Synchrotron Radiation in FCC-ee Interaction Region

Marian Lückhof
CERN and Universität Hamburg

The FCC-ee

FCC-ee is one of the future circular collider options with 80 km to 100 km circumference, designed for e^+e^- collisions. It is supposed to run at several collision energies from 90 GeV to 350 GeV. [ea14]
Synchrotron radiation can be a serious source for backgrounds in case of circular lepton colliders. It scales as follows with particle energy E_0, bending radius ρ and circumference L:

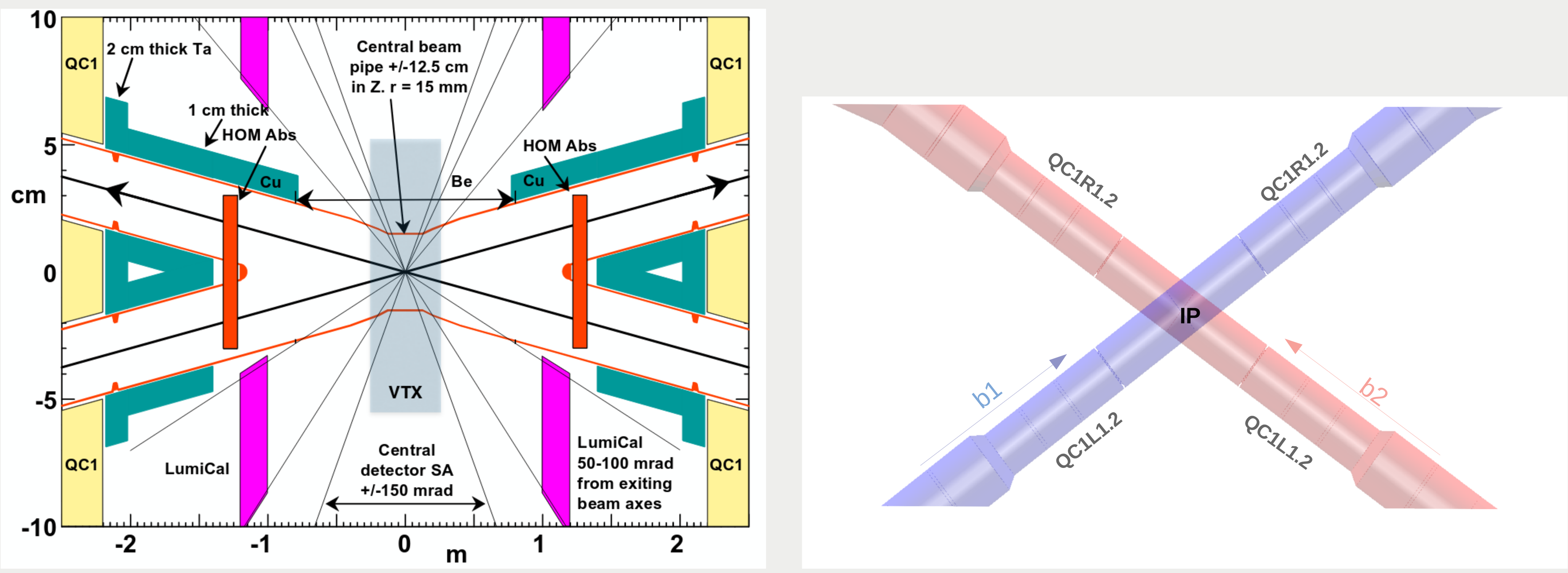
$$U_0 = \frac{4\pi r_e}{3\,(m_0c^2)^3}\frac{E_0^4}{\rho}$$

$$\langle P_{SR}\rangle = \frac{U_0}{T_0} = \frac{4\pi c r_e}{3\,(m_0c^2)^3}\frac{E_0^4}{\rho L}$$

A significant level of synchrotron radiation can be expected, possibly limiting machine performance and detection conditions in the **interaction region (IR)**, where accelerator and detector are combined to produce and observe collisions in the **interaction point (IP)**. For FCC-ee, the maximum energy loss from synchrotron radiation was limited to 50 MW per beam which is one of the driving limits for the design.

FCC-ee Interaction Region & Geometry

The interaction region requires careful design to provide **high luminosity at tolerable (or better minimized) background rates** and at the same time reliability at different collision energies [BBS17]. The IR design includes a crossing angle of 30 mrad (figure (a)). A practical implementation from MDISim is shown in figure (b), considering the two beam pipes of b1 and b2, meeting in the central interaction point.



(a) (b)

Figure: (a) schematic view on the interaction region of FCC-ee [Sul18]. (b) realization in MDISim. Note the enhanced scaling in x and y compared to z.

The Tool-Set - MDISim

Designing the interaction region requires a set of simulation tools, as not only geometry but also beam parameters and particle physics have to be combined in a flexible way. Therefore, the development of MDISim, **M**achine **D**etector **I**nterface **Sim**ulations was initiated [BB15].
This top-level interface combines different codes in three steps :

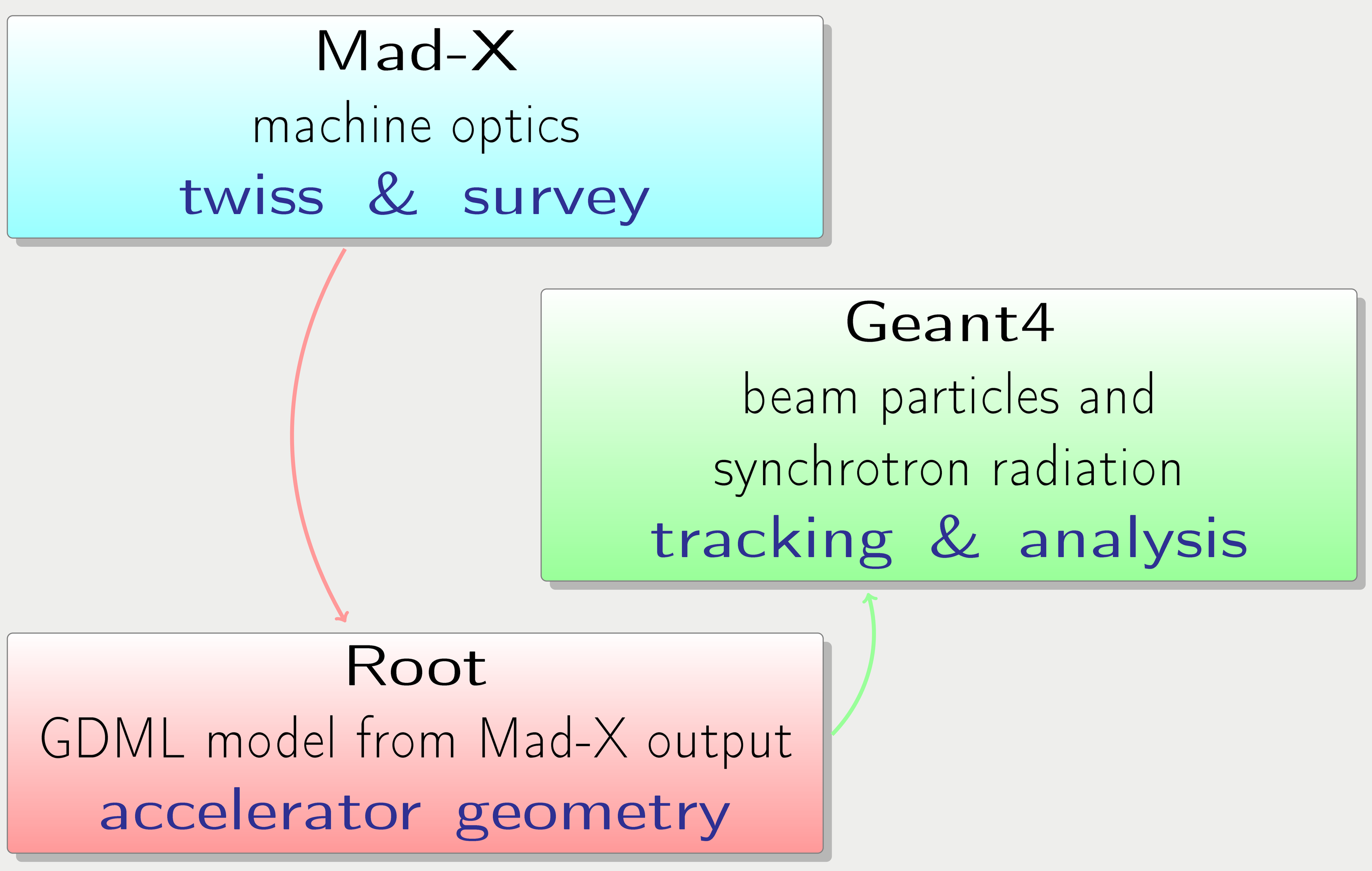
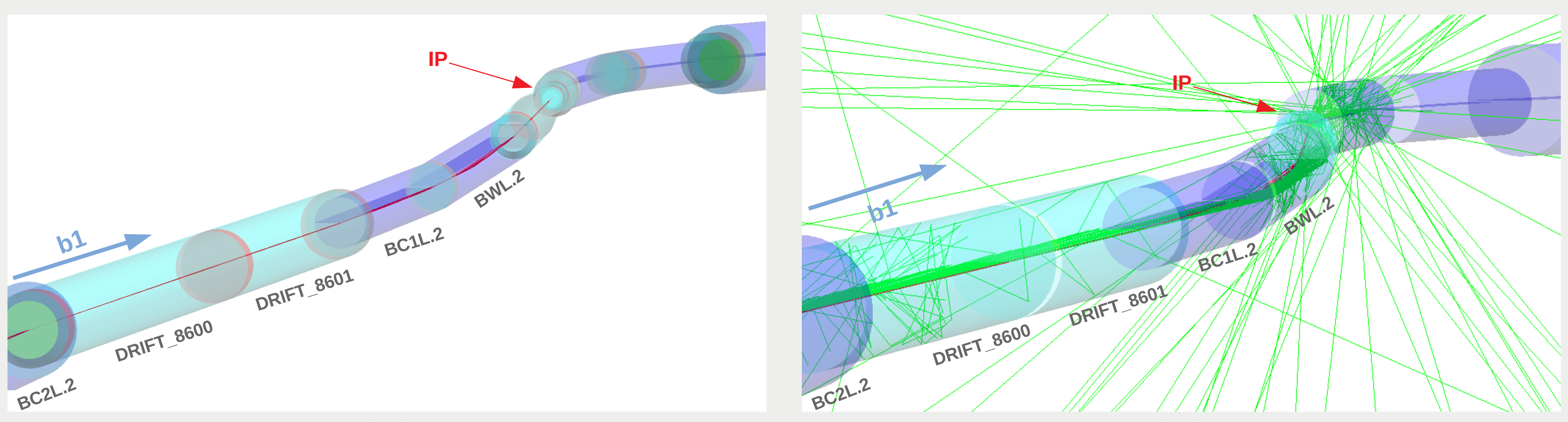


Figure: The three blocks that are combined with MDISim to study synchrotron radiation backgrounds in the machine-detector interface.

Synchrotron Radiation - Tracking in Geant4

To study synchrotron radiation in detail, Geant4 reads beam energy and beam size as input to generate and track the beam through the lattice. The resulting tracks of synchrotron radiation photons can be displayed using Root and the TEve display manager.
Full tracking information allows detailed analysis of several issues during or after the simulation run.
To start off the study, only b1 is considered, assuming a completely symmetric layout:



(a) (b)

Figure: (a) tracking only beam particles upstream of the IP. (b) tracks of synchrotron radiation photons.

Analytic Estimates

How many photons per bunch crossing? What are average power and energy?
Estimating amount and nature of synchrotron radiation is an important step of the study and also possible with MDISim. The table below summarizes key parameters for upstream dipoles and final-focus quadrupoles.

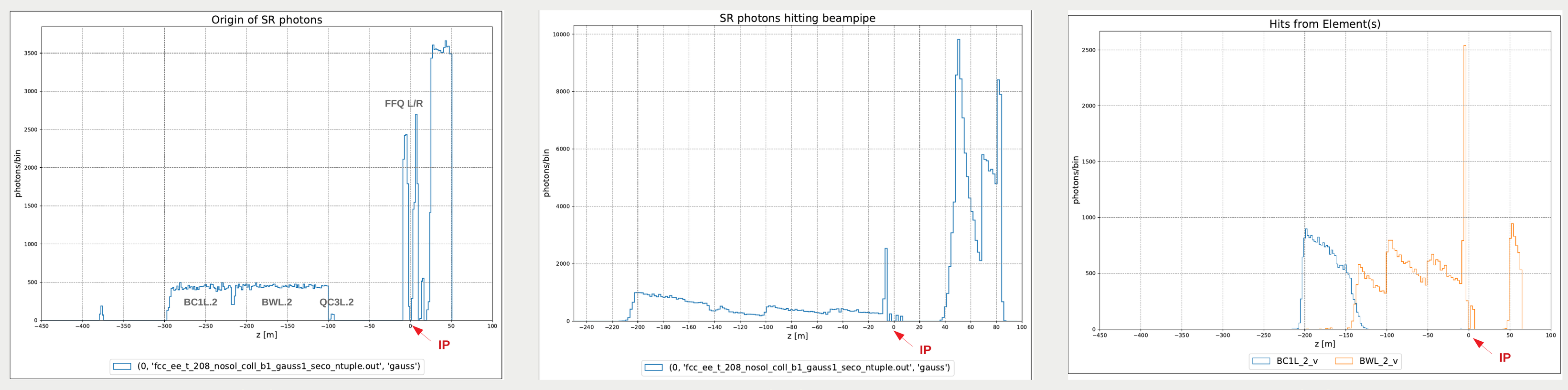
Magnet	S [m]	L [m]	Angle [mrad]	E_c[keV]	$n_\gamma/e^\pm$	ρ[m]	B [T]	Power [kW]	$\geq$ 10 MeV	n_{tot}	$<E_\gamma>$ [keV]
BWL.2	214.2	114	-0.7879	93.2	2.96	1.45×10^5	-0.00421	0.456	5.6×10^{-49}	8.30×10^{11}	28.7
BC1L.2	293.1	74.83	-0.4935	88.9	1.86	1.52×10^5	-0.00401	0.273	3.27×10^{-51}	5.20×10^{11}	27.4
BC2L.2	549.2	61.99	1.038	226	3.91	5.97×10^4	0.0102	1.46	2.11×10^{-21}	1.09×10^{12}	69.5

Magnet	S [m]	L [m]	E_c[keV]	$n_\gamma/e^\pm$	B_x[T]	B_y[T]	Angle [mrad]	Power [kW]
QC1L1.2	3.4	1.2	368	0.1232	-0.00819	-0.0145	0.0749	0.0328
QC1L2.2	4.48	1	517.7	0.1444	-0.00869	-0.0217	0.124	0.0384
QC1L3.2	5.56	1	776.9	0.2167	-0.0081	-0.0341	0.278	0.0576
QC2L1.2	7.11	1.25	553.1	0.1929	0.0029	0.0248	0.176	0.0513
QC2L2.2	8.44	1.25	1013	0.3534	0.00426	0.0455	0.592	0.0939

Table: Estimates on synchrotron radiation from different types of magnets. Upper table: last three bending magnets. Lower table: final focus quadrupoles.

Contributions from Single Elements

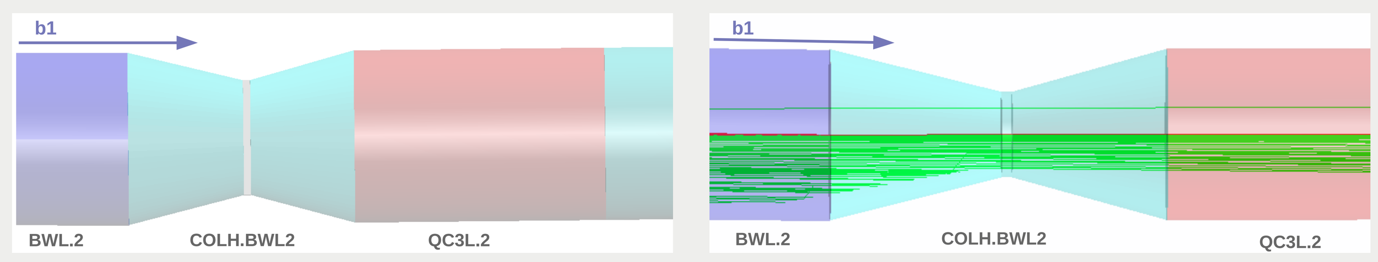
How many photons are generated in a magnet, where are they produced and where do they hit the beam pipe?
Designing the interaction region also means to know which elements contribute most to the photon background and specific characteristics of these elements. Tracking the beam upstream allows not only to count all hits from photons on the beam pipe (figure (b)), but also the point of origin (figure (a)).
Further we can decompose these distributions into single elements (figure (c)).



(a) (b) (c)

Figure: (a) origin of photons upstream. (b) full spectrum of hits on the beam pipe. (c) decomposed spectrum, only showing contributions from last two bending magnets.

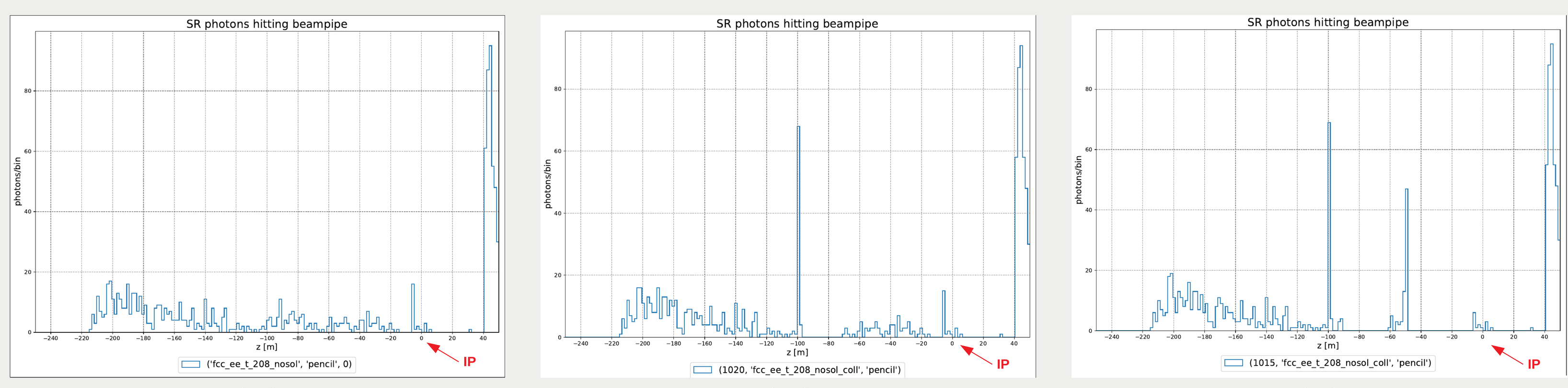
Collimation



(a) (b)

Figure: (a) collimator right after the last bending magnet upstream of b1. (b) tracks of photons, partially blocked by the collimator.

One possible measure to protect the interaction region from synchrotron radiation is to place **collimators** at certain locations. By using movable jaws, these elements allow to restrict the physical aperture and block a significant amount of photons already a long distance upstream, far from the interaction point to further suppress additional backgrounds.
MDISim allows to directly study the effect of these elements on synchrotron radiation background (also in terms of reflections and secondary backgrounds).



(a) (b) (c)

Figure: (a) unperturbed distribution of hits on the beam pipe. (b) although clearly shadowing a certain region upstream, a single `COLH` cannot effectively reduce the background at the interaction point. (c) a combination of several collimators might be required. **Note: Data-set different from above.**

Status and Outlook

- MDISim allows flexible combination of different powerful codes
- collimators: positions, combinations, apertures and secondary backgrounds
- collimators and masks: clean interaction point and detector conditions, machine protection
- increase statistics in Geant4 to allow more realistic estimates

References

[BB15] Helmut Burkhardt and Manuela Boscolo, *Tools for Flexible Optimisation of IR Designs with Application to FCC*, no. CERN-ACC-2015-279, TUPTY031. 3 p.

[BBS17] M. Boscolo, H. Burkhardt, and M. Sullivan, *MDI Studies: Layout and Synchrotron Radiation Estimate in the FCC Interaction Region*, Physical Review Accelerators and Beams **20** (2017), no. 1 (en).

[ea14] F. Zimmermann et al., *FCC-ee Overview*, Proceedings of HF2014, Beijing, China (2014).

[Sul18] M. Sullivan, *IR Layout with SR Masks and Shielding - Workshop on Mechanical Optimisation of the FCC-ee MDI*, January 2018.