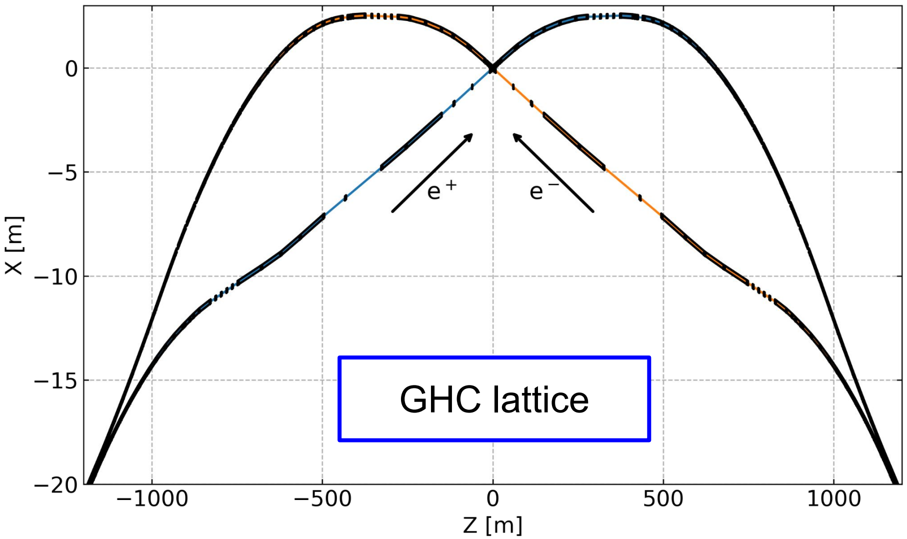
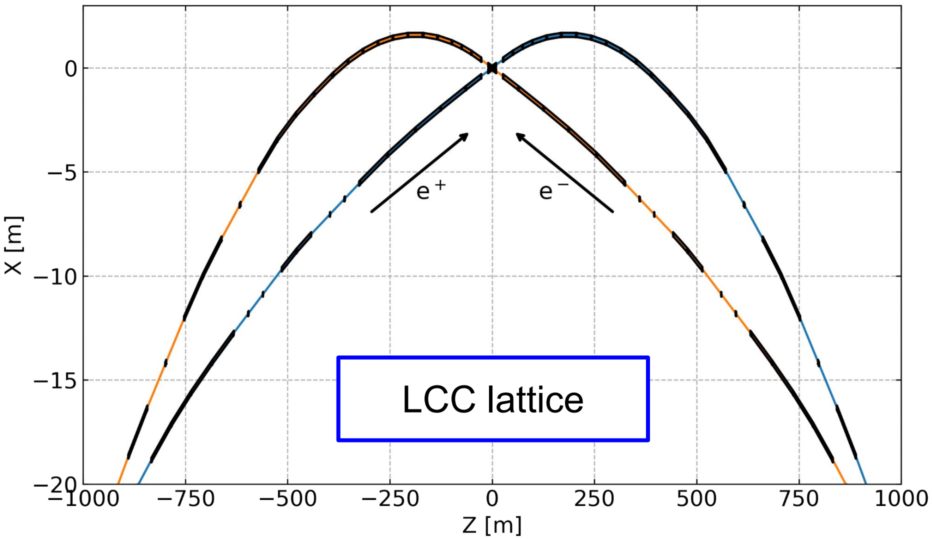
Synchrotron Radiation Background Studies @ FCC-ee

K.D.J. André for the MDI study group

FCC-ee lattice | GHC and LCC 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.

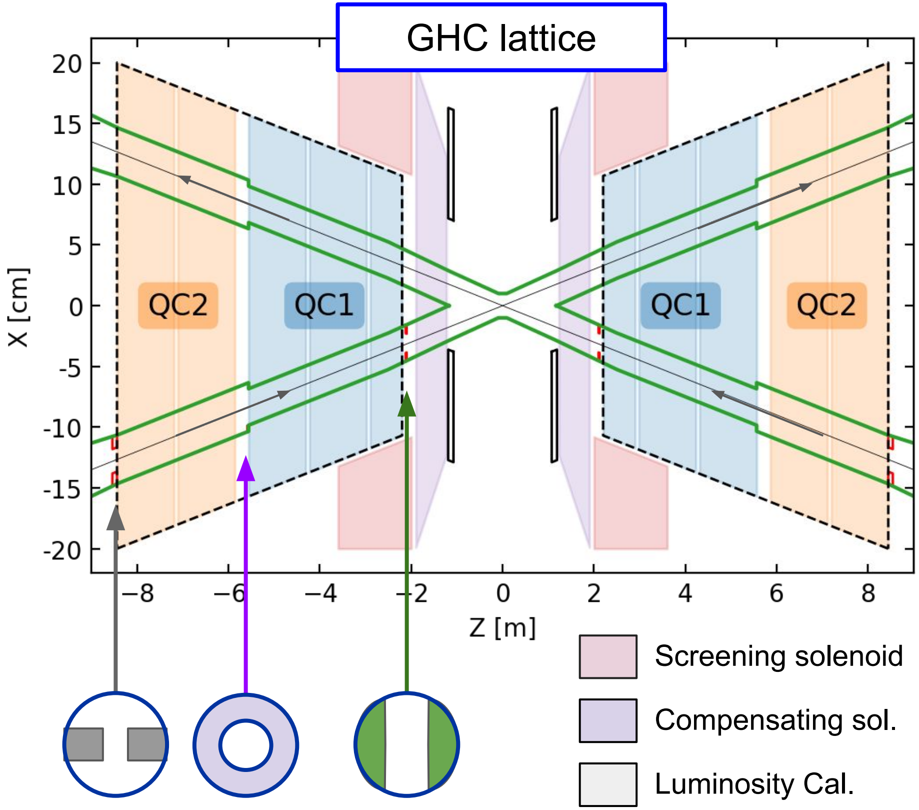
The model features: the (anti-)solenoid field map, a detailed central beam pipe with a **10mm** radius, **6 synchrotron radiation collimators**, and **2 masks.**

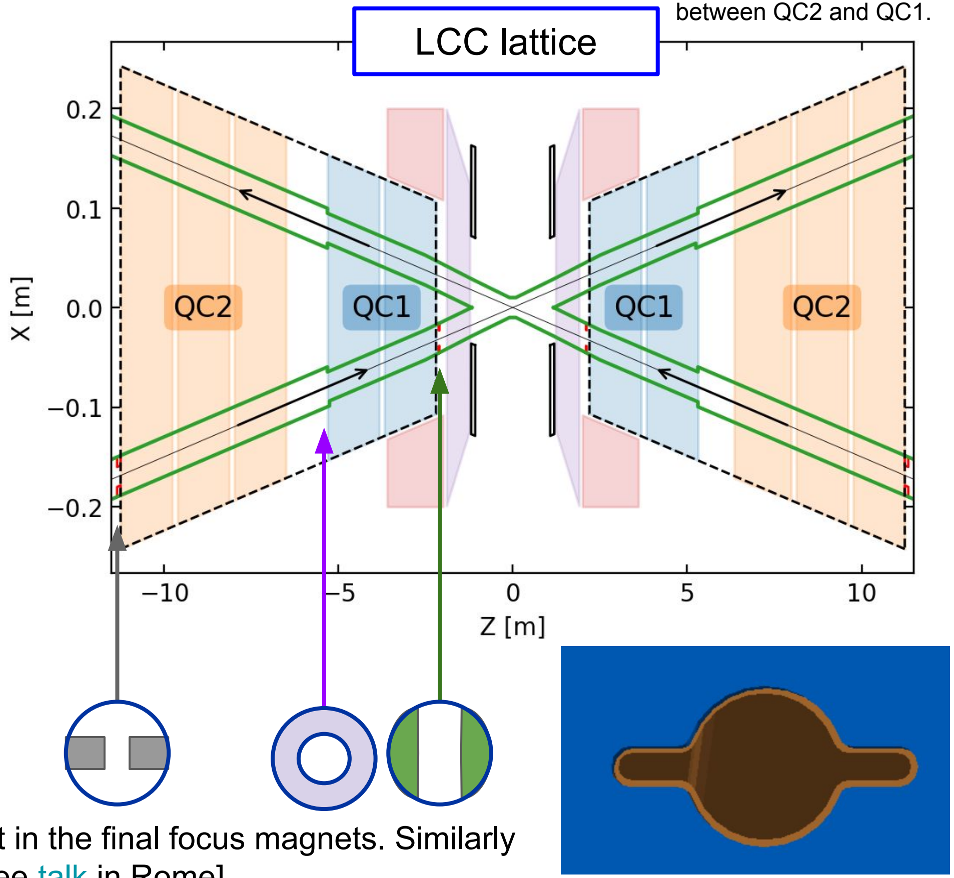
The lattice design upstream the IP is based on weak dipoles (**134 keV critical energy**), short straight sections and implements a **30 mrad crossing angle** at the IP.

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

FCC-ee lattice | GHC and LCC IR designs

The LCC Z lattice at Z energy does not yet feature a 1.19m drift between QC2 and QC1.

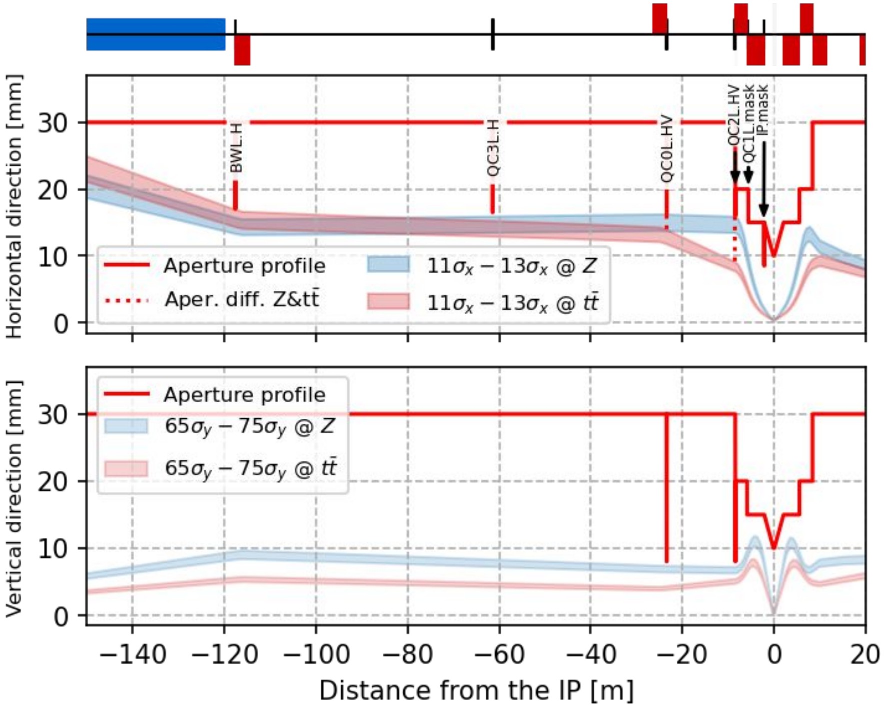




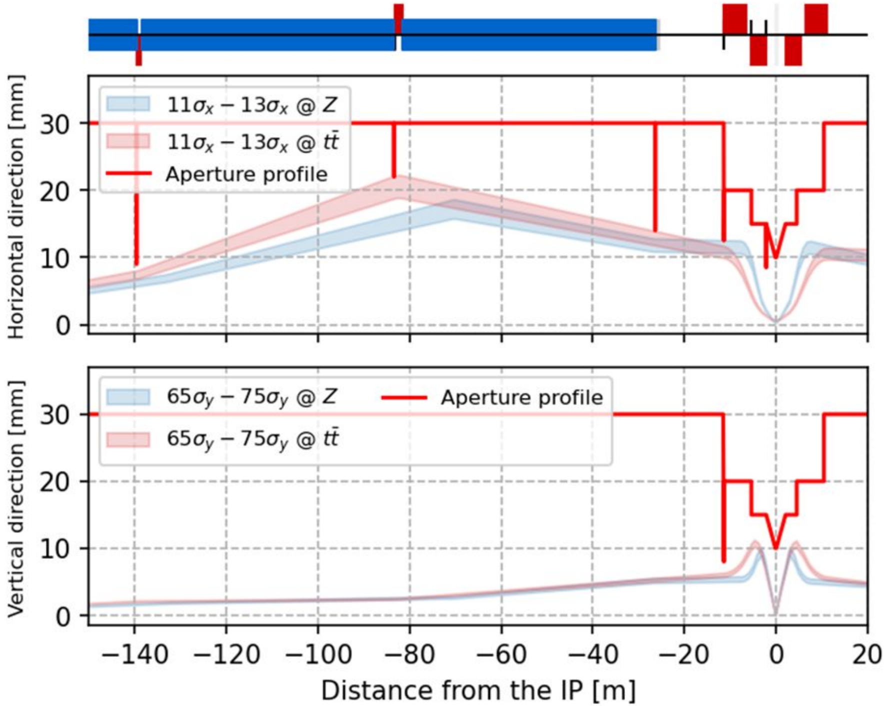
30mm beam pipe including horizontal winglets in the IR except in the final focus magnets. Similarly to R. Kersevan model in order to minimize pressure bumps [See talk in Rome].

Synchrotron radiation collimation (GHC & LCC)

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 in unit of sigmas for GHC and LCC lattices for comparison.



GHC lattice



LCC lattice

SR collimation comparison for both lattices

GHC:

- The position of SR collimators are constrained to in-between dipoles for **s<-120m** from the IP and can be freely placed in the **~110m drift section upstream the IP**. Larger flexibility with the optics design and less space constraints between elements to place collimators.

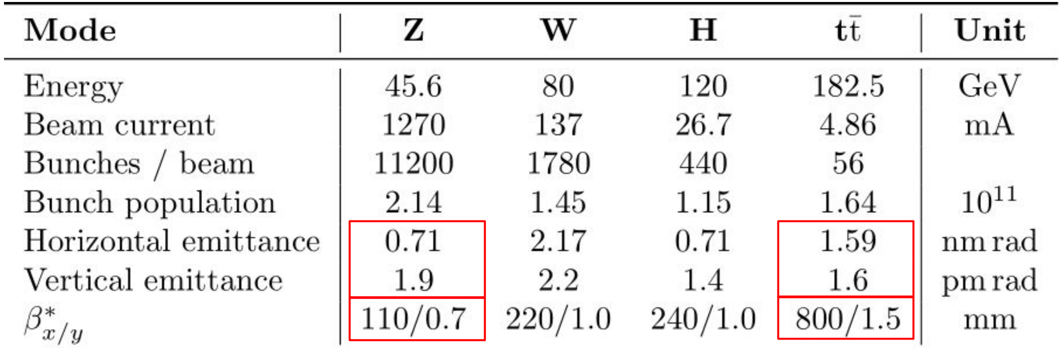
LCC:

- The position of SR collimators are constrained to in-between dipoles for **s<-30m** from the IP and can be freely placed in the **~20m drift section upstream the IP**. Smaller flexibility with the optics design and more space constraints between elements to place collimators.

Beam model | Core and halo description

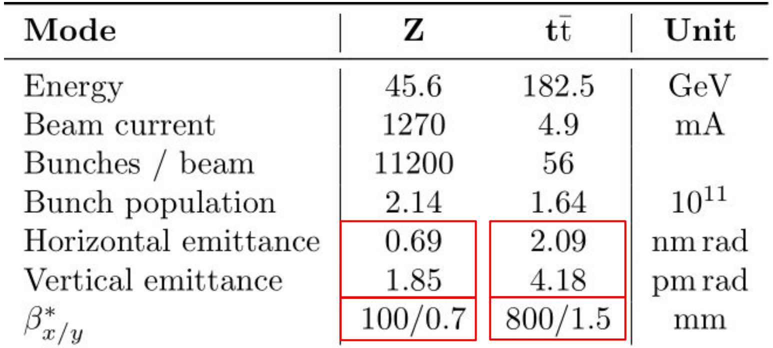
Studies from M. Sullivan [1, 2] showed the transverse beam halo create a large amount of synchrotron radiation mainly from the final focus quadrupoles, hence it needs to be modeled and studied.

- **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.
- **Non-zero closed orbits** have been studied as effective models resulting from optics correction.



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 GHC V23 [3]



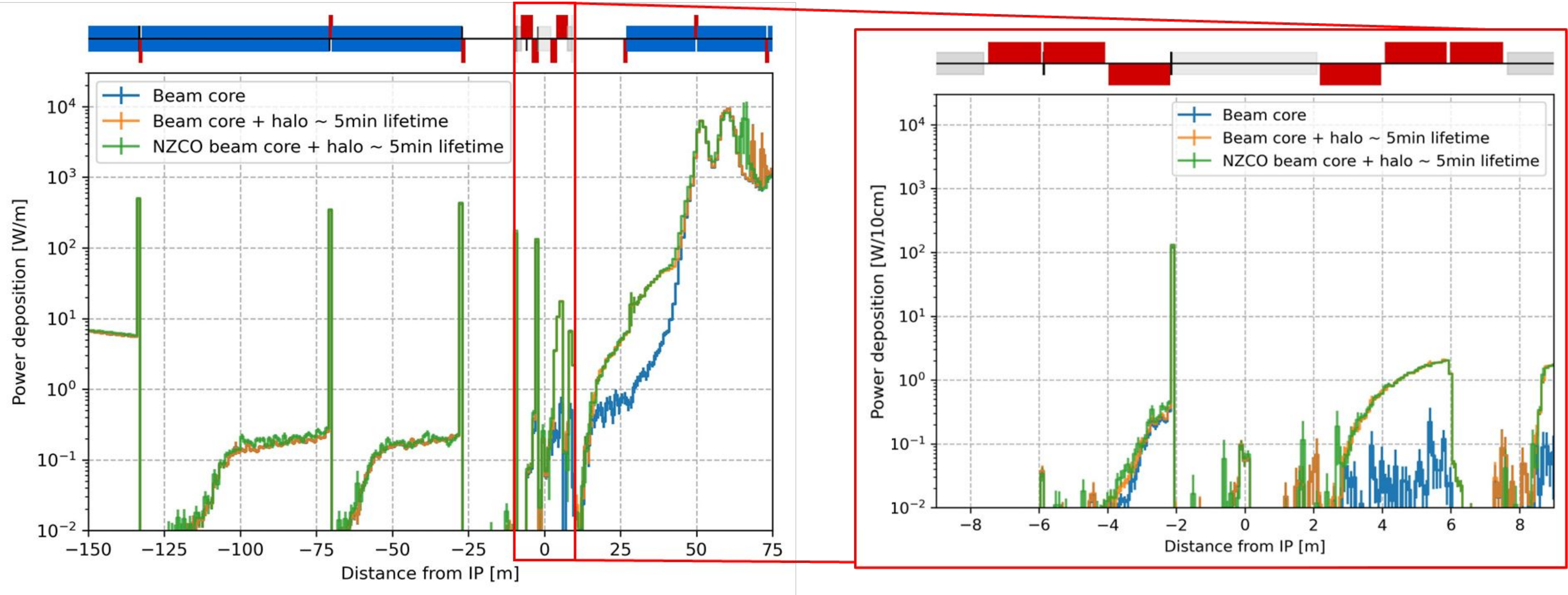
Mode	Z	$t\bar{t}$	Unit
Energy	45.6	182.5	GeV
Beam current	1270	4.9	mA
Bunches / beam	11200	56	
Bunch population	2.14	1.64	10^{11}
Horizontal emittance	0.69	2.09	nm rad
Vertical emittance	1.85	4.18	pm rad
$\beta^*_{x/y}$	100/0.7	800/1.5	mm

Beam parameters for LCC V24 [4]

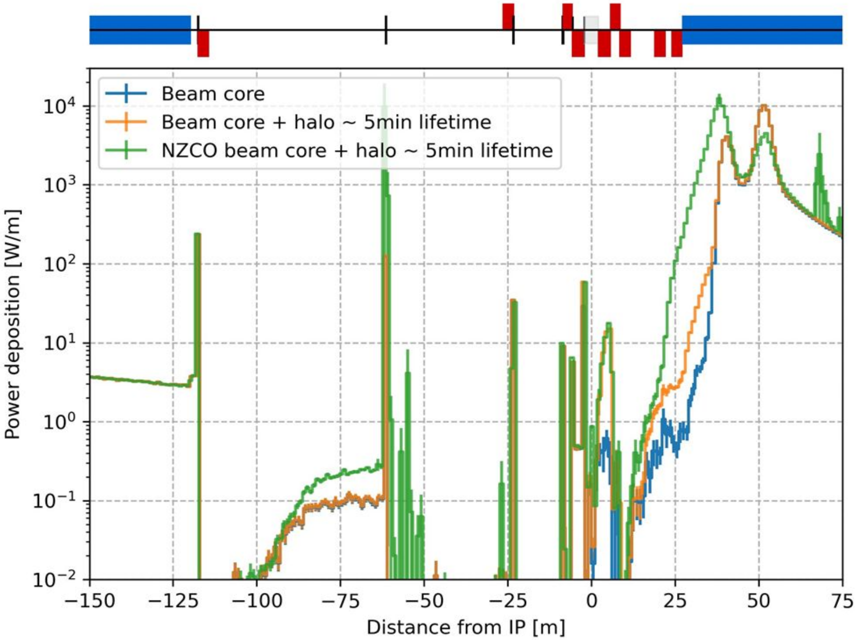
SR power deposition @ 45.6 GeV (LCC lattice)

The power deposition in the CC and FF magnets **is minimal**.

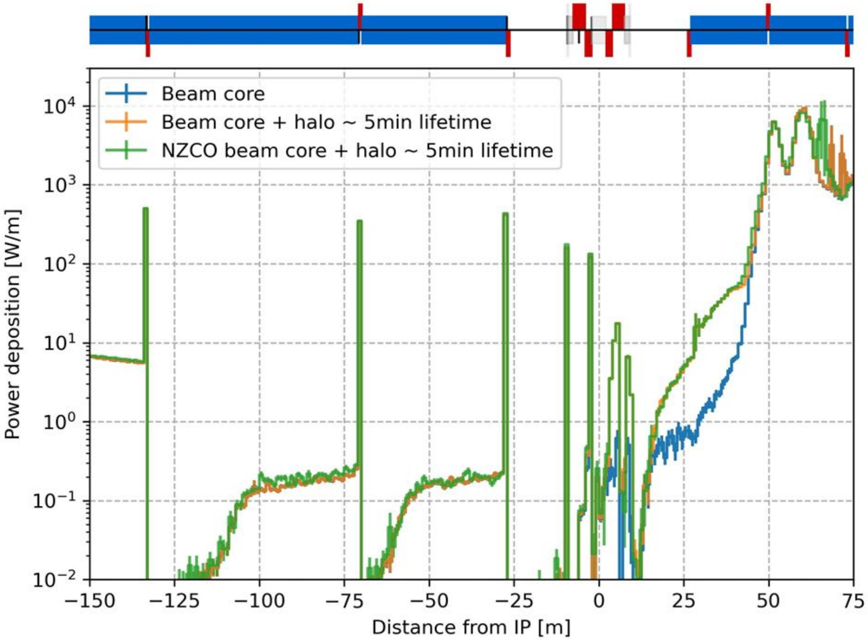
The power deposition on SR collimators and QC1-mask (**120W**) is larger w.r.t. the GHC lattice.



Results at **Z energy**

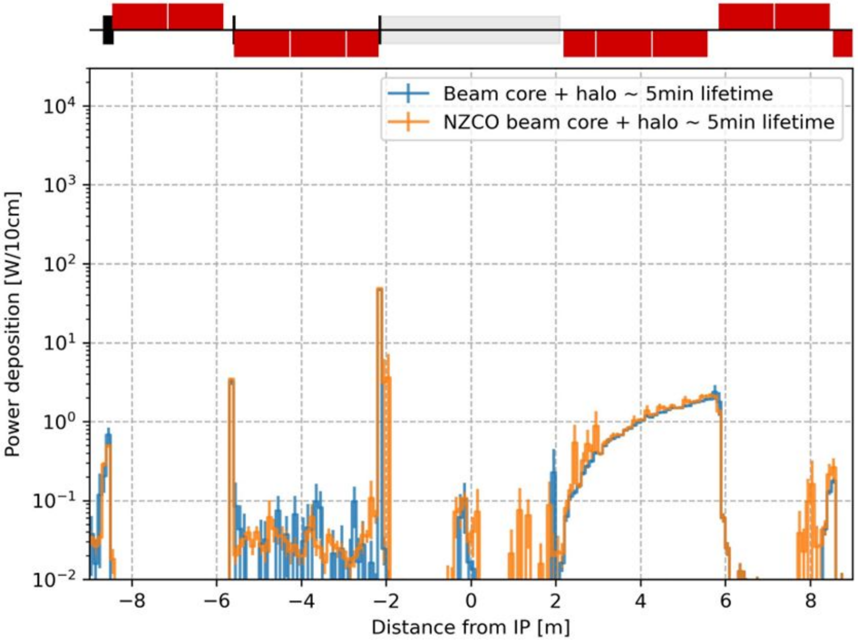


GHC - SR power deposition summary
1% of the particles in the tails, with beam lifetime equivalent to 5 min, and 100 um X&Y and 6 urad PX&PY applied to the NZCO beam core.

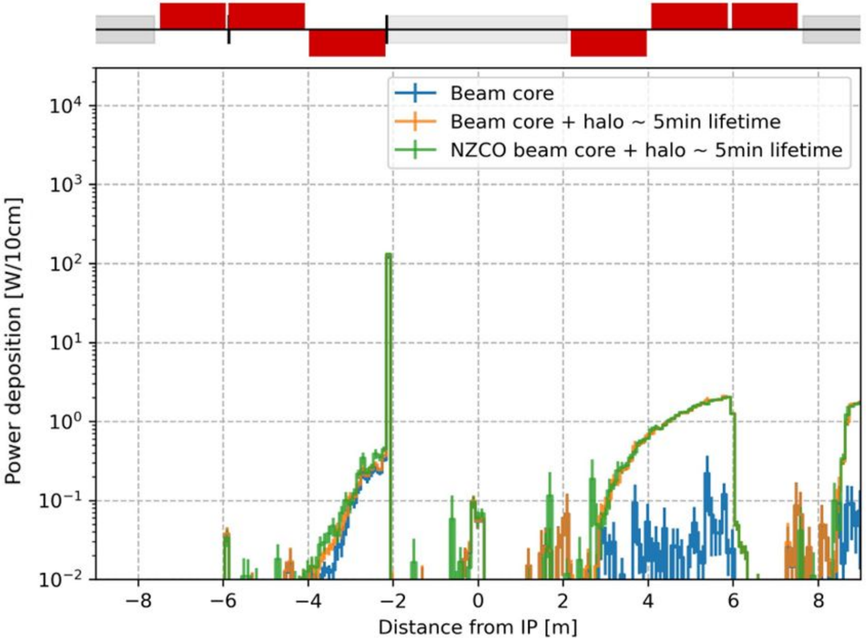


LCC - SR power deposition summary
1% of the particles in the tails, with beam lifetime equivalent to 5 min, and 100 um X&Y and 6 urad PX&PY applied to the NZCO beam core.

Results at **Z energy**



GHC - SR power deposition summary
1% of the particles in the tails, with beam lifetime equivalent to 5 min, and 100 um X&Y and 6 urad PX&PY applied to the NZCO beam core.

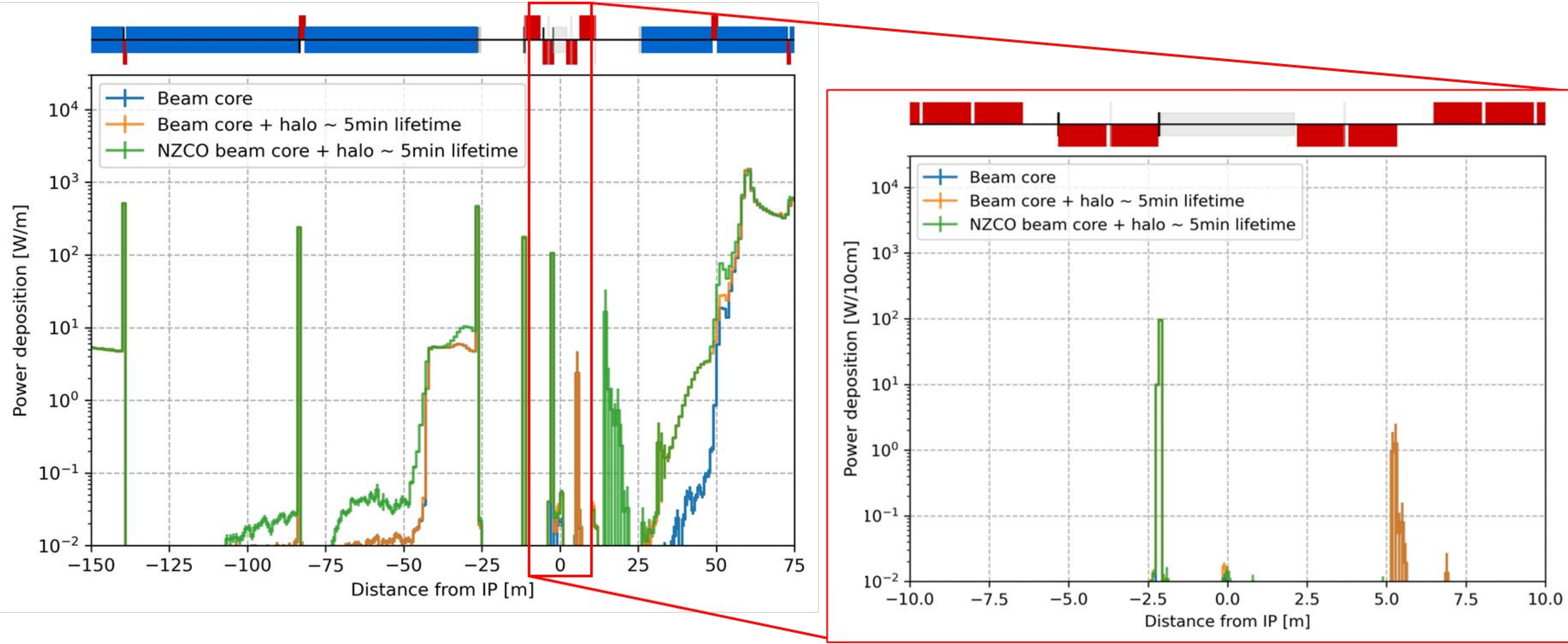


LCC - SR power deposition summary
1% of the particles in the tails, with beam lifetime equivalent to 5 min, and 100 um X&Y and 6 urad PX&PY applied to the NZCO beam core.

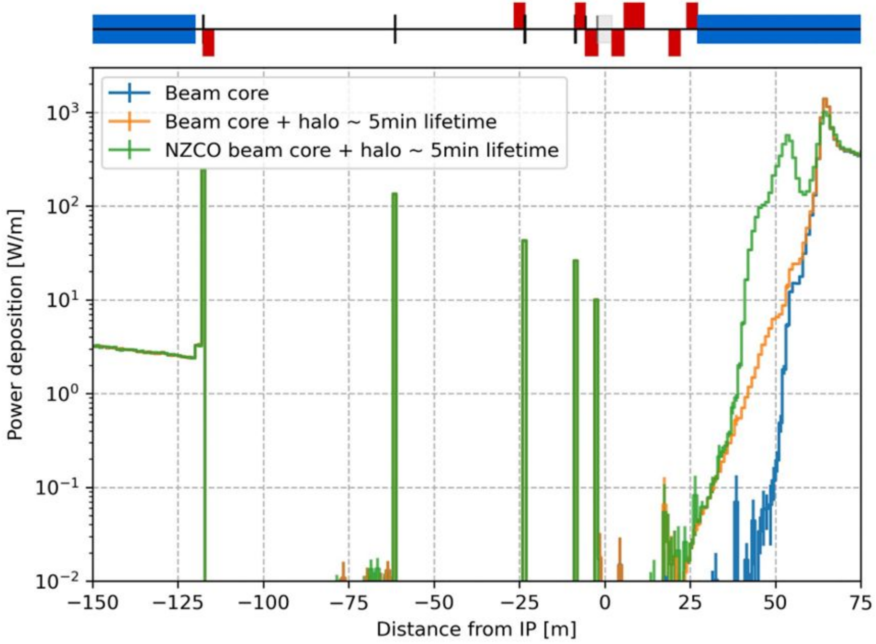
SR power deposition @ 182.5 GeV (LCC lattice)

The power deposition in the CC and FF magnets **is minimal**.

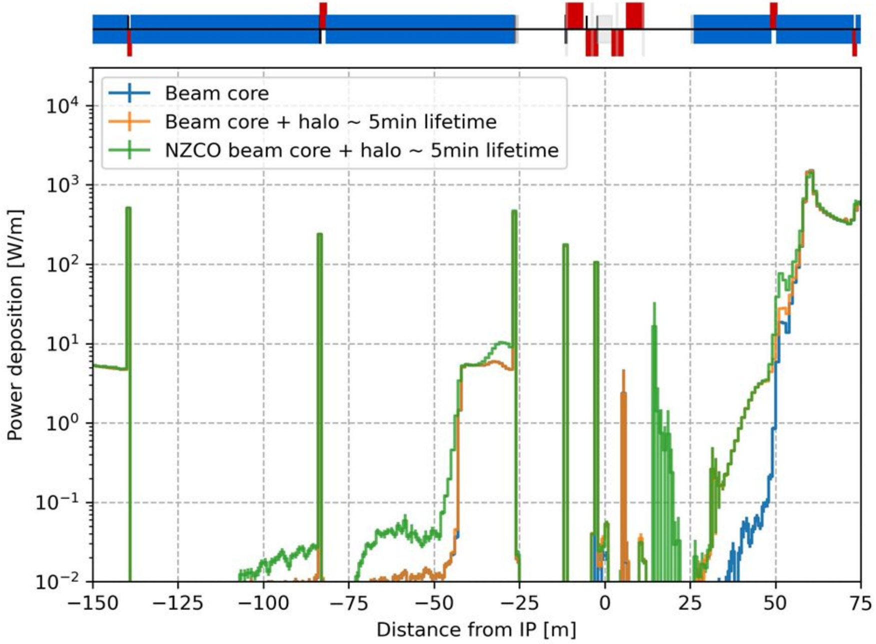
The power deposition on SR collimators and QC1-mask (**100W**) is larger w.r.t. the GHC lattice.



Results at **tt energy**



GHC - SR power deposition summary
1% of the particles in the tails, with beam lifetime equivalent to 5 min, and 100 um X&Y and 6 urad PX&PY applied to the NZCO beam core.



LCC - SR power deposition summary
1% of the particles in the tails, with beam lifetime equivalent to 5 min, and 100 um X&Y and 6 urad PX&PY applied to the NZCO beam core.

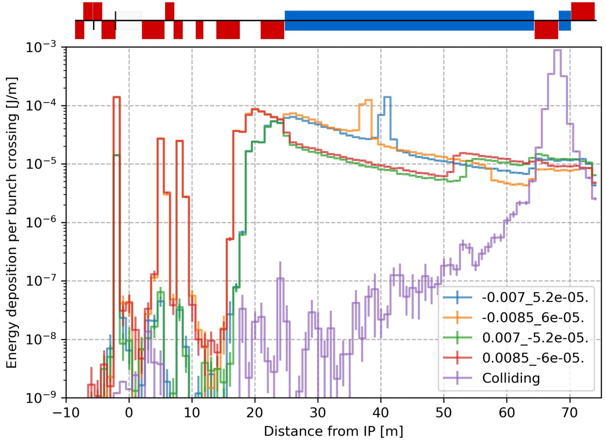
SR from top-up injection

Preliminary studies at Z energy, assuming 10% of the bunch charge and same emittances for the injected and colliding beams with ±1% energy offsets. BDSIM simulations start 3 dipoles upstream the IP.

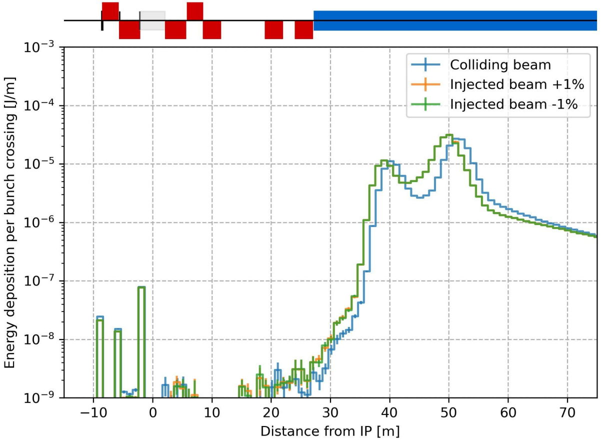
The **GHC** lattice, SR from the injected beam has a **similar energy deposition per bunch crossing w.r.t. colliding beam**.

The **LCC** lattice highlights more SR deposited downstream the IP emitted from the injected beam. Need for refined studies, *e.g.* distribution initialized in non-dispersive region for both lattices.

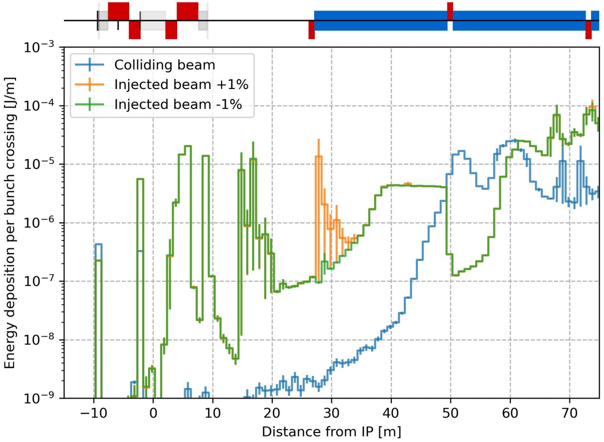
GHC lattice (V22) off-axis



GHC lattice (V23) off-energy



LCC lattice (V24) off-energy



Summary

- The BDSIM model features a Ø60mm beam pipe with horizontal winglet except in the final focus region, resulting in a modified SR power deposition distribution, particularly for the SR collimators and masks.
- Simulations with beam core (also considering non-zero closed orbits) and transverse tails have been performed **at Z and tt energies** for the **GHC and LCC lattices** with **similar power deposited** near the IP.
  - **The LCC lattice** shows better results regarding the SR from the transverse tails but highlights higher heat load on the collimator and the **mask** closest to the IP **(10x w.r.t. GHC lattice).**
  - **The GHC lattice** provides better mitigation of the SR from the beam core but the SR from the **transverse tail causes more power deposition close to the IP.**
- Preliminary results highlight a **reduced SR heat load around the IP and on the mask with off-energy injection for the GHC lattice**, still more refined studies are needed also for to investigate the LCC lattice.

Future plans:

➢ Include the x-ray reflection in the BDSIM model see details in [5].

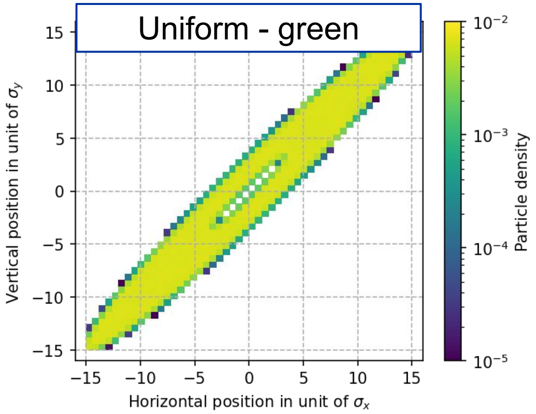
➢ Ongoing discussions to collect background sources (position, time, energy, etc..), to be used by our detector colleagues.

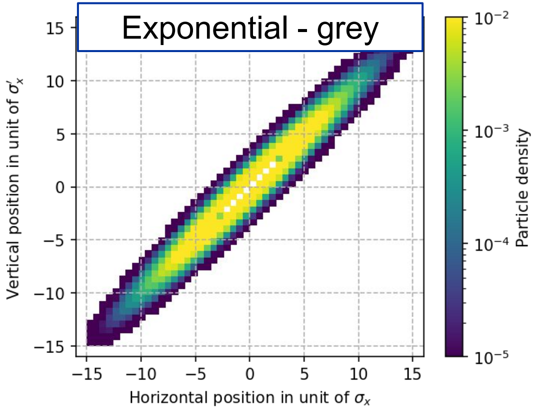
➢ Top-up injection must be refined for GHC and LCC studies and, investigate the effects of imperfections such as optics mismatch, larger emittance, etc..

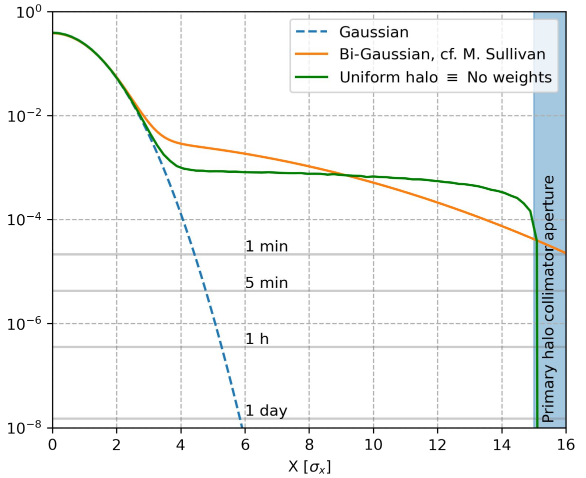
Thank you
for your attention

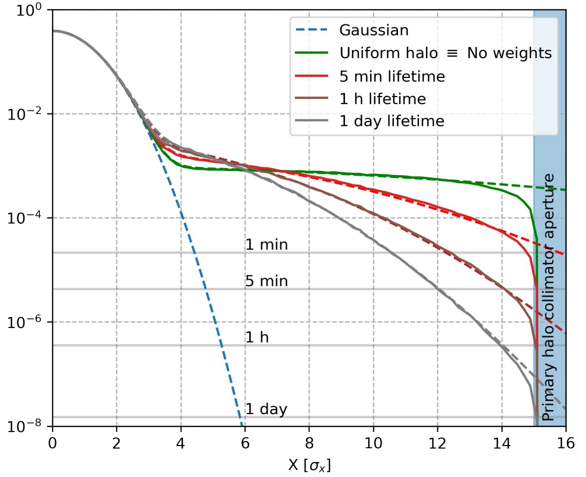
Beam model | Weighted halo description

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









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).

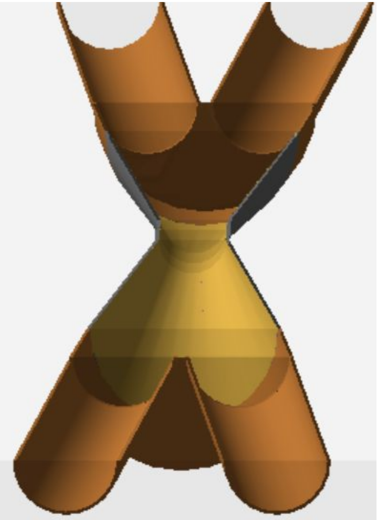
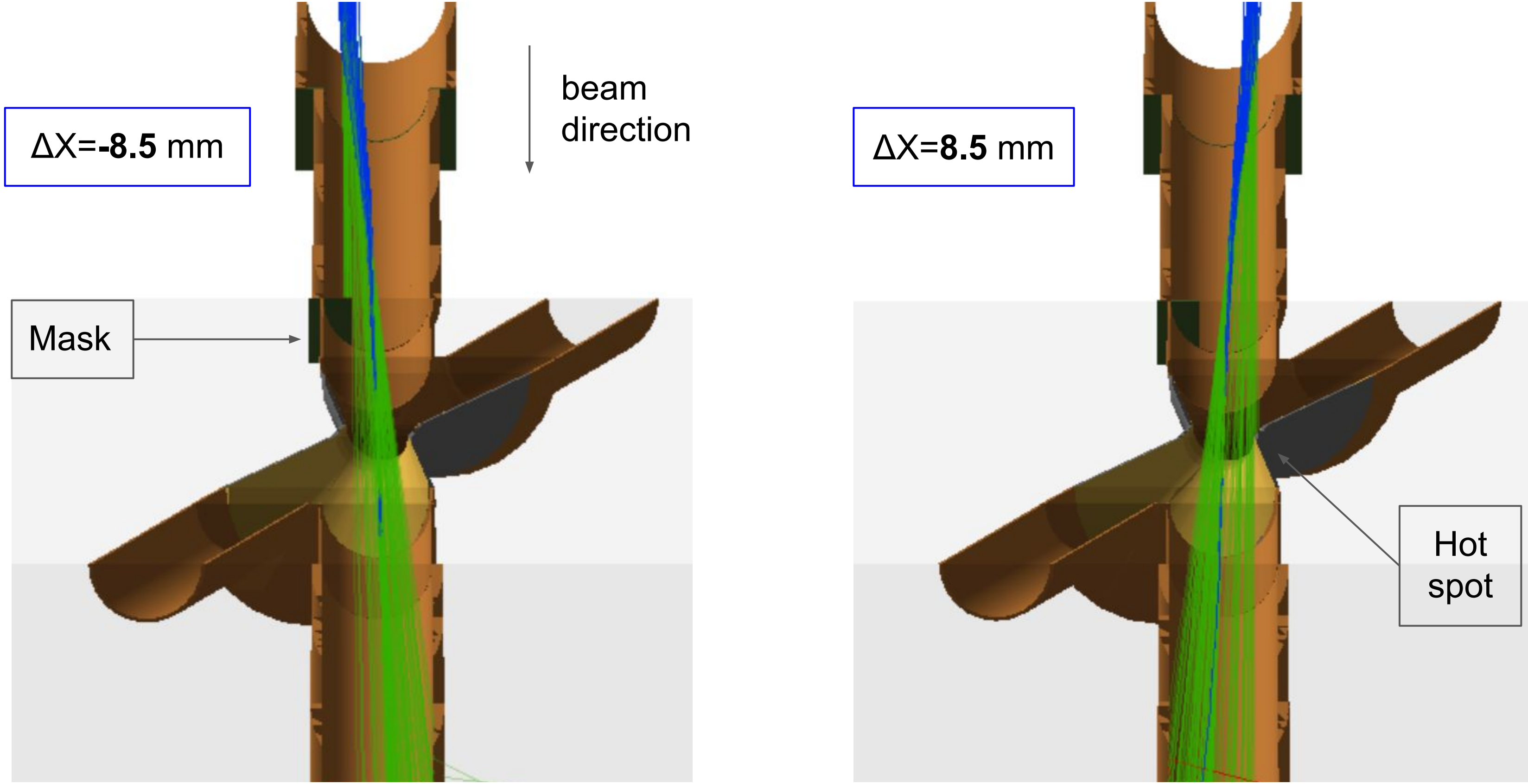
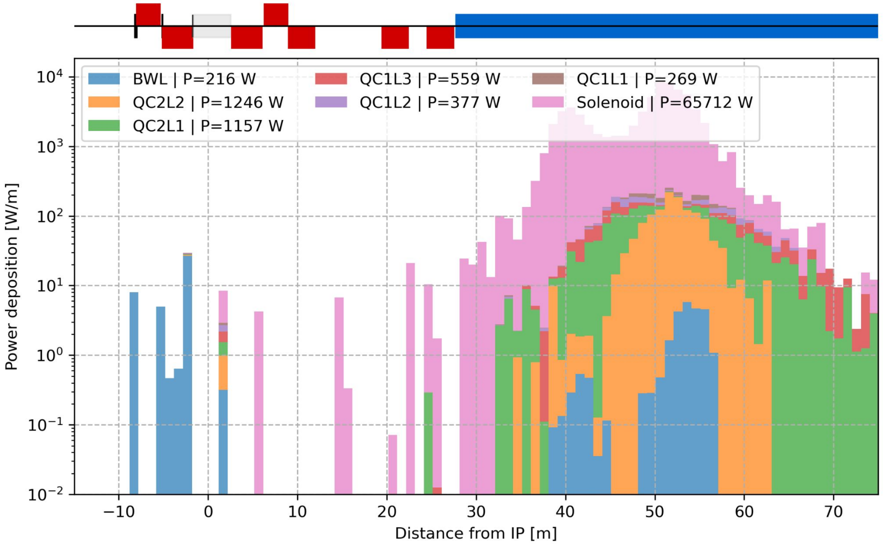


Illustration of the two extremes at Z

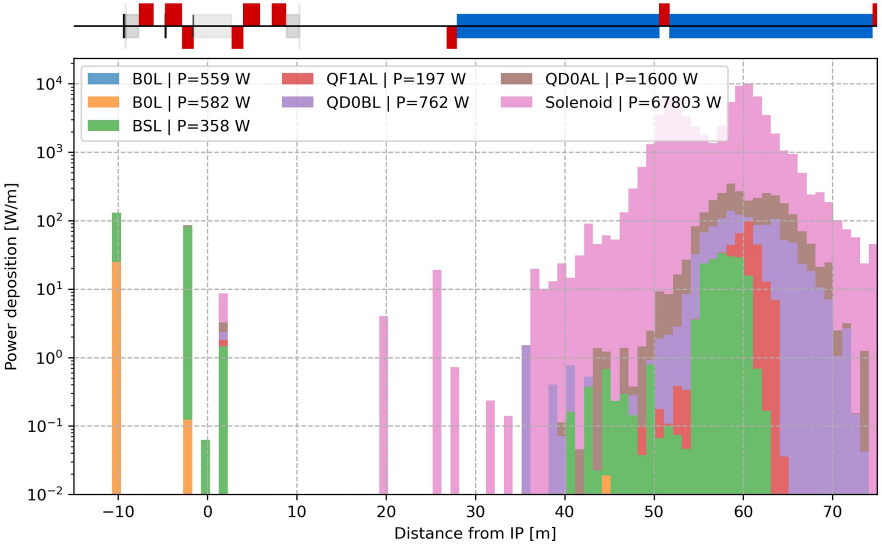


Detailed SR power deposition from the beam core



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.

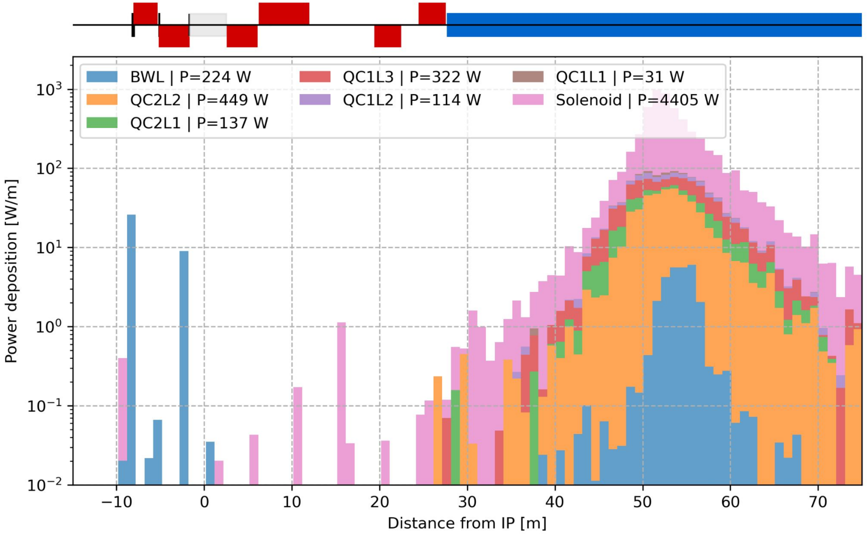
GHC lattice



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

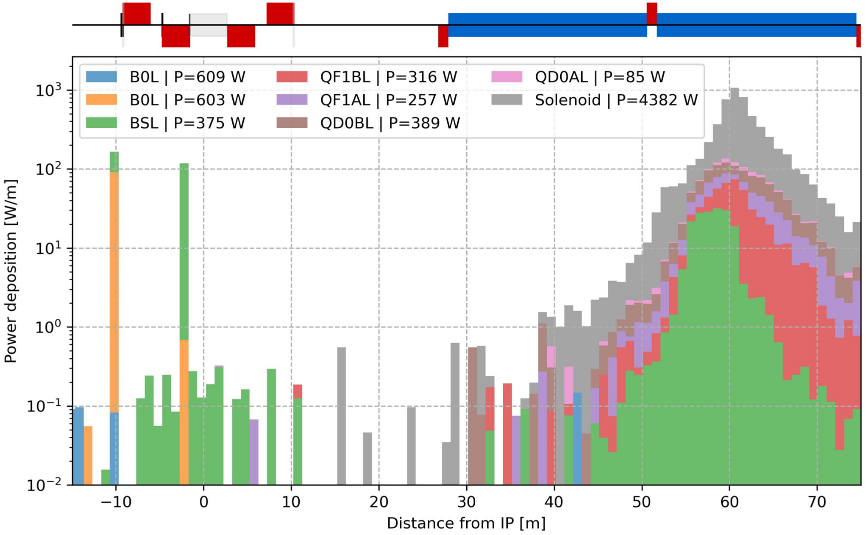
LCCO lattice

Detailed SR power deposition from the 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