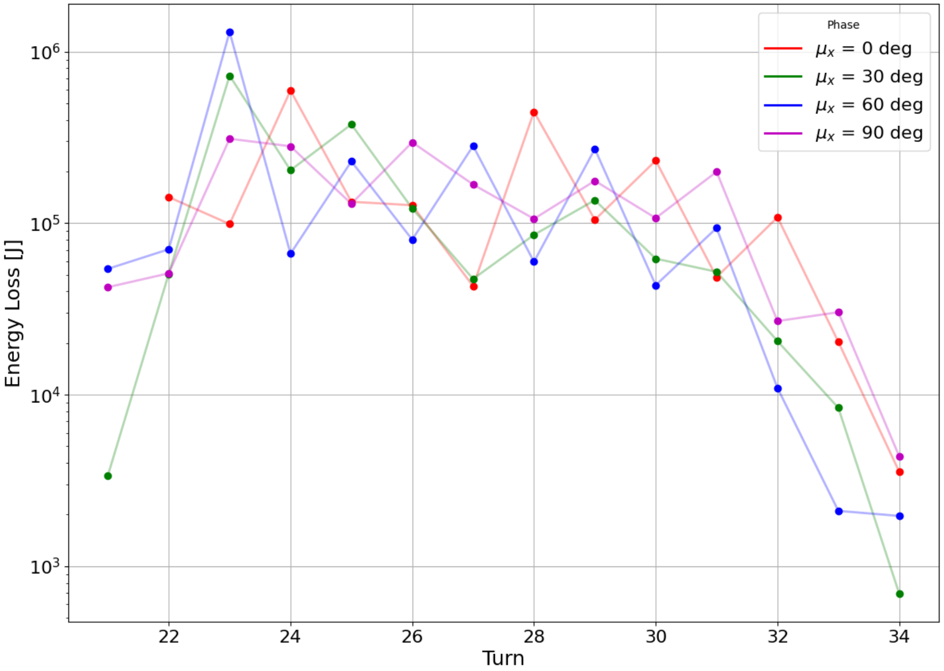
$\tau = 3$



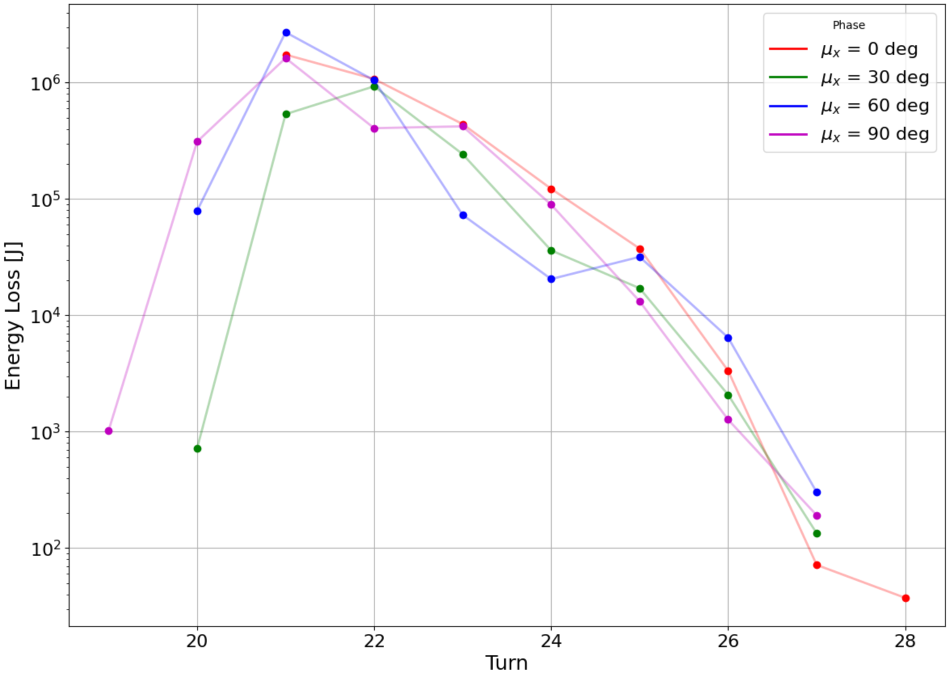
Losses at the tertiary collimator (tct.v.1.b1)

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

$\tau = 6$

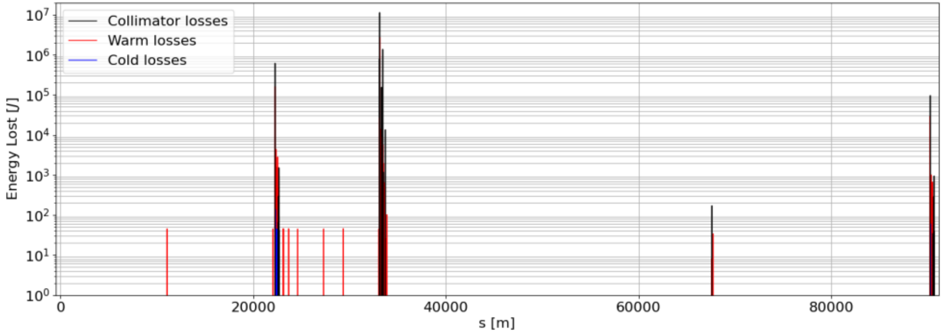


$\tau = 3$

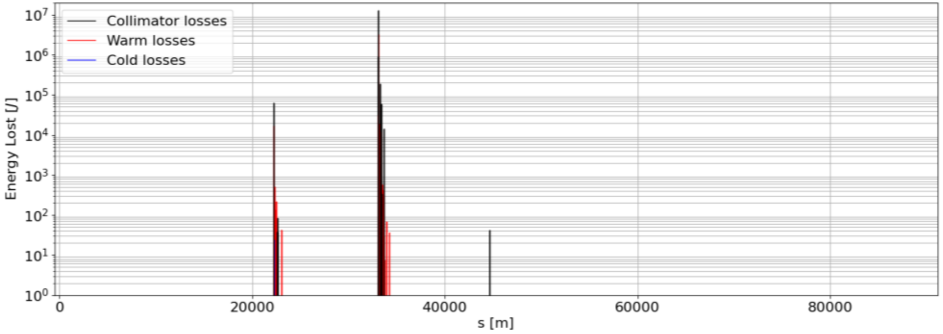


TCP.V aperture scan

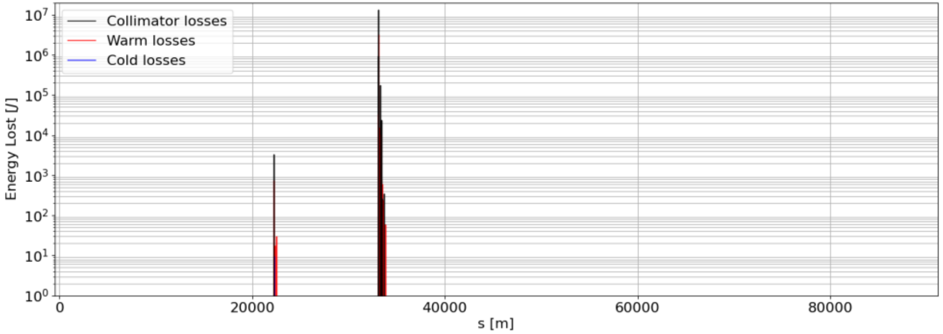
$\delta_{TP} \sim 30 \quad \delta_{SP} \sim 10$



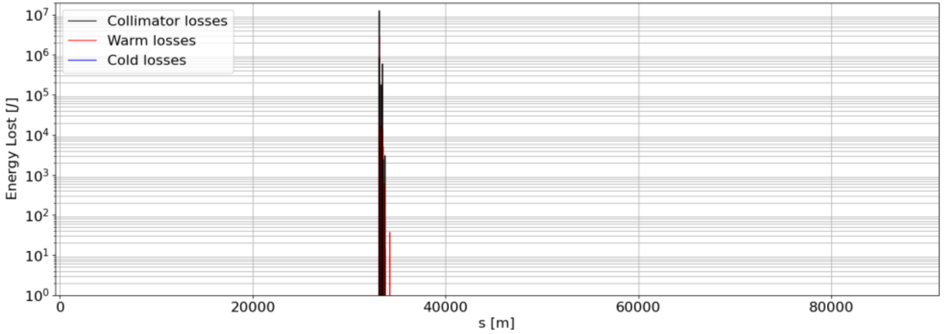
TCP.V.B1 APERTURE 35 SIGMA



TCP.V.B1 APERTURE 25 SIGMA



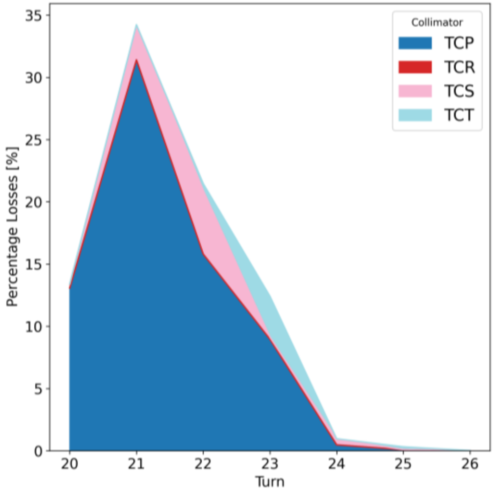
TCP.V.B1 APERTURE 20 SIGMA



TCP.V.B1 APERTURE 15 SIGMA

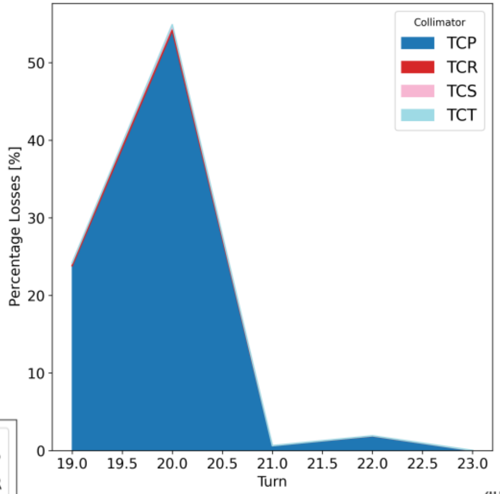
TCP.V aperture scan: loss across coll

$\delta_{TP} \sim 30$ $\delta_{SP} \sim 10$



TCP.V.B1 APERTURE

35 SIGMA

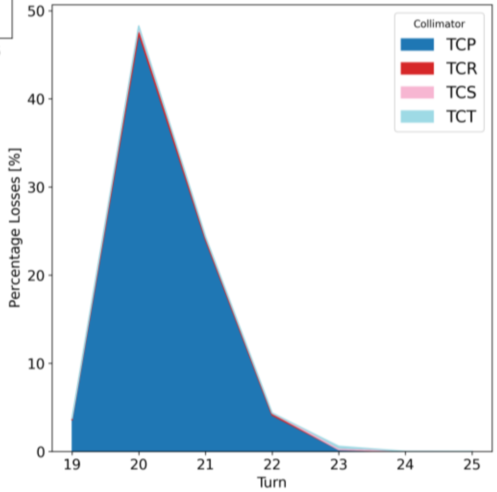


TCP.V.B1 APERTURE

25 SIGMA

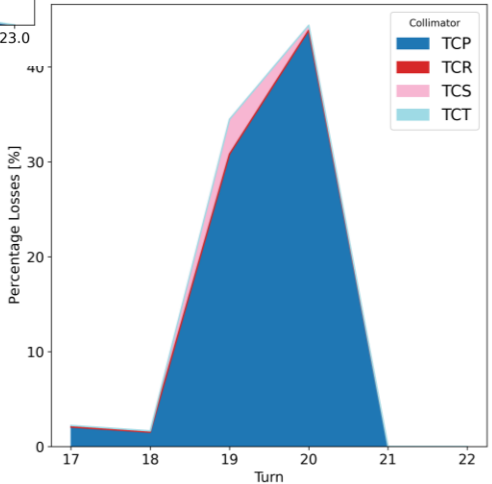
TCP.V.B1 APERTURE

20 SIGMA

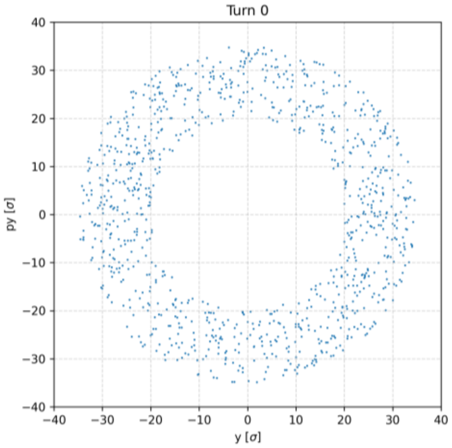


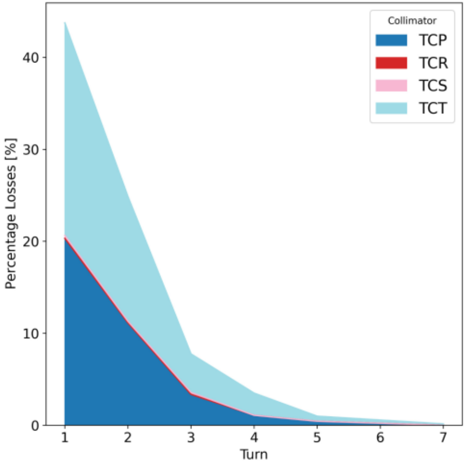
TCP.V.B1 APERTURE

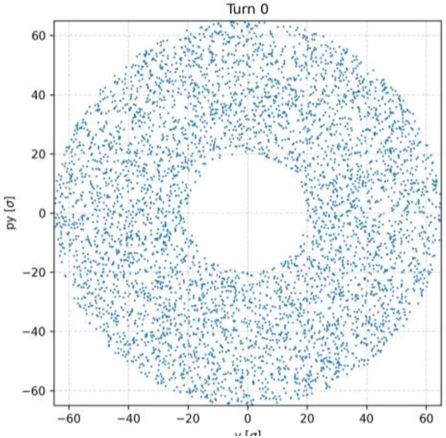
15 SIGMA

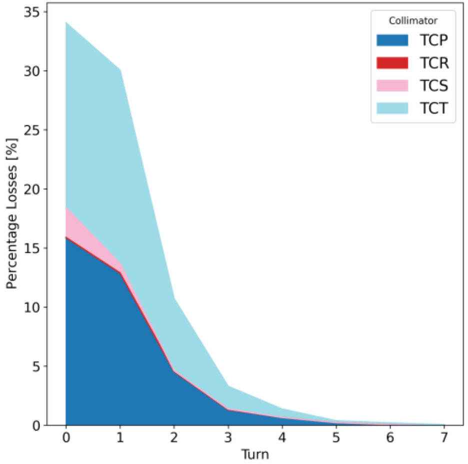


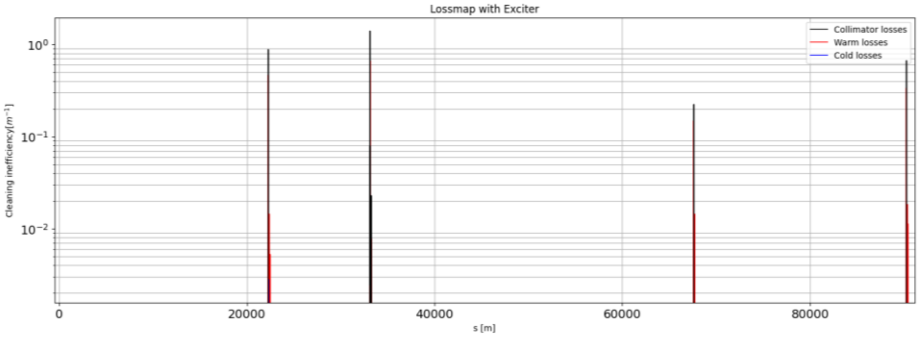
Out of DA beams



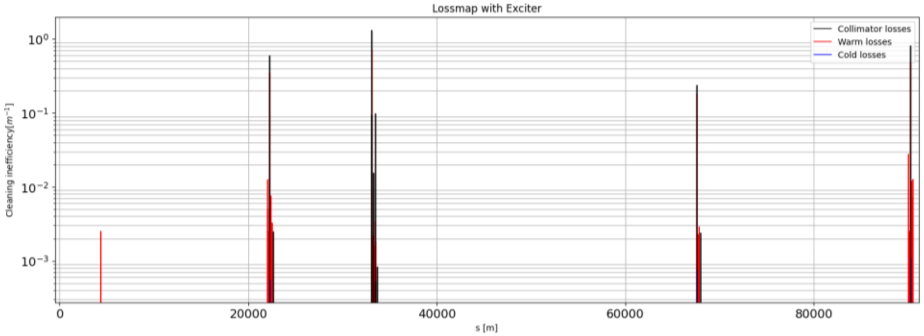






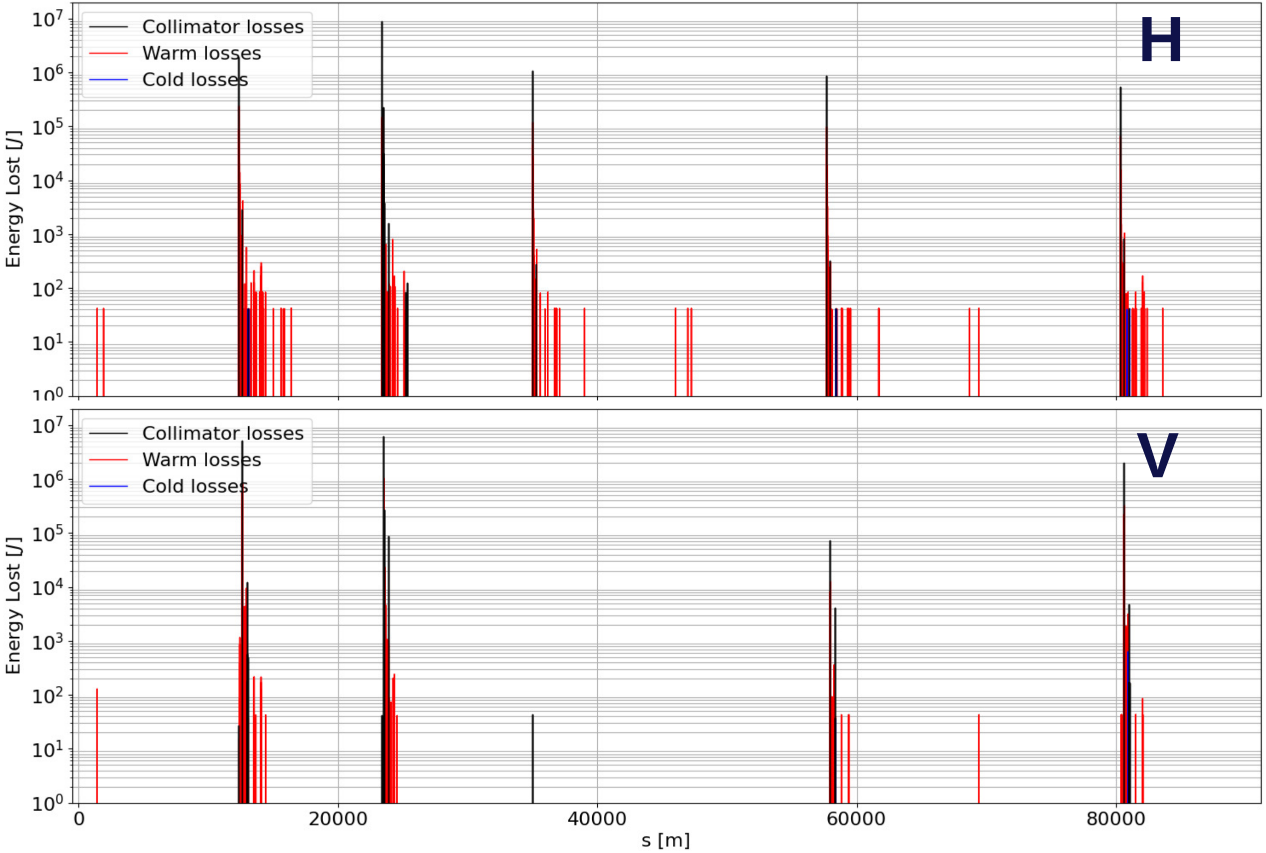


Beam btw 20-35 sigma, out of DA



Beam btw 20-35 sigma, out of DA

LLSS common optics



- No significant improvements.
- Still see vertical blow up once out of DA.
- More losses in the aperture.