FIRST LOOK AT INJECTION BACKGROUNDS

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Outline

- **Introduction**
  - Beam loss scenarios
  - FCC-ee collimation overview
- **Top-up injection & case studies**
  - Injected beam
  - Circulating beam
- **Background estimate**
  - Workflow overview
  - Preliminary results
- **Conclusions & future steps**

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FCC-ee beam loss scenarios

Important to investigate different beam loss scenarios and identify the ones to protect against. Currently **the focus is on the Z mode**, and the status is:

- **Generic beam halo losses**
- Beam losses from **interactions with residual gas**
- Beam losses from **beam-beam interactions**
- Beam losses due to **fast instabilities**
- Beam losses from **top-up injection** (this talk)

(Giacomo's talk) — 1^{st} iteration at tracking level done

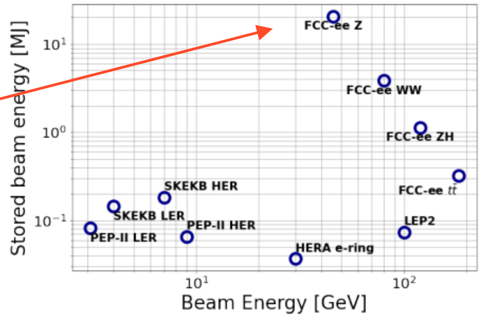
- Beam losses from **Touschek scattering**
- Injection failure

Work in progress

- SuperKEKB-like sudden beam loss events
- Beam losses from interactions with thermal photons
- Extraction failure
- Other failures: power supplies, RF, missing beam-beam, feedback ...

Not started

FCC-ee collimation overview



FCC-ee presents unique challenges:

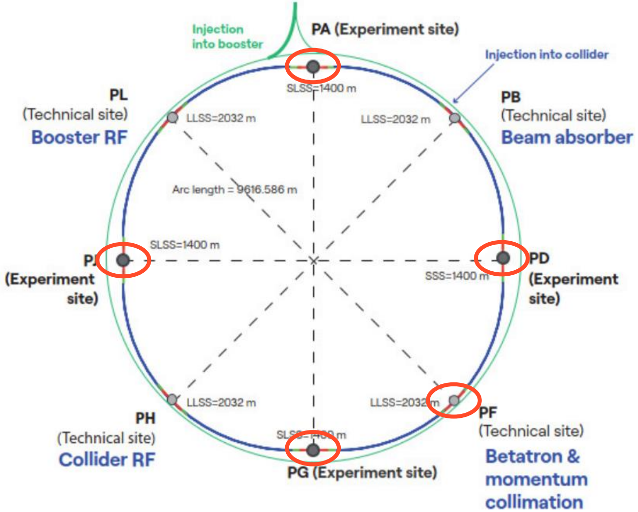
- At Z pole 17.5 MJ of stored beam energy (two orders of magnitude bigger than any other lepton collider).
- Beams are highly destructive.

Collimation system must:

- Protect the machine and the detectors from unavoidable beam losses.
- Minimize background for the experiments.

Collimation setup (for details see Giacomo's talk on Tuesday):

- Global system in PF: 2 stage betatron + momentum.
- Experimental IRs: SR collimators and mask + robust tertiary collimator.
- Local protection for injection, extraction, etc..
- Secondary particle shower absorber.



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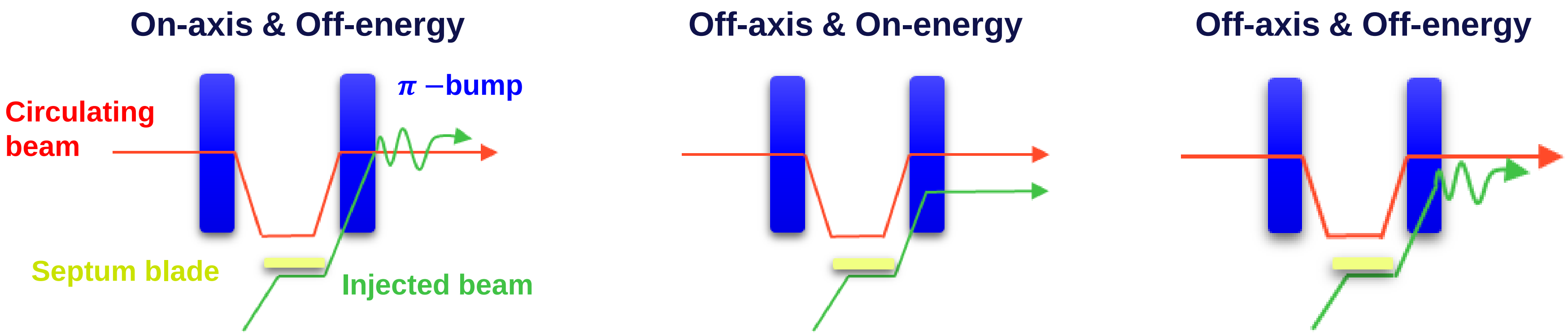
Top-up Injection for FCC-ee

For more information see Yann's talk.

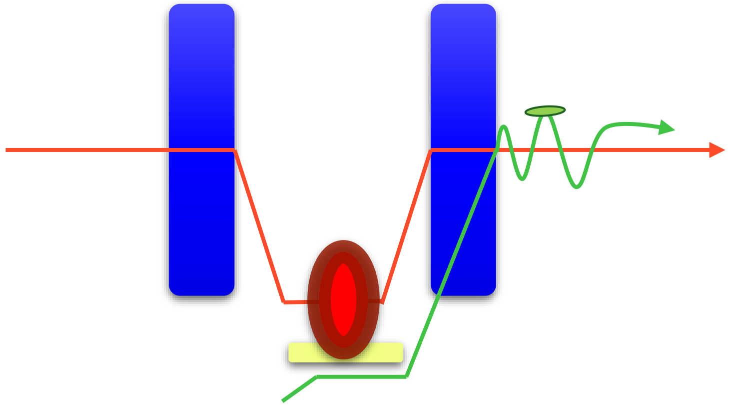
- Beam lifetime during collisions well below 1h → **top-up injection scheme required**.
- **Z-mode most critical for injection** → up to **1 % of full beam intensity is injected** every 3 s.
- **On-axis & Off-energy current baseline scheme.** Hybrid mode, i.e., Off-axis & Off-energy, is considered as an option, and as baseline for W-mode.
- Off-axis & On-energy injection scheme not feasible for synchrotron radiation (SR) levels at the SR mask collimator.



Top-up Injection for FCC-ee

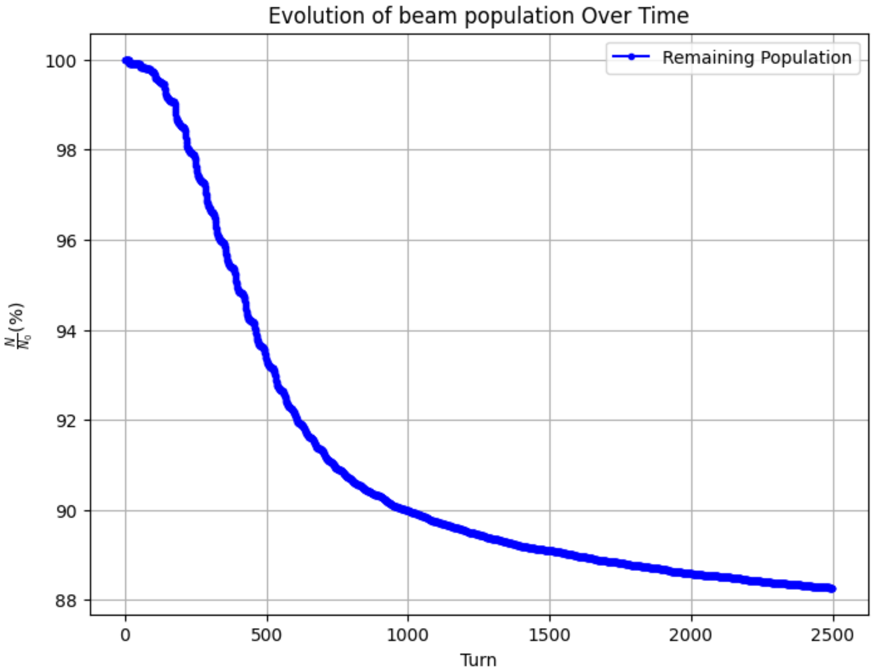
We focus on ring losses during the injection process. The cases of interest include:

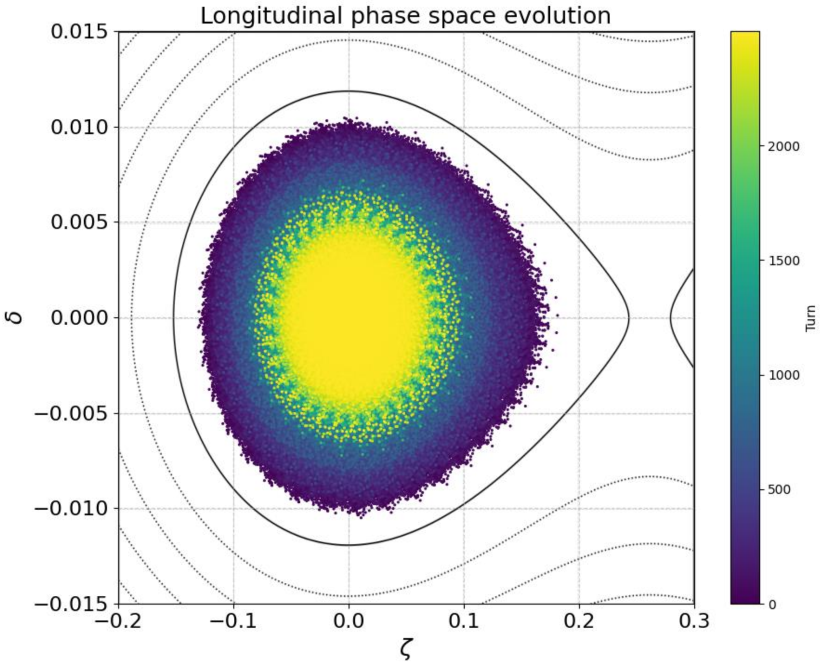
- Perfect injection:
  - Injected beam, both baseline scheme and hybrid mode.
  - Losses due to the bump: the beam circulating in the collider must be brought close to the injected one. In this procedure part of the beam is scraped at the septum/absorber placed at the injection point. Core beam and halo beam are treated separately.
- Injection failures (work in progress):
  - Issues with the bump, like partial closure.
  - Mismatched injected beam, like higher energy offset or not perfectly on axis.



Injected beam - baseline

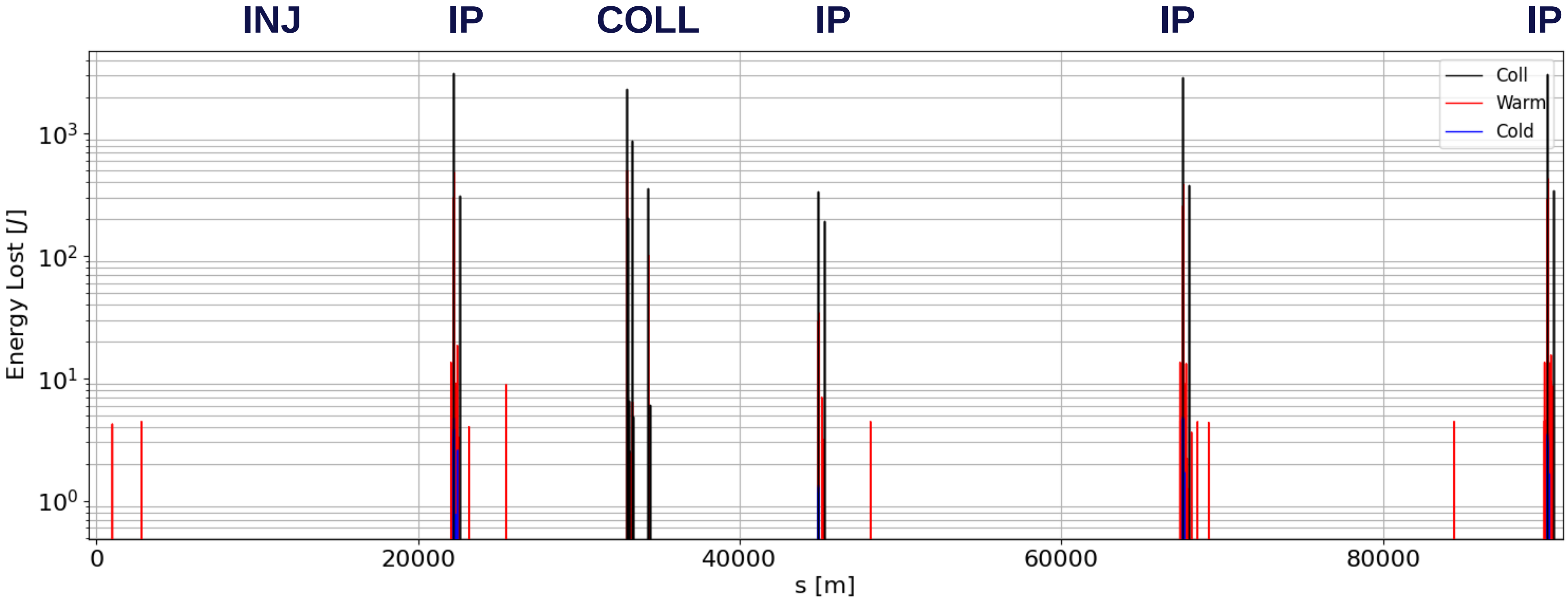
- Beam distribution is generated at the **injection point in the chromatic orbit** with designed injection parameters.
- **Injection efficiency is assed at 88%** for lattice V25.1_GHC.





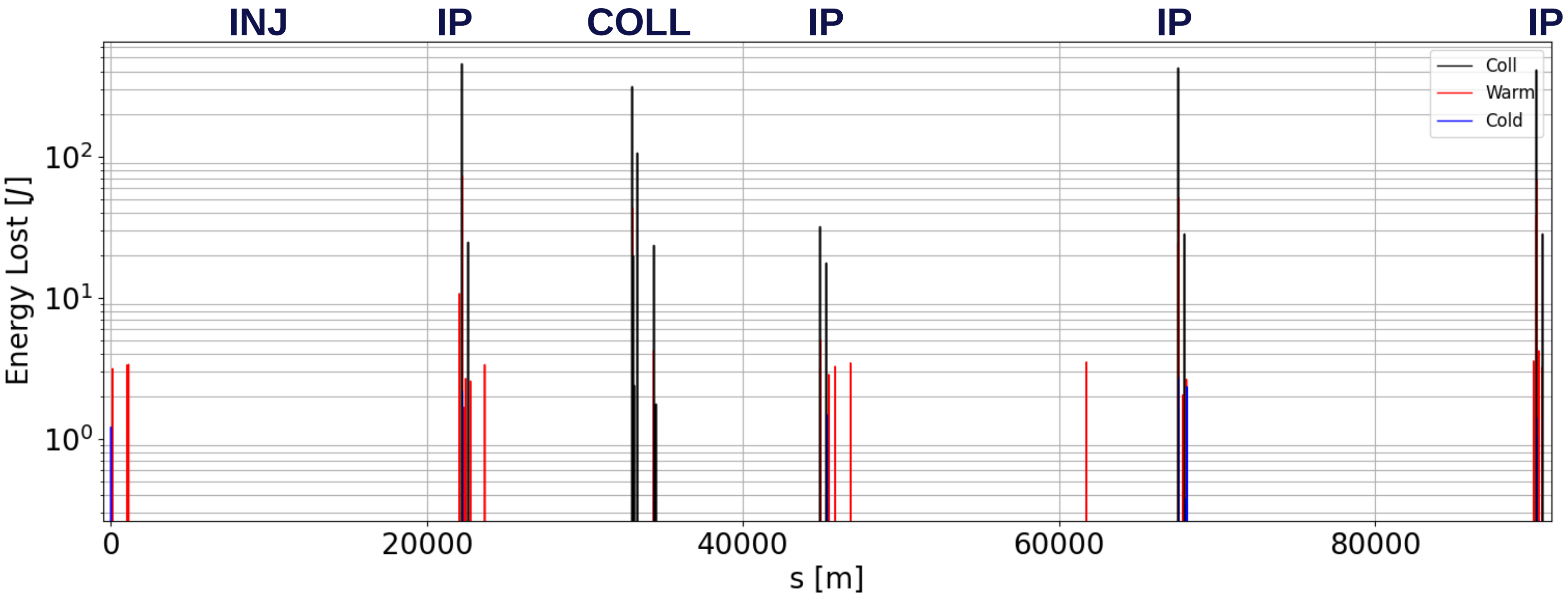
Injected beam - baseline

- The **12% of the injected beam is lost** and distributed along the whole ring.
- The tertiary collimator close to the IPs get as much losses as the collimation insertion in PF.
- Note that this is a **perfect injection**! As observed at **SuperKEKB**, the **losses coming from the injected beam could be dangerous**, collimation efficiency must be assessed.



Injected beam – hybrid mode

- In hybrid mode the beam is generated with lower energy offset, compesated by an horizontal offset.
- Injection efficiency increase up to 98.5% hence only **1.5% of the injected beam is lost** and distributed along the whole ring. With respect to the on-axis scheme, the hybrid mode presents better performances.



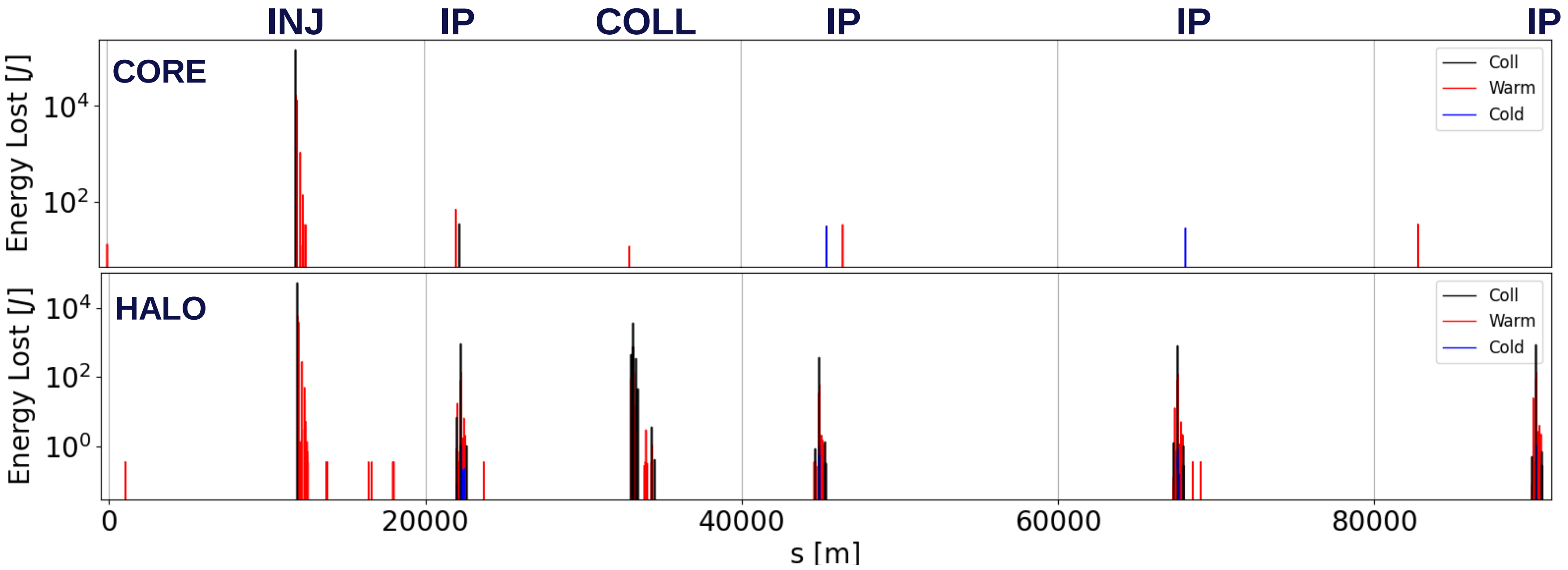
Circulating beam

- A collimator is introduced at the injection point, as a placeholder for the absorber (not yet being designed).
- **Core beam**:
  - **Losses** are expected to **be focused on the collimator before the septum**.
  - Assumed storing **99% of the total beam energy**.
  - The leakage to the experiment is expected to be small.

- **Halo beam**:
  - Circular sector between $5\,\sigma$ and 11σ.
  - **To be optimized with a more realistic description** of the halo (studies undergoing).
  - Assumed storing **1% of the total beam energy**.
  - Will be **mostly scraped at the septum** when bumped $\rightarrow$ primary source of losses at the injection point.

Circulating beam

- **Almost 50% of the halo is lost at the injection point** and the leakage to the experiment is significant and need further investigation.
- No significant contribution from the core beam.



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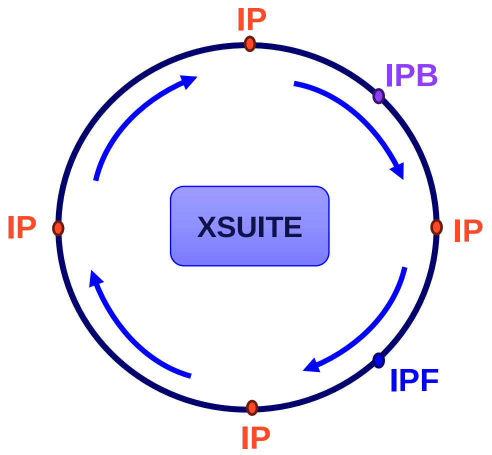
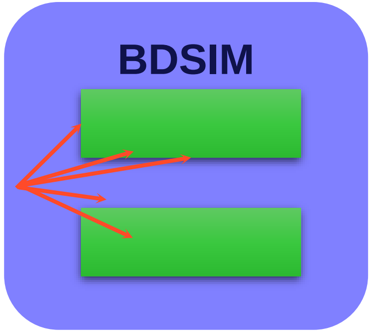
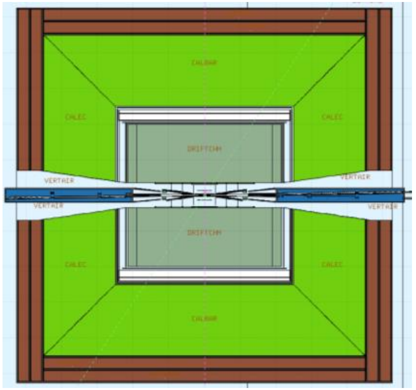
Background simulation workflow

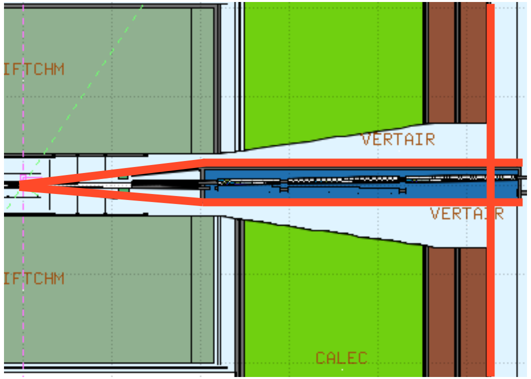
For more details on the geometry see Alessandro's talk.





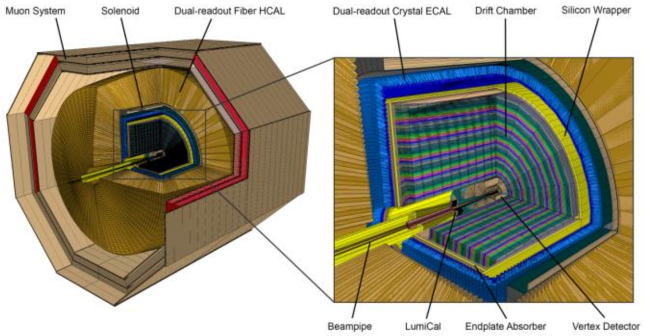
FLUKA





WE ARE HERE!

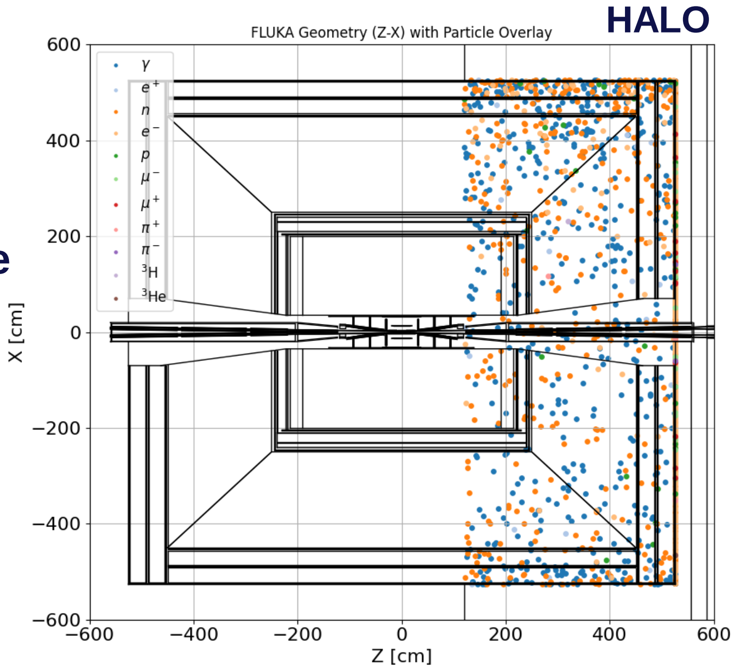
IDEA

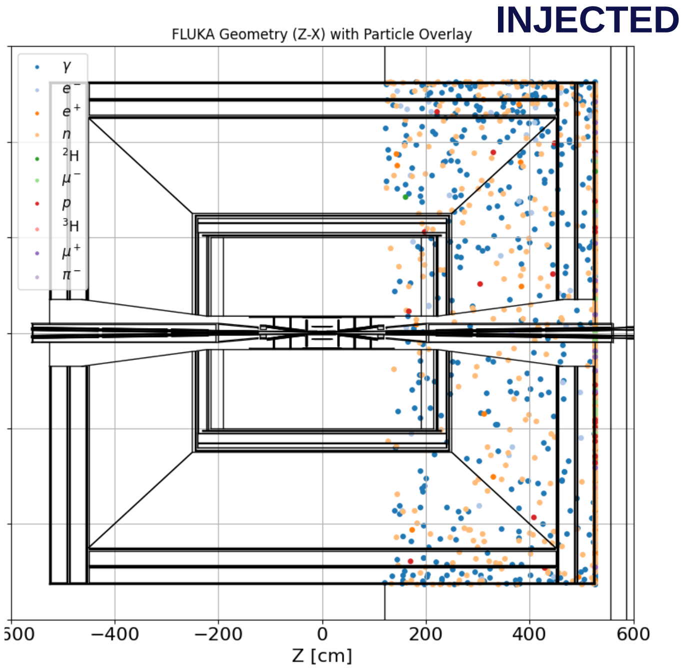


Should be extended to other detector design.

Preliminary results on injection background

- Returning to the injection scenario, the **hits on the tertiary collimator were input into the FLUKA geometry** and propagated up to the interface.
- Preliminary results shows that **a fraction of the secondary particles reach the experiment**, but further investigation is needed.





- **Assessment with detector simulation tools are needed to obtain a final estimate of the injection background!**

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Conclusion and Future Steps

- Simulations of several beam loss scenarios are ongoing to assess collimation efficiency and possible backgrounds at the experiments.
- In particular, the **injection conditions have been reproduced and investigated.**
- The **injection efficiency** has been assessed at ~ **88%** for the lattice V25.1_GHC.
- In addition, **even a perfect injection scheme causes losses** from part of the halo bumped onto the septum at every injection.
- **The workflow for the background estimate has been established and preliminary results for some scenario have been presented.**

Next steps include:

- Introducing more realistic distribution for the halo.
- **Study of injection failures**: only one of the kicker fires, the bump doesn't close correctly, etc…
- **Mismatched injected beam** distribution.
- **Background estimate with detector simulation.**

Thank you
for your attention!

Backup

On-axis & Off-Energy injection scheme

- Beam extracted from the booster is transported to and then injected into the collider.
- The injected beam has an **energy offset** of +**0.95%** and is placed into the chromatic orbit**.**
- Energy offset + dispersion at injection point → **horizontal separation between the injected and circulating beams**.
- **Injected beam undergoes rapid synchrotron oscillations** until it merges with the circulating one**.** At **IPs they overlaps** due to the zero dispersion → no increase in SR.
- **Circulating beam must be brought closer to the injected one**: a bump (2 kickers at π-phase advance), bump height is $10\ \sigma_{inj} + septum\_thicknes$ where the septum is 2.8 mm thick (so far). The beam is at $5\ \sigma_{circ}$ from the septum → **septum at** ~ $\boldsymbol{12.4\ \sigma_{circ}}$ (note that the primary horizontal collimator is at 11 σ_{circ})**.**
- **Bump on for only 1 turn**, during which the septum is the primary aperture.
- **Beam halo** will be **scraped at the septum** → absorber before the septum is needed and being developed among the FLUKA team.
- **Leakage could reach experiments** generating backgrounds → Estimate is required.

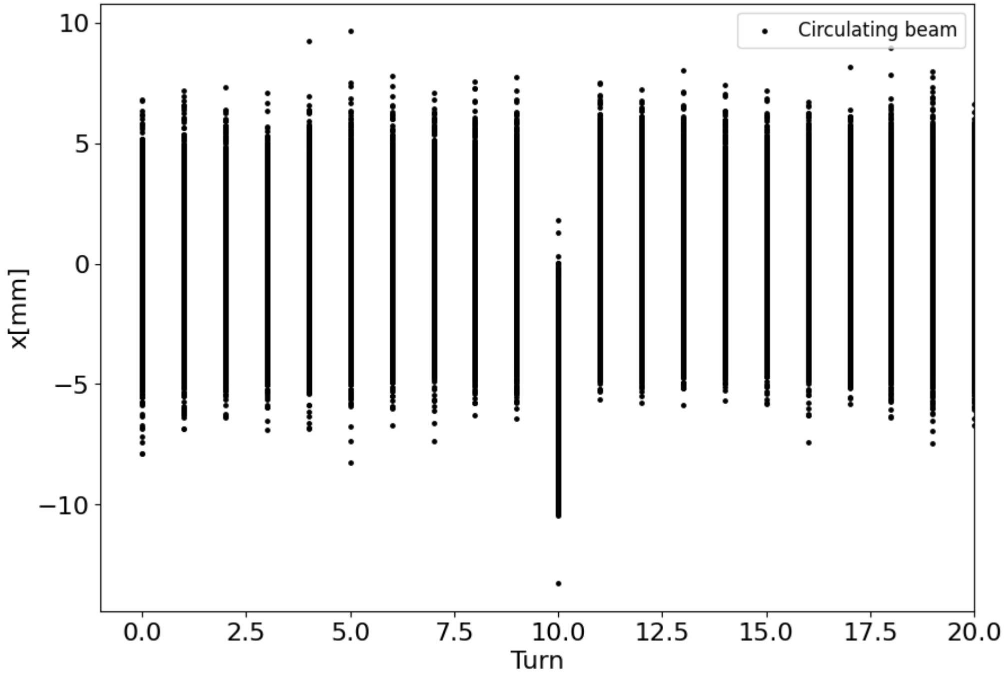
Circulating beam

- In both cases, the beam is bumped towards the injected one **only for 1 turn.**

- **Important to control the bump,** to ensure not only that the bump is closed but also that is on only for the necessary amount of time!

- Any error on the bump set-up could cause beam losses/backgrounds.

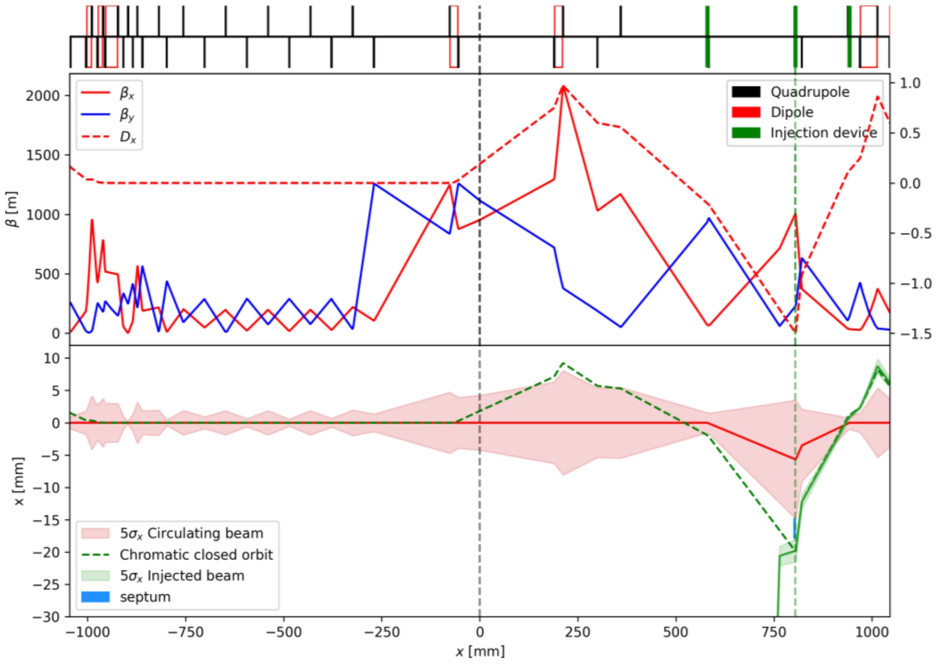
- Absence of failures cannot be guaranteed, scenarios in which the kickers partially fire or don't do at all need to explored.

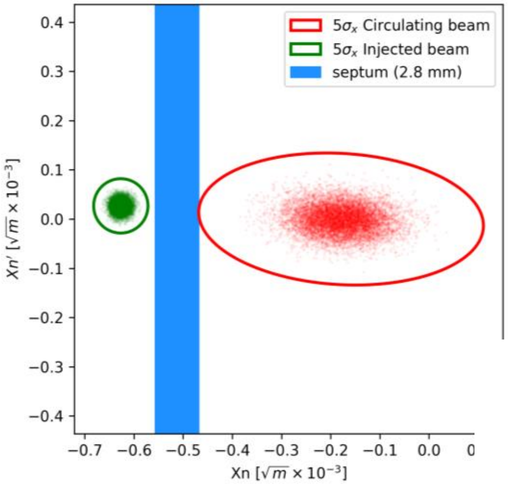


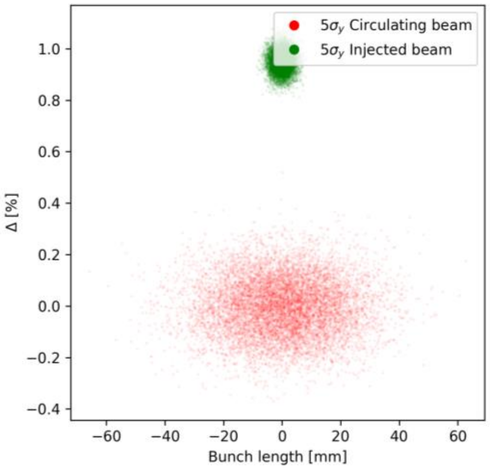
Simulation framework

- Tools for the simulations:
  - Xsuite for multi-turn tracking,
  - BDSIM interface for particle-matter interaction in the collimator.
- Implemented in a **new framework** under optimization, in collaboration with Kyriacos see his presentation on .., to make the simulation more accessible and universal. Specially for the implementation of the bump which is now ‘lattice independent’.
- Building on the **V25.1_GHC** available.
- Included in the simulation:
  - Synchrotron Radiation (quantum model),
  - RF cavities + magnet tapering,
  - detailed aperture model,
  - halo+momentum+tertiary collimators, see Giacomo’s talk
  - SR collimator and mask,
  - wiggler matched to target vertical emittance ($\epsilon_y = 2.1\ pm$),
  - beam-beam effect: Beamsstrahlung and BhaBha.

On-axis & Off-Energy injection scheme

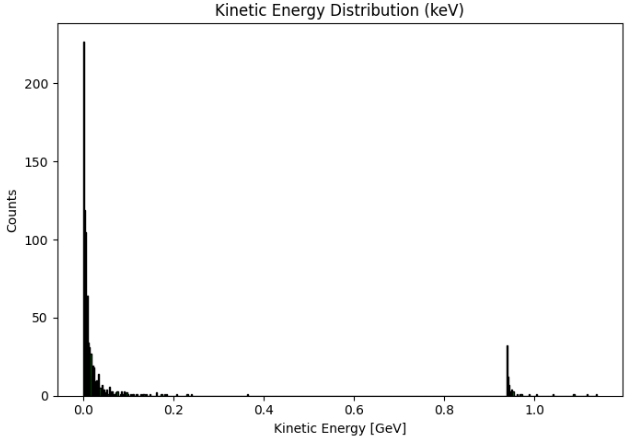


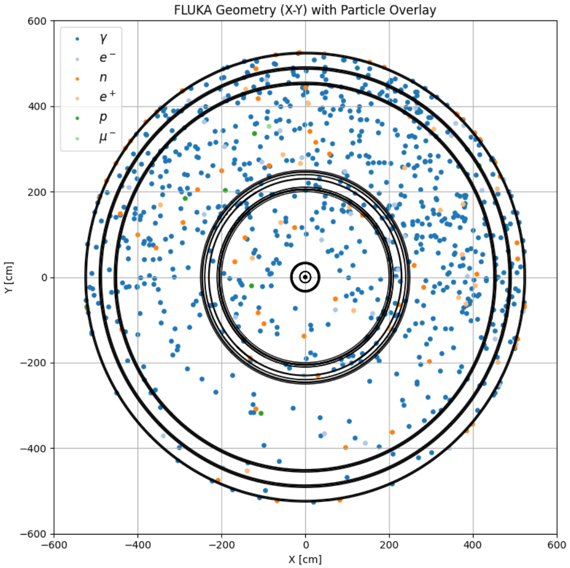


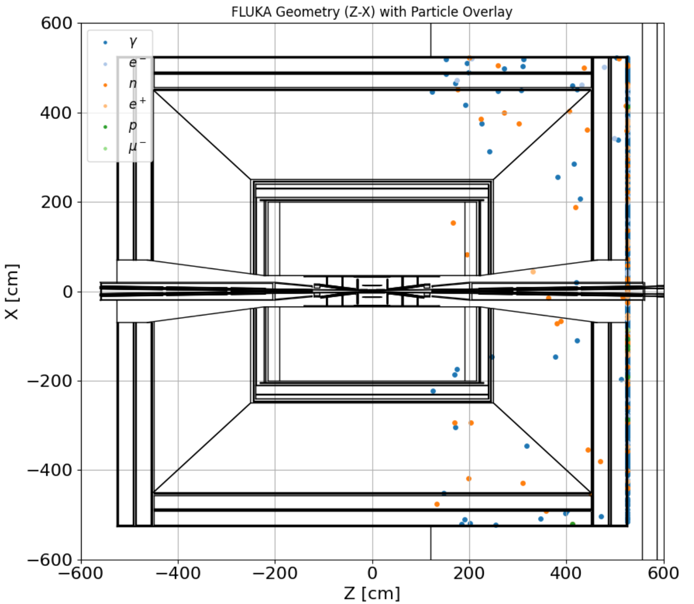


Mention to Fast INSTABILITY

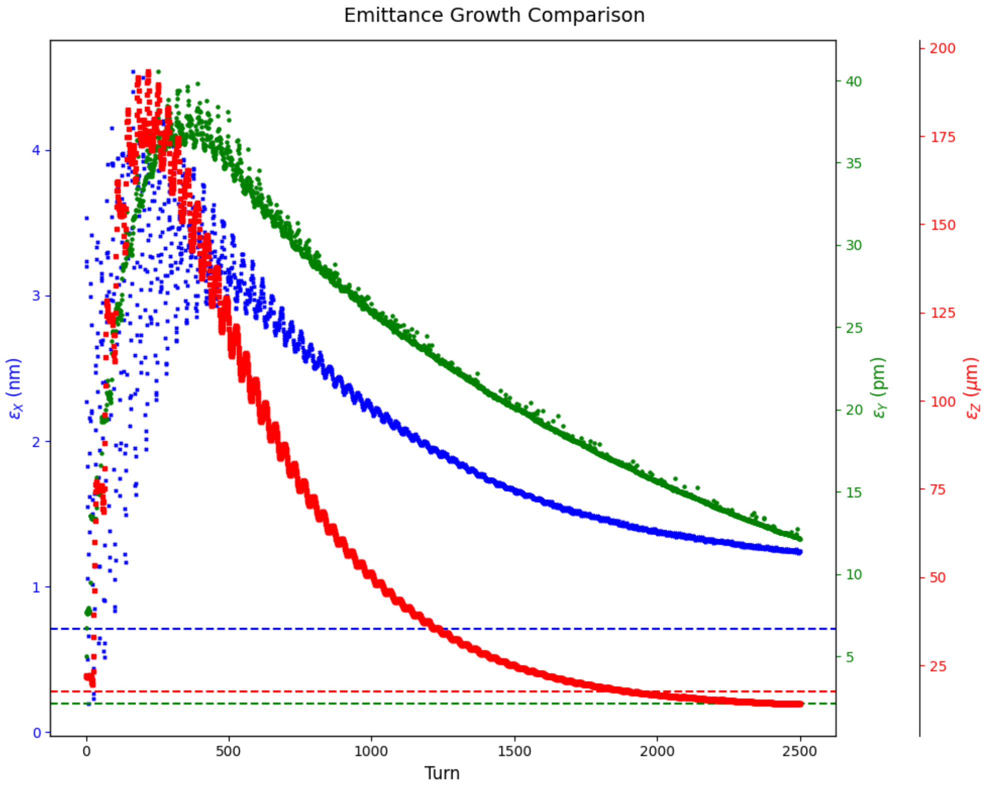
Same workflow can be applied to other beam losses scenario.
For instance, the fast instability case, in which the beam oscillation amplitude grows exponentially in time, is under investigation.
Preliminary results show particles reaching the detectors.

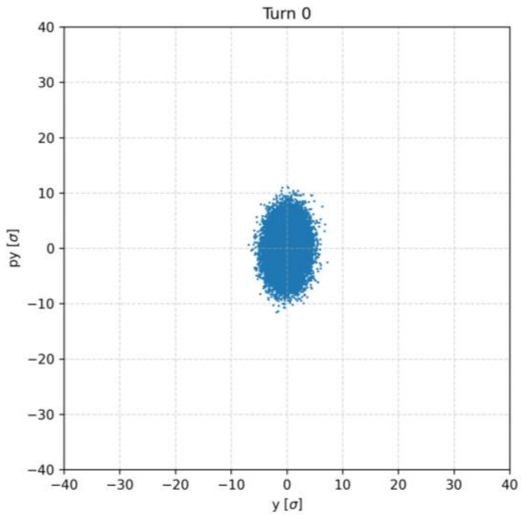


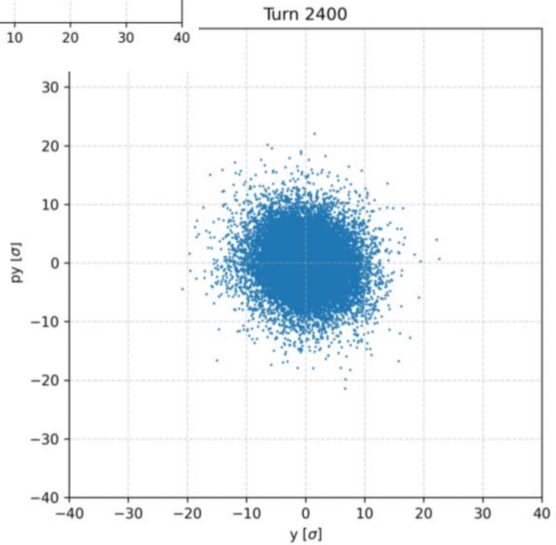




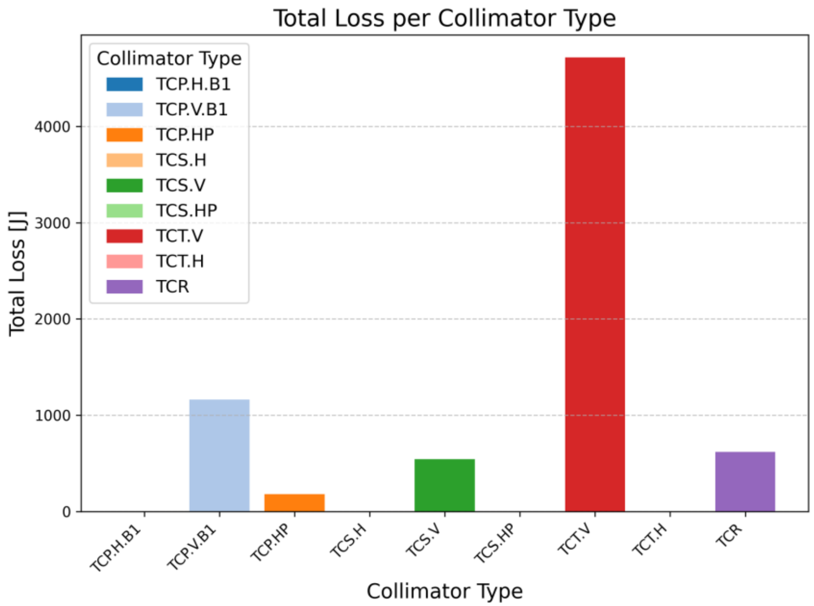
Emittance blow up







Case studies: Injected beam



NB: Losses in the TCT should be divided by the number of tcts (4), same for TCR(6)