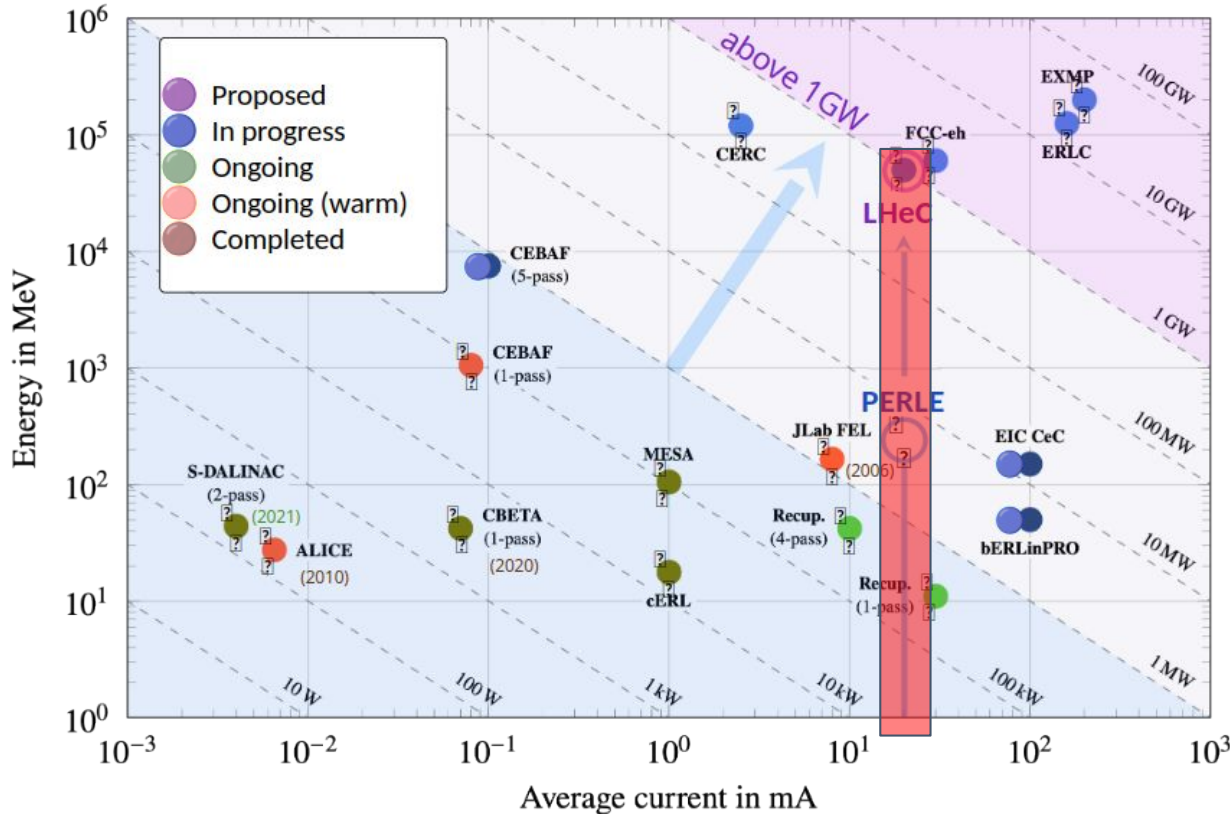




Beam halo formation and collimation at PERLE

Arnaud CIEPLAK
Supervisor : Achille STOCCHI
Co-supervisor : Oleksy FOMIN



At 20 mA, even a 0,1% beam loss is critical:
($P_{\text{loss}} = I_{\text{loss}} \times E$)

- Merger, 7 MeV: 140 W
- 1st pass, 89 MeV: 1.78 kW
- 3rd pass, 253 MeV: 5.06 kW

If deposited in a 4 K cryomodule, this heat load is unacceptable and could damage the system.

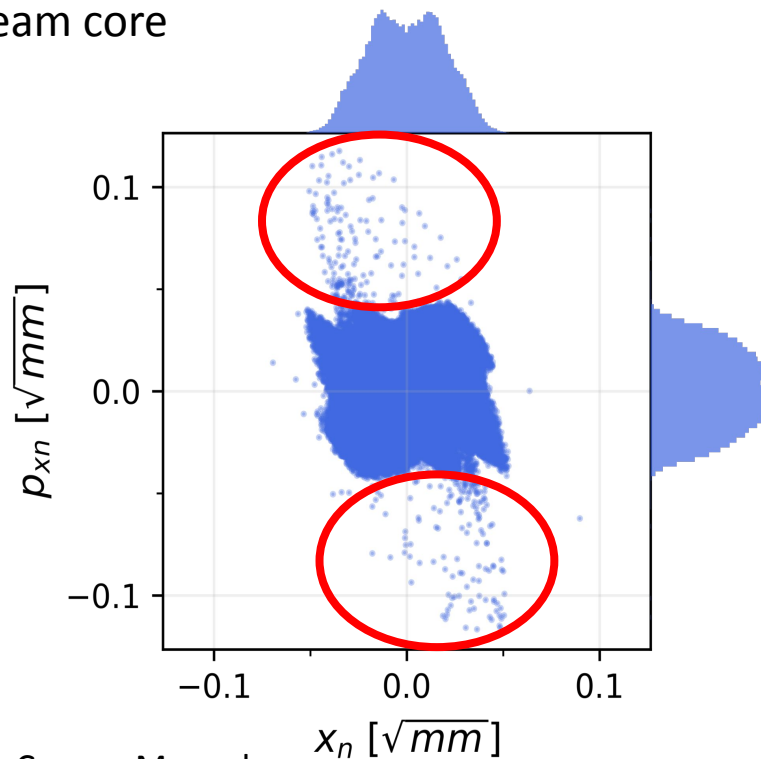
→ Mitigation: remove particles most likely to be lost downstream, i.e. halo particles, using collimators.

- Demonstrate multi-turn and **high current** operation



Beam Halo :

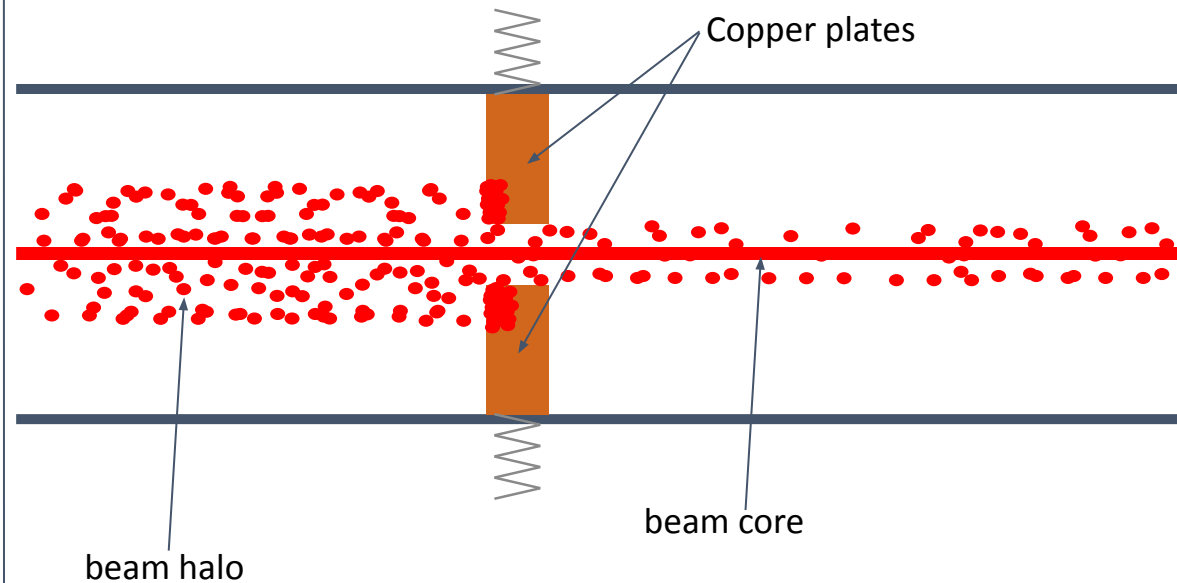
Low-density population of particles surrounding the beam core



Courtesy: Connor Monaghan

Collimator

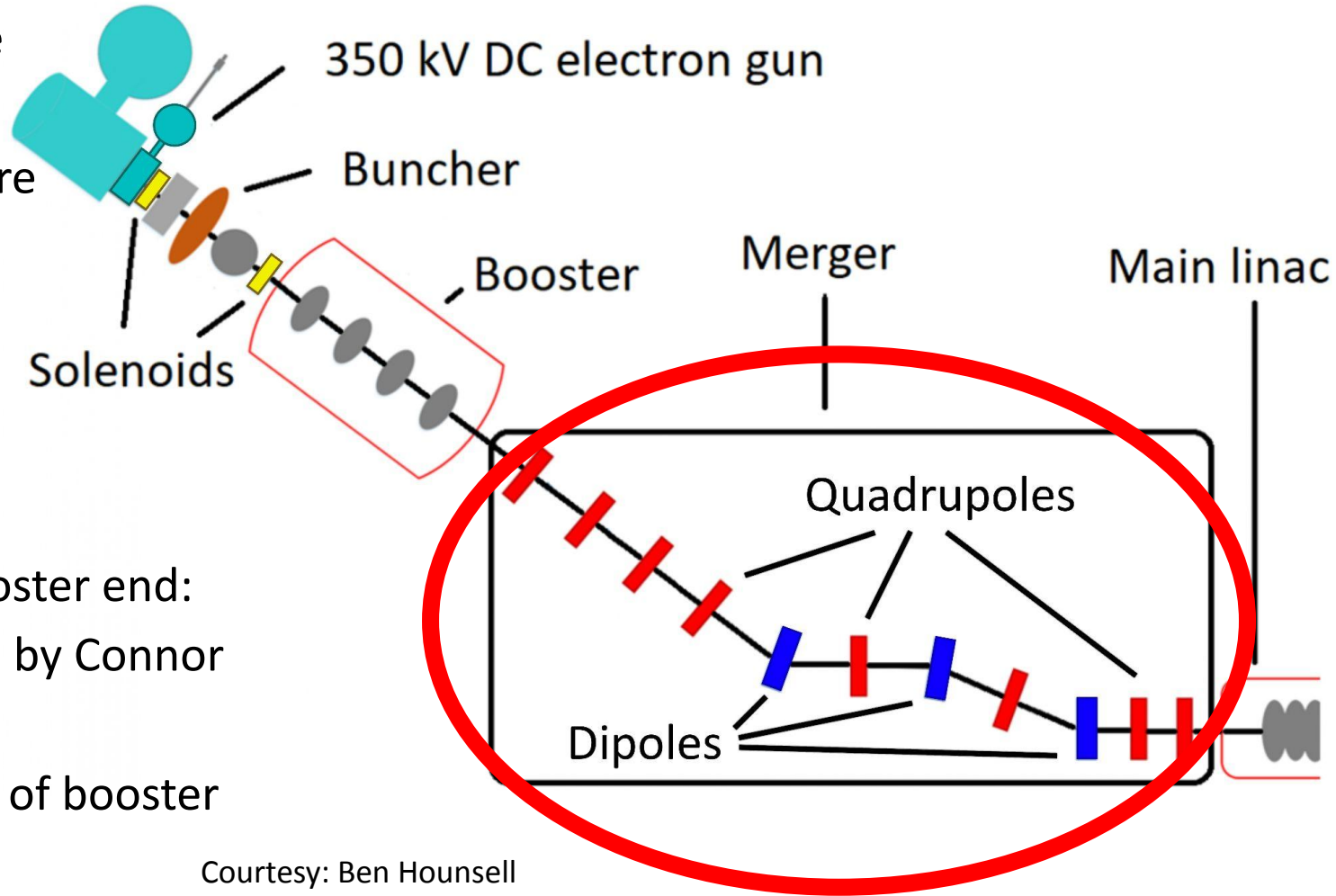
The collimator intercepts halo particles while the beam core passes through





Lattice : Merger

- Collimators are placed in the merger to intercept halo particles at low energy, before the main linac
- DC gun and solenoids are under commissioning
- From the buncher to the booster end:
 - OPAL simulations performed by Connor Monaghan
 - 1000 random configurations of booster cavity misalignments



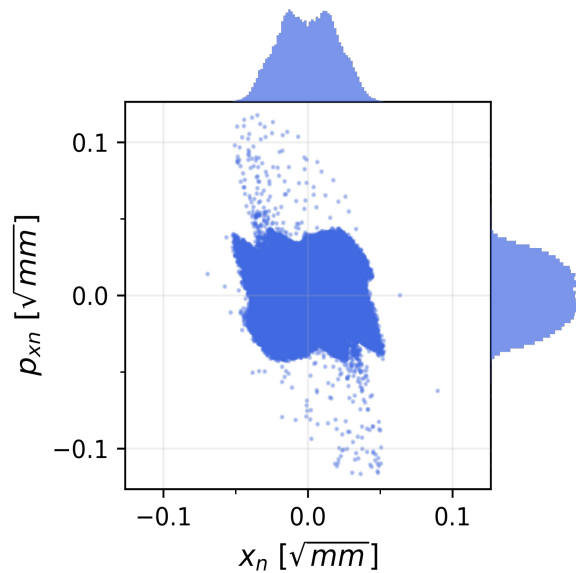


Semi-analytical study



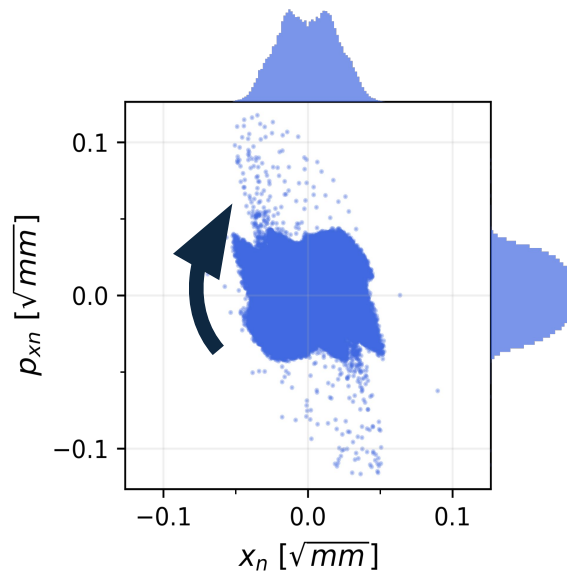
Collimation methodology

Transverse phase-space distribution taken at the end of the booster

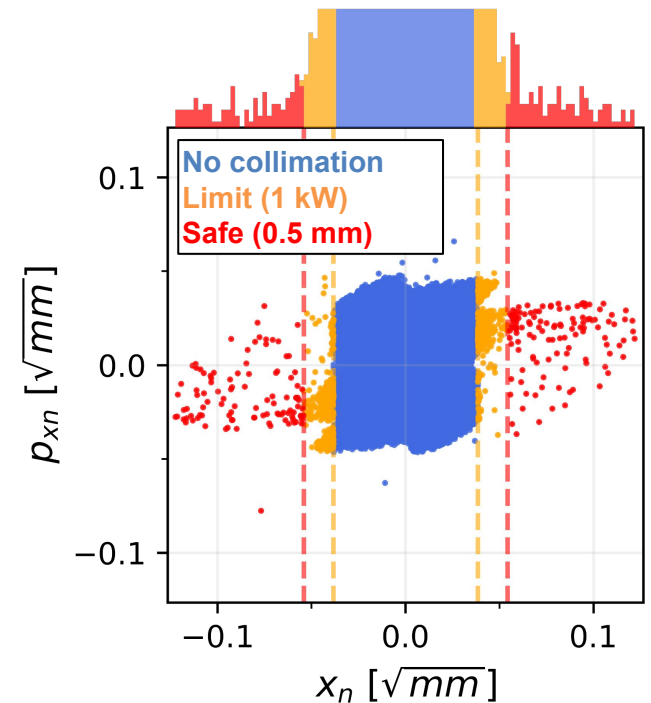


$$x_n = \frac{x}{\sqrt{\beta}}, \quad p_{xn} = \frac{\alpha x + \beta p_x}{\sqrt{\beta}}$$

The distribution rotates naturally ($p_x \rightarrow x$)

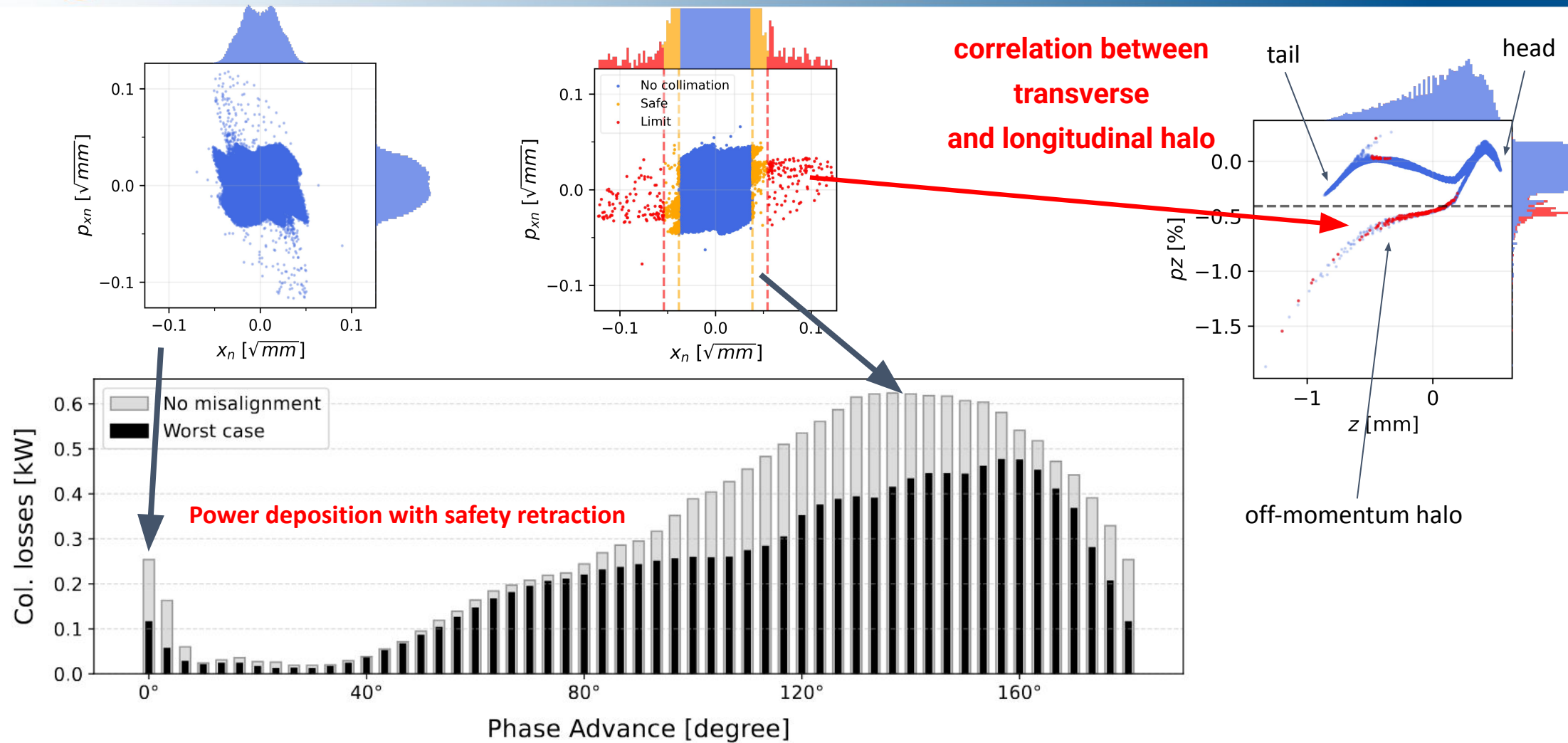


Halo particles reach large transverse amplitudes and can be intercepted



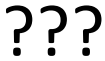


Collimation efficiency vs phase advance



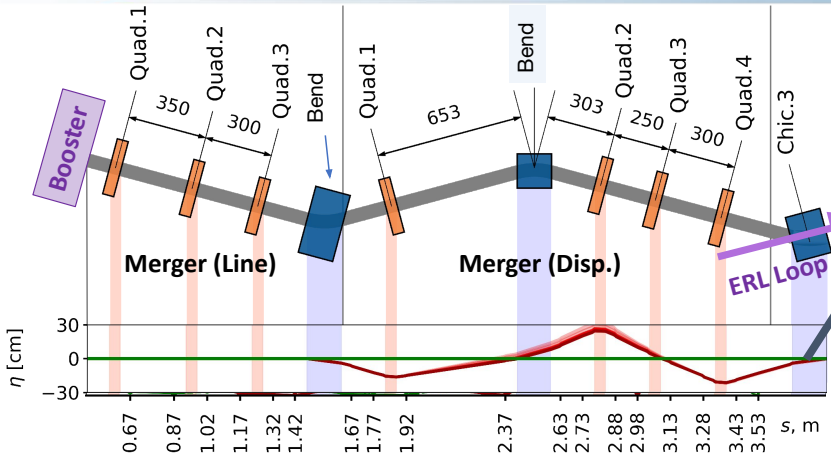


Bmad simulation





Longitudinal Halo collimation

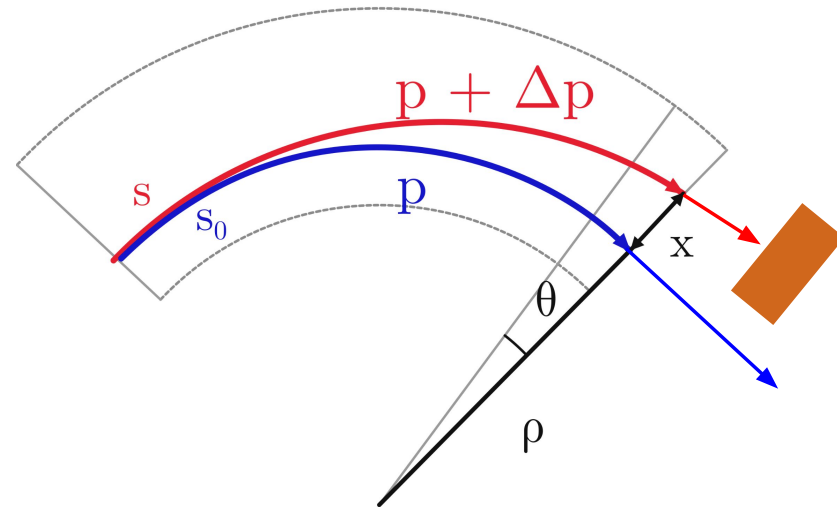


Three dipole Merger

Dispersion, η - converts momentum offset into transverse displacement

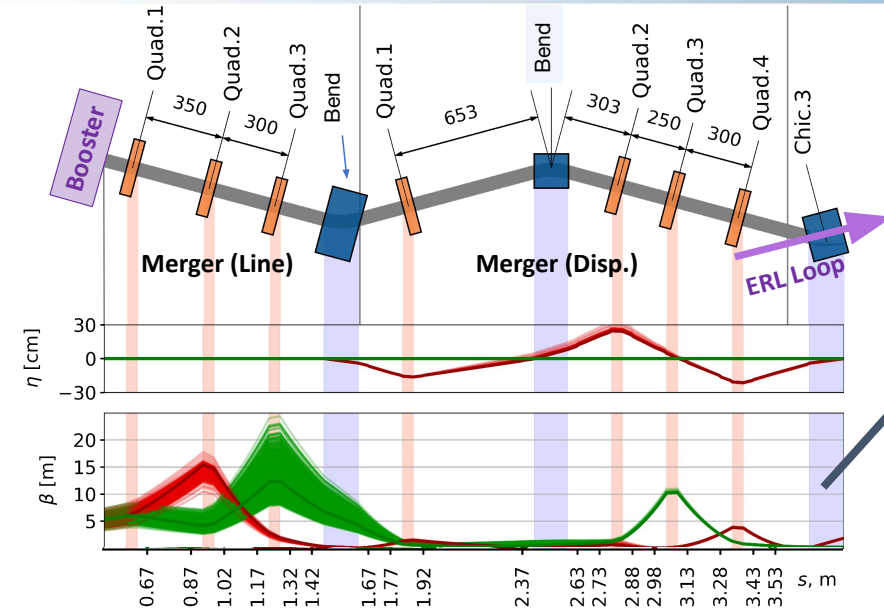
Particles with different momentum follow different trajectories in dipoles.

At the collimator, high dispersion helps separate energy halo from the core.





Transverse Halo collimation



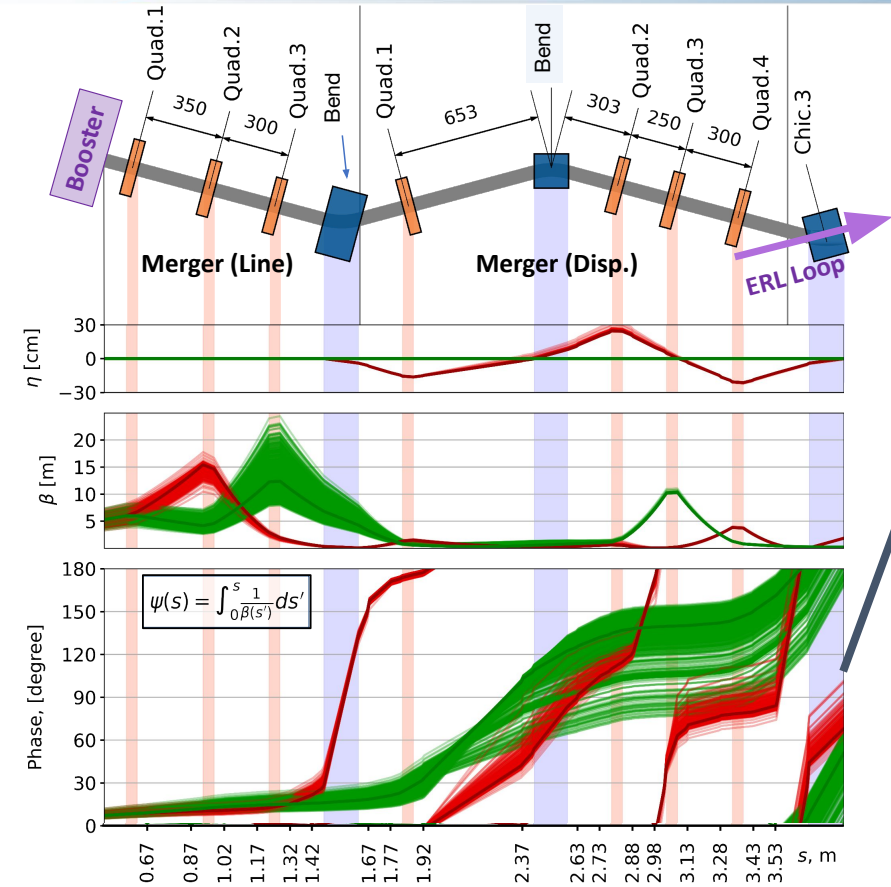
Beta function define the beam size within this formula : $\sigma = \sqrt{\beta \varepsilon}$

Where, ε is the emittance

so we have sigma-max ~ 1 cm



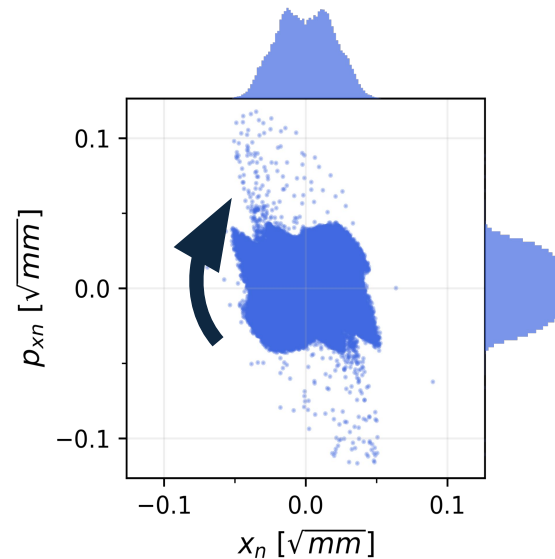
Transverse Halo collimation



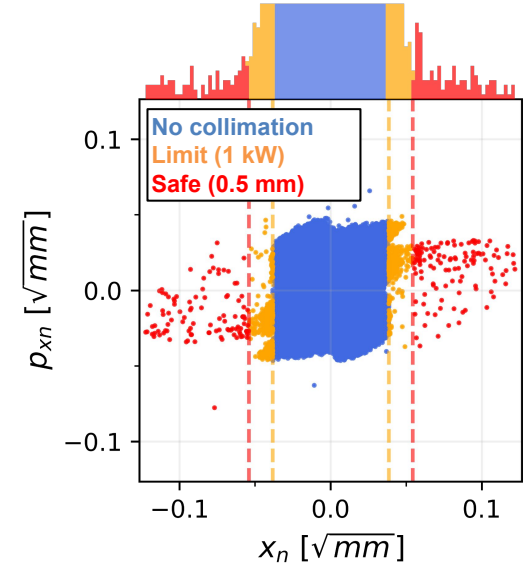
Phase advance :

$$\psi(s) = \int_0^s \frac{1}{\beta(s')} ds'$$

end of booster, $\psi = 0^\circ$

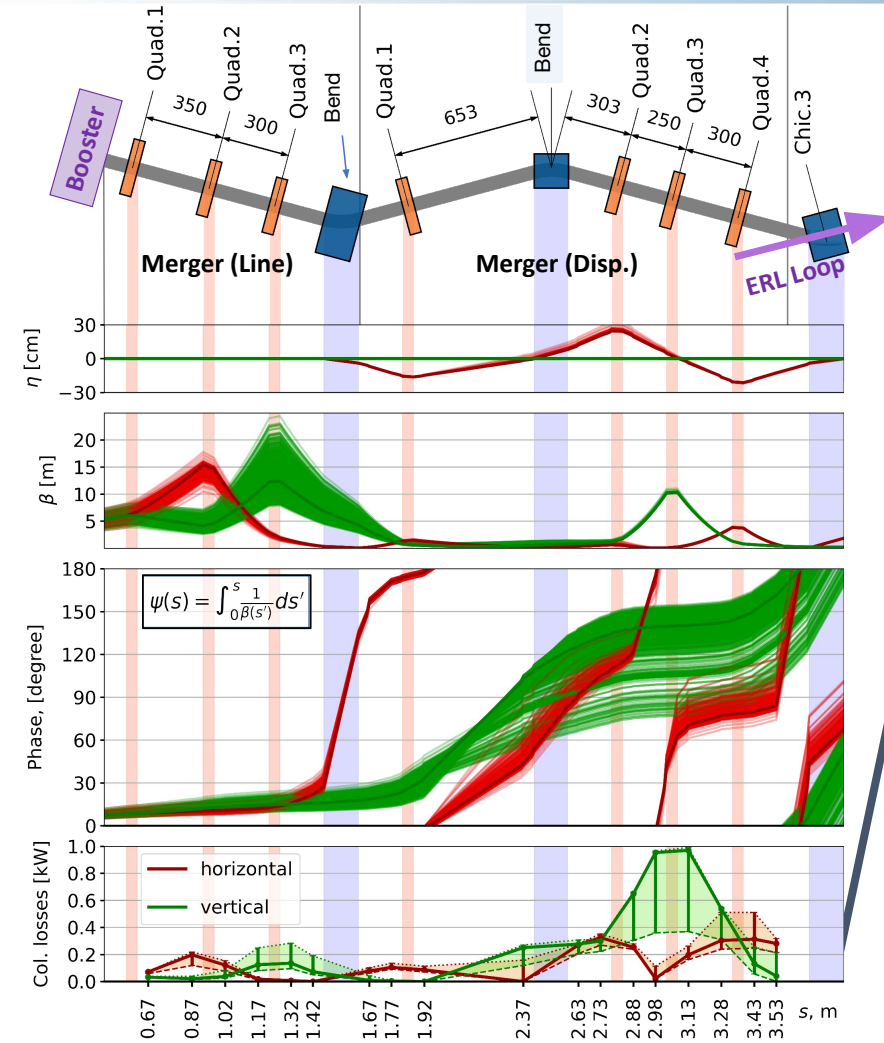


$\psi = 140^\circ$ (optimal)





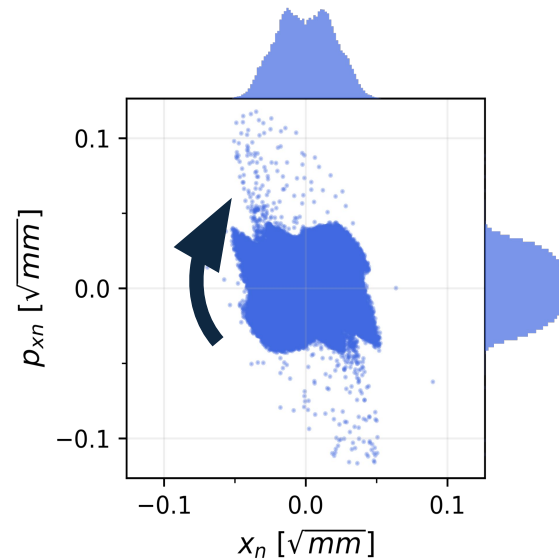
Transverse Halo collimation



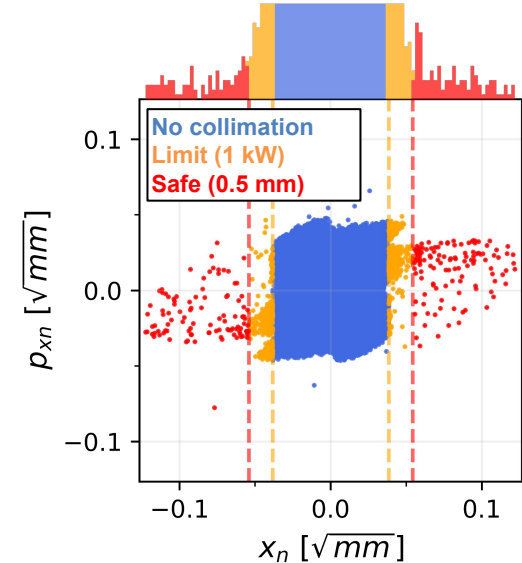
Simulation of collimation losses

Power deposition with a 0.5 mm safety margin
Retracted from 1kW limit per jaw

end of booster, $\psi = 0^\circ$

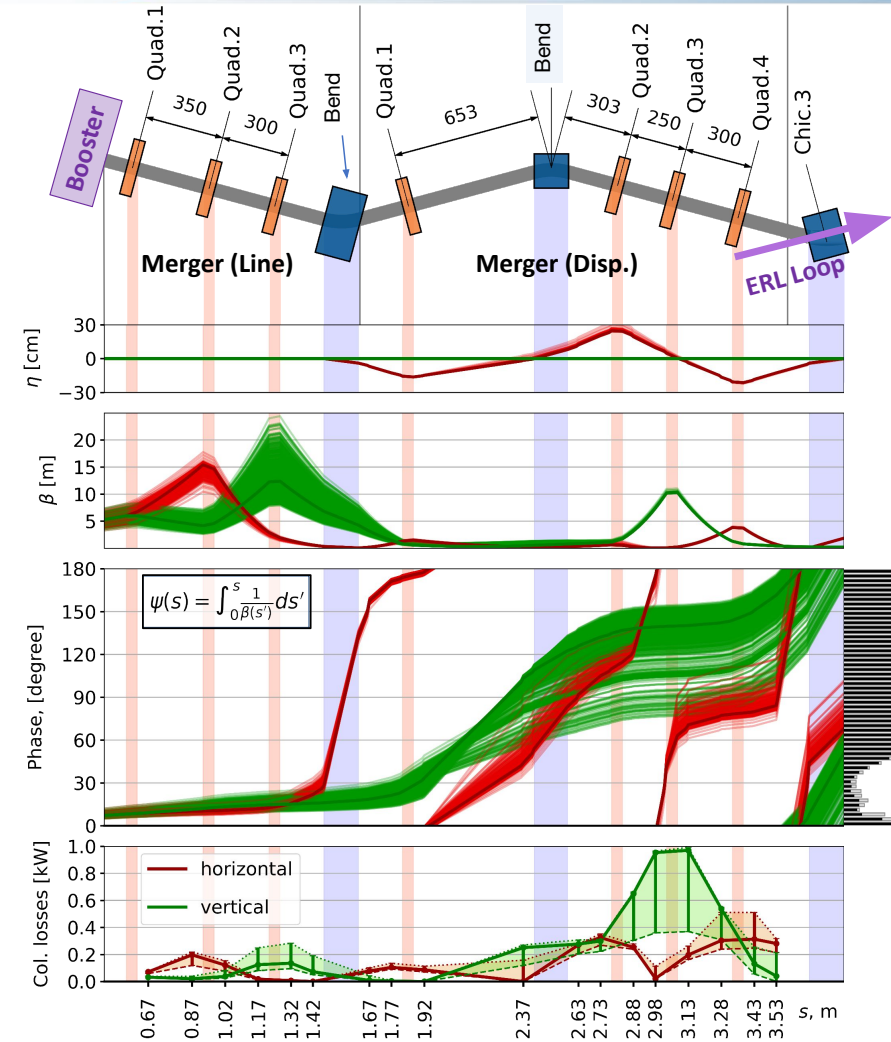


$\psi = 140^\circ$ (optimal)



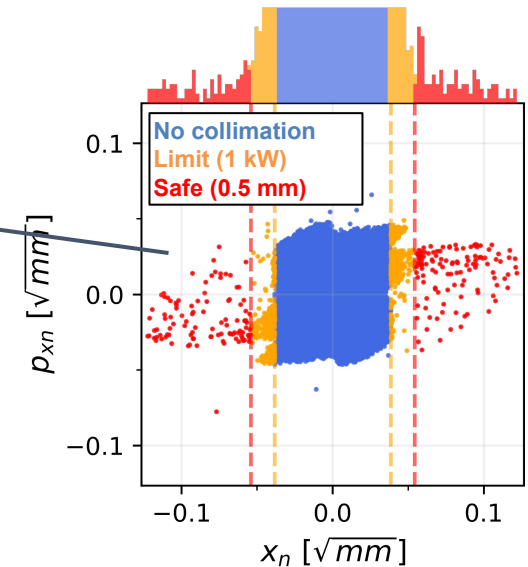


Comparison between Bmad simulation and the semi-analytical model



Collimation losses analysis :

- There is a good agreement between the semi-analytical study & this Bmad tracking simulation
- furthermore we can see the impact of the beta function on collimation efficiency





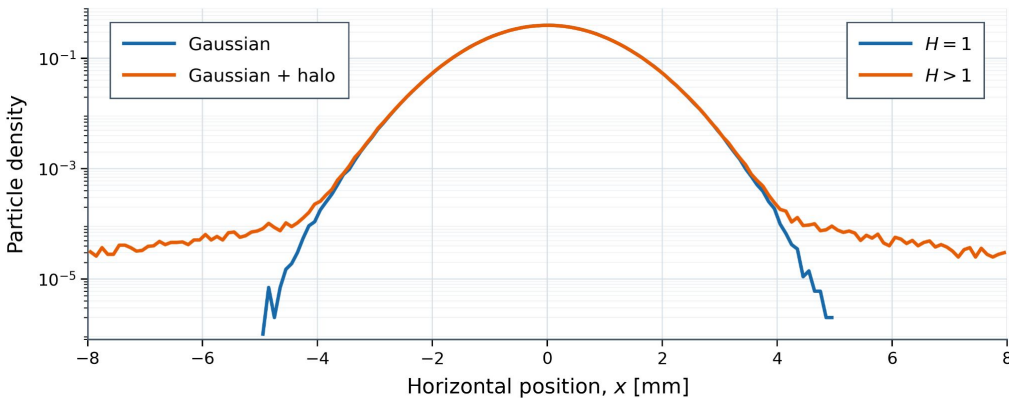
Quantitative analysis



Particles farther from the beam core are more likely to be lost

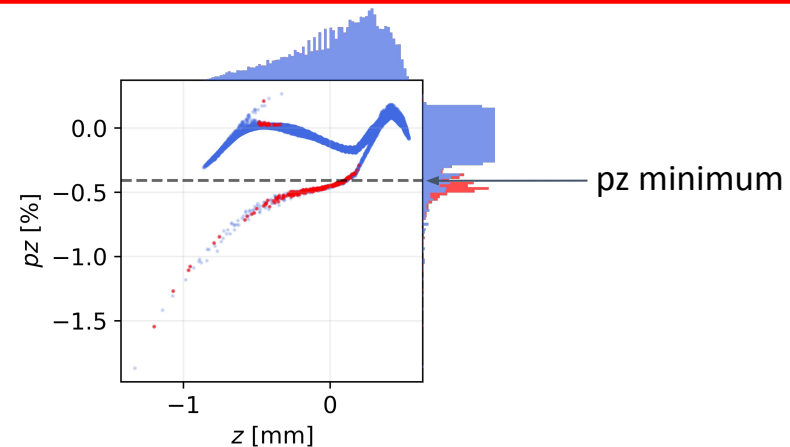
Transversal (Halo factor)

$$H_i \equiv \frac{\sqrt{3}}{2} \frac{\sqrt{I_4^i}}{I_2^i} - 2$$



Longitudinal (cleaning efficiency)

$$\eta_{\text{coll long}} \equiv \frac{N_{\text{coll}}(pz < pz_{\text{min}})}{N_{\text{tot}}(pz < pz_{\text{min}})}$$

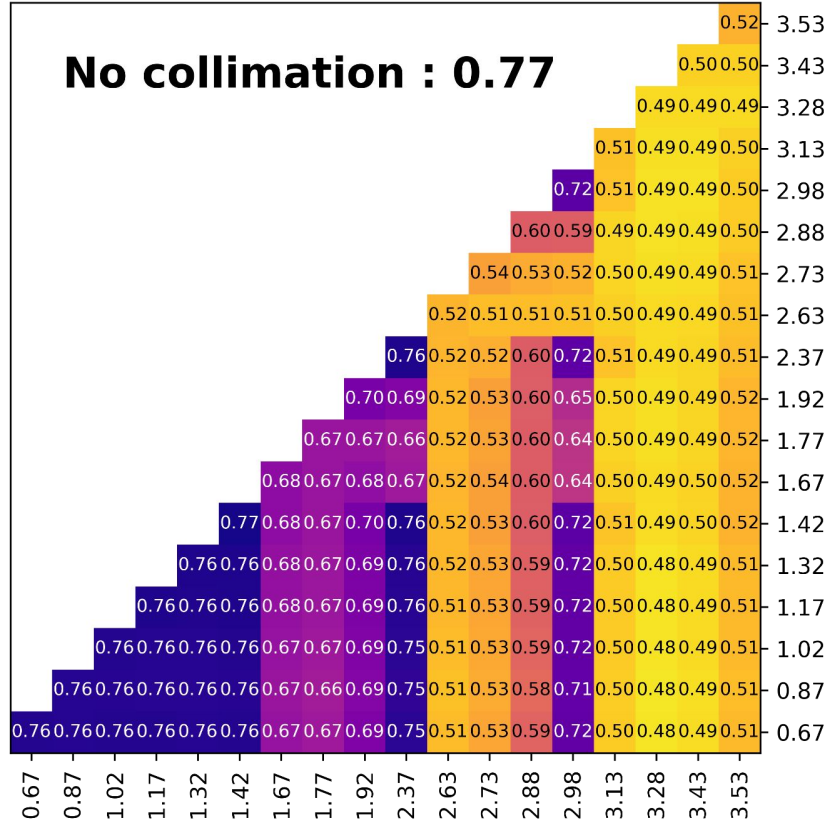




2D Heat map for collimator placement

Halo factor (Horizontal plane)

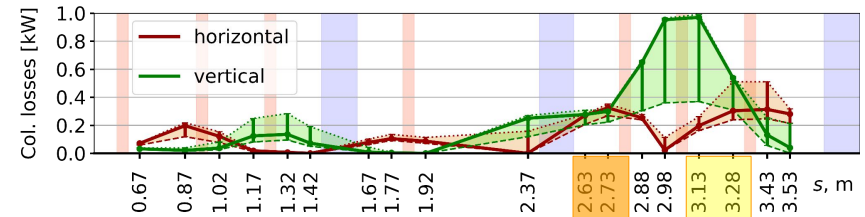
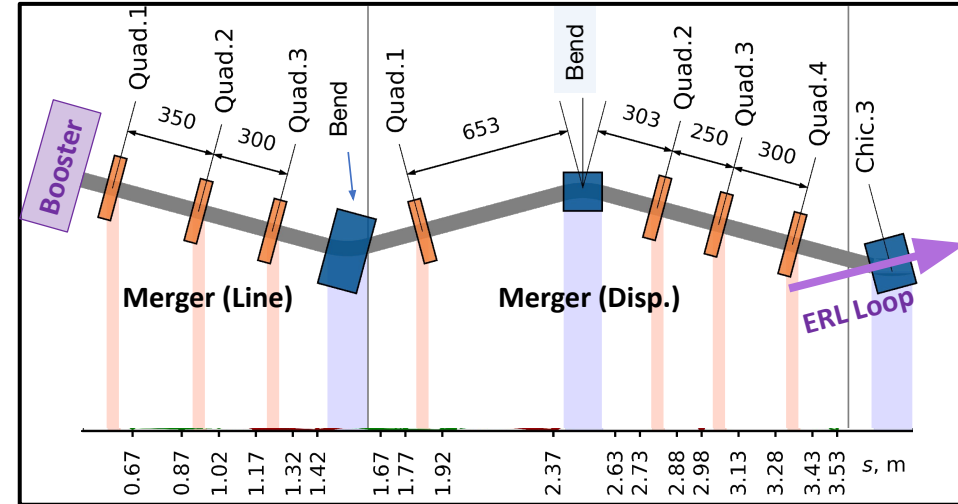
No collimation : 0.77



Collimator 2 position, s [m]

Collimator 1 position, s [m]

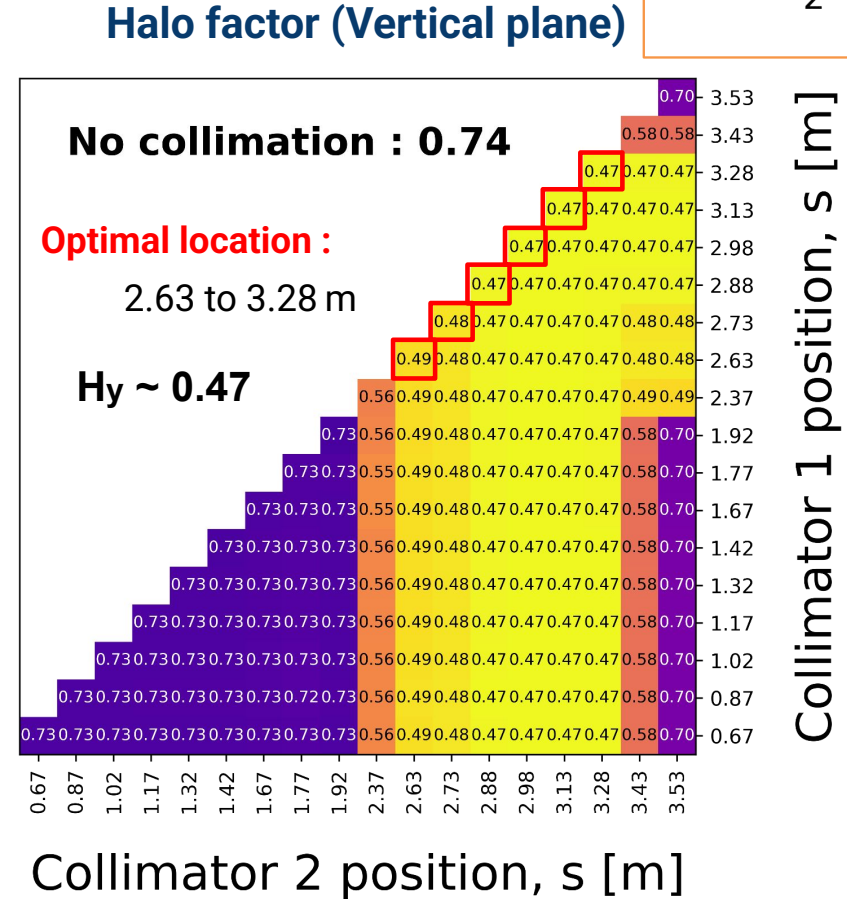
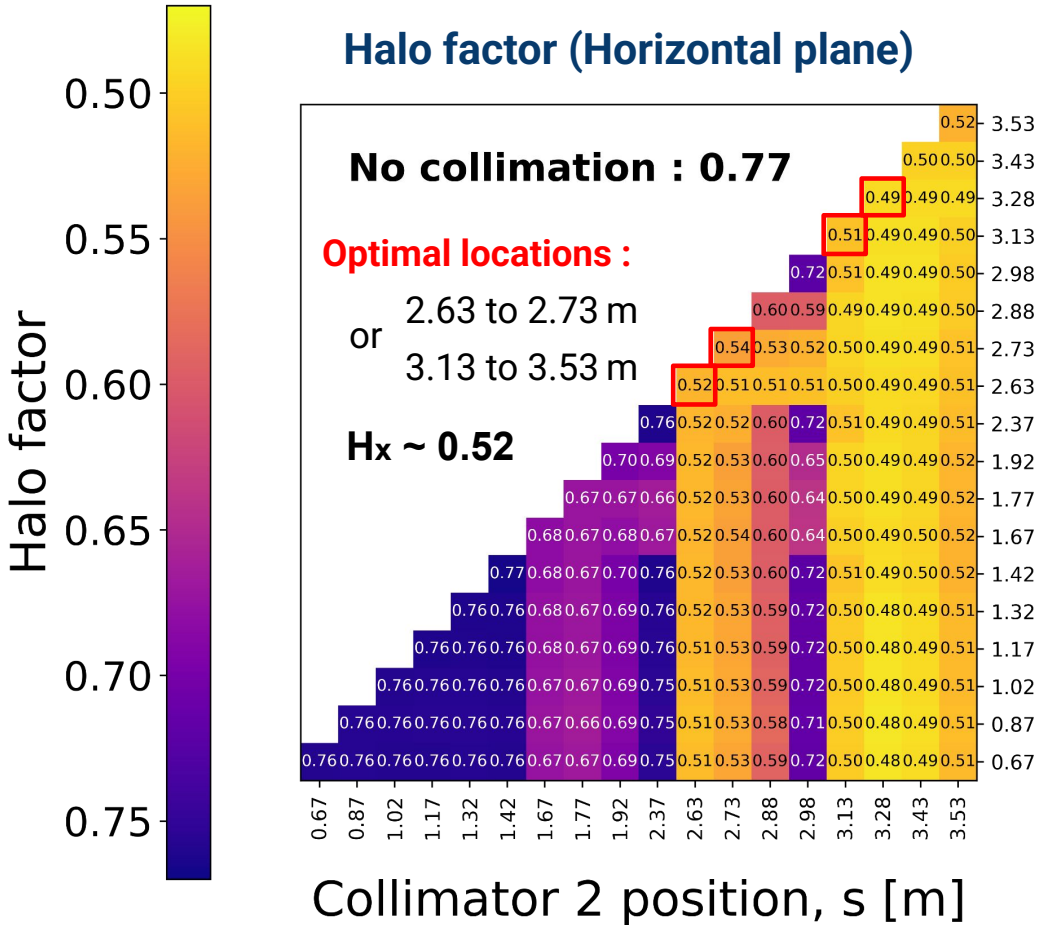
$$H_i \equiv \frac{\sqrt{3}}{2} \frac{\sqrt{I_4^i}}{I_2^i} - 2$$





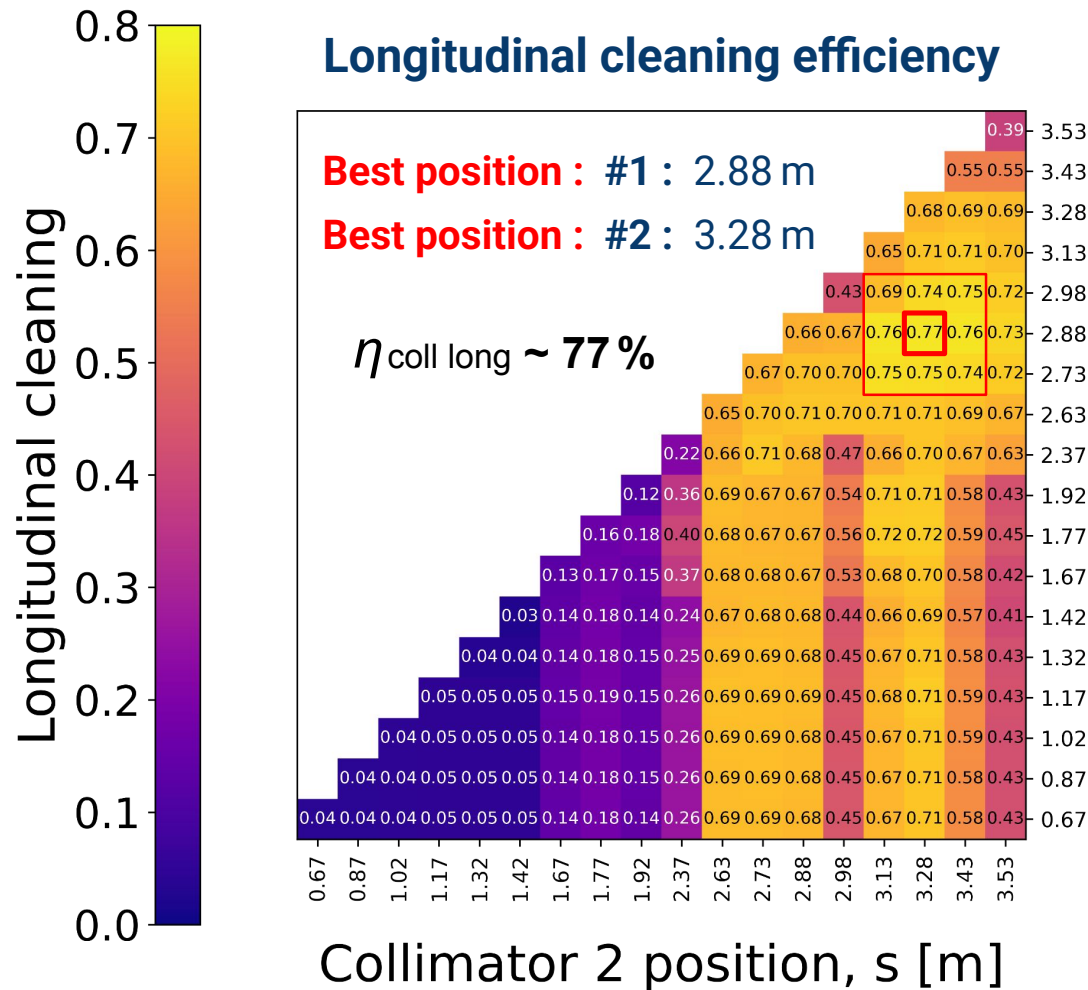
2D Heat map for collimator placement

$$H_i \equiv \frac{\sqrt{3}}{2} \frac{\sqrt{I_4^i}}{I_2^i} - 2$$

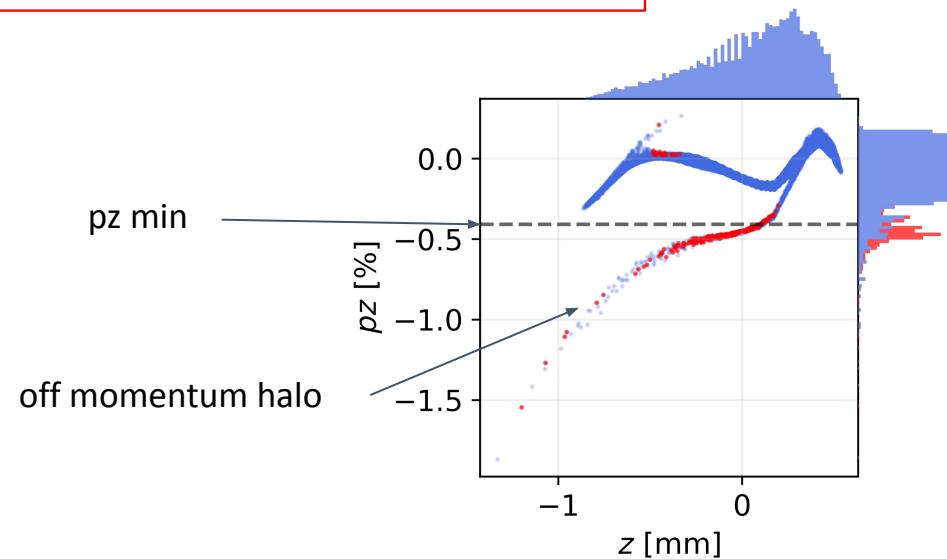




2D Heat map for collimator placement



$$\eta_{\text{coll long}} \equiv \frac{N_{\text{coll}}(pz < pz_{\text{min}})}{N_{\text{tot}}(pz < pz_{\text{min}})}$$



Optimal locations :

- Two collimator system : 2.73 to 2.98 m and 3.13 to 3.43 m



Semi-analytical study

- Safety margin settings with a 0.5 mm margin
- Collimation efficiency vs phase advance

Bmad simulation

- Good agreement with the semi-analytical study
- Quantitative metrics - H-factor & longitudinal cleaning efficiency
- One collimator system : 2.63 to 2.73 m or 3.13 to 3.28 m
- Two collimator system : 2.73 to 2.98 m and 3.13 to 3.43 m

Outlook

- Geant4 : energy deposition and secondary particle production
- Mechanical implementation
- Field non-linearities

Thank you



Backup



Assessing Corrector-Integrated Quadrupoles for PERLE

Compact correctors → **nonlinear off-axis fields**

Beam size trade-off: space charge ↔ halo from nonlinearity

cERL kick maps (measured) → real-field validation

OPERA + BMAD → emittance, steering, halo impact

→ Design limits & lattice placement for PERLE

[THP2103 \(A. Fomin\)](#)

