RADIATION ENVIRONMENT IN THE FCC-EE ARCS

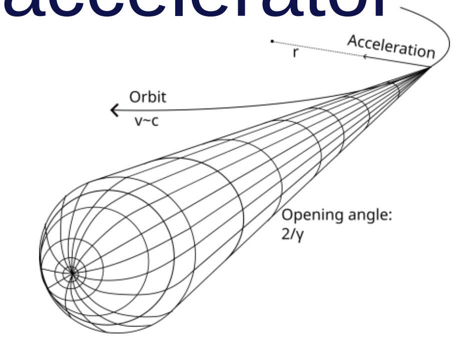
B. Humann, A. Lechner

Thanks to F. Valchkova Georgieva, R. Kersevan, M. Morrone, J. Bauche, C. Jaemyr Eriksson, L. van Freeden, R. Garcia Alia, M. Hofer

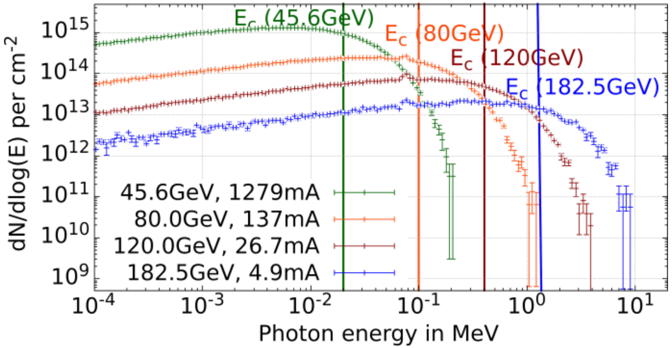
Outline

- **Why are these types of simulations required?**
- **What was done previously? What is the concept now?**
- **Radiation load due to SR in the FCC-ee collider ring**
- **Cumulative dose values in the tunnel due to the SR coming from the high energy booster**
- **Summary and outlook**

Synchrotron radiation (SR) in the accelerator environment



- SR is **em radiation** emitted by charged particles moving along a curved trajectory
- Beam energies ranging from *45.6GeV* to *182.5GeV*:
  $\Delta E/\text{turn} \propto \frac{E^4}{m_0^4 \rho}$ → significantly more for higher energies
  (*ttbar*: **9.2GeV/turn**, *Z*: **38MeV/turn**)
- Higer relevance for radiation load:
  critical energy $\propto E^3$ (splits spectrum in two parts of equal power) determines the shielding efficiency as various physical effects are important



- SR power in FCC-ee always **50MW/beam** per design → higher beam current for lower beam energies (Z: 1.28A, ttbar: 4.9mA)

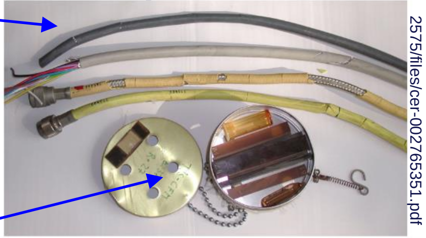
Radiation load challenges: physical properties

Different issues: one distinguishes between **cumulative** and **instantaneous** effects

Cumulative dose is an issue for radiation sensitive equipment, including

- Cables
- Cable connectors
- Optical fibres (for BI)
- R2E (electronics)
- Organic insulation material in the magnet coils (resin, epoxy)

Examples from LEP



https://cds.cern.ch/record/1112575/files/cer-002765351.pdf

In this presentation, the cumulative dose is always normalized to ***1 year of operation*** *(1.2x10^7s)*

Heat deposition in the tunnel

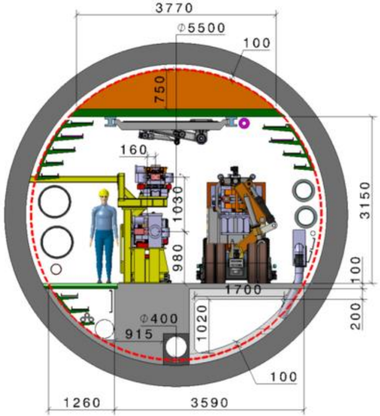
- In superconducting components, heat load an issue for magnet itself
- In FCC-ee, it is mostly an issue for the tunnel environment. The *heat* that is produced by the collider systems must be *evacuated* by the ventilation system. Therefore, the heat load due to SR should be kept at a minimum.

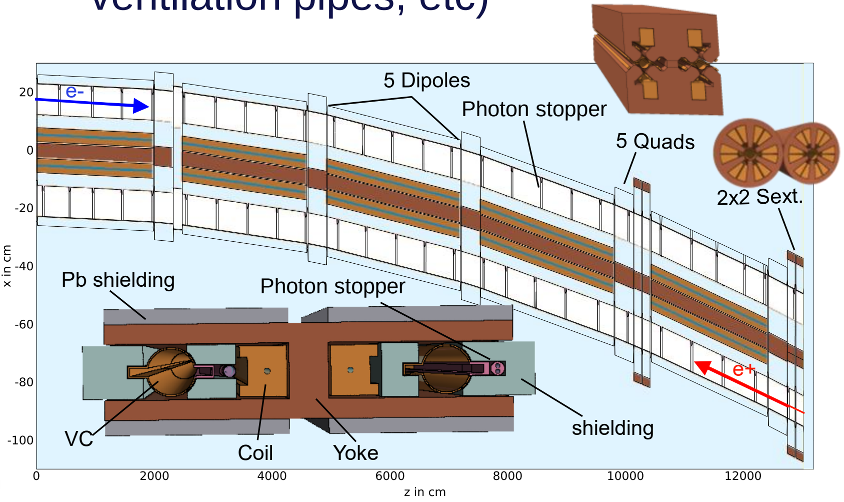
Problems due to **excessive radiation load** already were observed in the **LEP** machine. Therefore, anticipating radiation related issues and ***providing solutions for a low radiation environment in FCC-ee*** is crucial.

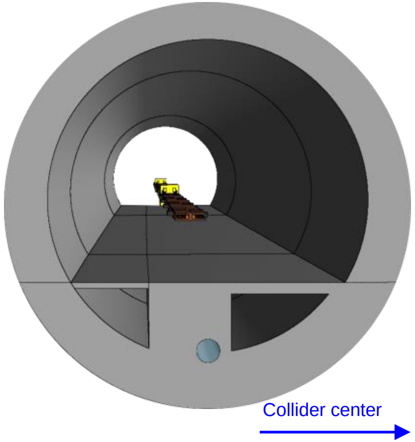
Geometry layout and simulation setup

- 130m long part of the arc (~2.5 half cells)
- 50 photon stoppers in total (2 in MQ, rest in MBs)
- VC: 2mm thick Cu, 60mm diameter, winglets
- 35 cm beam separation
- 5 dipoles (2x19m, 21m, 2x22m)
- 5 quadrupoles (2.9m)
- 2x2 sextupoles (1.3m)

- Additional shielding: lead blocks next to absorbers and above/below photon stoppers
- Integrated in tunnel geometry with a simplified model (no cable trays, ventilation pipes, etc)



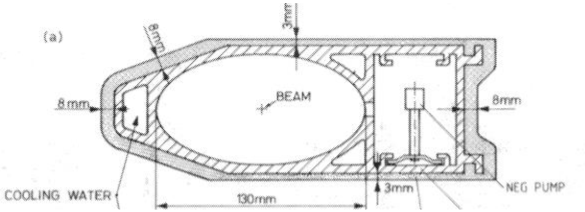




Tunnel layout: F. **Valchkova**
Photon stopper design/placement: M. **Marrone**, R. **Kersevan**
Magnet design: J. **Bauche**, C. **Jaemyr Eriksson**, L. **van Freeden**

Radiation shielding in LEP vs FCC-ee

LEP: 3-8mm Pb directly attached to aluminum VC of the arc magnets (continuous shielding). Possible due to lower circumference 27km, lower beam energies (98-104.5GeV) and beam currents (6.2mA @ 98GeV).



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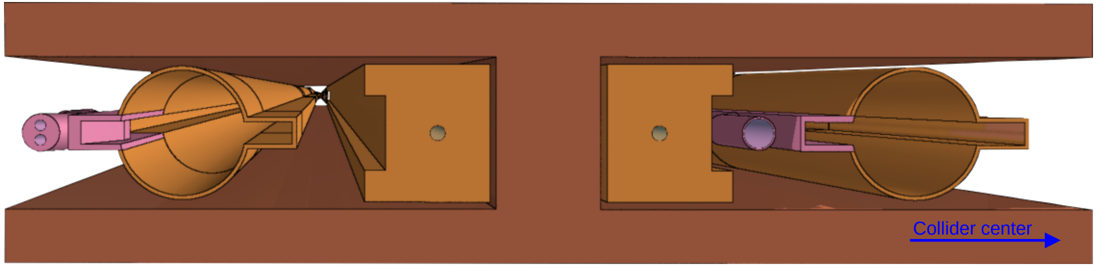
FCC-ee: circumference of 91km makes continuous shielding costly and impractical (e.g for the bake out of the vacuum system), instead the use of **localized photon stoppers** integrated within the vacuum system that *intercept the primary SR fan*, so photons are not directly lost on VC wall

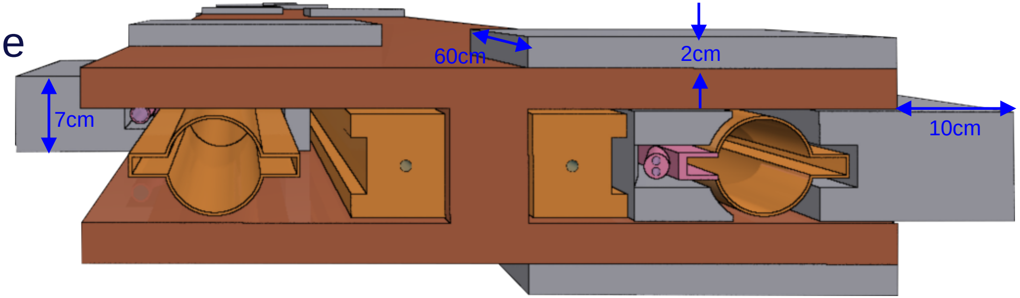


- 30cm in length (~1kg), CuCrZr
- Every ~5.5m in the arc dipoles
- One type of absorber
- The SSS is protected by the photon stoppers in the dipoles
- Photon stoppers need to be actively cooled due to high SR power load (~0.6kW/m)

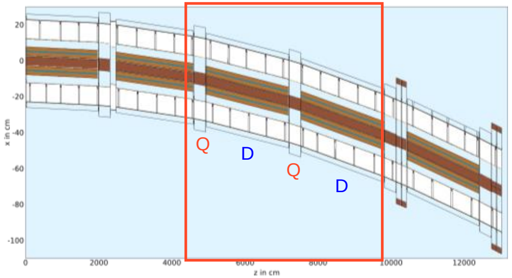
Photon stopper and **shielding** design for FCC-ee

As we will see in the next slides, additional shielding is unavoidable

- **Shielding dimensions**: **60cm length** (15cm overlapping on each side), 10cm extending externally
- Next to VC but with **5mm gap** to allow for bake out and no danger for heat sink
- Material: **Pb**
  - low cost, good absorption properties, but soft if high purity (container would be required)
  - Material impurities possibly an issue for RP, which lead to radioactive waste
  - Half-life time should be below 30 years → further material optimisation necessary
- **Pb layer on top/bottom** of magnets to reduce dose leakage in the vertical plane: 2cm thick, 60cm long
- Additional weight: **2300kg/MB**→ must be considered in mechanical engineering design



Power dissipation in one FODO cell



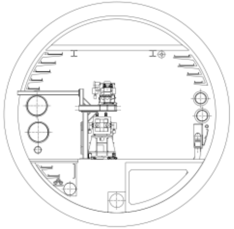
	ZH (120 GeV)		ttbar (182.5 GeV)	
Radiation shielding:	*w/o*	*with*	*w/o*	*with*
Photon stoppers	74.3%	73.9%	70.1%	69.8%
Radiation shielding	N/A	**19.3%**	N/A	**21.6%**
Vacuum chambers	3.3%	3.0%	3.5%	3.3%
Dipoles	17.0%	3.1%	18.6%	4.3%
Quadrupoles	<0.1%	<0.1%	<0.1%	<0.1%
Environment	**5.3%**	**0.6%**	**7.8%**	**1.0%**

The absorbed power shows that the **additional radiation shielding is highly efficient** in reducing the heat load in the tunnel environment.

However, the power in the radiation shielding requires **active cooling** of that component. This must be considered for the choice of material.

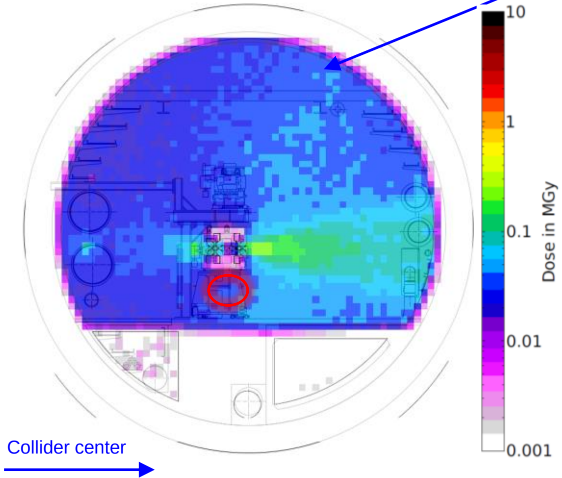
Absorbers are as expected more efficient for **ZH case**, but the power distribution already shows that **similar shielding as in ttbar is necessary** when looking at the power going onto the tunnel otherwise.

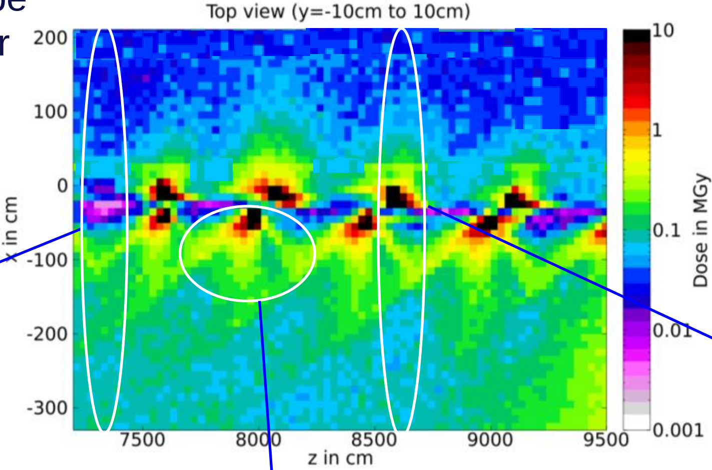
Dose levels in the tunnel (ZH vs ttbar)



At MQ Position

Dose levels below the MQ must be **lowered significantly** to allow for a well protected spot for radiation sensitive equipment (currently around 30kGy). A solution with **~0.5-1kGy/op. time** should be found.



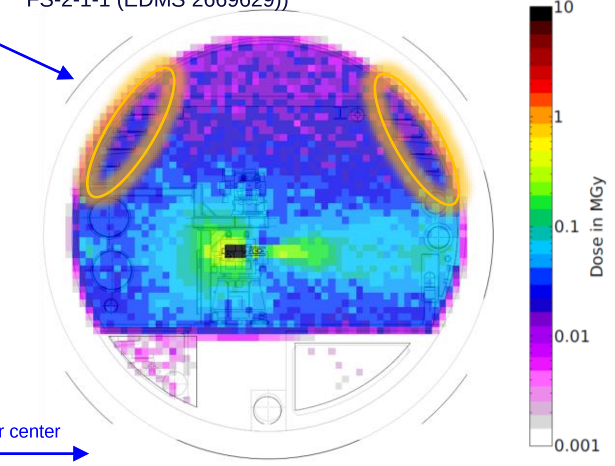


For the internal beam, a more elaborate shielding scheme needs to be found to reduce the high dose levels due to backscattering on the photon stoppers

At ABS Position

At the most intense radiation areas around the photon stoppers, the dose levels reach around 10kGy-30kGy in the areas of the **cable trays.**

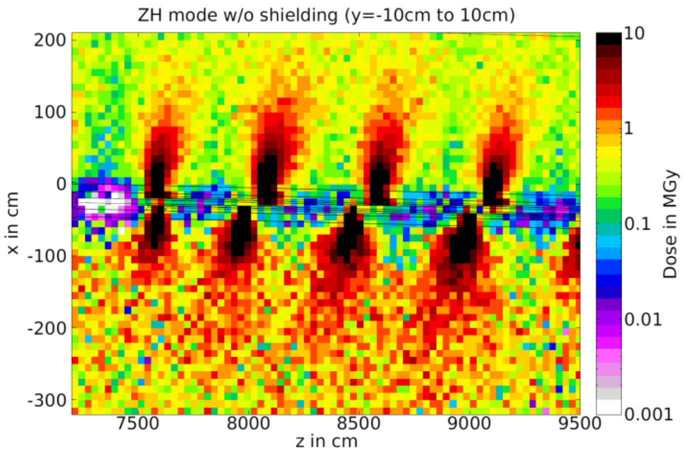
Threshold for cables: **~100kGy/full operational time** (CERN Safety Guideline SG-FS-2-1-1 (EDMS 2669629))



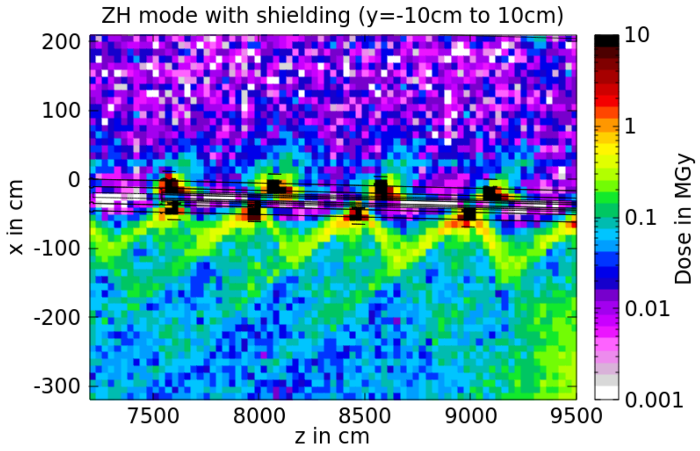
Dose levels in the tunnel (ZH vs ttbar)(i)

Is shielding for ZH really necessary?? Yes, unfortunately it is.

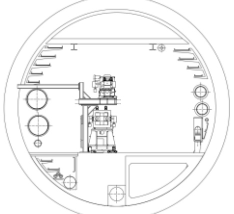
1. Heat load in the tunnel environment (see slide 8)
2. Cumulative dose levels: if only photon stoppers w/o shielding several 100kGy/year (!) in cable location. Adding shielding reduces the value to a few tens of kGy. **(also see A. Lechner's presentation on Thursday)**


ZH mode w/o shielding (y=-10cm to 10cm)

Adding shielding around the absorbers

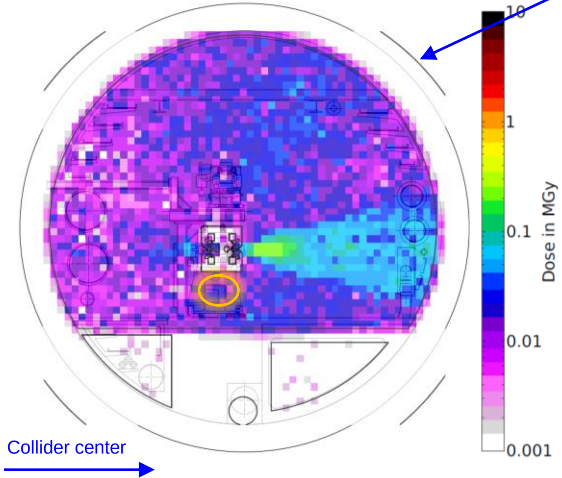

ZH mode with shielding (y=-10cm to 10cm)

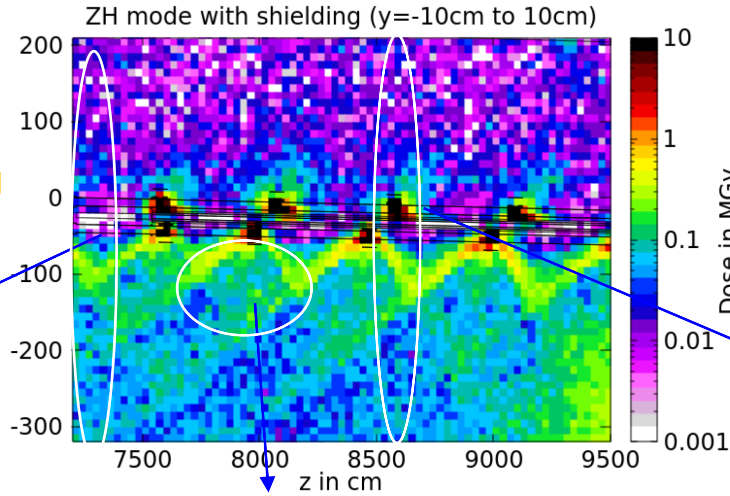
Dose levels in the tunnel (ZH vs ttbar) (ii)



At MQ Position

Dose levels below the MQ have improved significantly compared to ttbar, but to provide a safe location for electronics also **substantial additional shielding is required** here.

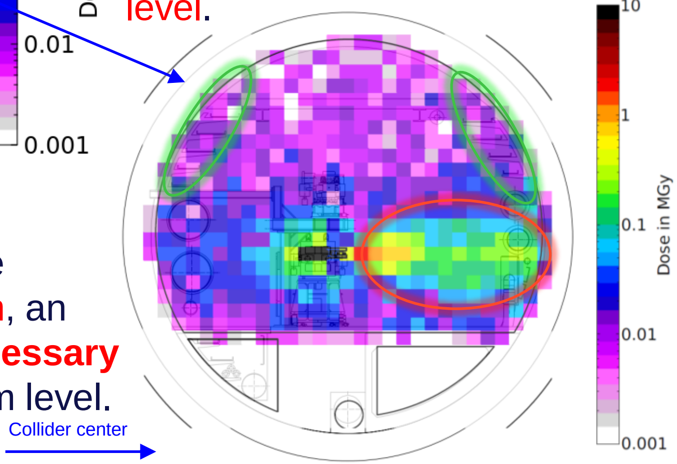




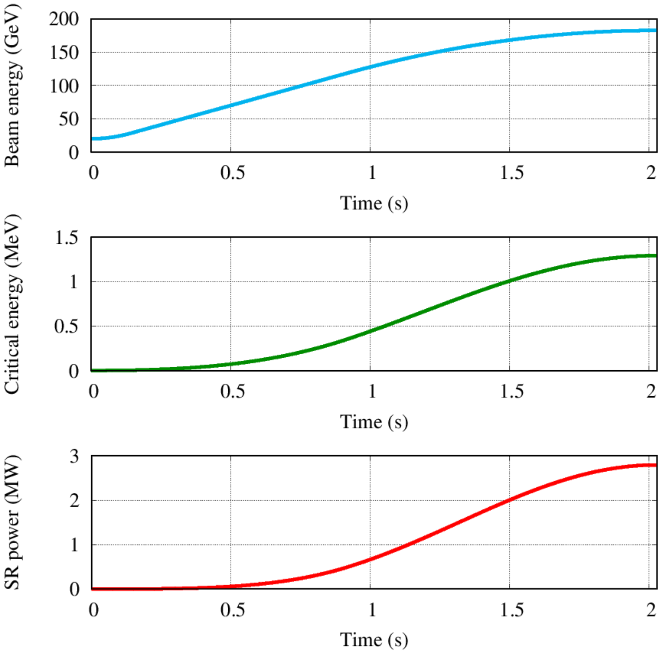
For the ZH operation mode the lead shielding is currently sufficient for the external beam. For the internal beam, an **improved shielding scheme is necessary** to reduce the does levels at the beam level.

At ABS Position

The photons stoppers prove to be efficient at the external beam, reducing the dose level to **<10kGy/year at the cable tray** locations. On the opposite side, the excessive dose levels are still seen at the internal beam level.



High energy booster: operation mode and geometry



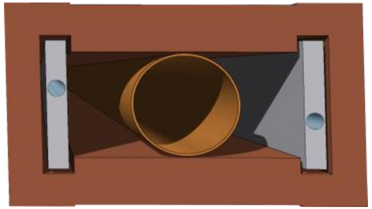
Flat-top not shown

- Booster ramps energy from **20GeV-182.5GeV** (ttbar)
- Energy is sometimes as high as collider energy, but beam current is significantly lower → less impact expected
- Magnets (**2cm and 4cm thick iron yoke**) have one circular, 1.5mm thick, **Cu VC with a 60mm** diameter that is alternating filled with e+/e-. Along the booster, there are **no absorbers**. Additionally, the **coils** are made from **Aluminum** which has worse absorption properties than copper
- What is the effect of those changes for the radiation load?

- *Preliminary study* to see general dose levels → model with only one dipole

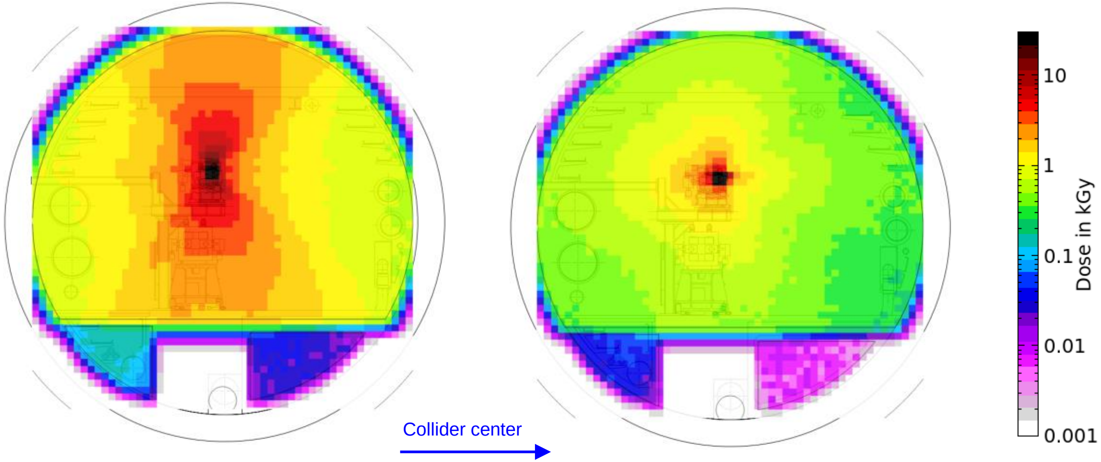
Booster: cumulative dose in the tunnel

2cm yoke



4cm yoke

Different scale as to other dose plots



4cm thick yoke option is **preferable** in terms of radiation load (up to ~300Gy/year).

For the **2cm option**, around **1kGy** is reached in the vicinity of the cable trays, which would account for **~10% of the total acceptable dose**. This would lead to even more constraints for the radiation shielding in the collider magnets as the dose levels are adding up.

Summary and Outlook

- **Radiation shielding is inevitable for both ZH and ttbar operation modes**; it is highly desirable that the shielding is installed for all operation modes to keep the dose levels as low as possible
- A first shielding design was proposed, which shows a promising reduction of the dose levels, but a **further optimization** (i.e. further reduction) is required in order to allow to achieve dose values **below 10kGy/y** at the upper cable trays (which should allow the use of Cat 1 cables)

- Furthermore, a strategy for the **electronics in the tunnel** has to be elaborated; this might include **locally shielded areas**, which enable a further reduction of the dose values for mini-racks

- Dose levels from the **booster** are most likely **negligible** if 4cm yoke is used

Thank you
for your attention.