FCC

Results and prospects of radiation level studies in the FCC-ee IR

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Introduction

In the FCC-ee interaction regions machine equipment exposed to several radiation sources

→ FLUKA studies to estimate the relevant quantities (power deposition, radiation levels) and contribute to component design

- similar studies for the arc by B. Humann at 37th and 40th Technical infrastructures coordination meeting

Results

Focus on tunnel environment around the IP:

- beamstrahlung dump
- synchrotron radiation from the beam outgoing from the IP
  - SR absorbers currently under design by Roberto Kersevan not included

Prospects

Radiation studies for the detector and FFQ (not yet addressed)

Reference beam parameters

	Z	ttbar
beam energy [GeV]	45.6	182.5
# of bunches/beam	10000	36
bunch intensity [10^{11}]	2.43	2.64
beam current [mA]	1280	5

Radiation effects studied with FLUKA

Radiation affects material properties, lifetime and performance through:

- INSTANTANEOUS DAMAGE
  - heat deposition
  - quench of superconducting magnets

↓

relevant quantities:
total power [W], power density deposition [mW/cm3]

- LONG-TERM DAMAGE
  - ionizing dose build-up
  - atomic displacement build-up
  - deterioration of detector capability

↓

relevant quantities:
dose [Gy], **DPA,**
1 MeV neutron-equivalent fluence [cm-2]

- SINGLE-EVENT EFFECTS
  - perturbation of active-electronics operation

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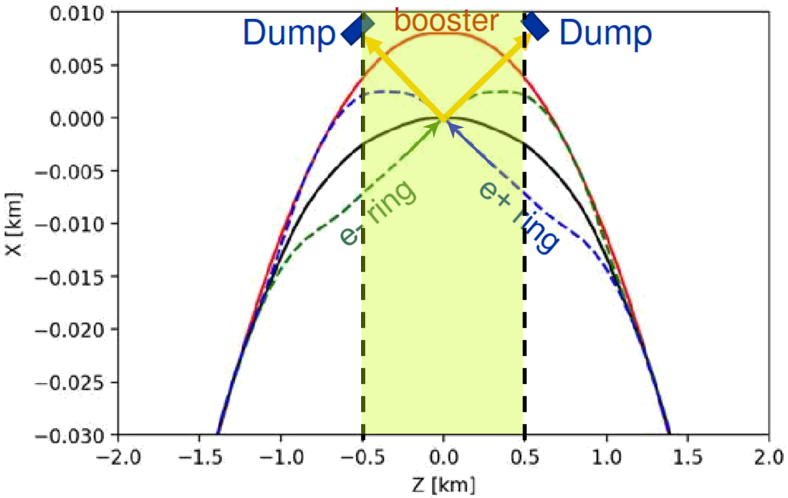
relevant quantities:
high-energy hadron equivalent (HEH-eq) fluence [cm-2], thermal neutron equivalent fluence [cm-2]



Current results

Focus on power deposition and radiation levels in the tunnel within ±500 m from the IP

- beamstrahlung radiation
- synchrotron radiation from outgoing beam

Sources

Synchrotron radiation

photons emitted by beam particles when bent by the magnets

- design constraint: 50 MW per beam
- beam incoming to the IP: dangerous for detector but little power
- beam outgoing from the IP: not a concern for the detector but strong bend → **~160 kW** (first 500 m)

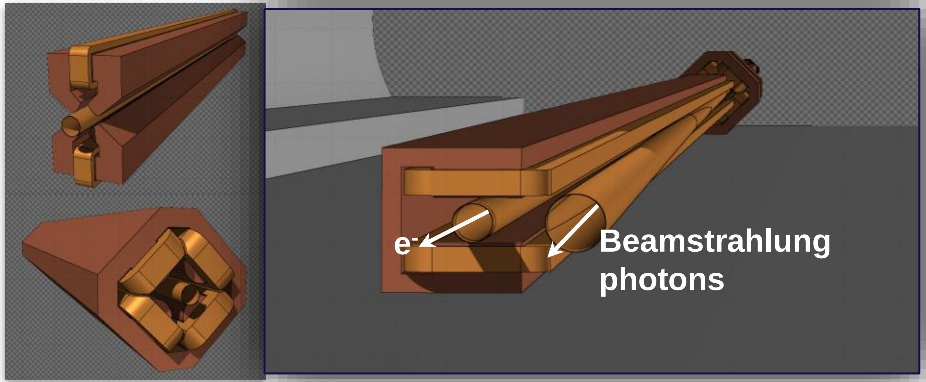
Beamstrahlung radiation

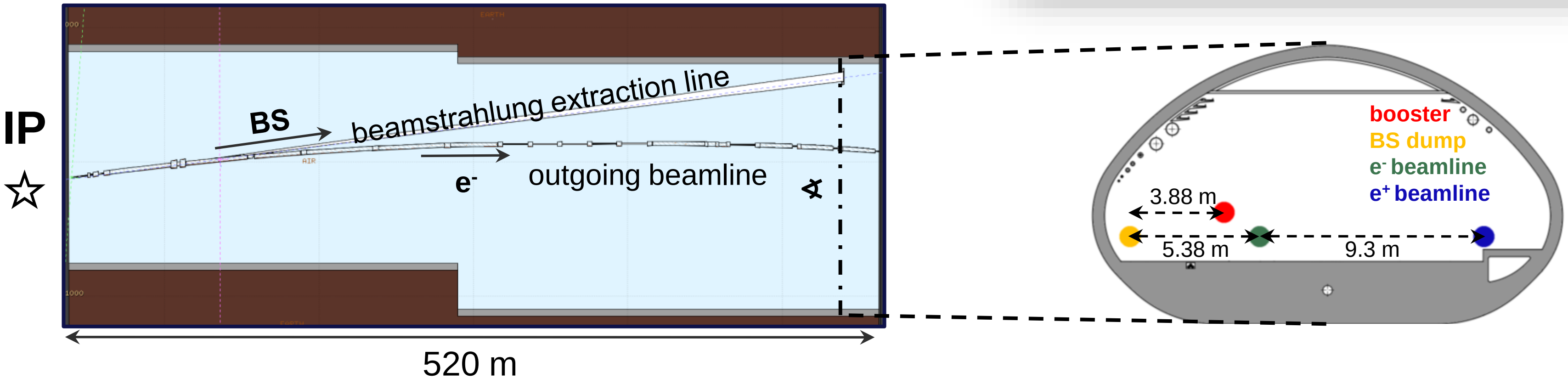
photons emitted in the EM field of the counter-rotating bunch in the IP

- two intense photon beams produced at each IP, collinear to the outgoing beams
- **369 kW** @Z-pole, **76 kW** @ttbar
- two high-power beam dumps per IP needed

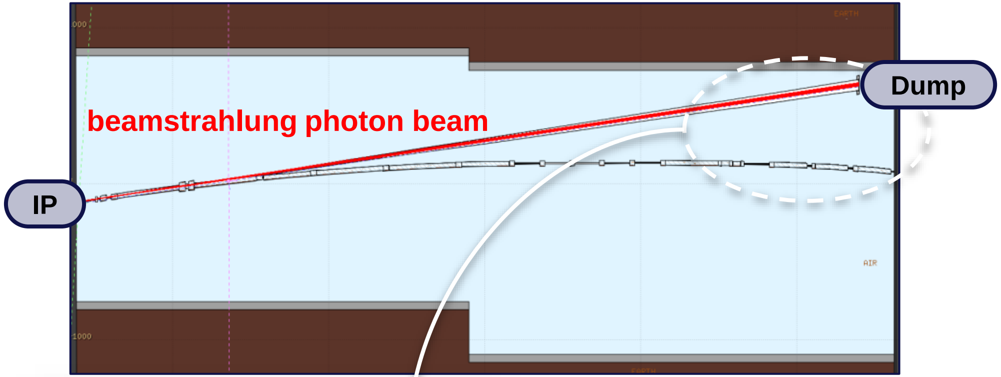
FLUKA geometry of the FCC-ee IR (right of IP)

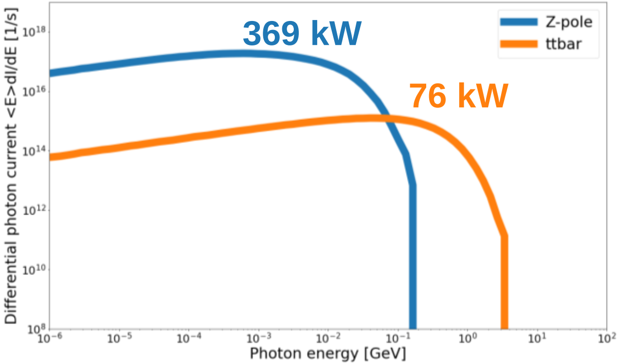
- **concrete tunnel** surrounded by soil
- outgoing beamline: **copper beam pipe** + **magnets** (including magnetic fields)
- conical **copper extraction line**
- **beamstrahlung dump** and shielding



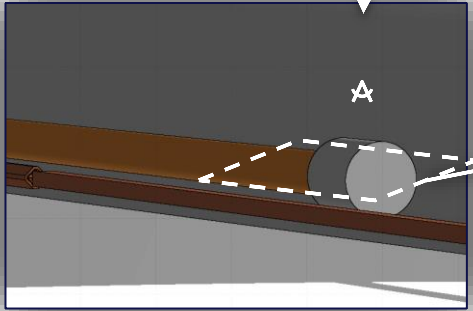


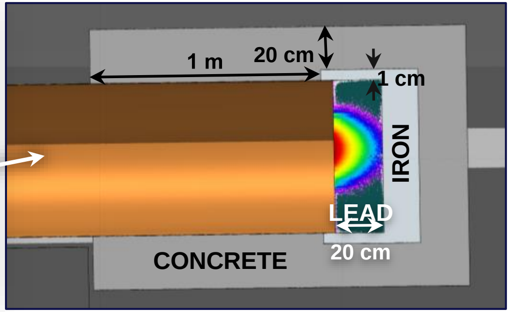
Source – Beamstrahlung radiation

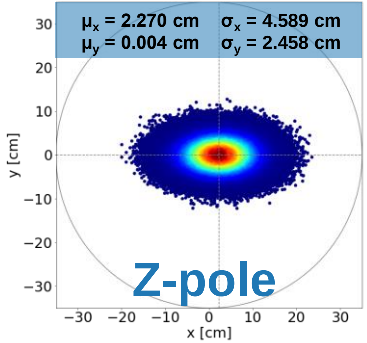


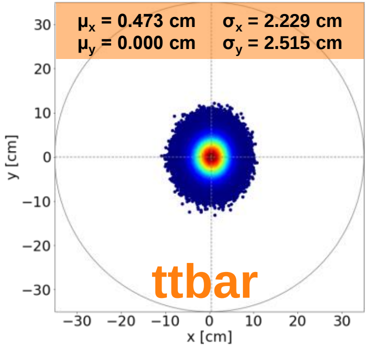


Beam dump:
→dispose of this power
→shielding to contain the radiation showers



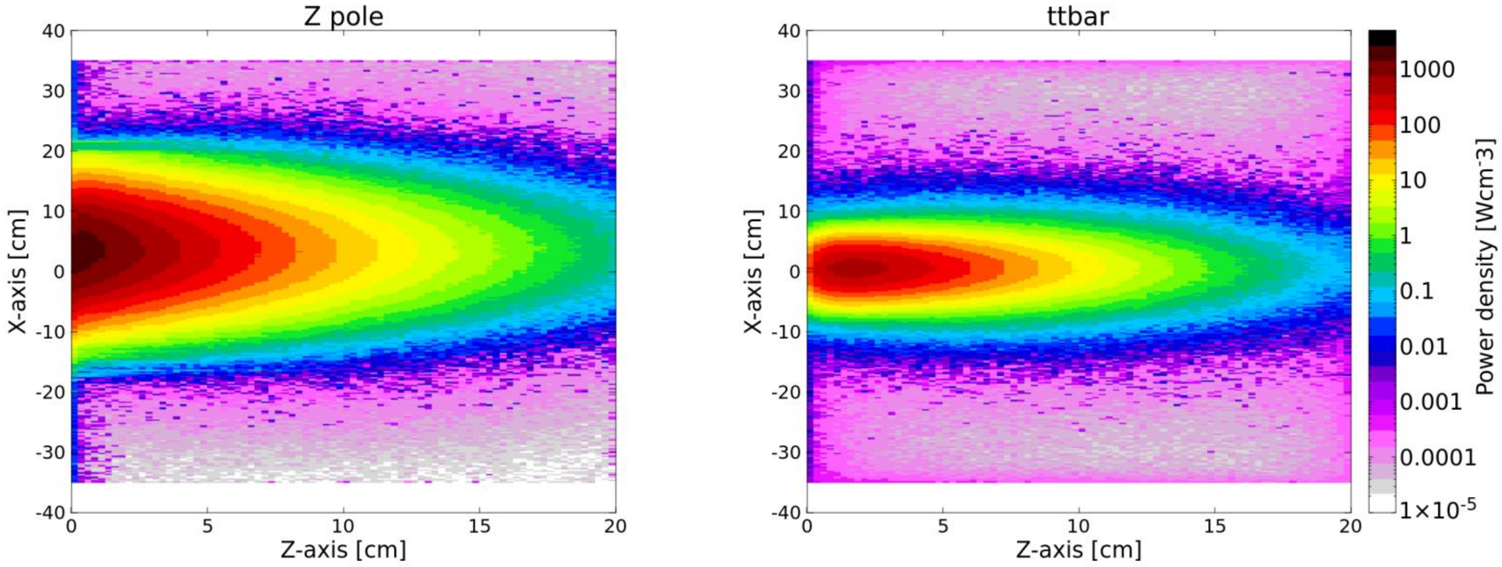






Power density in the liquid lead dump

Horizontal plane: average for y in [-1,1] cm around the impact centre



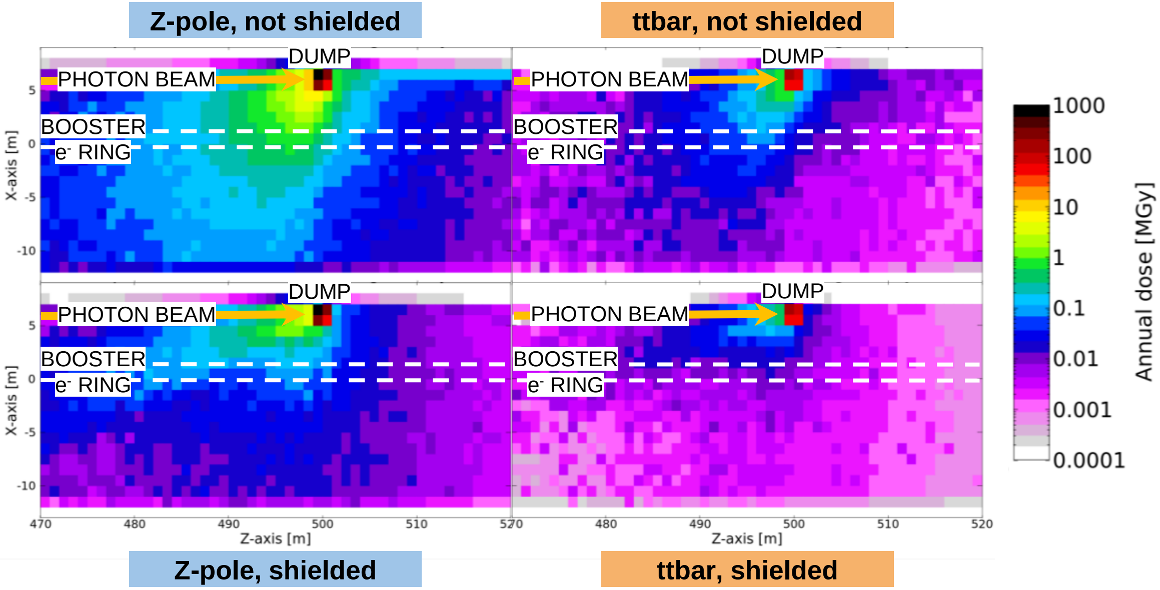
Results for graphite dump core in FCC week 2023 talk:

Beamstrahlung dump and radiation levels in the experiment IRs

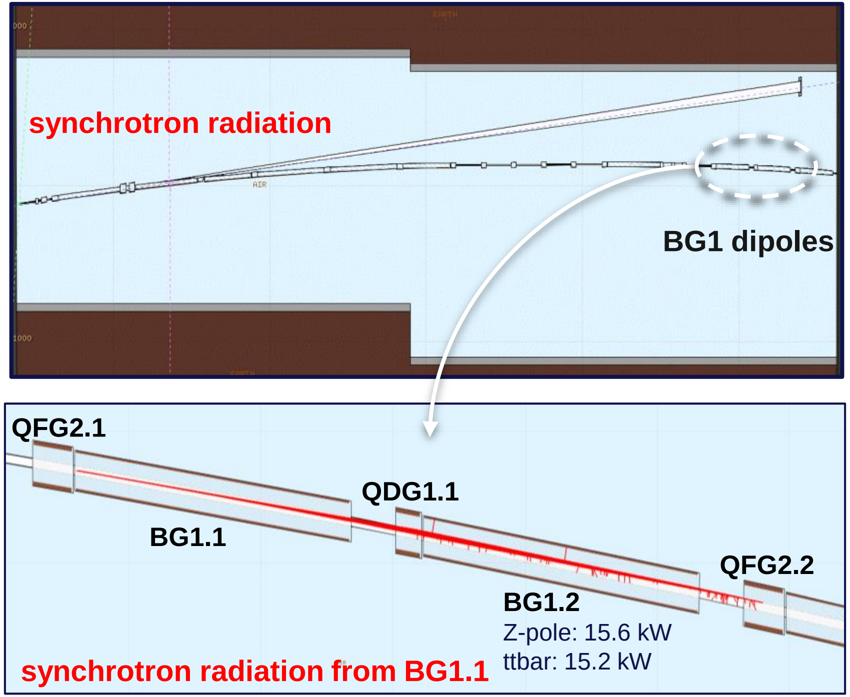
Beamstrahlung dump – Tunnel radiation levels

Total ionizing dose from beamstrahlung photon beam in the vicinity of the lead dump

- **highest dose @Z-pole without shielding**: up to few MGy around the dump, around 1 MGy at booster and e$^-$ ring
- proposed shielding reduces the dose by a factor ~10 at booster and e$^-$ ring
- placing the dump at 500 m avoids having this radiation environment close to the detector
- <u>optimization of shielding dimensions required</u>



Source – Synchrotron radiation



Synchrotron radiation characterized for each dipole (E_c, power per unit length..):

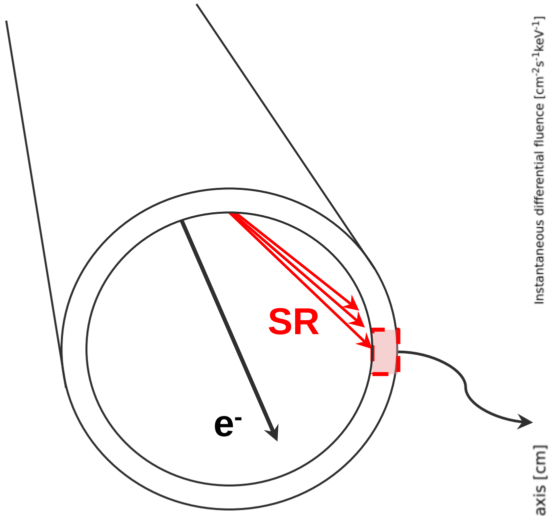
- ~**164 kW** emitted in the first 500 m
- ~37% of SR from the first dipole BC1 (4.2 kW) reached the BS dump
- most intense SR from BG1 dipoles

This setup will allow us to test the impact of SR absorbers once their design is ready

- including them in FLUKA geometry
- scoring the relevant quantities
- assessing their effectiveness
- modeling additional shielding if needed

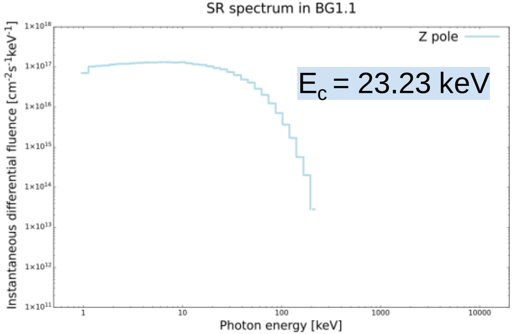
*not the design by Roberto Kersevan: no absorbers, not the final picture

Synchrotron radiation – Power deposition

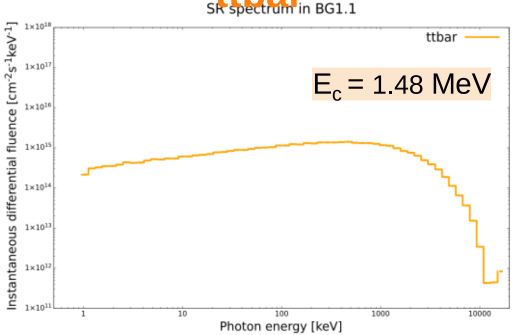


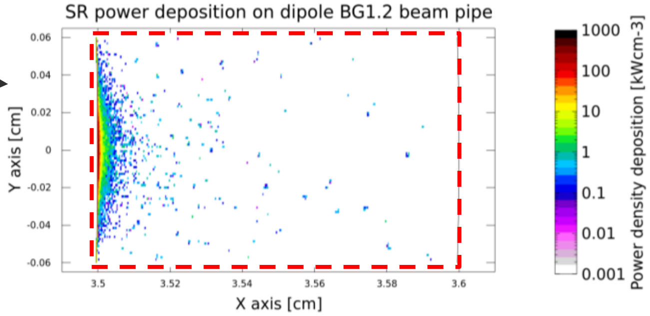
power deposition averaged along all the BG1.2 beam pipe* length

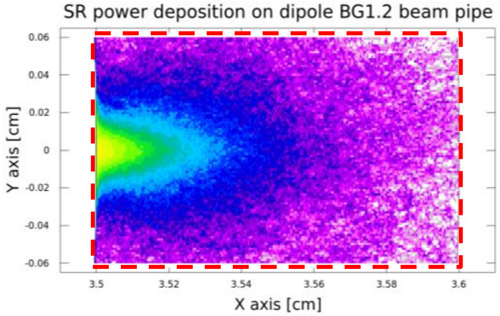
Z pole



ttbar





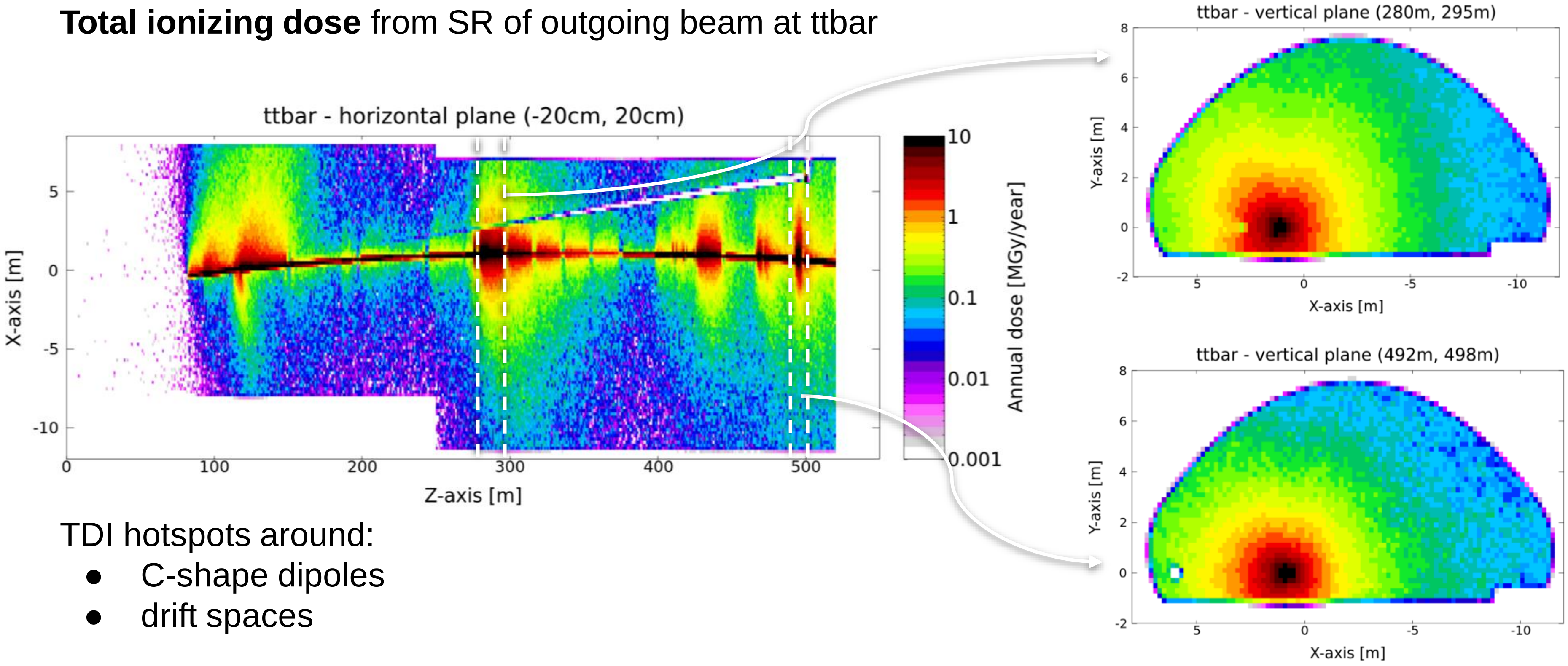


Same total power radiated at the two modes, but SR @ttbar much more penetrating

***not the design by Roberto Kersevan: no absorbers, not the final picture**

Synchrotron radiation – Tunnel radiation levels

Total ionizing dose from SR of outgoing beam at ttbar

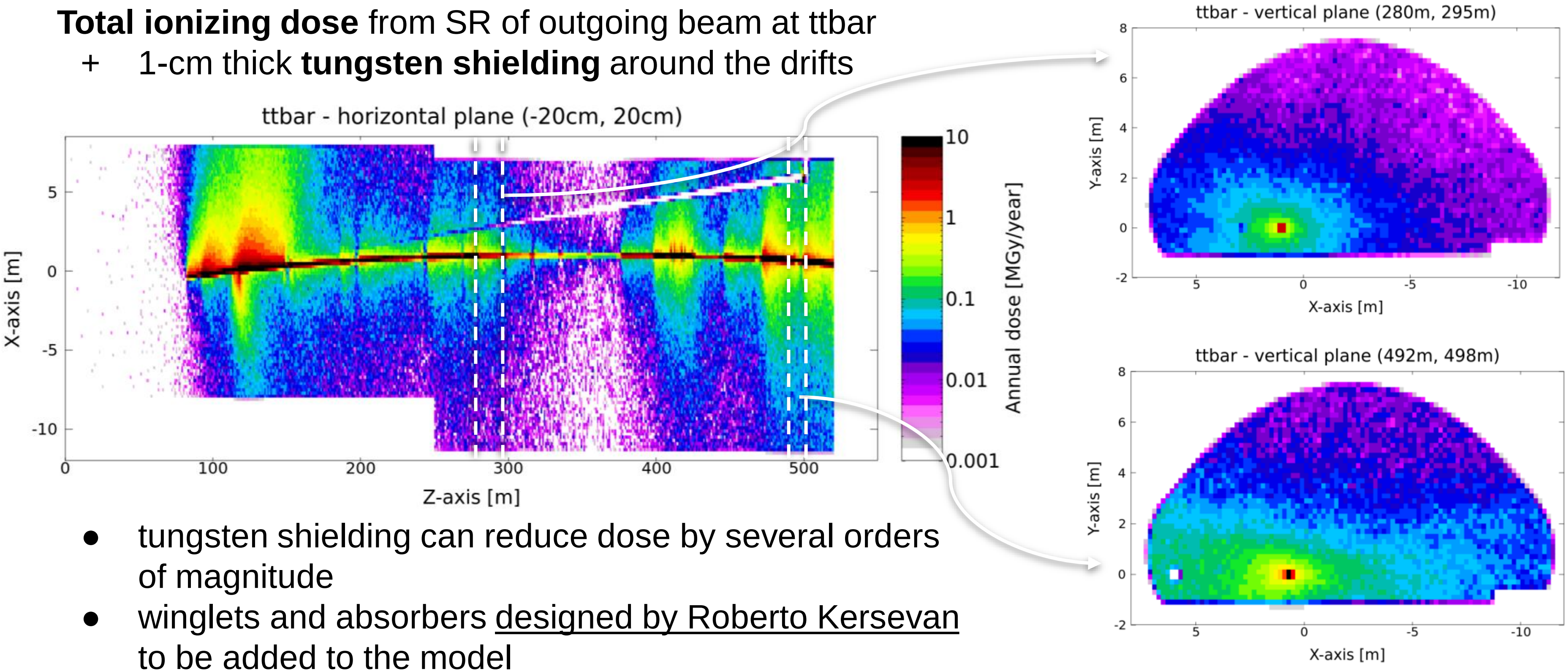


TDI hotspots around:

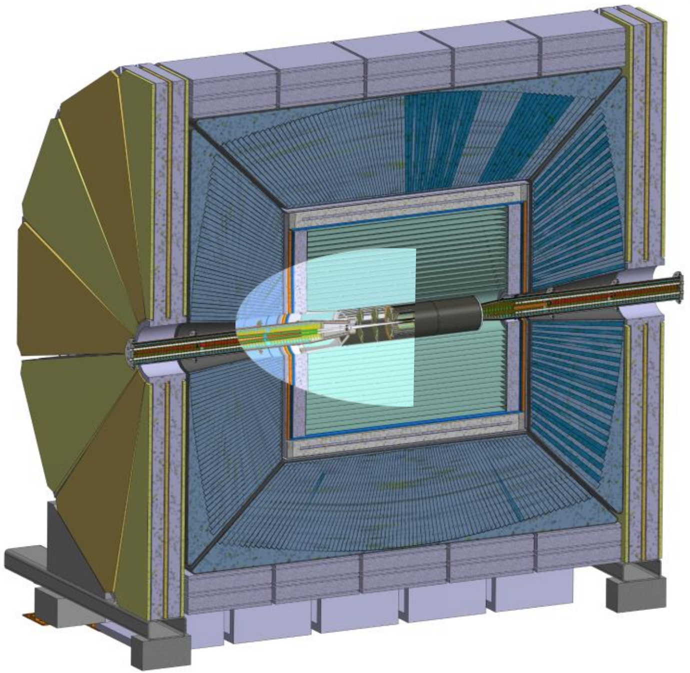
- C-shape dipoles
- drift spaces

Synchrotron radiation – Tunnel radiation levels

Total ionizing dose from SR of outgoing beam at ttbar
+ 1-cm thick **tungsten shielding** around the drifts



- tungsten shielding can reduce dose by several orders of magnitude
- winglets and absorbers designed by Roberto Kersevan to be added to the model

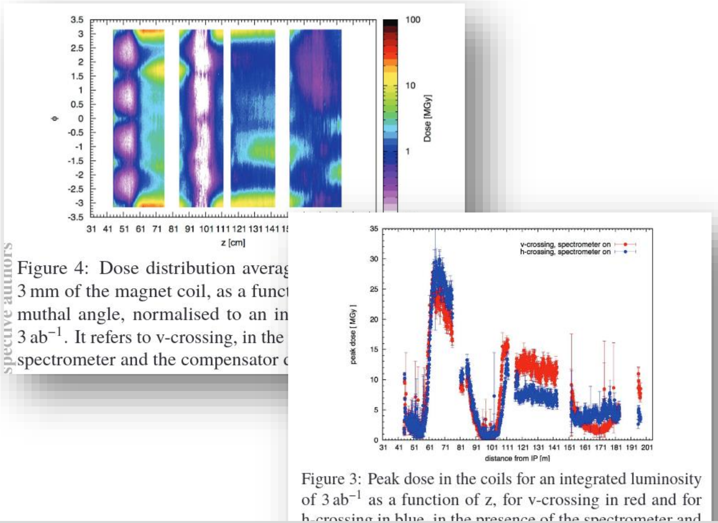


Prospects

Focus on final focusing quadrupoles and on detector (±10 m from the IP)

Next steps – Radiation load studies for final focus

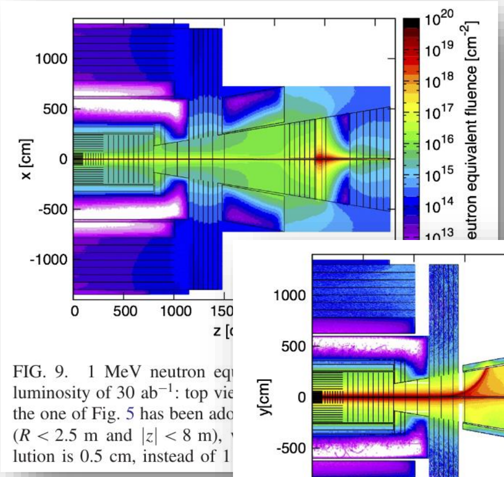
- At this stage, it cannot be excluded that the final focus magnets need to embed some internal shielding in order to avoid quenches and to reduce the cumulative radiation damage in the magnets (dose, DPA)
- As agreed with the MDI WG, <u>we are studying these aspects with FLUKA</u>, under consideration of the different source terms contributing to the radiation load (e.g. radiative Bhabha)
- WIP: a) **build the FLUKA model** of the central IR region, in particular final focus magnets, b) **model the different source terms** in FLUKA
- Close collaboration ongoing with other members of the MDI WG

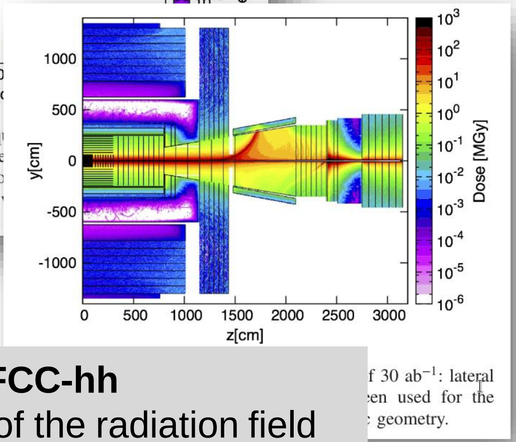


Our previous final focus radiation studies for **FCC-hh**
Interaction region design driven by energy deposition, Phys. Rev. Accel. Beams 20, 081005, 2017

Next steps – Radiation damage in detector

- As one of the further steps, the plan is to calculate with FLUKA the radiation damage in the detector (dose, 1 MeV neutron-equivalent fluence in Si), similar to our previous studies for FCC-hh
- Requires building a **geometry model of the detector** in FLUKA, with effective simplification where needed (vertex) – close collaboration with detector experts ongoing
- The individual **contribution of different radiation sources requires a careful assessment** – established collaboration within MDI WG





Our previous studies for **FCC-hh**
M. I. Besana, Evaluation of the radiation field in the future circular collider detector
Phys. Rev. Accel. Beams 19, 111004, 2016

Source terms for FF and detector radiation studies

In IP:

- Bhabha (in particular radiative Bhabha): from BBBrem + GuineaPig++, simulated in Key4hep and BDSIM by Andrea and Kevin
- Beamstrahlung (local losses may be minimal): from GuineaPig++ by Andrea
- Incoherent pair production: from GuineaPig++ by Andrea
- $Z \rightarrow qq$: may be simulated in Pythia

From incoming beam:

- Synchrotron radiation: from G4 simulations by Kevin (but can also be done natively in FLUKA)
- Beam halo losses (leakage from collimation insertion): from Xtrack simulations by Giacomo
- Beam-gas (Coulomb scattering, Bremsstrahlung): natively in FLUKA

Conclusion

Summary

- Developed a first FLUKA geometry model for FCC-ee experimental insertion, for the moment including the outgoing beam, the Beamstrahlung extraction line and a toy-model of the Beamstrahlung dump
- Beamstrahlung and synchrotron radiation from the outgoing beamline included as radiation sources
- Provided preliminary estimates of power deposition in machine equipment (room-temperature magnets) and radiation levels in the tunnel, for the moment still without the SR absorbers developed by R. Kersevan
- The first results show that shielding solutions need to be developed to protect equipment in the tunnel (cables, electronics, etc.)

Conclusion

Next steps

- Continue the radiation level studies for the tunnel including the SR absorbers → develop a suitable shielding for tunnel equipment
- Extend the radiation load studies to the final focus magnets → assess the need of internal shielding in the FFQs to reduce the heat load to cryo, avoid quenches, reduce the long-term radiation damage
- Study the long-term radiation damage in the detector
- This requires extending the FLUKA geometry with the incoming beamline, FFQ, detector, SR masks, absorbers and collimators, and to including more radiation sources in the model calculations (radiative bhabha from IP, beam-gas scattering, SR from quads and detector solenoid)

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THANK YOU FOR YOUR ATTENTION!

Backup

Radiation effects to electronics and materials

Electronic components and systems exposed to a mixed radiation field experience two main types of radiation effects:

- **cumulative damage** – deterministic
  → evaluated through total ionizing dose (TID) [Gy]

1 Gy = 1 J/kg of ionizing energy deposition

- **Gy scale**: ok for commercial-based electronics (with qualifications if dose > 1 Gy)
- **>10 kGy**: only rad-hard electronics
- **MGy scale**: material damage

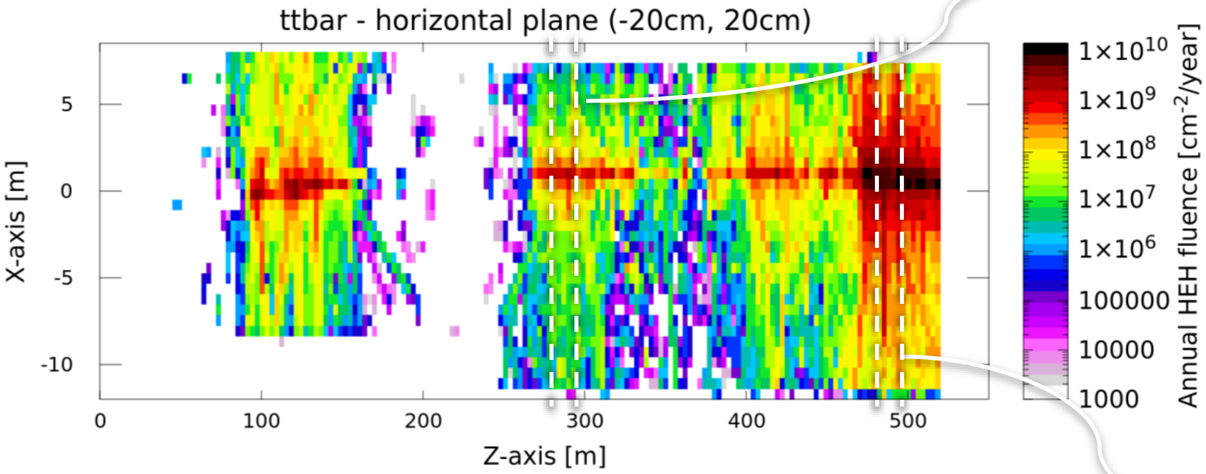
- **single event effects** (SEEs) – stochastic
  → probability of occurrence as a function of high-energy hadron equivalent (HEH-eq) fluence [cm^{-2}]

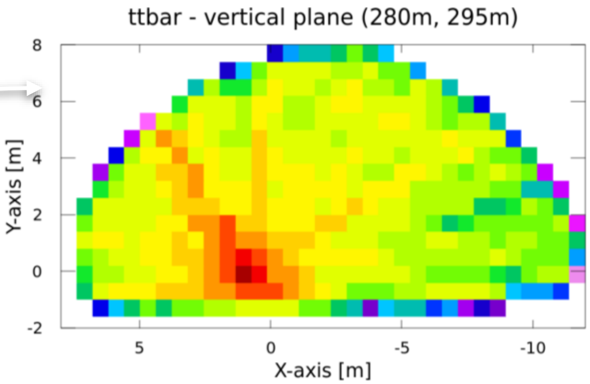
fluence of hadrons more energetic than 20 MeV
+
weighted fluence of neutrons less energetic than 20 MeV

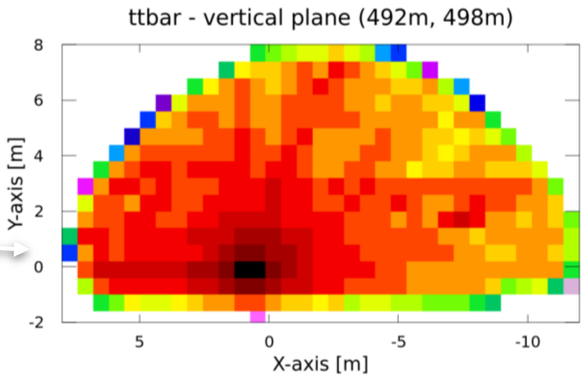
- **earth surface radiation**: HEH=10^5 cm^{-2}/year
- **LHC tunnel electronics (DS)**: HEH up to ~10^{10} cm^{-2}/year

Synchrotron radiation – Tunnel radiation levels

High-energy hadron fluence from SR of outgoing beam at ttbar







- HEH fluence dominated by neutrons (requires more statistics)
- almost unaffected by 1 cm of tungsten