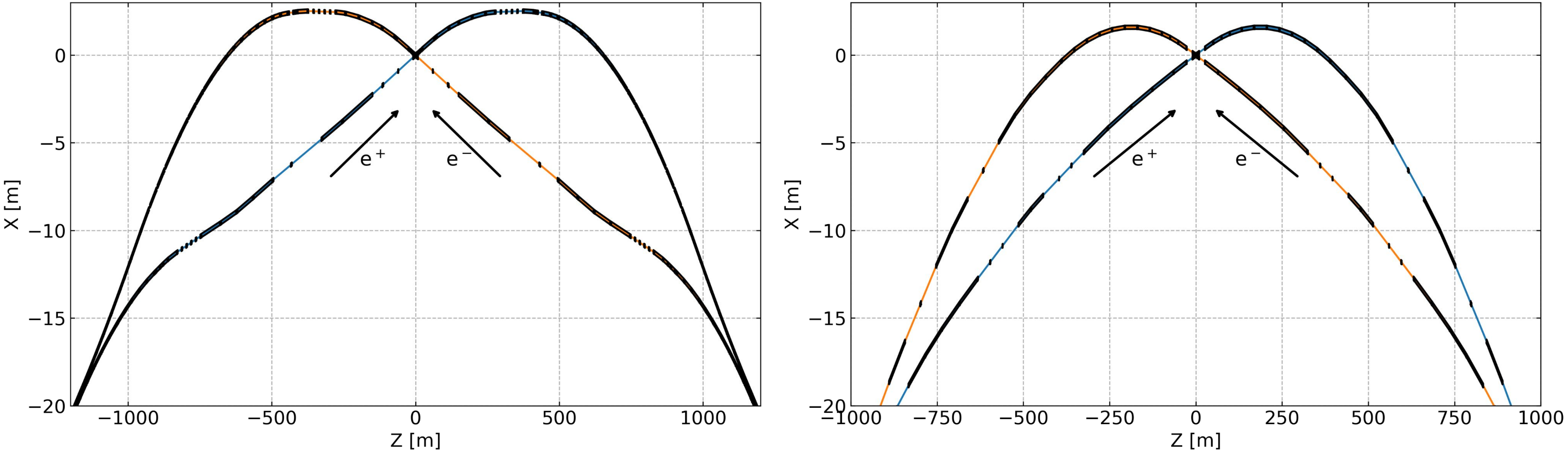
Synchrotron Radiation Background Studies @ FCC-ee

K.D.J. André for the MDI study group

FCC-ee lattice | baseline and LCCO IR design



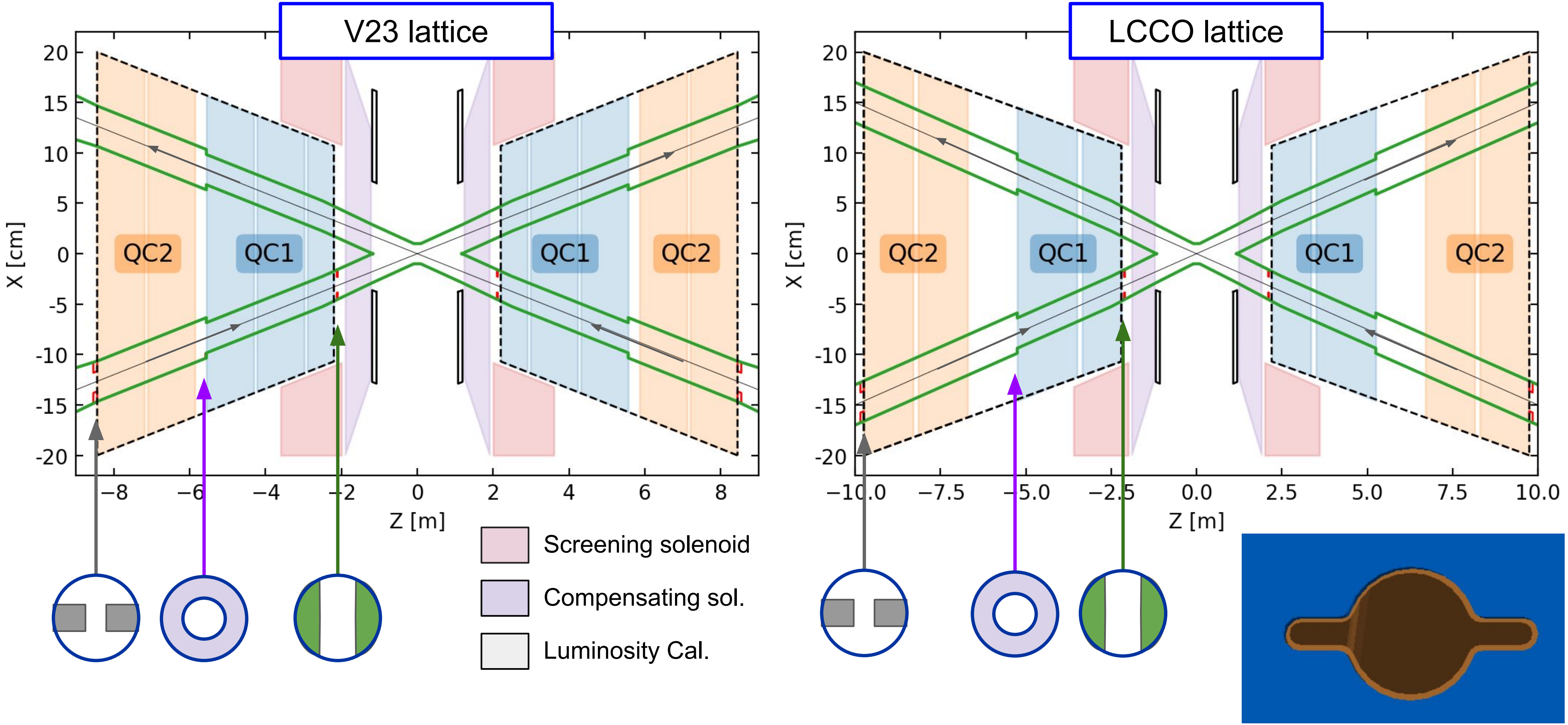
The lattice design upstream the IP is based on weak dipoles (**100 keV critical energy**), long straight sections and implements a **30 mrad crossing angle** at the IP.

The model features: the (anti-)solenoid field map, a detailed central beam pipe with a **10mm** radius, **6 synchrotron radiation collimators**, and **2 masks.**

The lattice design upstream the IP is based on weak dipoles (**156 keV critical energy**), short straight sections and implements a **30 mrad crossing angle** at the IP.

The model features: the (anti-)solenoid field map, a detailed central beam pipe with a **10mm** radius, **2 synchrotron radiation collimators**, and **2 masks.**

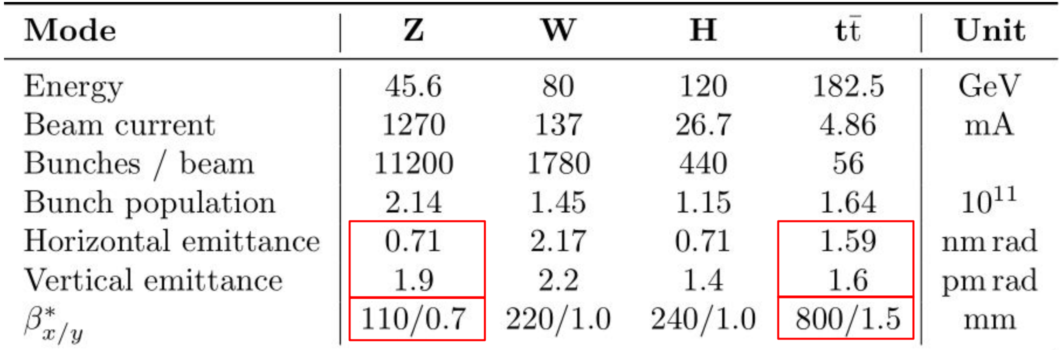
FCC-ee lattice | Baseline and LCCO IR designs



Beam model | Core and halo description

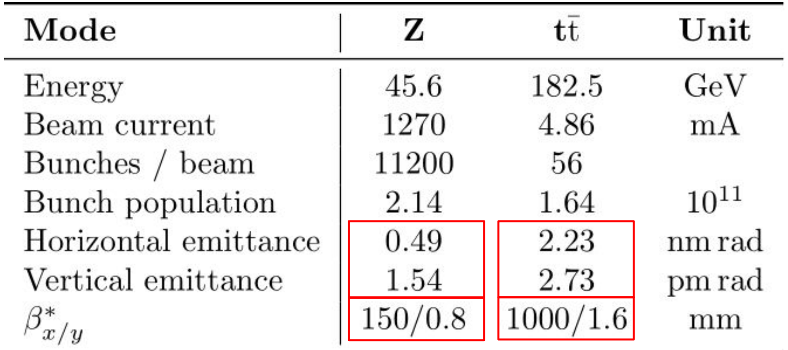
Studies from M. Sullivan [1, 2] showed the transverse beam halo create a large amount of synchrotron radiation mainly from the final focus quadrupoles, hence it needs to be modeled and studied.

- **The beam core** is defined as a **Gaussian distribution** based on the linear optics parameters,
- **The beam halo** is represented by a **phase-space correlated distribution** with
  - ➢ $X \in [3.5\sigma_x$ to $11\sigma_x]$, $X' \in [3.5\sigma'_x$ to $11\sigma'_x]$, $Y \in [4\sigma_y$ to $65\sigma_y]$ and $Y' \in [4\sigma'_y$ to $65\sigma'_y]$.
- Assuming **99%** of the particles **in the core** and **1% in the transverse halo**.
- The longitudinal beam distribution is Gaussian.
- The **rms positions and angles of the non-zero closed orbit** have been implemented.



Mode	Z	W	H	$t\bar{t}$	Unit
Energy	45.6	80	120	182.5	GeV
Beam current	1270	137	26.7	4.86	mA
Bunches / beam	11200	1780	440	56	
Bunch population	2.14	1.45	1.15	1.64	10^{11}
Horizontal emittance	0.71	2.17	0.71	1.59	nm rad
Vertical emittance	1.9	2.2	1.4	1.6	pm rad
$\beta^*_{x/y}$	110/0.7	220/1.0	240/1.0	800/1.5	mm

Beam parameters for V23 [3]

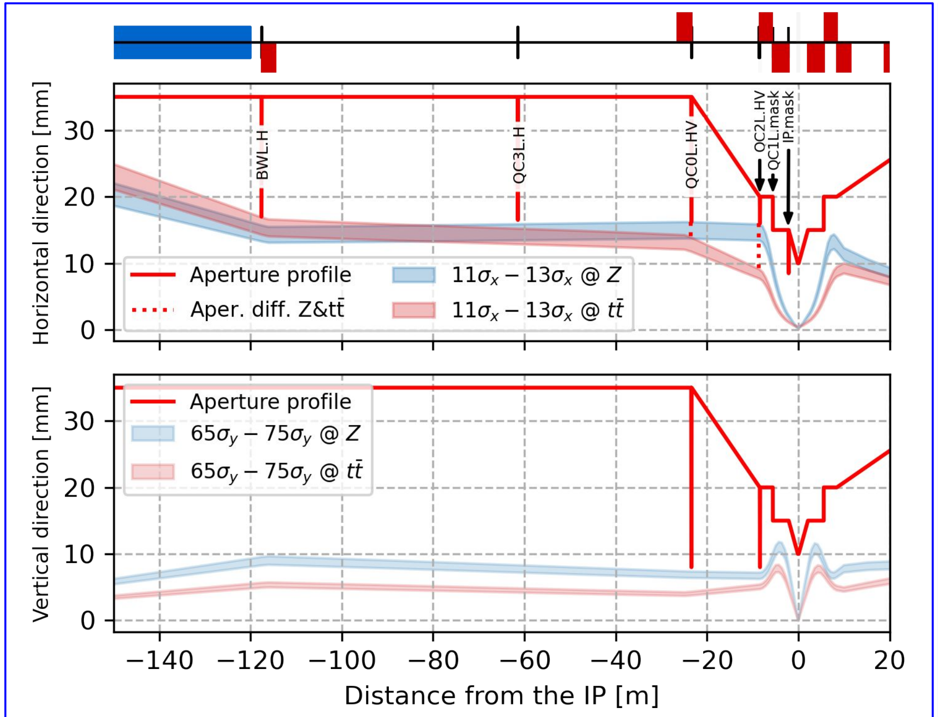


Mode	Z	$t\bar{t}$	Unit
Energy	45.6	182.5	GeV
Beam current	1270	4.86	mA
Bunches / beam	11200	56	
Bunch population	2.14	1.64	10^{11}
Horizontal emittance	0.49	2.23	nm rad
Vertical emittance	1.54	2.73	pm rad
$\beta^*_{x/y}$	150/0.8	1000/1.6	mm

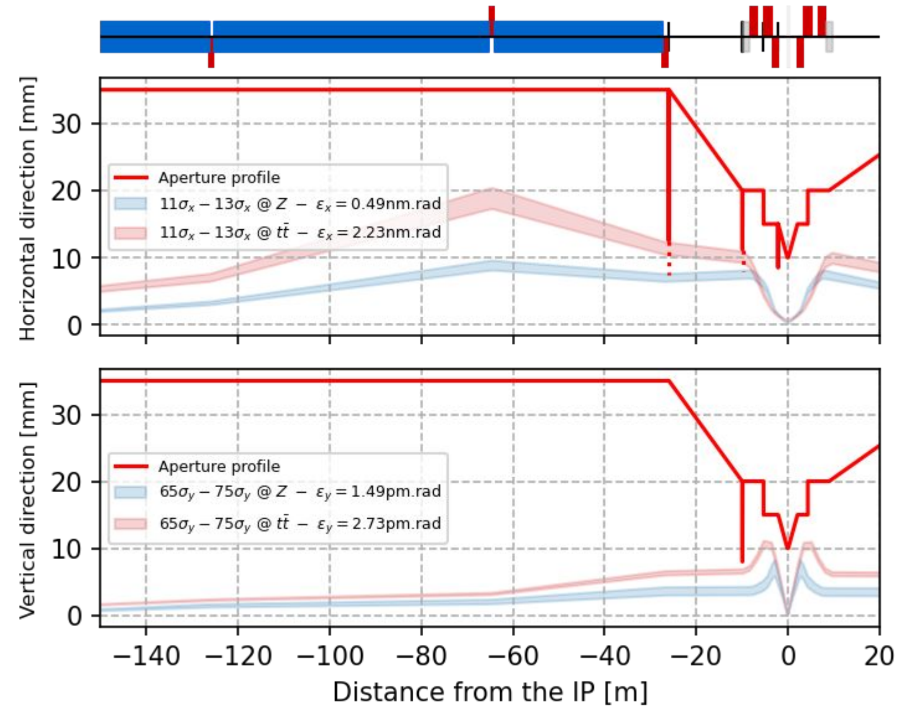
Beam parameters for LCCO72 [4]

Synchrotron radiation collimation (V23 & LCCO72)

Aperture bottleneck at 14.4 σ_x in BWL* or QC2L, primary and secondary halo collimators set to 11 and 13 σ_x respectively.
Same primary and secondary halo collimator apertures for LCCO lattice as in V23 (11 and 13 σ_x) for comparison.



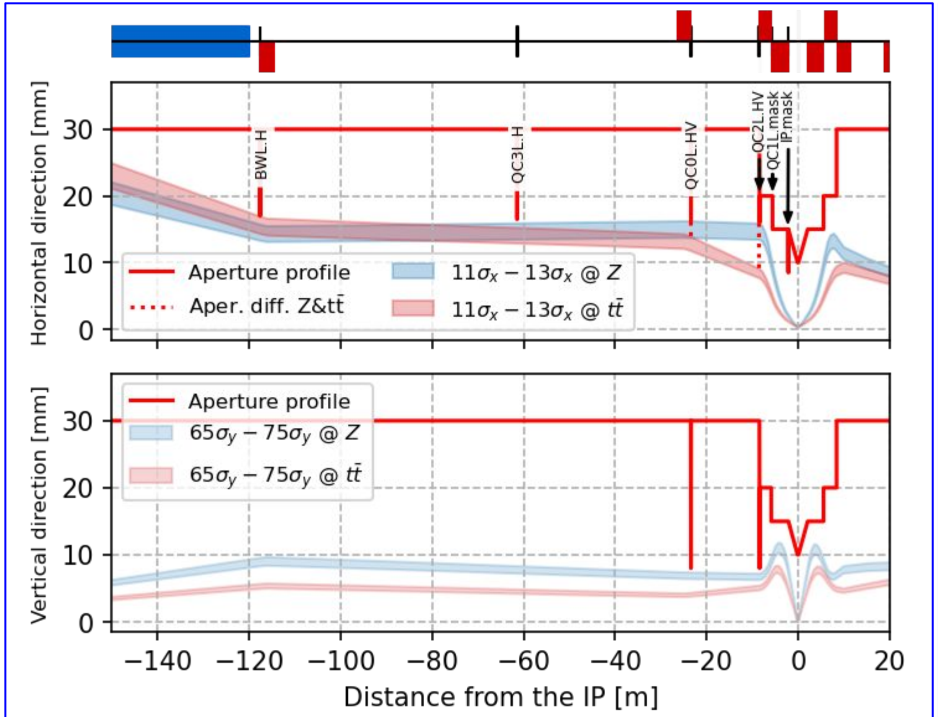
V23 lattice



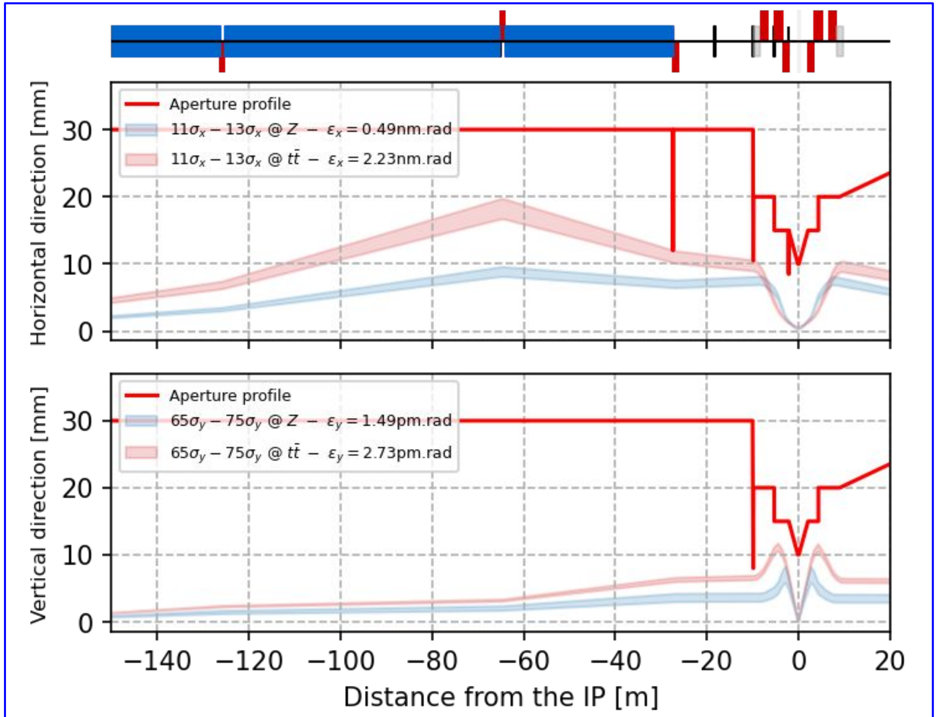
LCCO lattice

Synchrotron radiation collimation (V23 & LCCO72)

Aperture bottleneck at 14.4 σ_x in BWL* or QC2L, primary and secondary halo collimators set to 11 and 13 σ_x respectively. Same primary and secondary halo collimator apertures for LCCO lattice as in V23 (11 and 13 σ_x) for comparison.

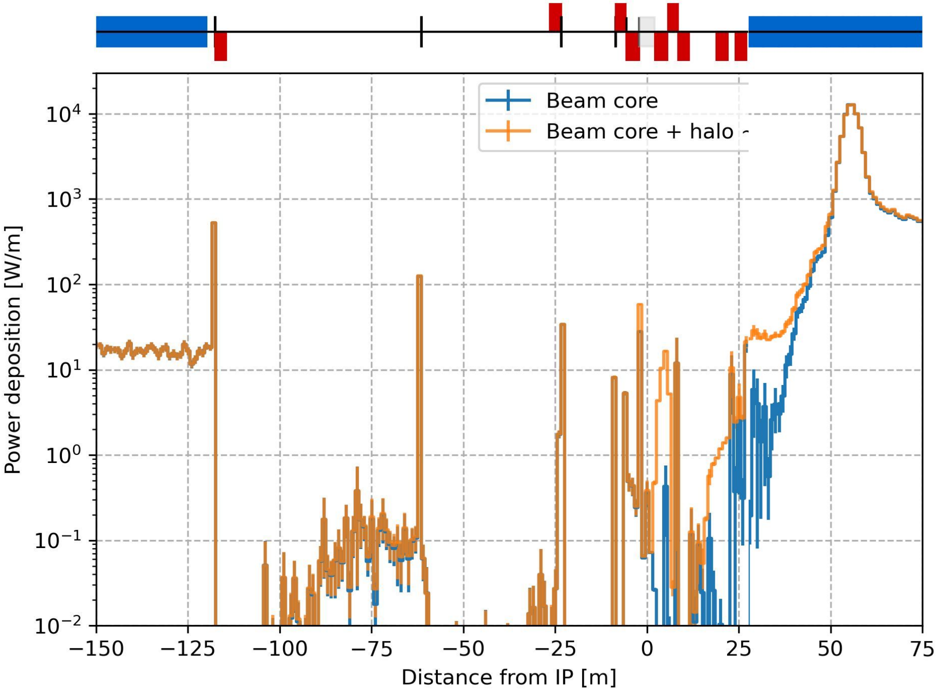


V23 lattice

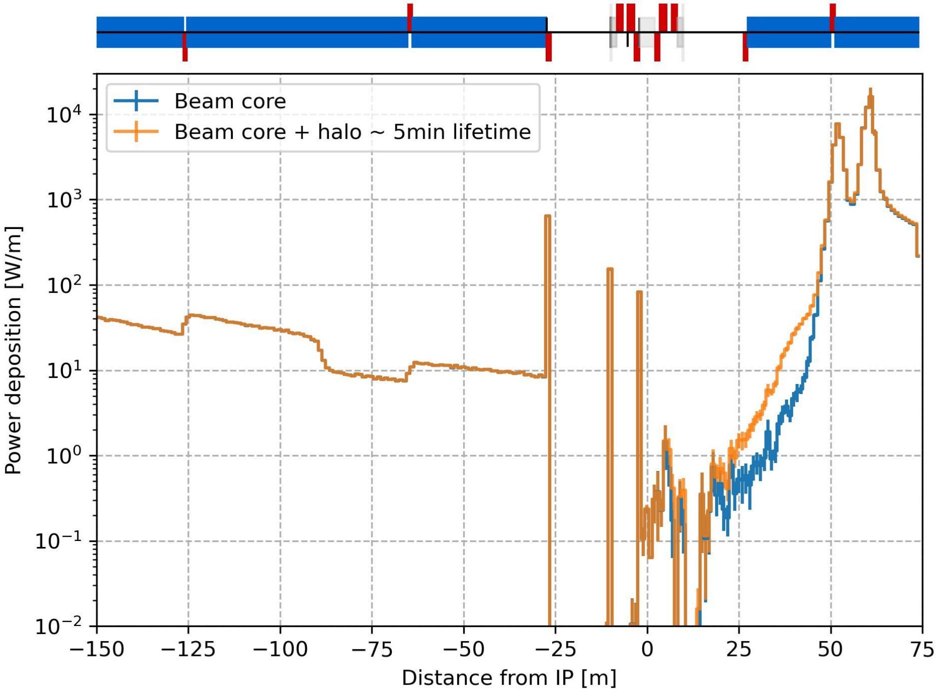


LCCO lattice

Results at **Z energy**

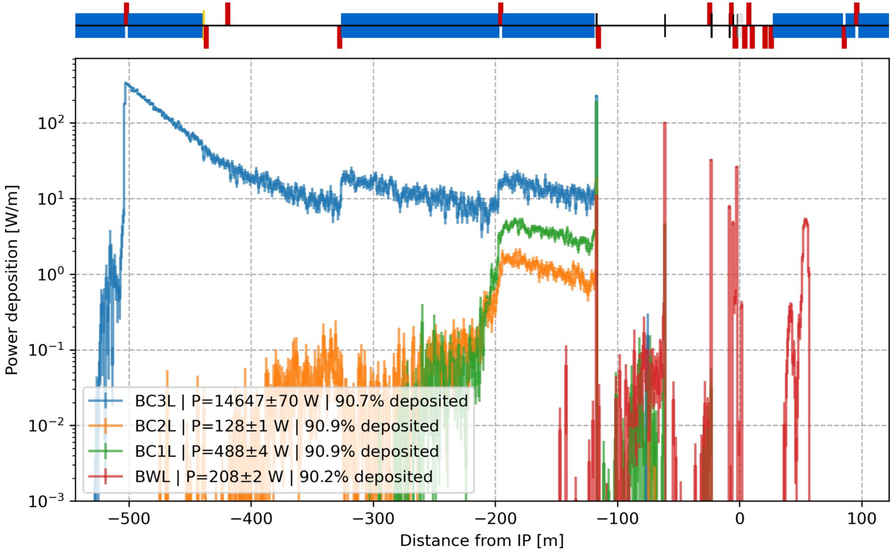


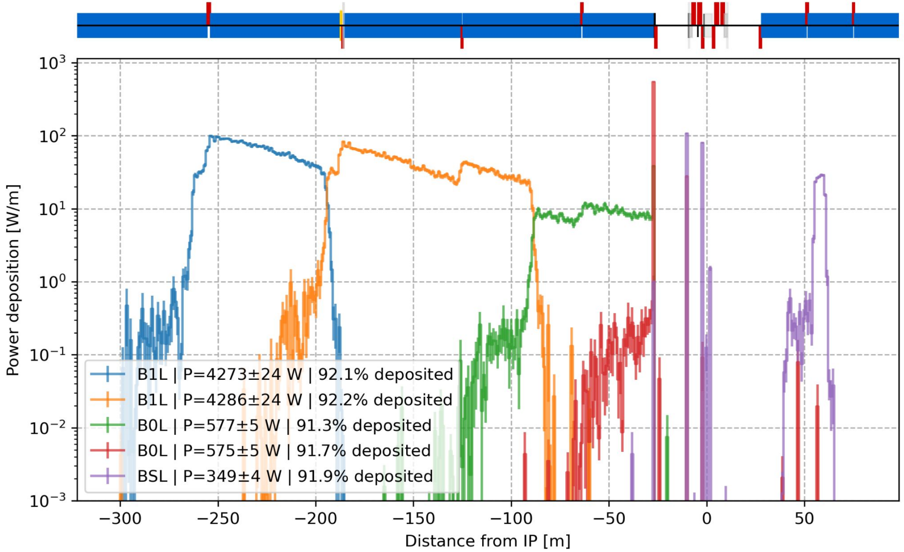
Baseline V23 - SR power deposition from beam halo
(1% of the particles in the tails)



LCCO - SR power deposition from beam halo
(1% of the particles in the tails)

Extension of the model from BC3L to BC3R





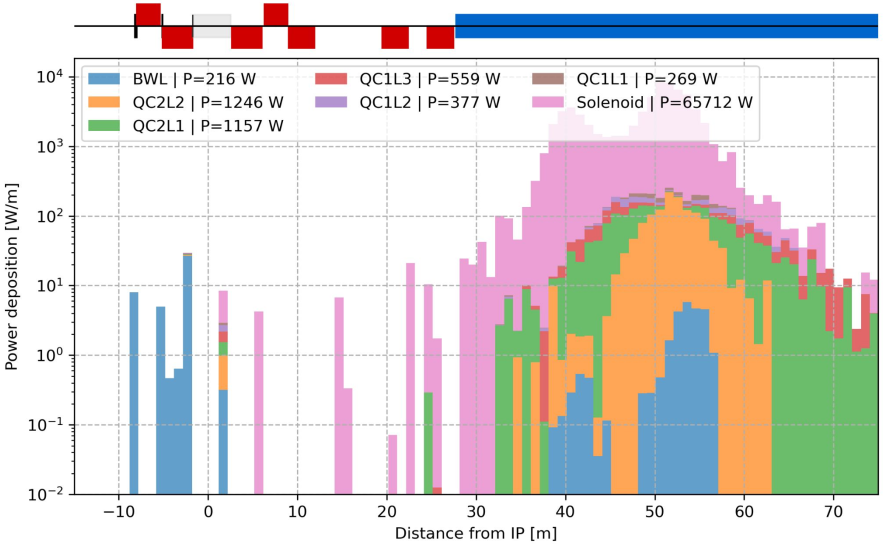
Synchrotron radiation from BC3L do not propagate further than the 2nd SR collimator. Only radiation from BWL reach the IP and hit BC1R. This conclusion may change once **x-ray reflection will be implemented**.

Synchrotron radiation from B1L do not propagate further than 75m from the IP. Radiation from B0L reach the first SR collimator. BSL emits photons that go beyond the IP.

V23 lattice

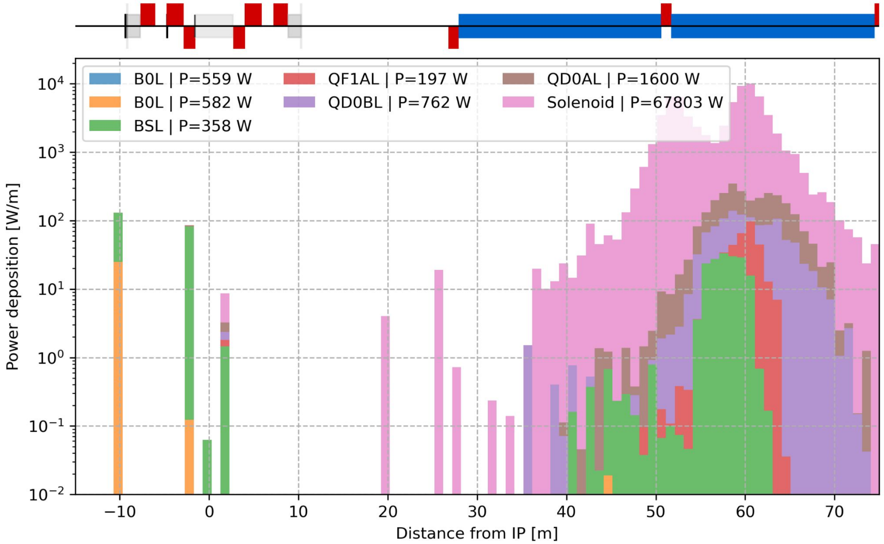
LCCO lattice

Detailed SR power deposition from beam core



Some SR from last dipole make it to the CC, the mask gets about 10W SR power deposited from the beam core, **efficient** SR collimators.

V23 lattice

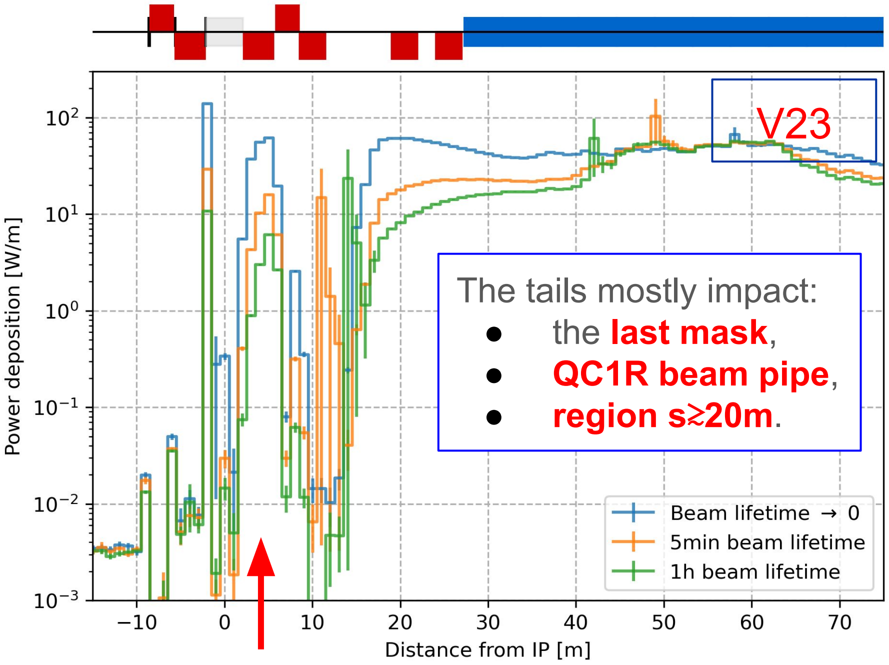


Some SR from last dipole make it to the CC, the mask gets a about 100W SR power deposited, **needs more** SR collimators?

LCCO lattice

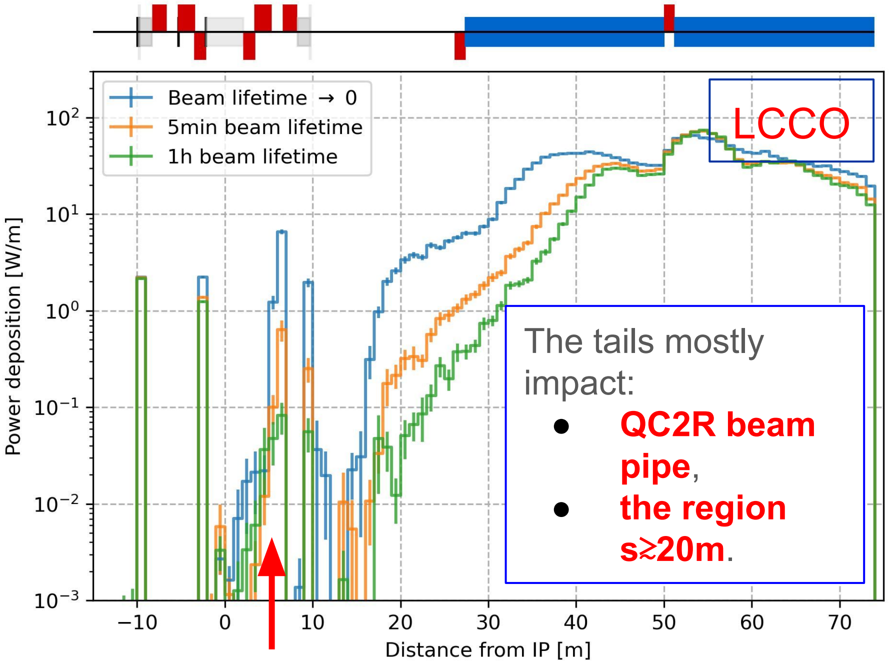
Transverse halo impact with beam lifetime @ Z energy

The transverse tails extend until the primary collimator apertures: $11\sigma_x/65\sigma_y$. The “beam lifetime → 0” corresponds to a uniform tail distribution and is shown as worse case scenario. The “5min beam lifetime” is considered in the collimation studies, see A. Abramov’s slides. 1h beam lifetime is given as point of comparison.



The tails mostly impact:

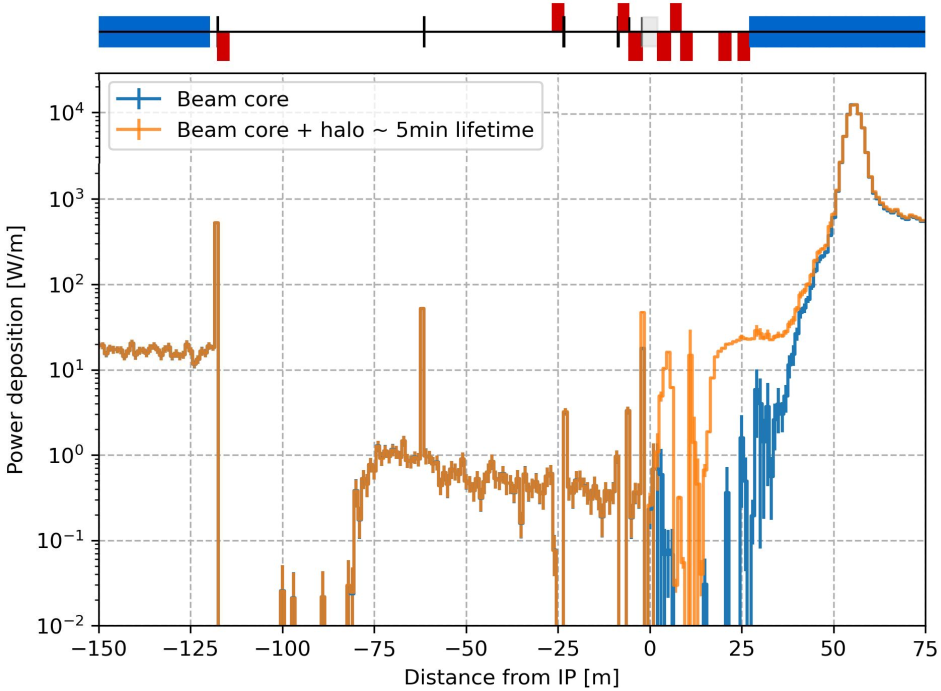
- the **last mask**,
- **QC1R beam pipe**,
- **region $s \gtrsim 20$m**.



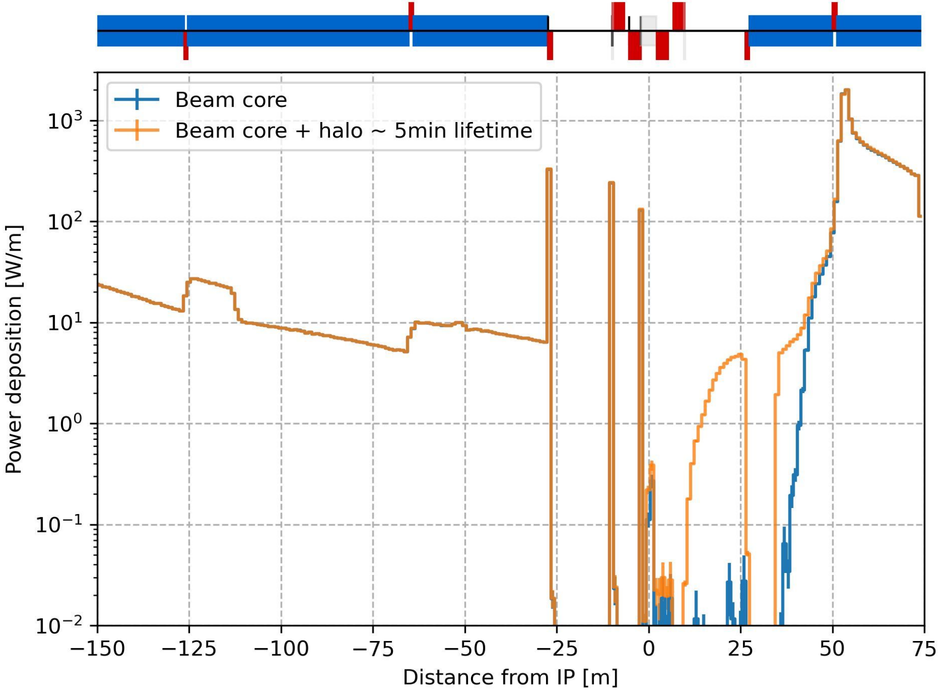
The tails mostly impact:

- **QC2R beam pipe**,
- **the region $s \gtrsim 20$m**.

Results at **tt energy**

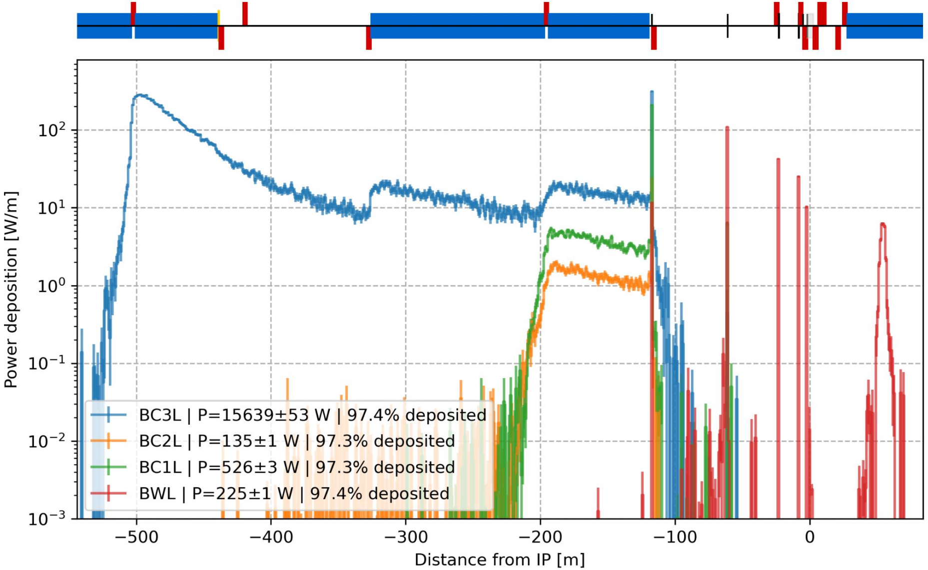


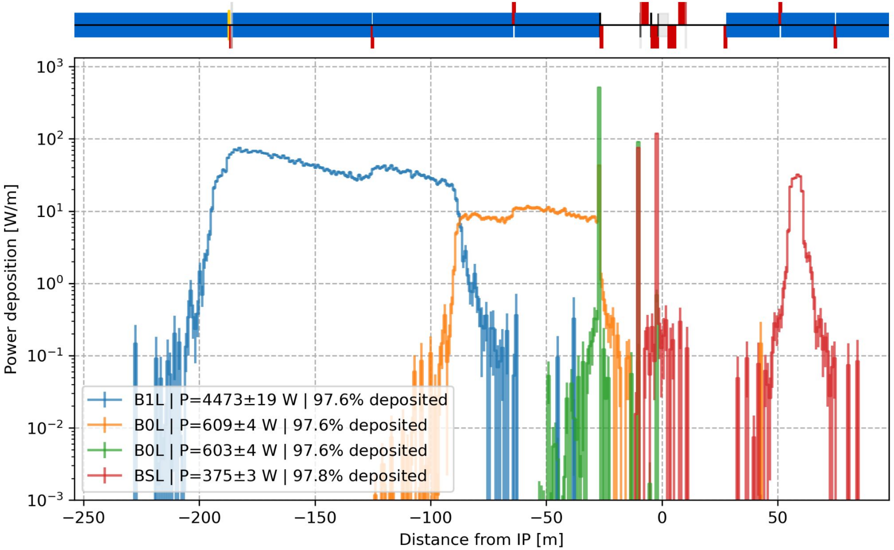
Baseline V23 - SR power deposition from beam halo
(1% of the particles in the tails)



LCCO - SR power deposition from beam halo
(1% of the particles in the tails)

Extension of the model from BC3L to BC3R





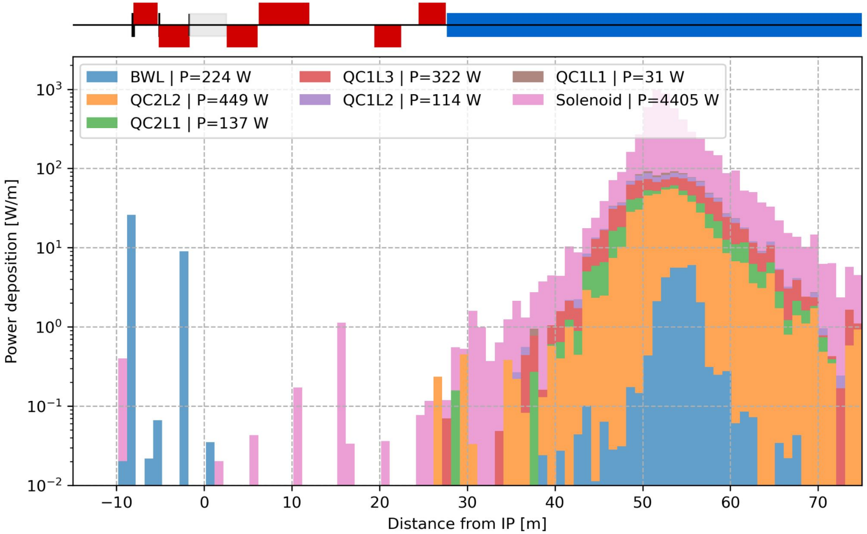
Synchrotron radiation from BC3L do not reach the IP **without x-ray reflection**. Only synchrotron radiation from BC1L make it to the last mask and from BWL beyond the interaction point.

Synchrotron radiation from B1L do not reach the IP **without x-ray reflection**. The synchrotron radiation from B0L make it to the last mask. Radiation from BSL go beyond the interaction point.

V23 lattice

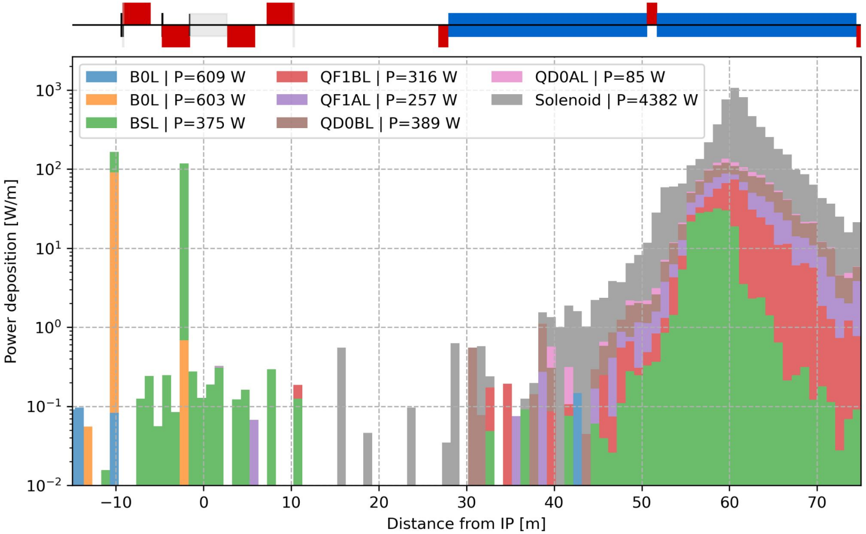
LCCO lattice

Detailed SR power deposition from beam core



Some SR from last dipole make it to the CC, the mask gets about 10W SR power deposited from the beam core, **efficient** SR collimators.

V23 lattice



Some SR from last dipole make it to the CC, the mask gets a about 100W SR power deposited, **needs more** SR collimators?

LCCO lattice

Summary

- The BDSIM model features a Ø60mm beam pipe with horizontal winglet outside the final focus region, impacts the SR flux reaching the SR collimators and masks.
- Simulations with beam core and transverse tail have been performed **at Z and tt energies** for the **V23-baseline and LCCO lattices** with equivalent power deposition in the vicinity of the particle detector,
    - **LCCO-V23** shows better results regarding the SR from the transverse tail but needs more collimation to mitigate the SR from the beam core **(especially in the mask)**
    - **Baseline-V23** shows better results regarding the SR from the beam core because the SR collimation is more effective (and mature) but the SR from the transverse tail causes more power deposition close to the IP.

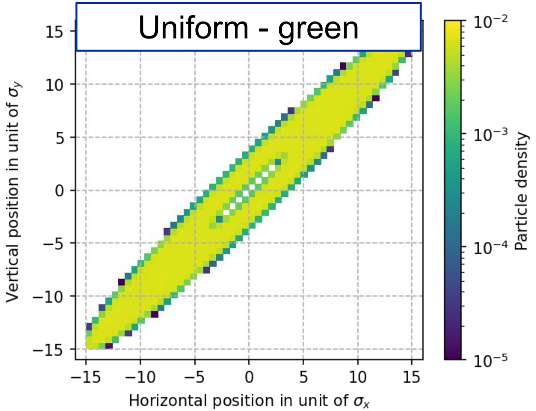
Future plans:

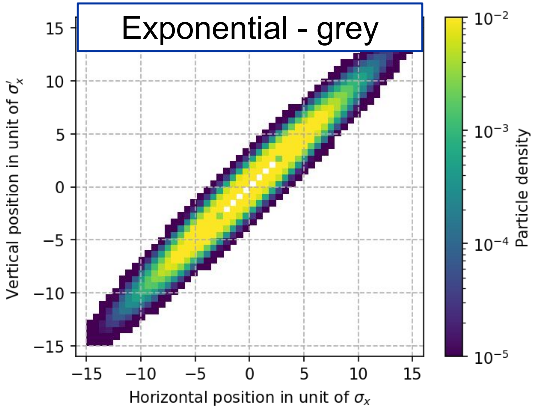
- ➢ Investigate the x-ray reflection in the GEANT4 model see details in [5],
- ➢ Compare the two solenoid compensation schemes, see A. Ciarma's slide.
- ➢ Top-up injection must be studied for the V23 lattice and optics design, investigate the effects of some imperfections such as optics mismatch, emittance blowup, etc..

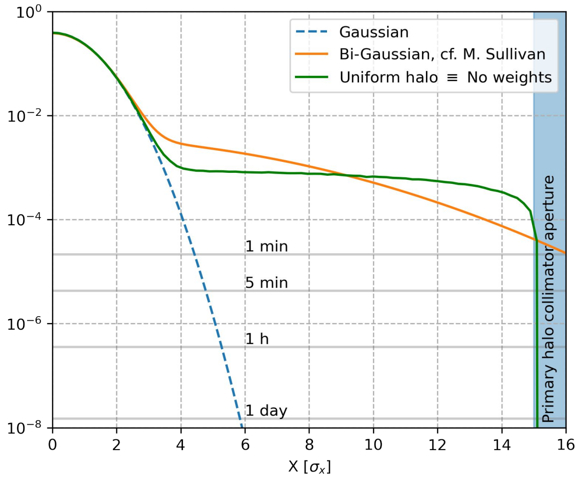
Thank you
for your attention.

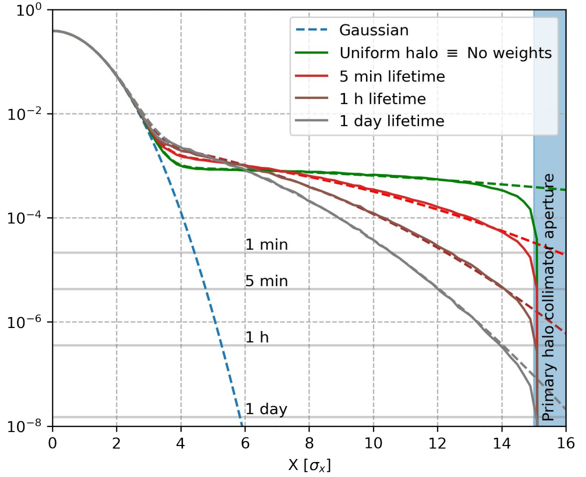
Beam model | Weighted halo description

Correlated uniform distribution vs. **correlated exponential distribution**.


Uniform - green


Exponential - grey





From the halo distribution one can extrapolate an equivalent beam lifetime [4] obtain from the halo distribution crossing the primary halo collimator aperture.

The halo tracked, extends to 100% of the primary collimator aperture to avoid particle losses in the aperture.

→ The impact of the beam lifetime and the transverse halo width have been investigated in the following studies.

Simulation tool, field map and physics models

BDSIM simulation tool (ref & website) that is based on GEANT4.

Use of the synchrotron radiation (*G4SynchrotronRadiation*) and low-energy electromagnetic physics (*G4EmPenelopePhysics*) from GEANT4.

Production energy cut at 10 eV (below the default in GEANT4) to prevent infrared divergence.

Implementation of the solenoid and anti-solenoid field map.

Implementation of a realistic central beam pipe in a GDML format.

The beam pipe is made of Copper.

The collimators (10cm) and masks (2cm) are made of Tungsten.

The MAD-X sequences (link) are converted as input files for BDSIM.

The beam parameters can be found in (ref).

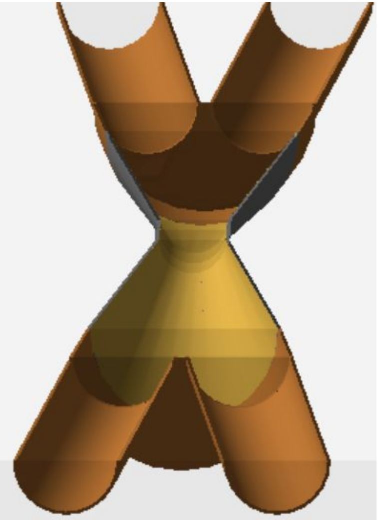
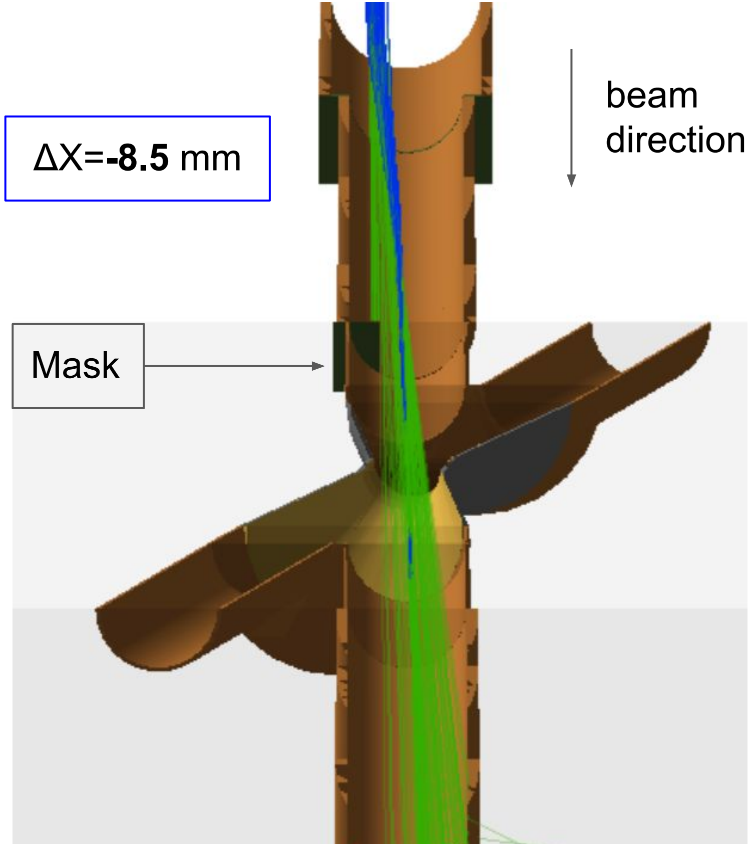
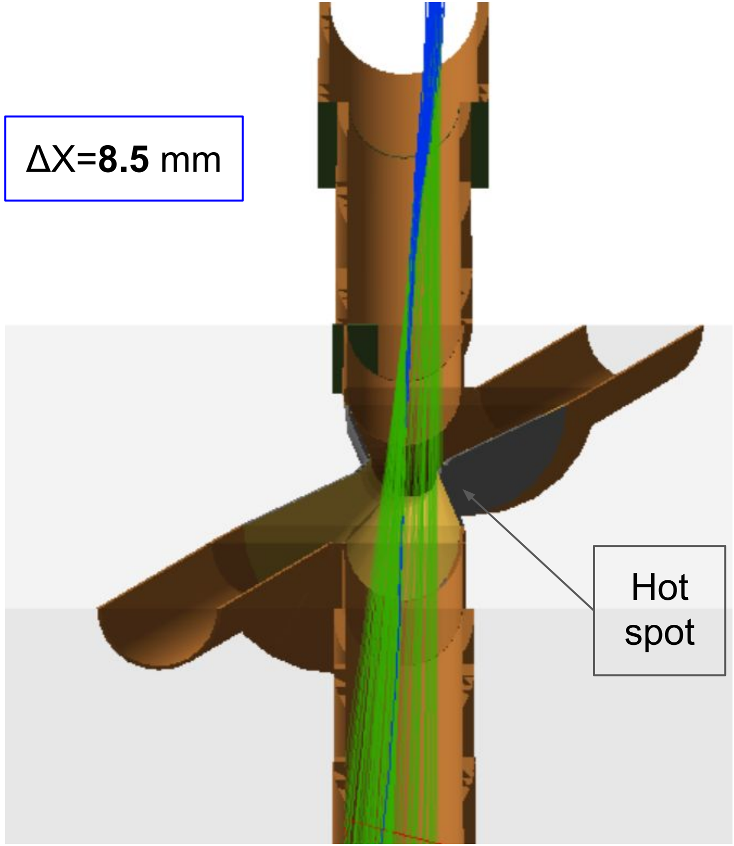


Illustration of the two extremes at Z



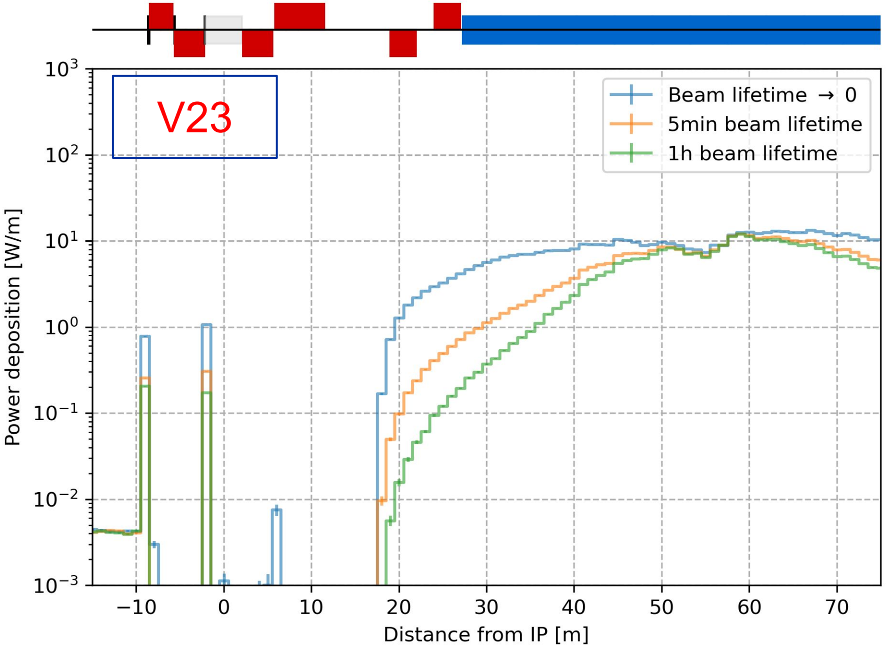
ΔX=**-8.5** mm

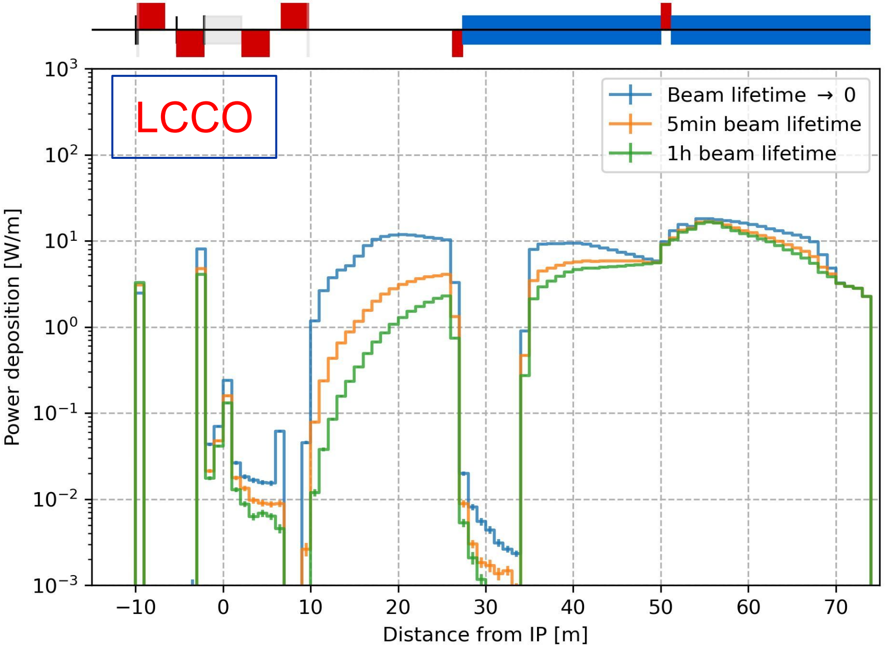


ΔX=**8.5** mm

Transverse halo influence with beam lifetime @ tt energy

The transverse tails extend until the primary collimator apertures: $11\sigma_x/65\sigma_y$. The "beam lifetime → 0" corresponds to a uniform tail distribution and is shown as worse case scenario. The "5min beam lifetime" is considered in the collimation studies, see A. Abramov's slides. 1h beam lifetime is given as point of comparison.



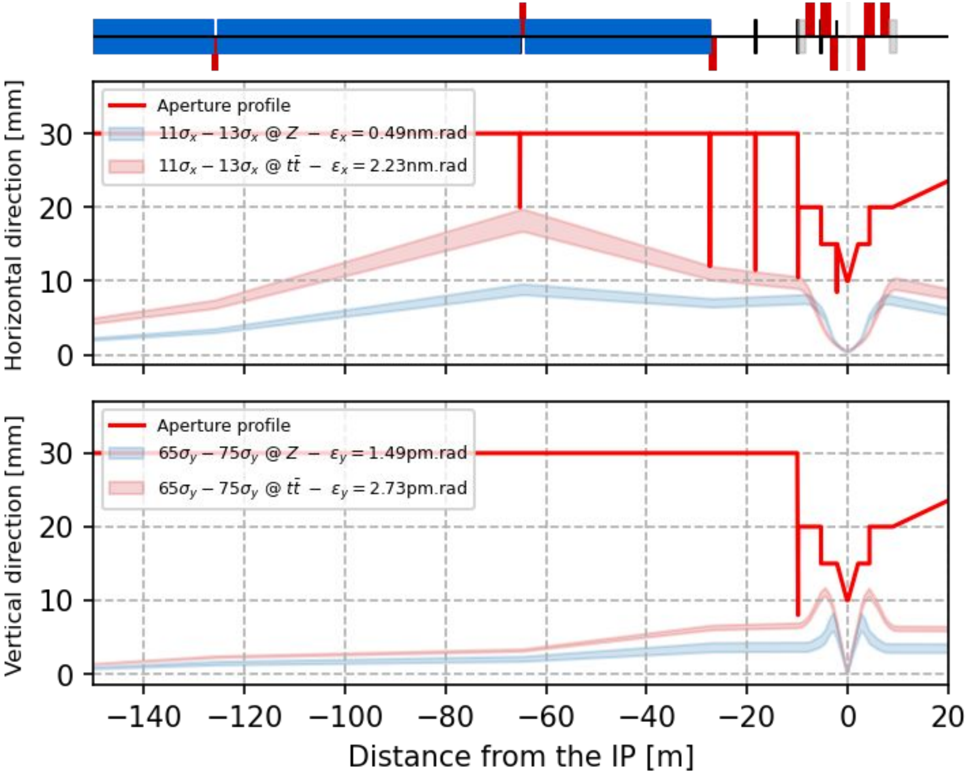


Additional SR collimators for LCCO lattice

Add SR collimators upstream the IP, in between the two last dipoles.

Then another SR collimator can be added in the last drift section.

The aperture of each SR collimators can be optimised.



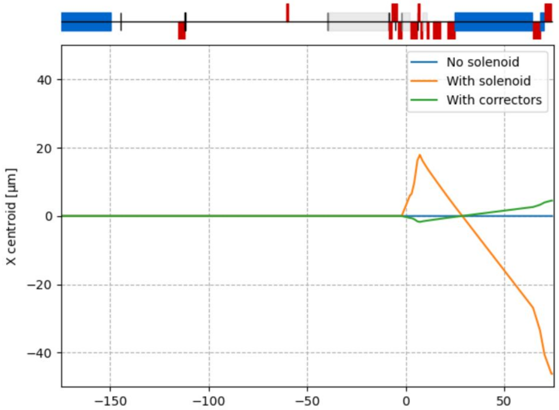
Orbit correctors around the IP | Z mode 45.6 GeV

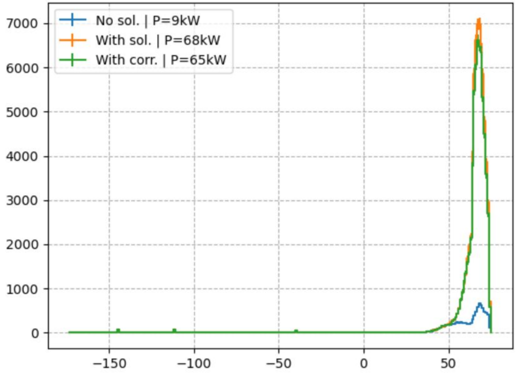
The original (anti-)solenoid field map has been modified by **H. Burkhardt** with 2 correctors on either side of the IP to correct the orbit in position and angle.

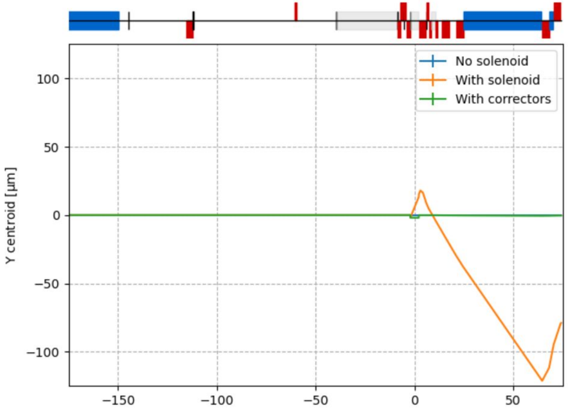
The orbit is corrected at Z energy. The field map with orbit correctors included radiate **3.2 kW** additional SR power (at Z energy).

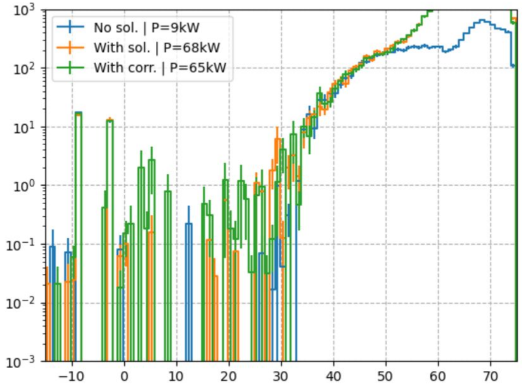
Next steps:

- Does it reduce the SR from quadrupoles downstream ?
- Impact considering transverse beam tail.
- Impact with NZCO.









Annex: SR collimation for the other energy modes

Assuming the same beam sizes as the Z operation the beam halo collimator apertures for W should be (9-11 σ_x) and (66-75 σ_y).

Assuming the same beam sizes as the tt operation the beam halo collimator apertures for H should be (13-15 σ_x) and (80-90 σ_y).

The collimation for W and H energies are subject to evolve with further development of the optics and lattice designs, *e.g.* V23.