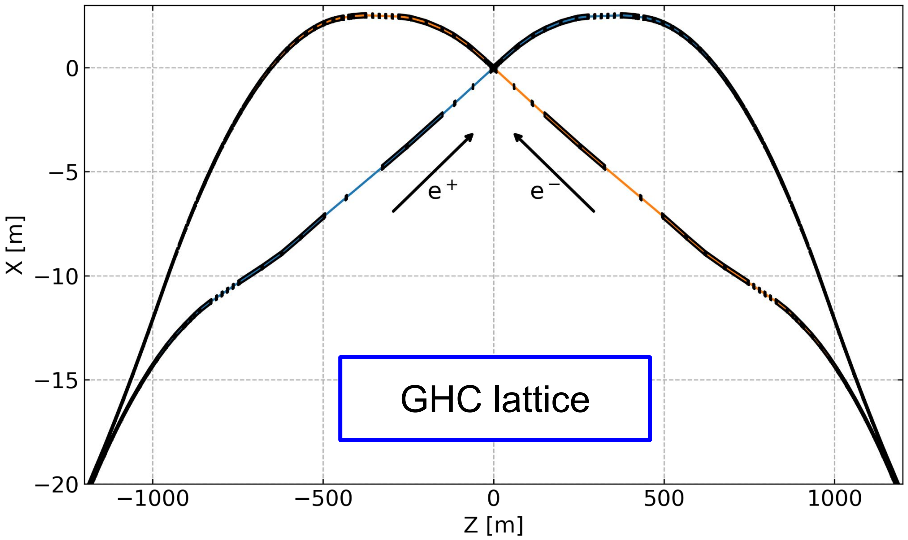
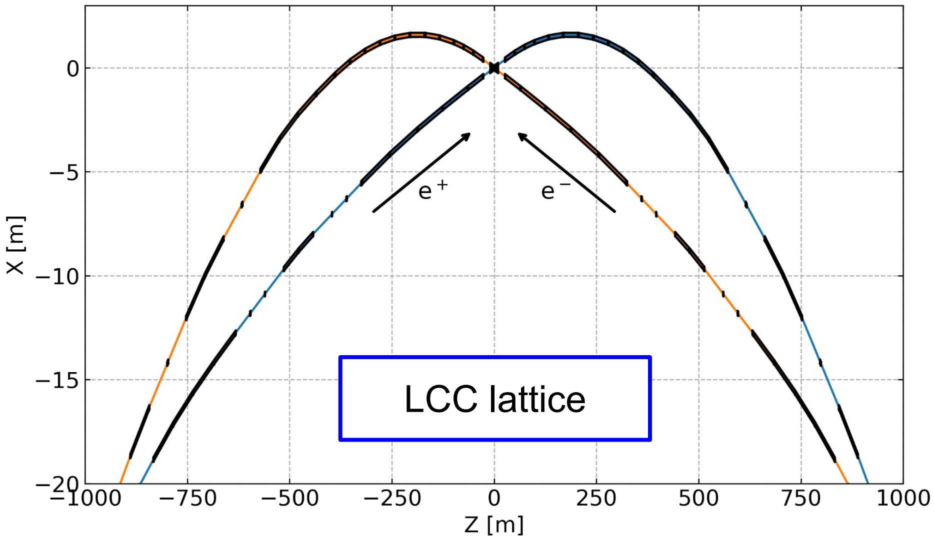
Synchrotron Radiation Background Studies @ FCC-ee

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.

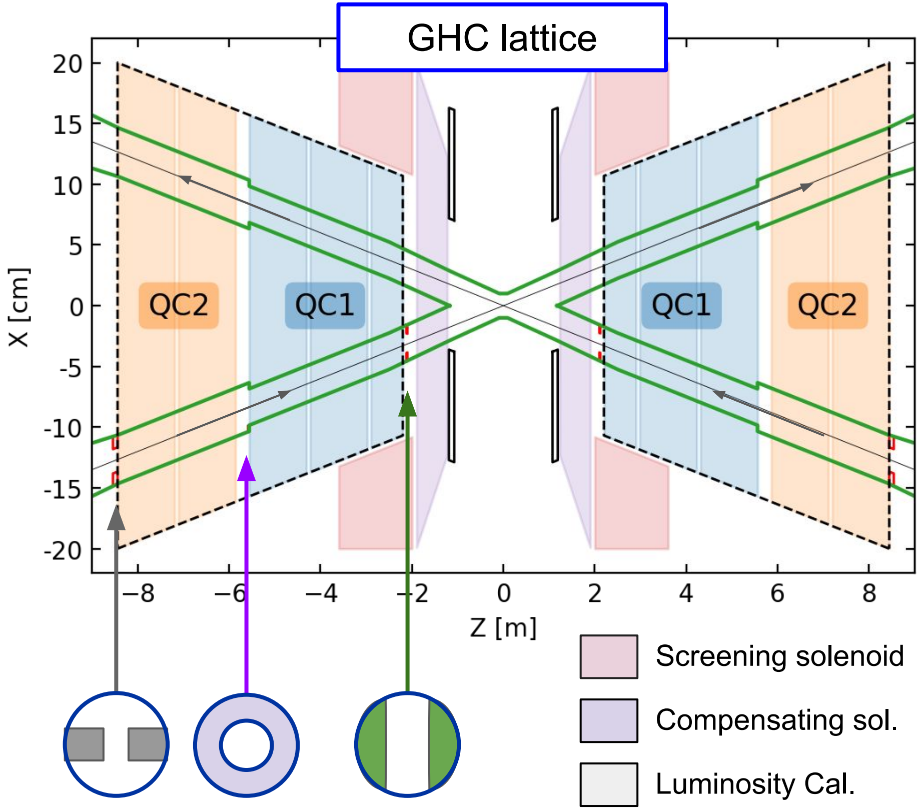
The model features: the (anti-)solenoid field map, a detailed central beam pipe with a **10mm** radius, **6 synchrotron radiation collimators**, and **2 masks.**

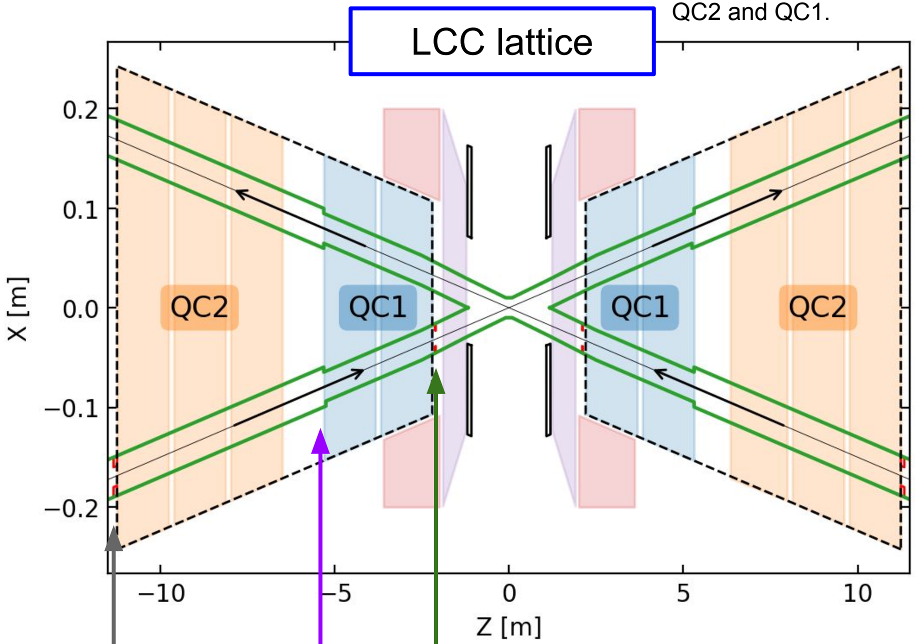
The lattice design upstream the IP is based on weak dipoles (**134 keV critical energy**), short straight sections and implements a **30 mrad crossing angle** at the IP.

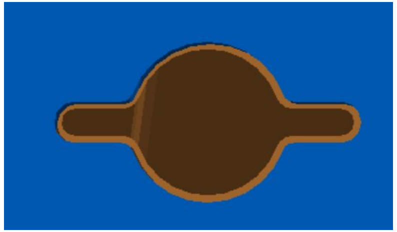
The model features: the (anti-)solenoid field map, a detailed central beam pipe with a **10mm** radius, **6 synchrotron radiation collimators**, and **2 masks.**

FCC-ee lattice | GHC and LCC IR designs

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



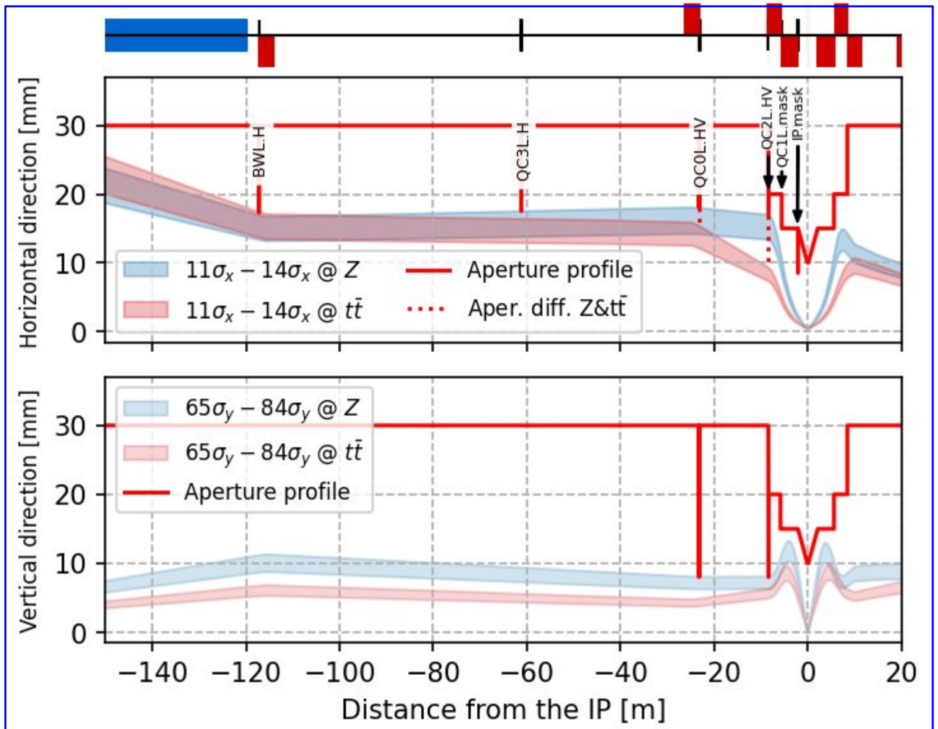




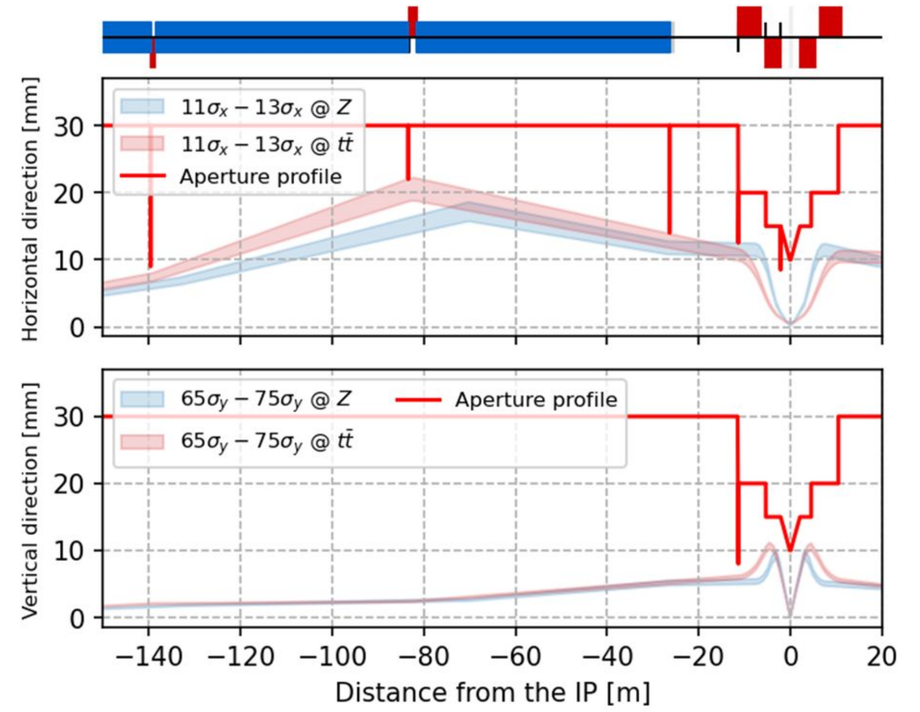
30mm beam pipe including horizontal winglets in the IR except in the final focus magnets. Similarly to R. Kersevan model in order to minimize pressure bumps [See talk in Rome].

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 GHC & LCC 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

Transverse beam tails/halo cause a large amount of synchrotron radiation mainly from the final focus quadrupoles, and needs to be modeled and studied; *c.f.* Sullivan [1, 2].

The beam core is defined as a **Gaussian distribution** based on the linear optics parameters, while **the beam halo** is represented by a **phase-space correlated distribution. The two distributions are mostly orthogonal.**

99% of the particles assumed **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 lattice errors and optics correction with 100 µm std in centroid position and 2 to 10 µrad std in centroid direction. The results are accumulated over many seeds.

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]

What the BDSIM model has/does & what it has not

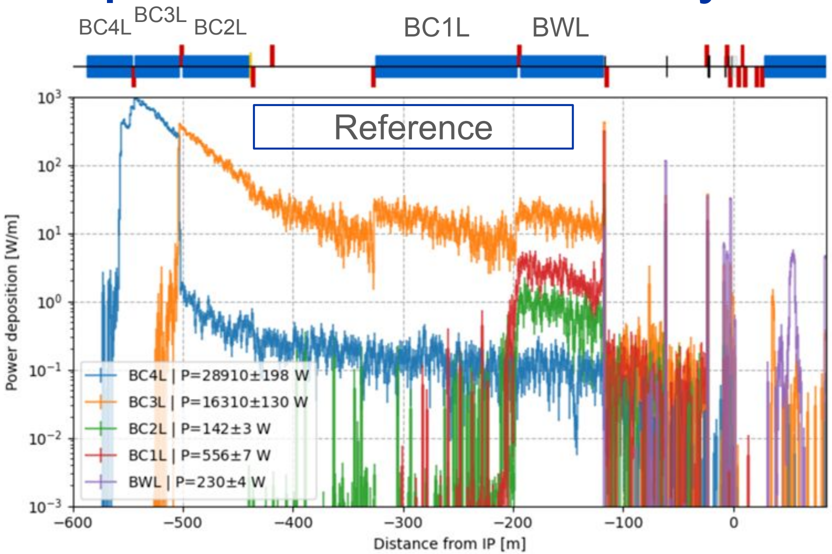
What the model has/does:

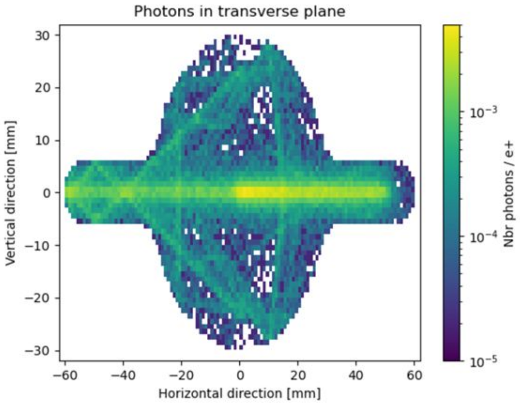
- **x-ray reflection** as implemented by H. Burkhardt in GEANT4, different from the model in *e.g.* Synrad+.
- **multiple beam** models available, beam **core**, **halo/tails**, **injection-like** beam.
- solenoid/anti-solenoid field map; could have QC1 field map included as well.
- the model can be extended as needed to include more dipoles or adjacent elements to the beam line.

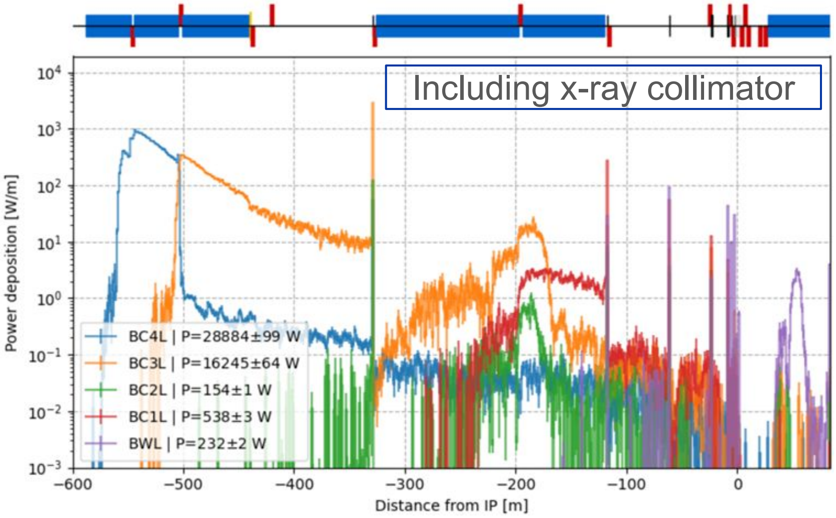
What the model hasn't/doesn't do:

- real magnet geometry, particularly in the central region, with the cryostat, structure, magnet coils, etc.. Probably not relevant for the studies performed.
- not made for multi-turn studies, Xsuite is.

Implementation of x-ray reflection



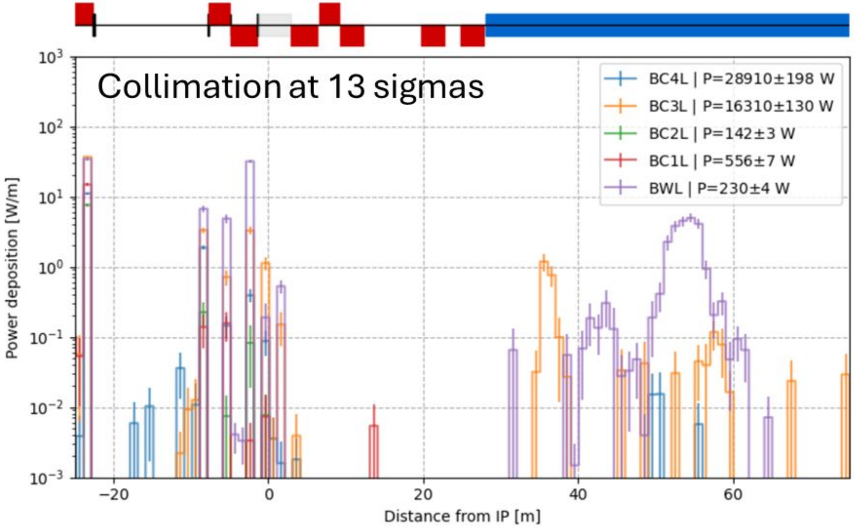


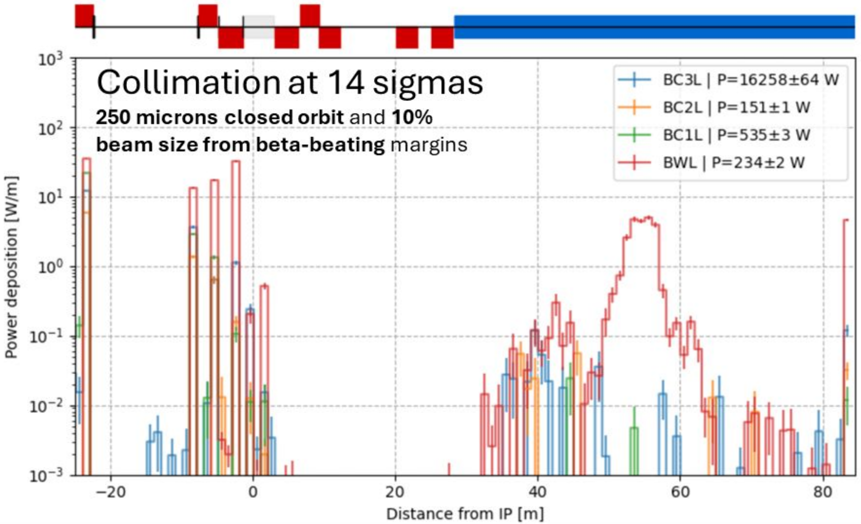


X-ray reflection makes photons propagate further also emitted from dipoles 450m away from the IP (or more).

Mitigation possible: SR collimator in the “polarimeter region”. To be investigated further considering space for polarimeter, background and tertiary halo collimator.

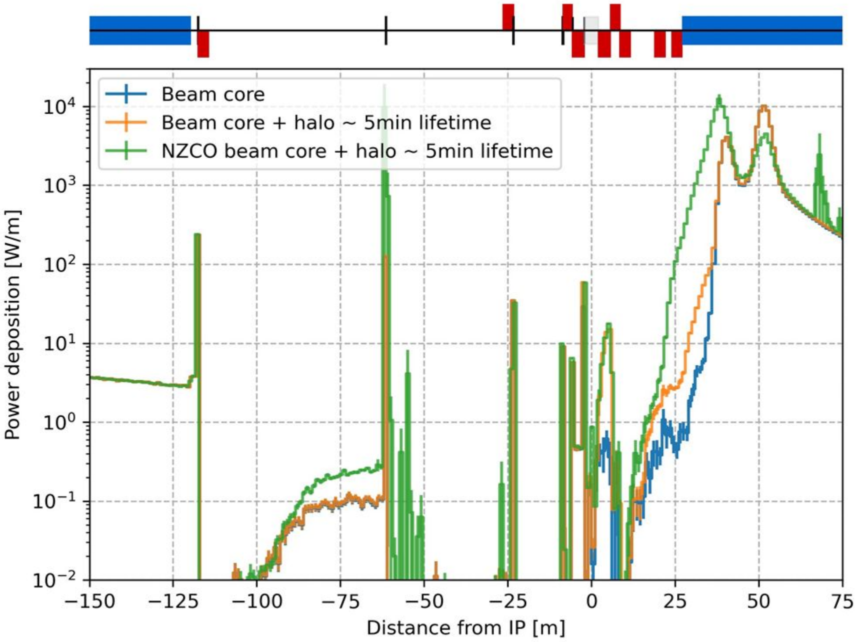
Implementation of x-ray reflection and mitigation (ref)



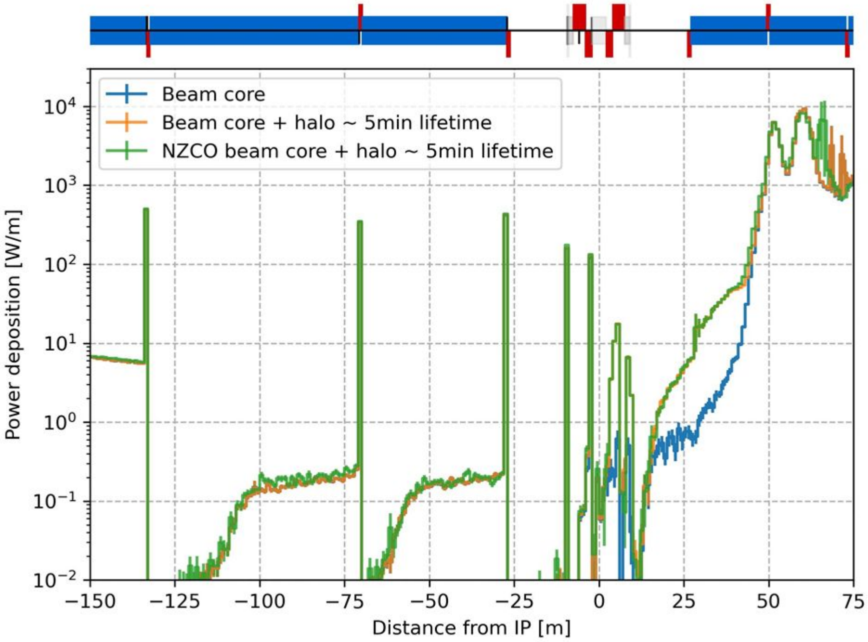


- **Similar power deposition** in the collimators and masks,
- **SR power deposition in the central chamber from BC3L** decreases although all SR collimators are more opened. X-ray reflection reduced by the first horizontal collimator.

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 std in X&Y and 6 urad std in PX&PY applied to the beam core (NZCO).



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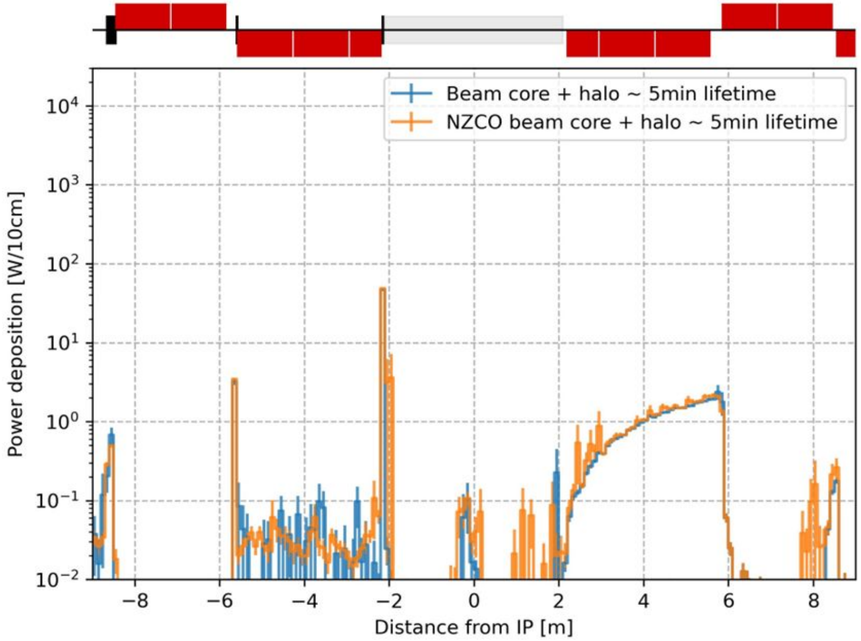

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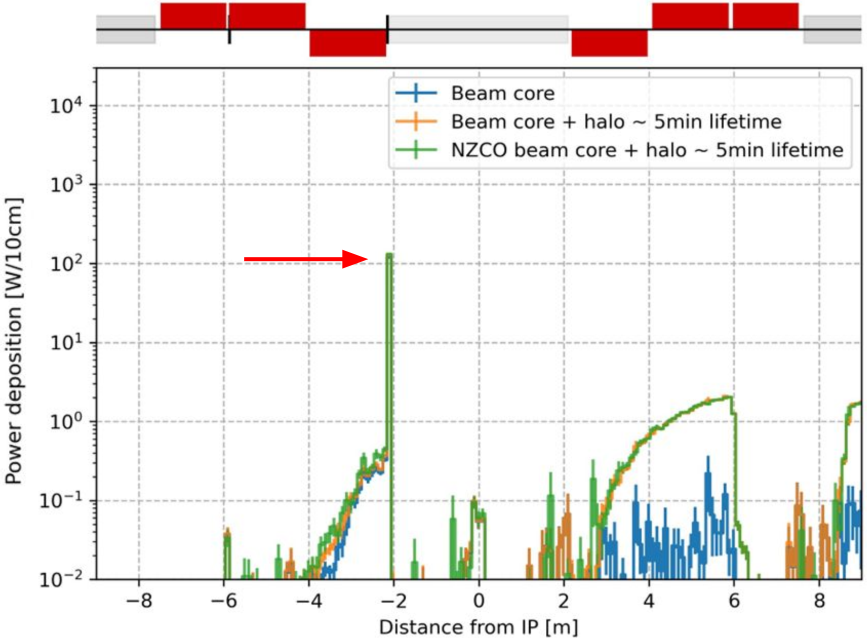
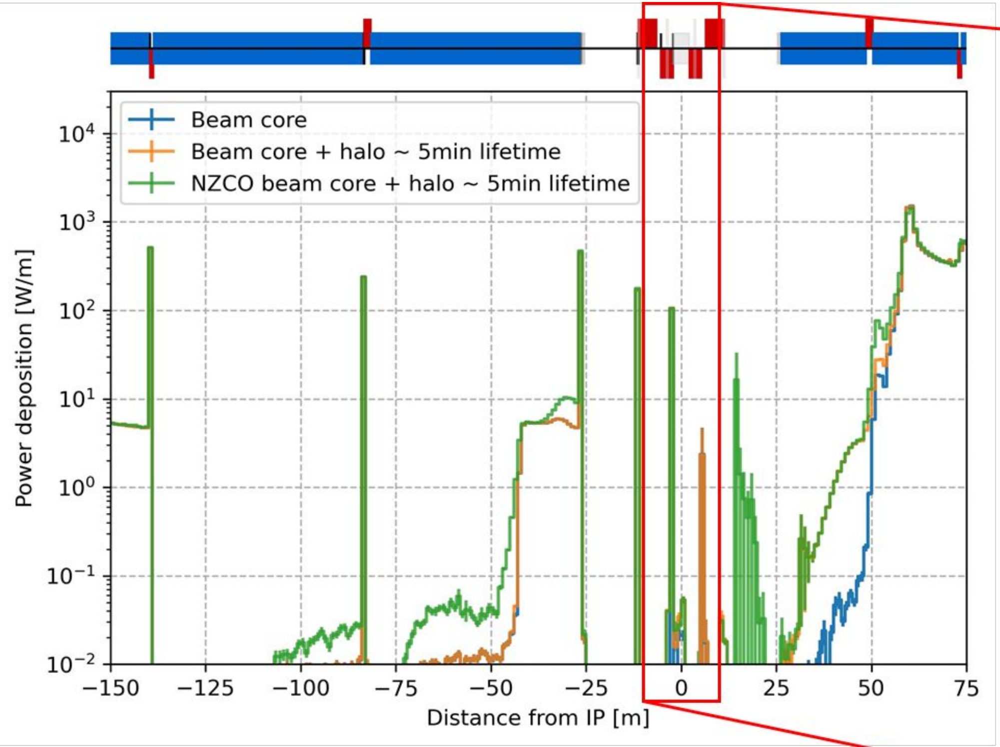


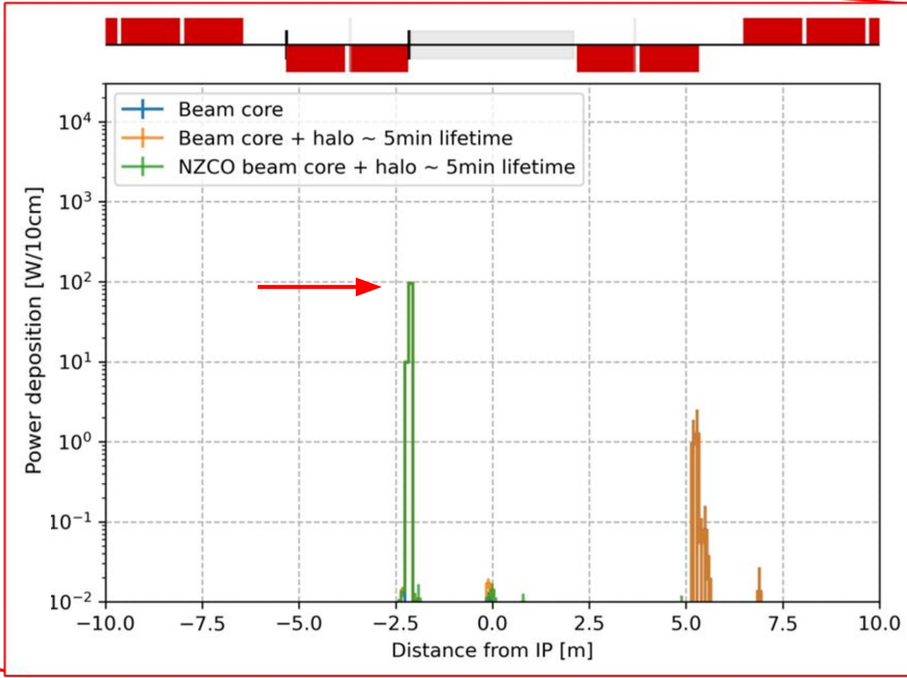
LCC - SR power deposition summary,
1% of the particles in the tails, with beam lifetime equivalent to 5 min, and 100 um std in X&Y and 6 urad std in PX&PY applied to the beam core (NZCO).

SR power deposition @ 182.5 GeV (LCC lattice)

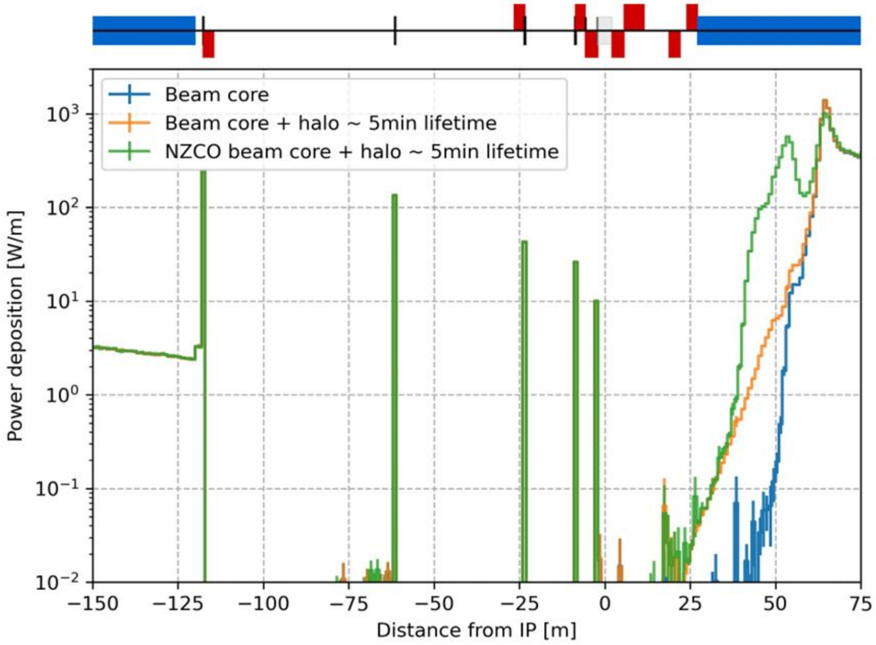
The power deposition in the CC and FF magnets **is minimal**.

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

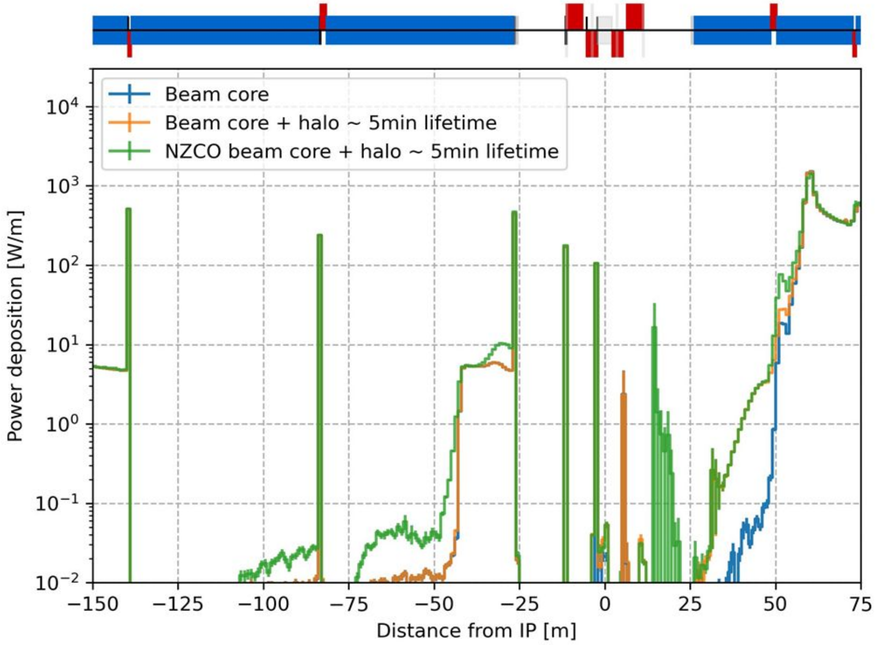




Results at **tt energy**



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



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

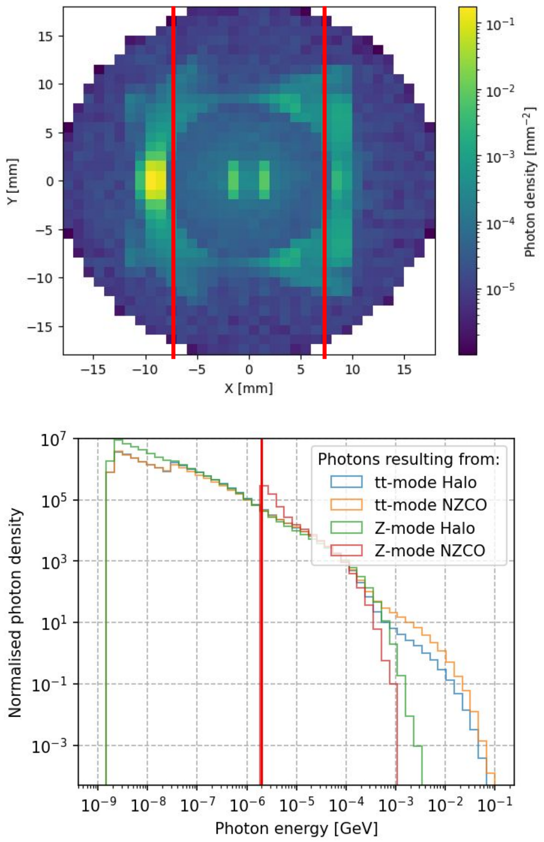
Photons to be tracked in the detector

Photons from GHC lattice simulations

- Transverse phase space at s=-2.2m (before the mask, ttbar)
- Energy spectrum (highlighting a cut at 2 keV)

Photons outside 18mm radius discarded (outside the beam pipe), to be combined with another sampler before the muon detector position, to differentiate photons already outside the beam pipe from photons that crossed the beam pipe within the detector.

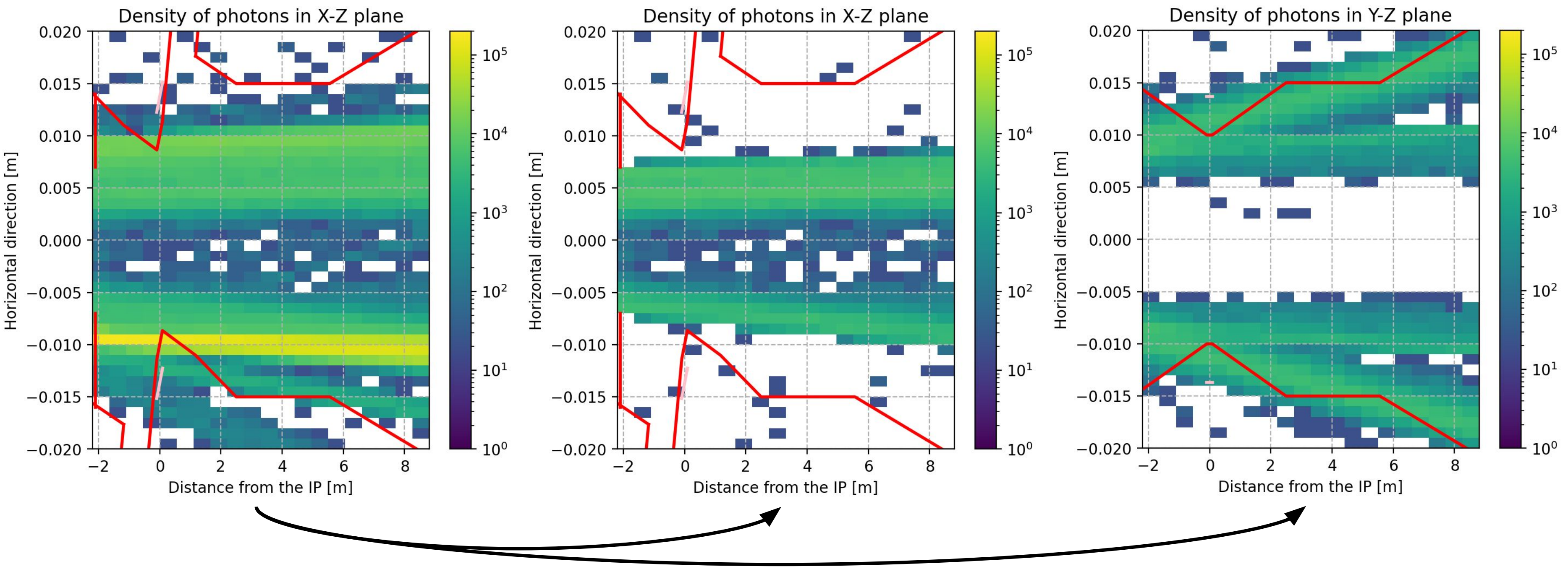
Only keeping photons with horizontal position x⩾7mm (mask limit) and that will have a radius exceeding 9mm at s=+8m so that the photons not likely to interact are not kept to save storage space. The photons that would interact with the crotch are not kept.



Photons with energy below 2 keV are unlikely to cross the beam pipe.

Example of a distribution of photons from beam halo/tails

As expected the photons propagating vertically towards the beam pipe are the most susceptible to interact in the detector (disregarding the mask scattering).



Including the mask aperture x⩾7mm

Photons from synchrotron radiation

V23 beam parameters

	GHC lattice	
Mode	Z	tt
Non-zero closed orbit	link to the hepevt files: (2urad, 6urad, 10urad)	link to the hepevt files: (2urad, 6urad, 10urad)
Comments	10M macroparticules, scaling of 21286 to a real bunch (99% ppb in the core)	5M macroparticules, scaling of 32472 to a real bunch (99% ppb in the core)
Halo/tail distribution	link to the hepevt file: 5min lifetime	link to the hepevt file: 5min lifetime
Comments	20M macroparticules, scaling of 107 to a real bunch (1% ppb in the core)	80M macroparticules, scaling of 20 to a real bunch (1% ppb in the halo)

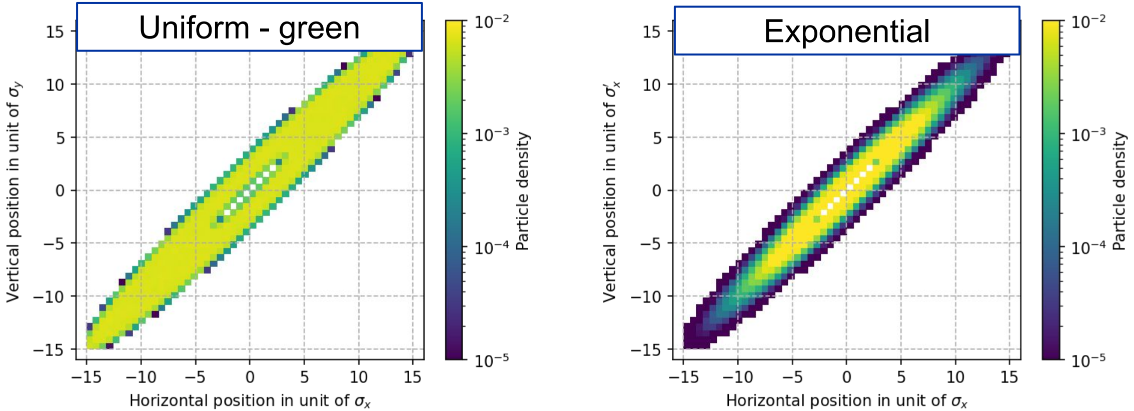
Summary

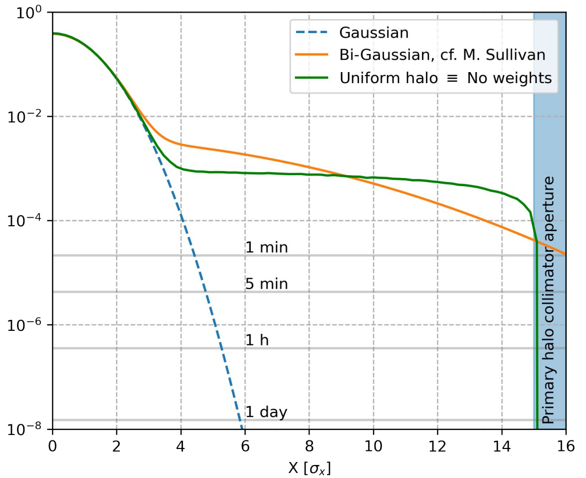
- The BDSIM model features a Ø60mm beam pipe with horizontal winglet except in the final focus region and **x-ray reflection (mirror-like) physics** has been implemented.
- SR Simulations from the beam core (considering non-zero closed orbits as an effective lattice with imperfections) and transverse tails have been performed **at Z and tt energies** for the **GHC and LCC lattices** with **similar synchrotron radiation power deposited near the IP**.
    - **The LCC lattice** results in smaller heat load from the transverse tails but highlights higher heat load on the collimators and the **mask closest to the IP (10x w.r.t. GHC lattice).** No x-ray reflection physics in simulations realised with this model.
    - **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.**
- **Background/Occupancy induced by synchrotron radiation in the sub-components of the detector are under study** together with detector/software colleagues using BDSIM outputs. A first set of photons from GHC (and soon LCC) lattices (Z and tt modes) resulting from halo and non-zero closed orbit simulations are available.
- X-ray reflection impact and mitigation with collimator(s) to be further investigated, as well as sufficient **statistics for photons tracking in detector** and improve the filters to record the most relevant photons.

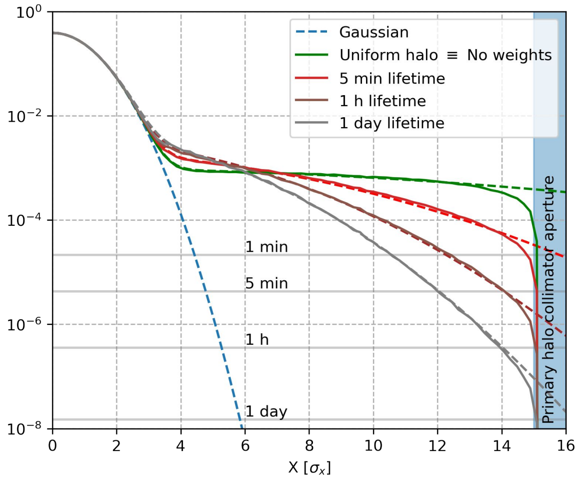
Thank you for your attention

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 (which is not the objective of SR studies).
→ 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).

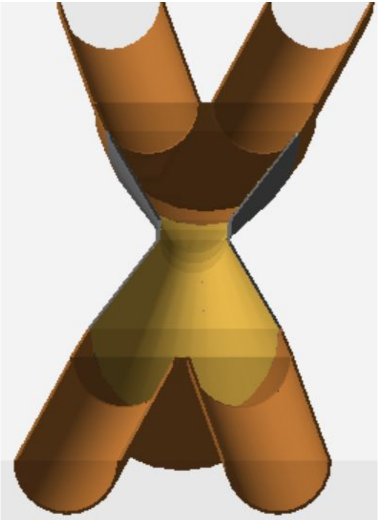
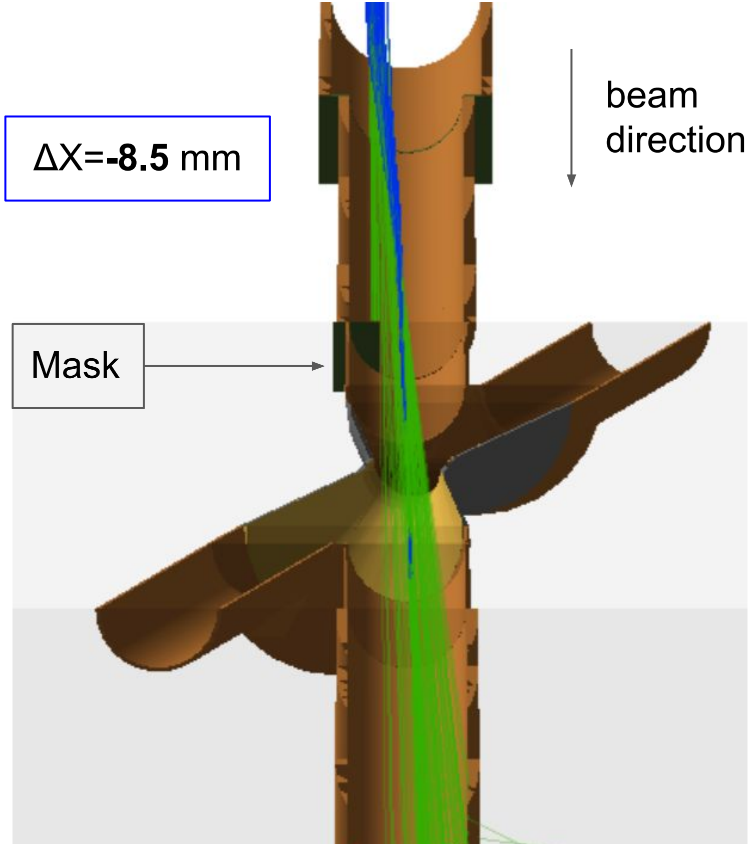
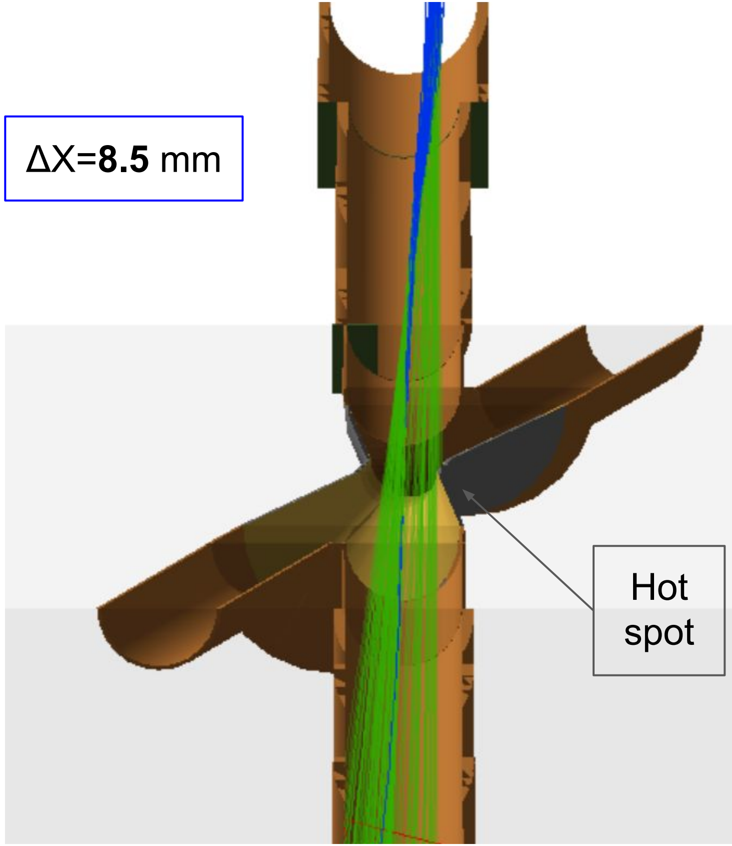
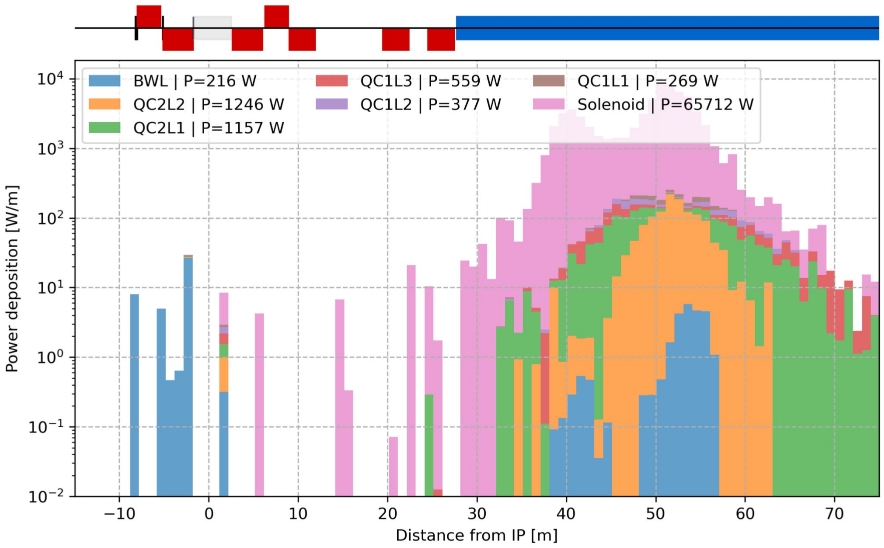


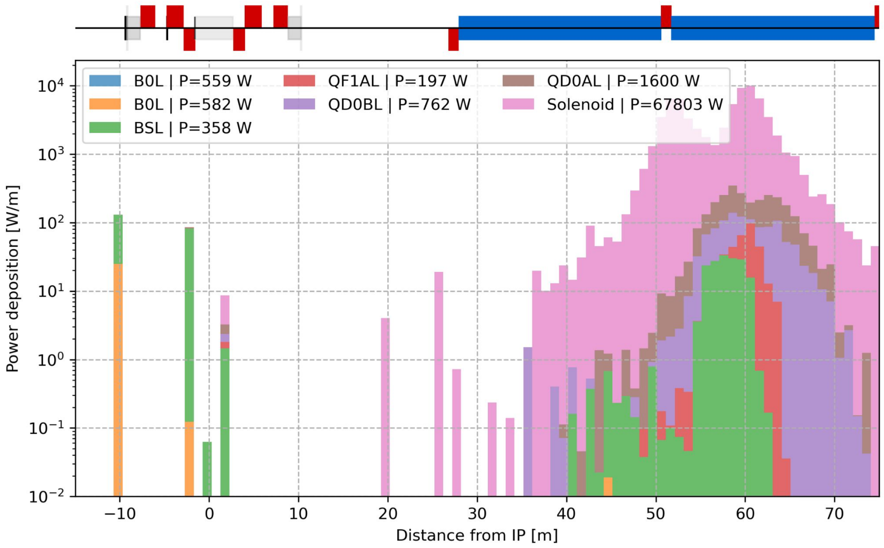
Illustration of the two extremes at Z





Detailed SR power deposition from the beam core





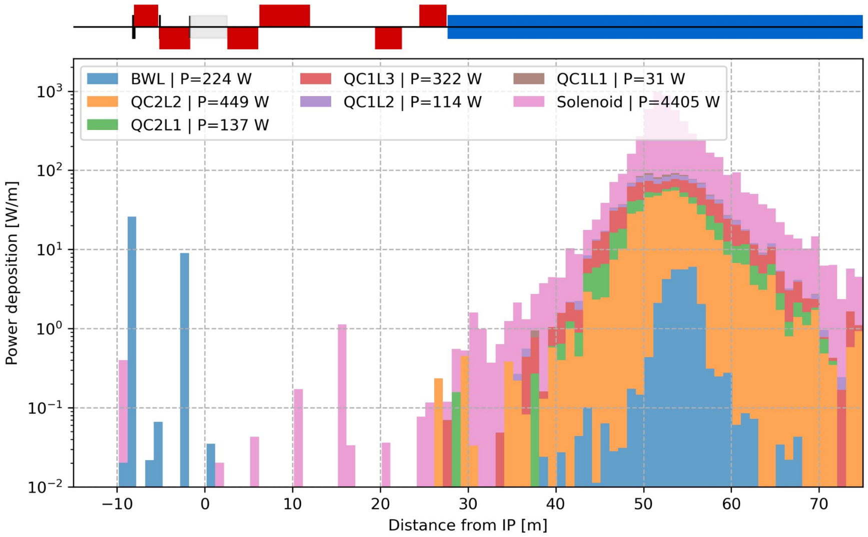
Some SR from last dipole make it to the CC, the mask gets about 10W SR power deposited from the beam core, **efficient** SR collimators.

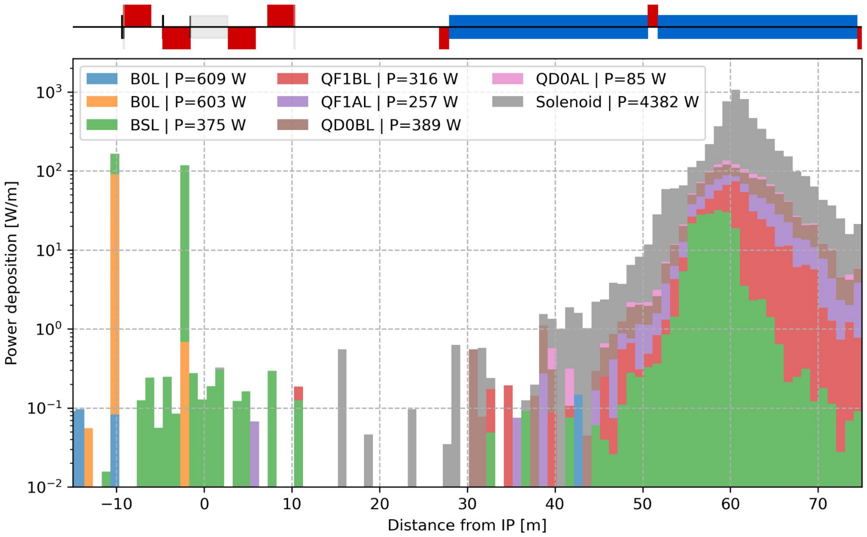
Some SR from last dipole make it to the CC, the mask gets a about 100W SR power deposited, **needs more** SR collimators?

GHC lattice

LCCO lattice

Detailed SR power deposition from the beam core





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V23 lattice

LCCO lattice