Synchrotron Radiation in the FCC-ee arcs – update to latest accelerator design

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With many thanks to J. Bauche, L. van Freeden, R. Kersevan, M. Hofer, M. Ady, F. Valchkova-Georgieva

28.02.2024

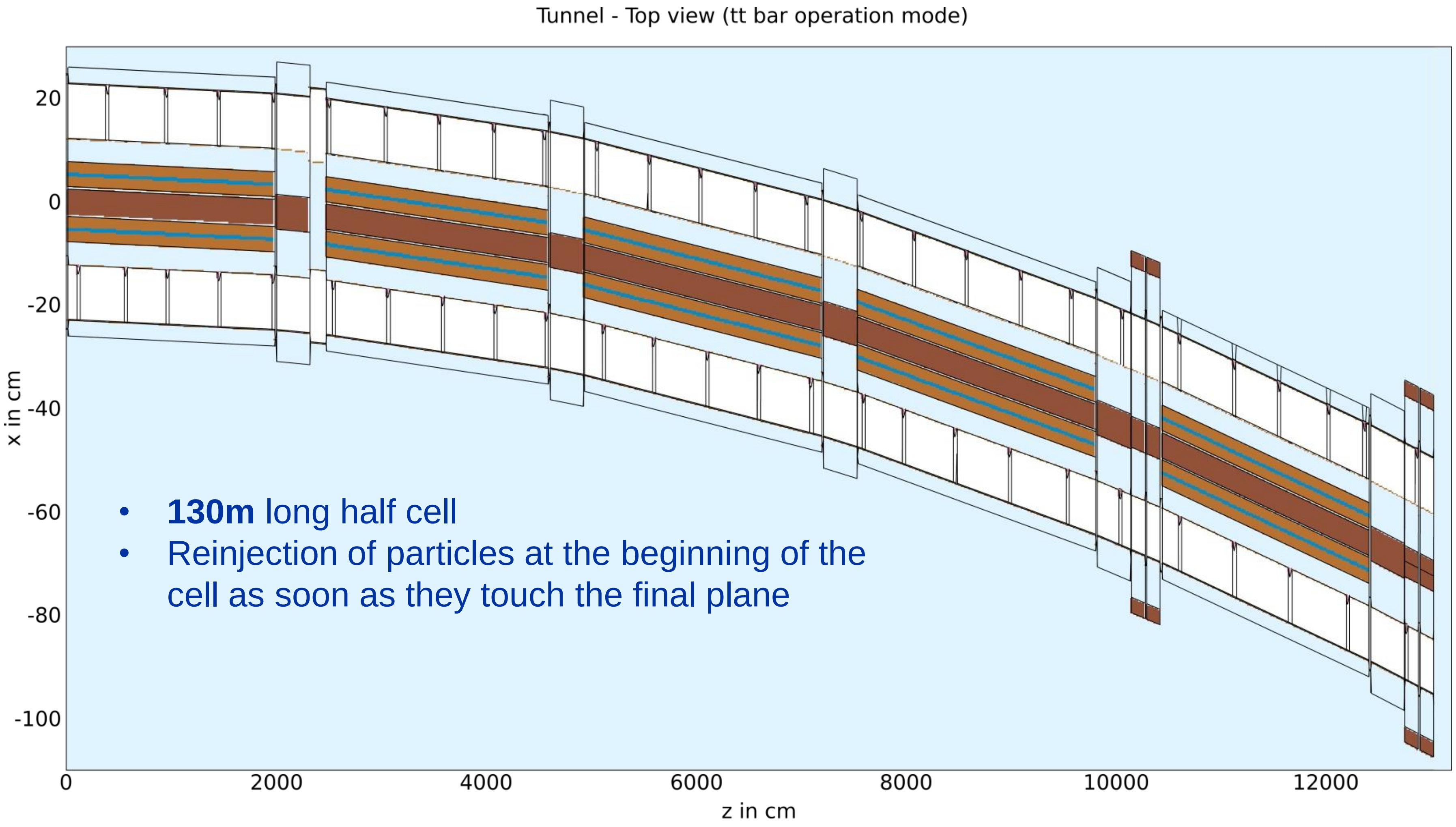
Aim of updated studies

- **Studies presented until end of 2023 date back to input from 2020, which is not really representative anymore**

- **Implemented (not so) recent changes:**
  - Beam separation: *30cm to 35cm*
  - Vacuum chamber diameter: *70mm to 60mm* → compromise for less volume and acceptable performance
  - New absorber design (thanks to R. Kersevan)
  - More recent optics file:
    - Dipole lengths: *19m, 21m, 22m* (which can consist of several dipoles connected to each other) → sustainable to work with three different dipole lengths?
    - Often only 15cm between the magnets (magnetic length!) → *sufficient space between the components when return coils added?*

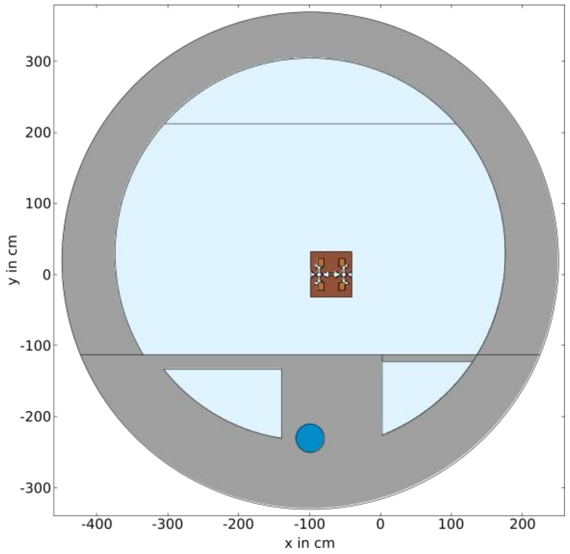
- **Goal:** perform simulations for all operation modes and develop the necessary for shielding.
  - **Today: Radiation load for ttbar (182.5GeV, 5mA) and Higgs (120GeV, 26.7mA). Baseline absorbers and conceptual shielding design**

Geometry layout



- **130m** long half cell
- Reinjection of particles at the beginning of the cell as soon as they touch the final plane

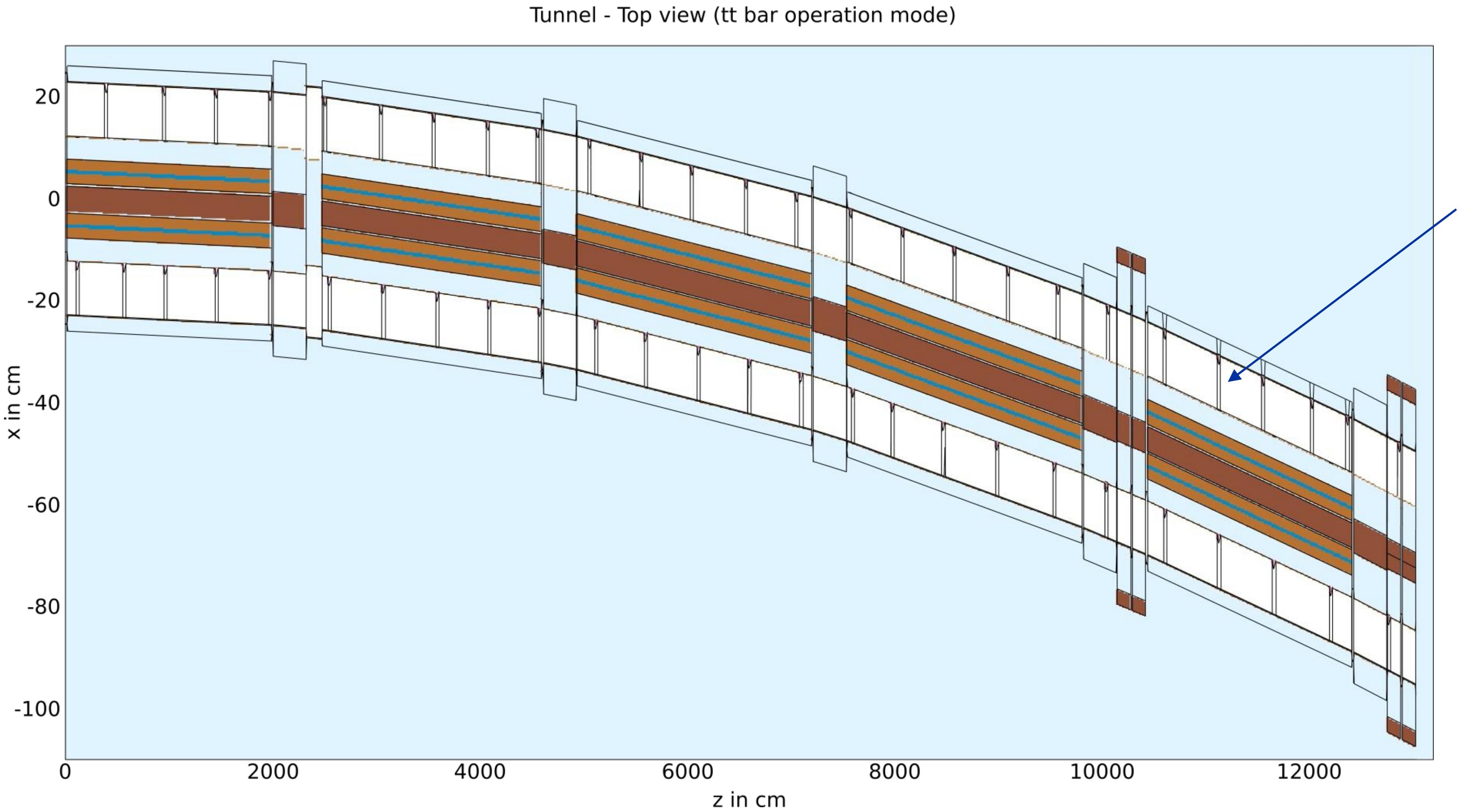
Tunnel – cross section



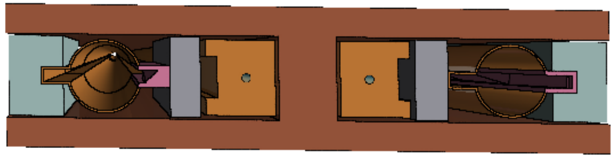
- No detailed design with cable trays, extraction pipes, etc.
- No alcoves yet

Thanks to F. Valchkova for the tunnel layout

Geometry layout - dipoles



Dipole

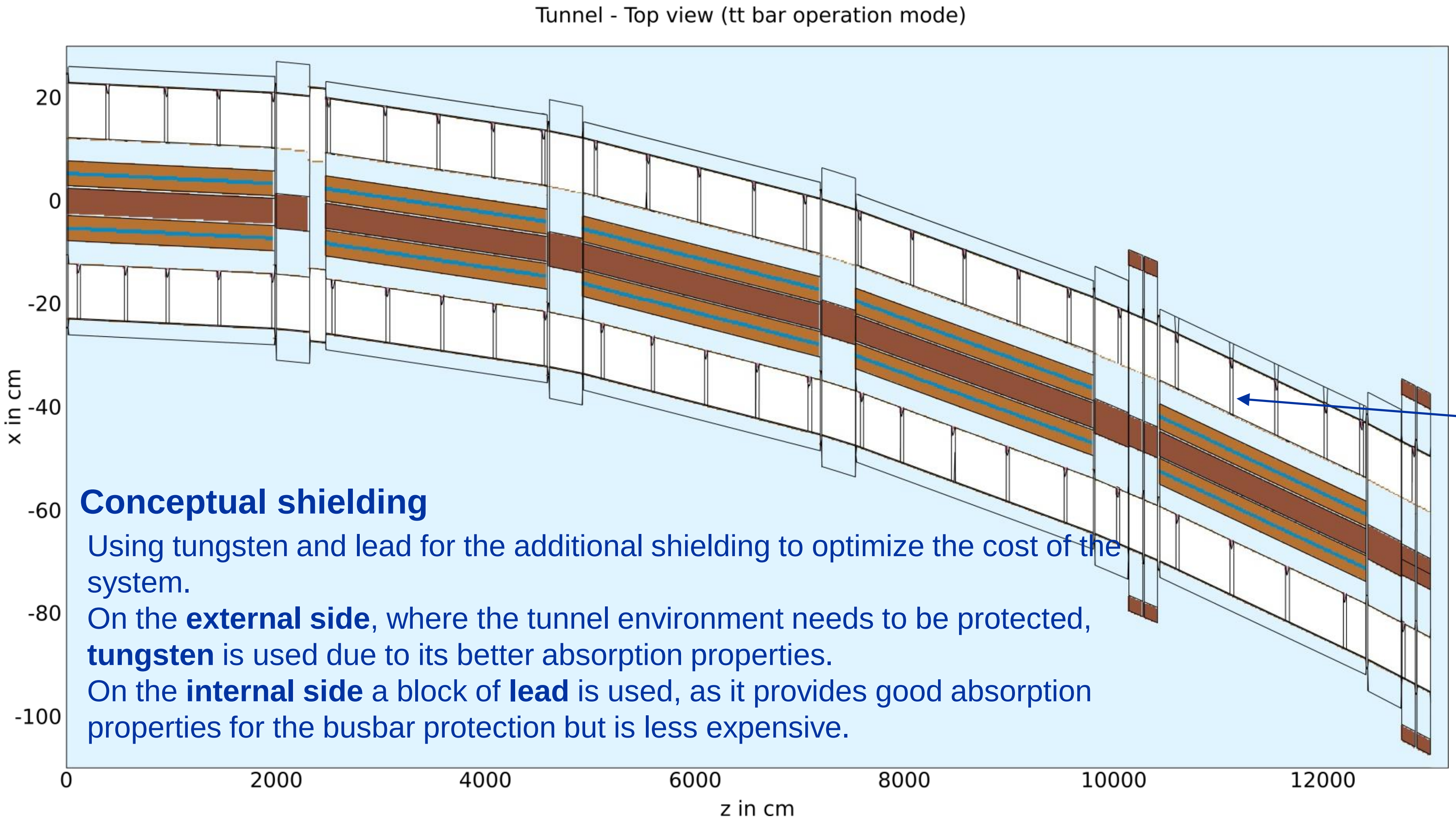


- 5 dipoles in half cell
- Iron yoke, copper busbars with water cooling
- Two different absorber schemes tested:

1) Only absorbers (pink)
2) Absorbers plus tungsten shielding on the external side and lead on the internal side

Thanks to J. Bauche and L.v. Freeden for the magnet design

Geometry layout – absorbers



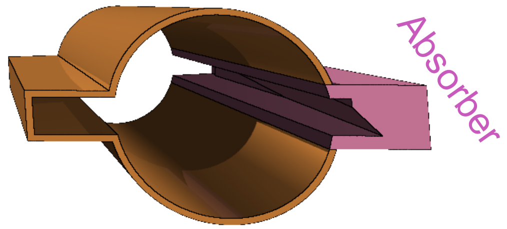
Conceptual shielding

Using tungsten and lead for the additional shielding to optimize the cost of the system.
On the **external side**, where the tunnel environment needs to be protected, **tungsten** is used due to its better absorption properties.
On the **internal side** a block of **lead** is used, as it provides good absorption properties for the busbar protection but is less expensive.

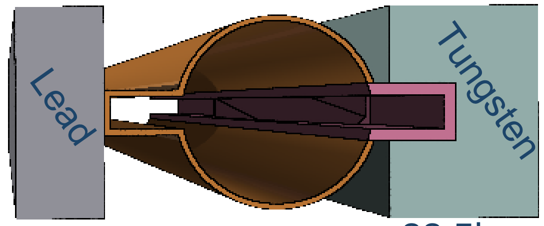
Absorber (ABS)

- Approximation of complex geometry
- Weight close to the weight of the actual absorber prototypes (1kg)
- CuCrZr, 30cm length
- 60cm length for conceptual shielding
- 52 ABS[1)] for both beams

ABS



ABS + concept. shield

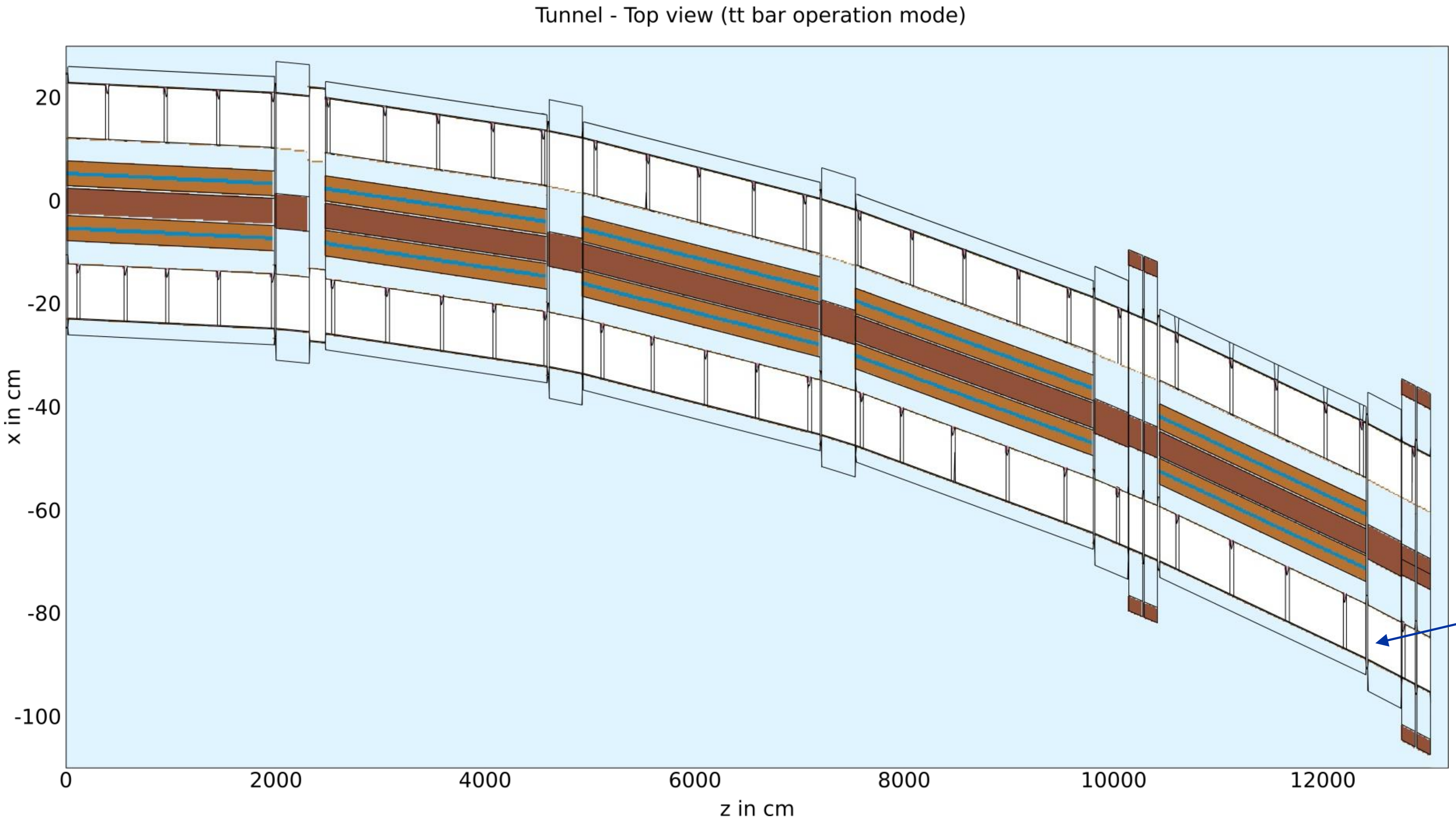


13.3kg

33.5kg

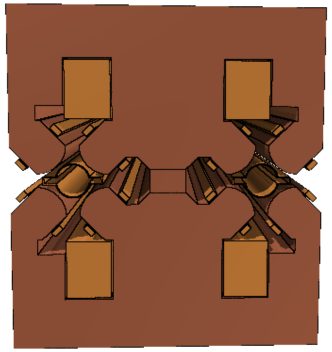
1) In this geometry there are only 50 ABS, as the last two would have been placed in an MS with too much space constraints

Geometry layout – quadrupoles

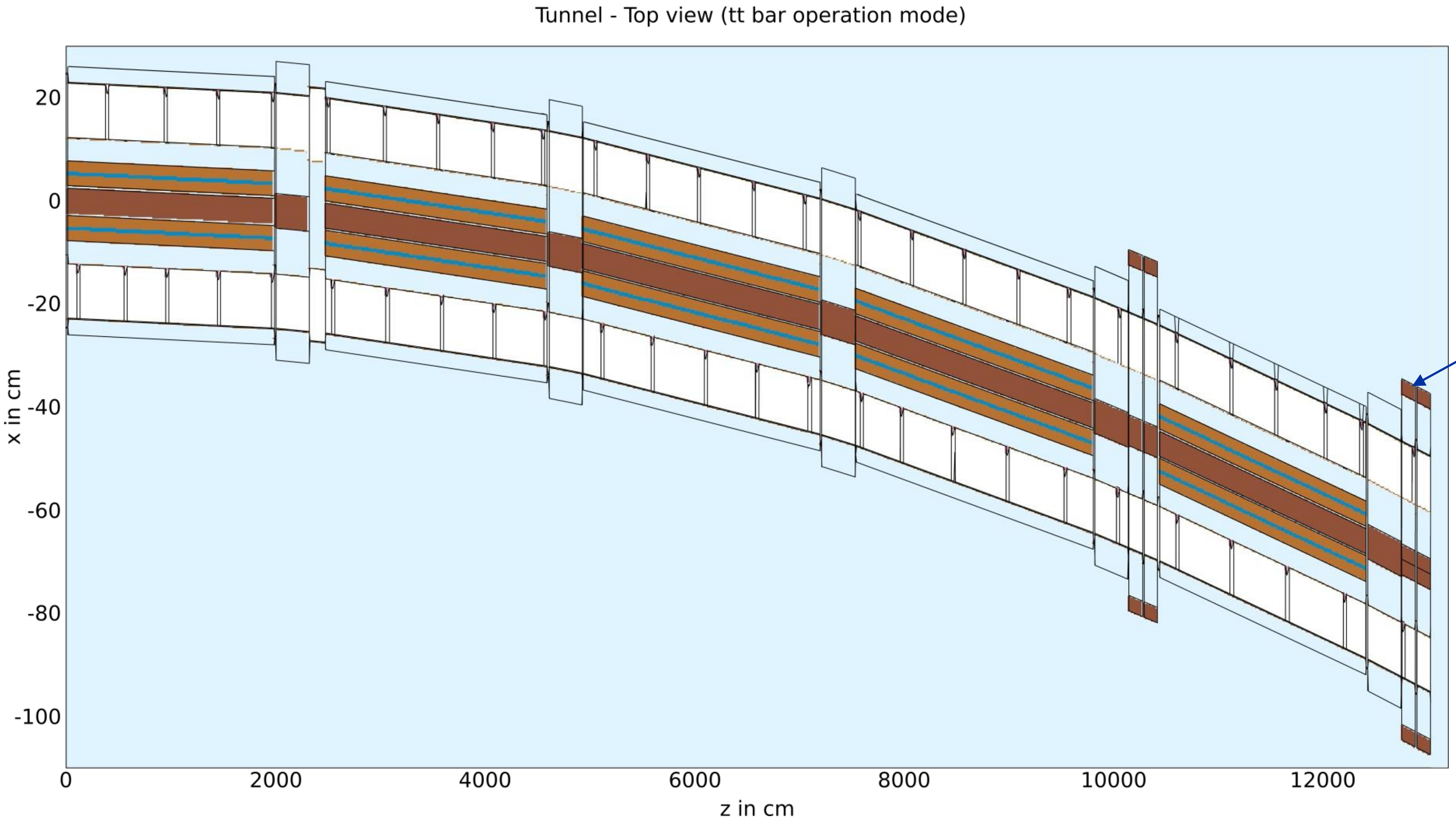


Quadrupole

- Implemented without return coils
- Drift spaces between MQ and MB sometimes only 15cm
- One MQ has ABS placed in it
- 5 MQs in half cell

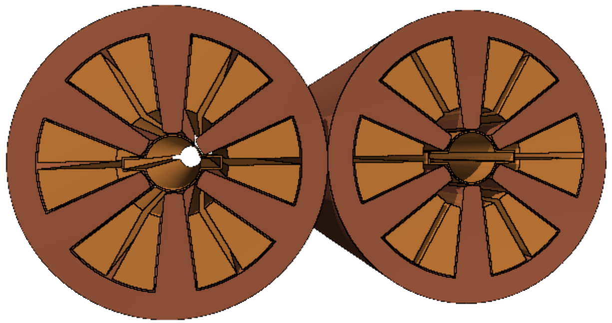


Geometry layout – sextupoles



Sextupole

- 2x2 MS in the half cell
- 1.3m length



Absorbed power per half cell for the *baseline layout* – Higgs vs ttbar

	Higgs	ttbar
MBs (w/o VC)	27.1kW	28.8kW
MB VC	3.4kW	4kW
MQs (w/o VC)	1.5kW	1.7kW
MQ VC	0.4kW	0.4kW
MSs (w/o VC)	0.01kW	0.04kW
MS VC	0.003kW	0.02kW
ABS (w/o VC)	118.3kW	112.8kW
ABS VC	4.8kW	4.4kW
Tunnel (Air, Concrete)	8.7kW	12.3kW
TOTAL	**164.2kW**	**164.4kW**

- Total power of half cell: 164kW (~100kW of SR for full ring)
- By design, the total power distribution is comparable for both operation modes, but the power sharing is different.

- **Power deposition on the absorbers**:
  - Higgs: 75% of total power
  - ttbar: 71% of total power

  → Absorbers are more efficient for Higgs

- The *impact on the tunnel environment* should be studied closely, as 5% (Higgs) and 7% (ttbar) of the total power are deposited there.

- The absorbed power on the vacuum chambers is significant. It should be understood, if such values are sustainable

Additional shielding: tungsten block on the external beam absorbs up to 0.7kW, for the other blocks the absorbed power goes up to 0.3kW.

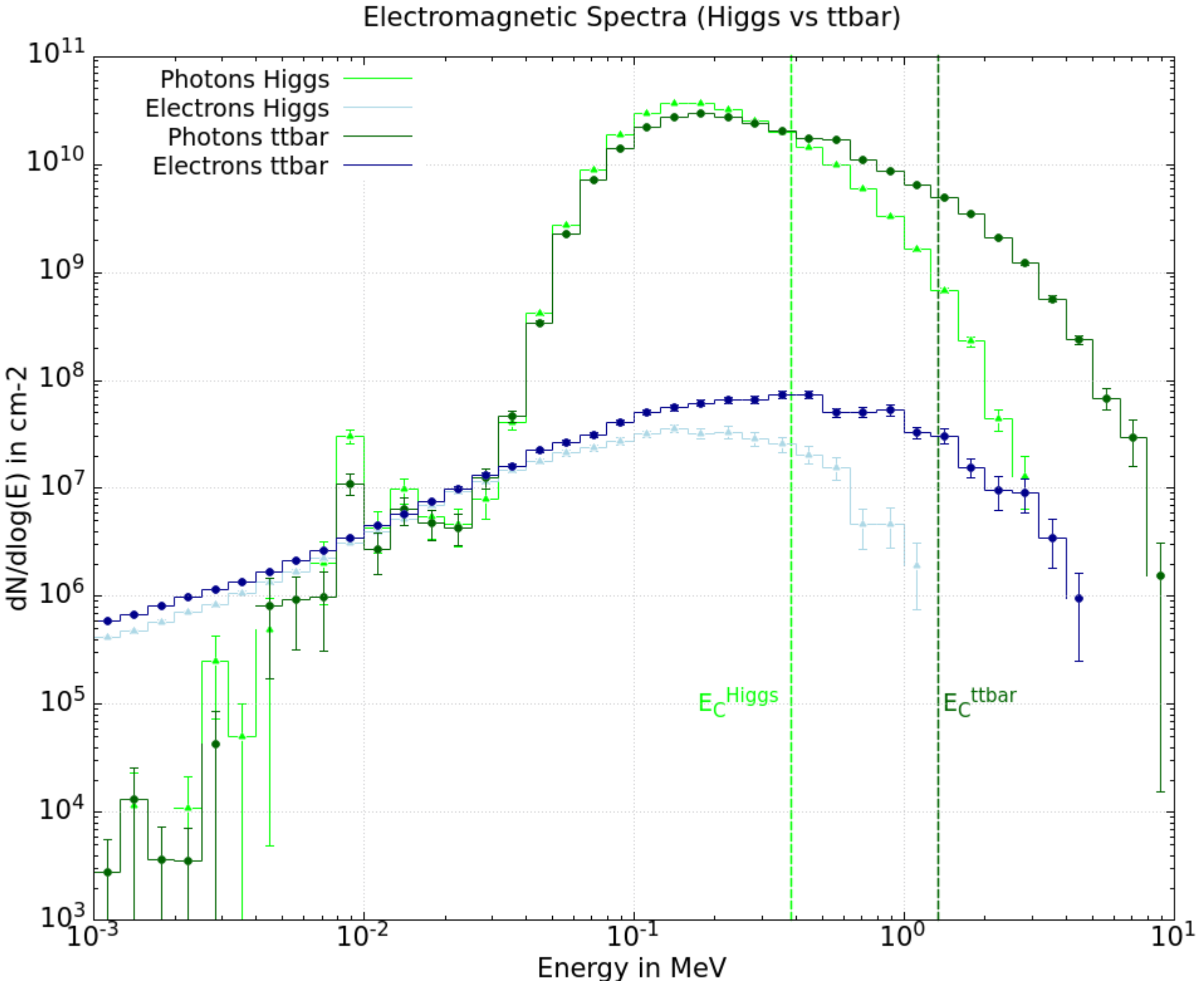
Electron and photon spectrum in the tunnel

- Critical energy: half of the power is emitted with particles below this energy and other half above this energy

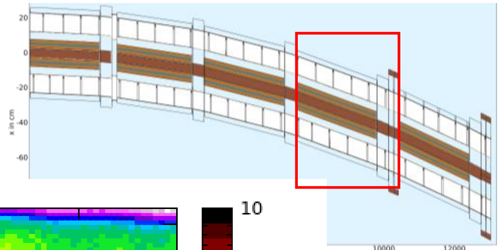
    - Higgs: **0.382MeV**
    - ttbar: **1.34MeV**

    → ttbar mode is more penetrating
- Spectrum is normalised to beam current

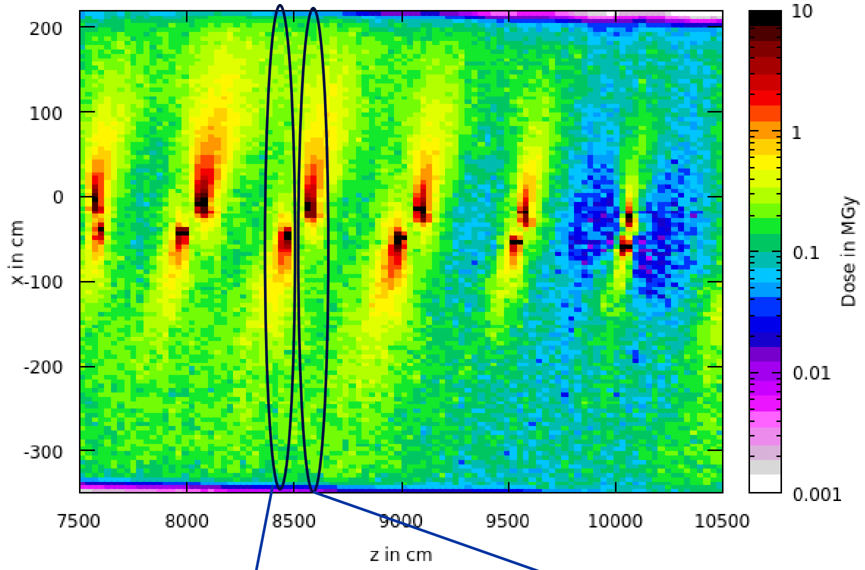
- Less electrons visible for Higgs, as the absorbers are more efficient due to the softer SR



Dose levels in the tunnel w/o add. shield.



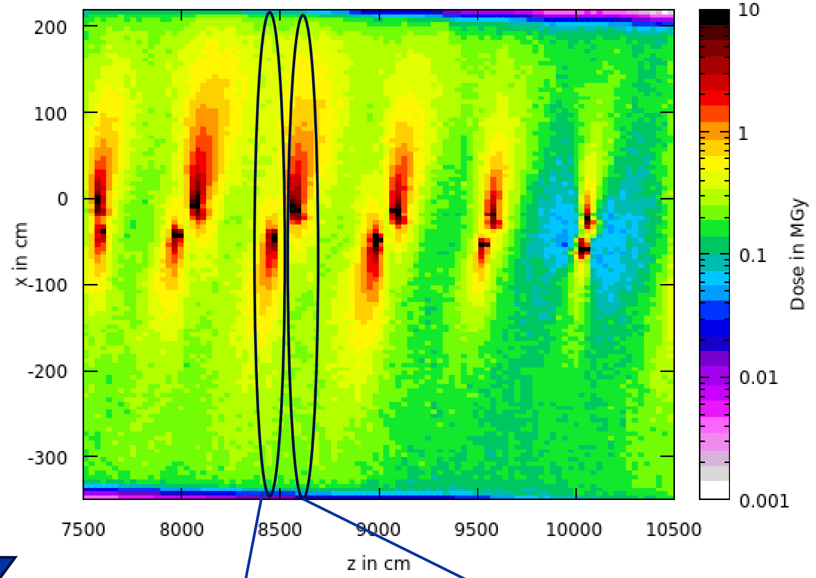
Higgs

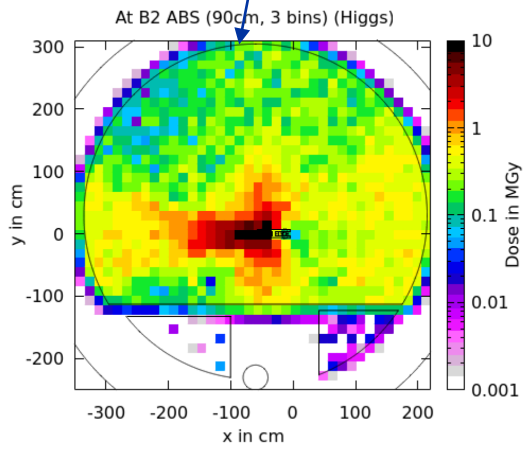


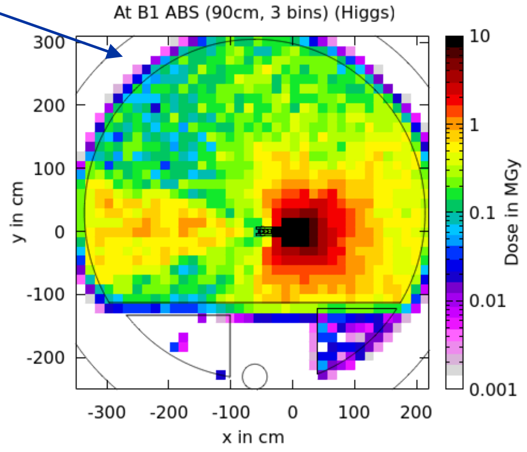
Hot-spots due to ABS in the longitudinal position of the absorbers themselves.

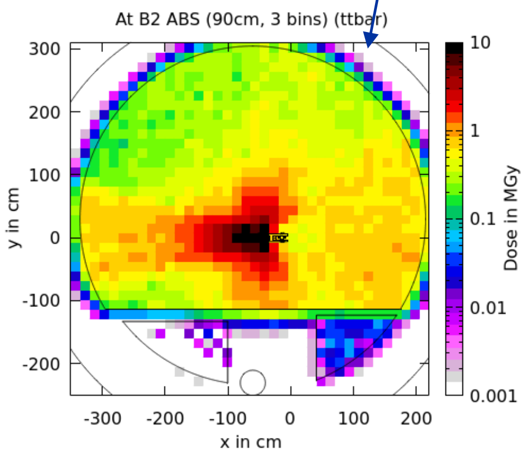
Higgs to ttbar: up to a factor of three difference → Higgs contribution is significant

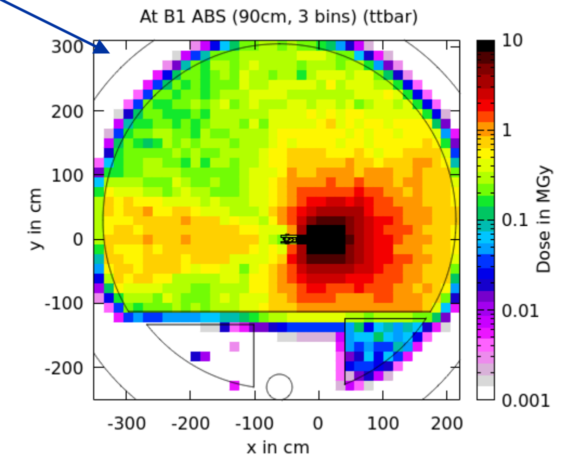
ttbar





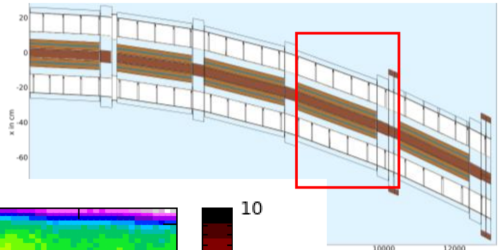




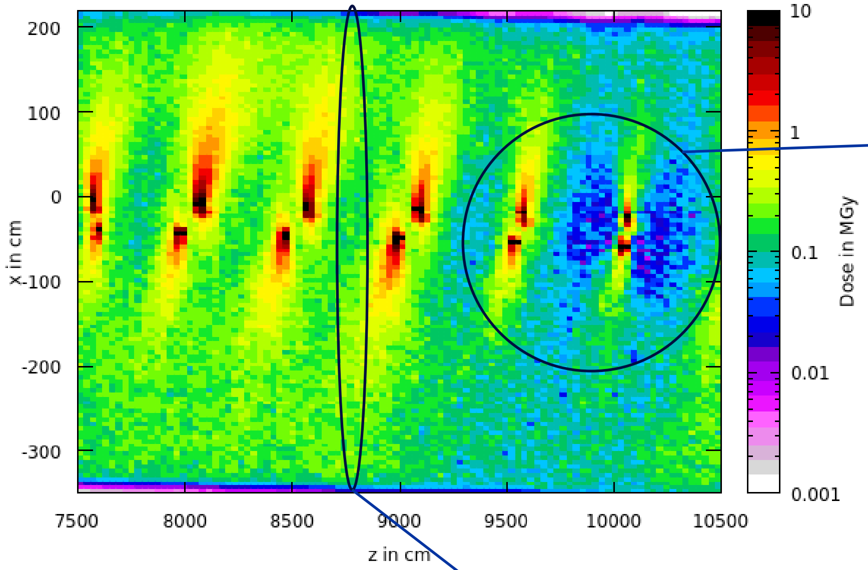


The dose levels are given for 10^7s of operation

Dose levels in the tunnel w/o add. shield.

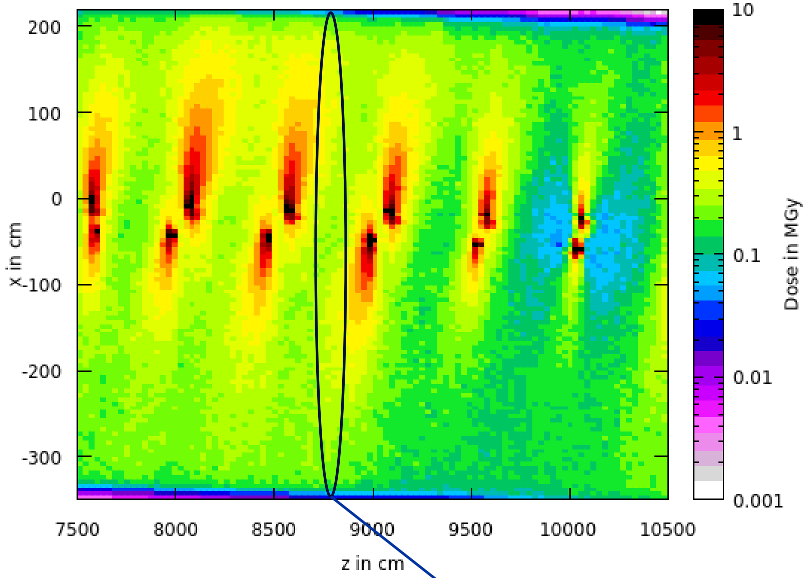


Higgs

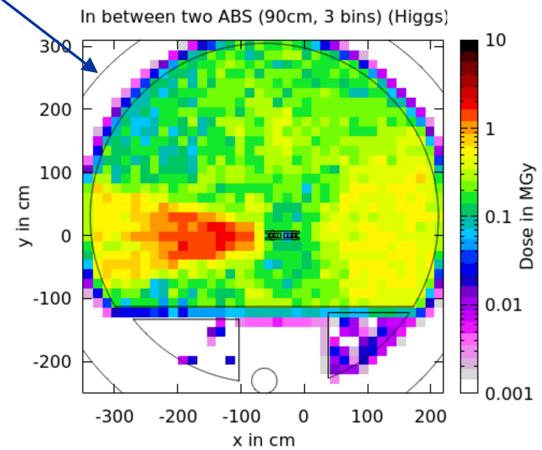


Areas of lower dose due to MQs and MS that provide a better shielding due to their geometry

ttbar

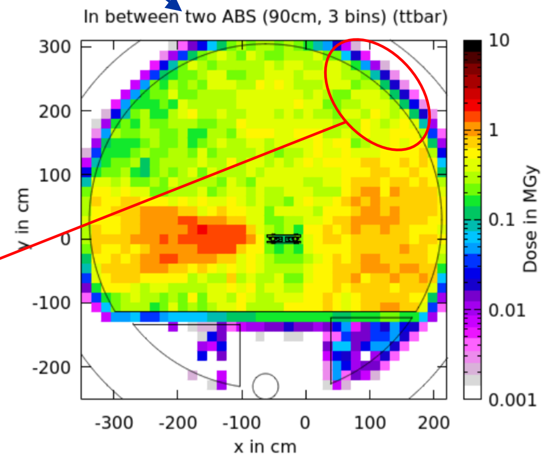


Like ttbar operation, substantial shielding is also required for the Higgs mode.



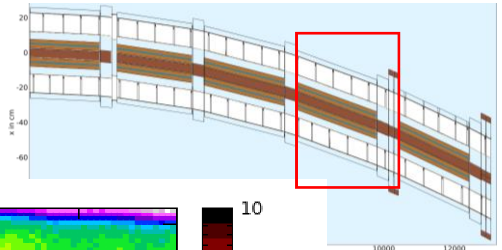
Dose levels in between the absorbers unacceptably high. Needs significant reduction of dose levels.

→ i.e.: Cables can withstand up to 300kGy, but we obtain up to 600kGy/year in the places where cables should go



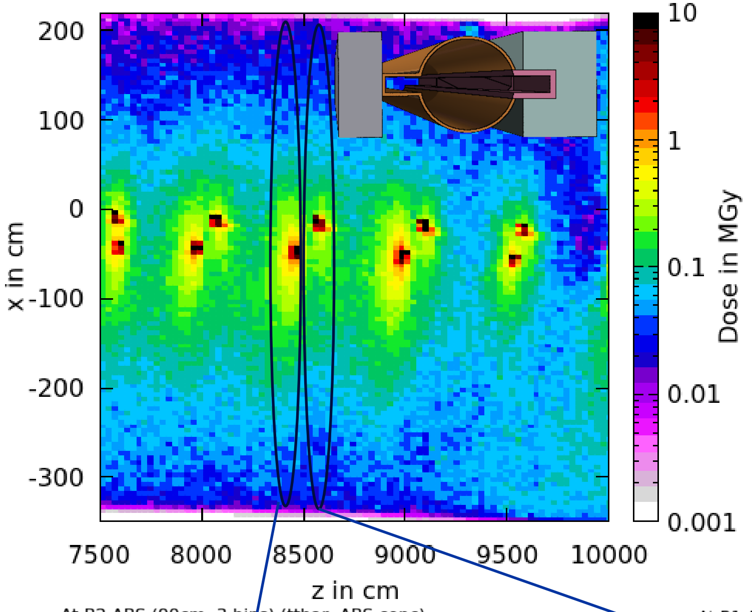
The dose levels are given for 10^7s of operation

Dose levels with added concept. shield.



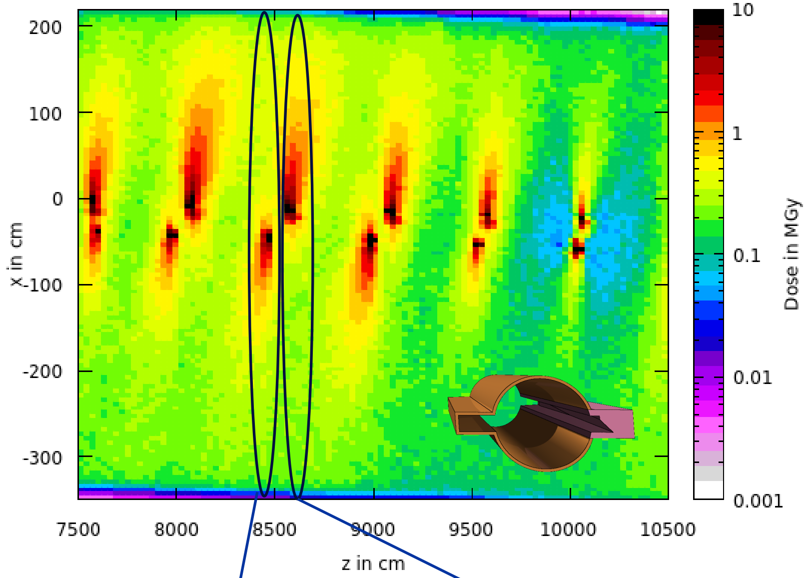
ttbar

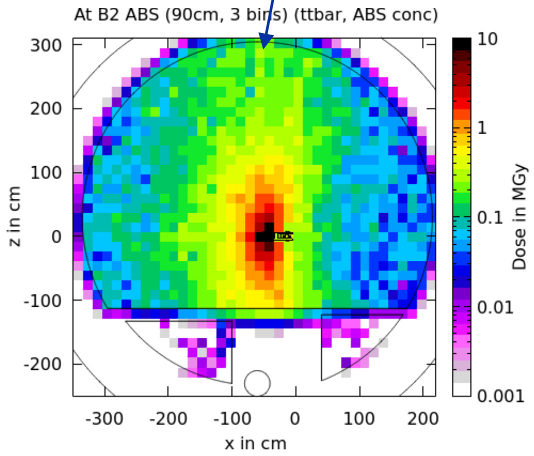
Conc. shield ttbar

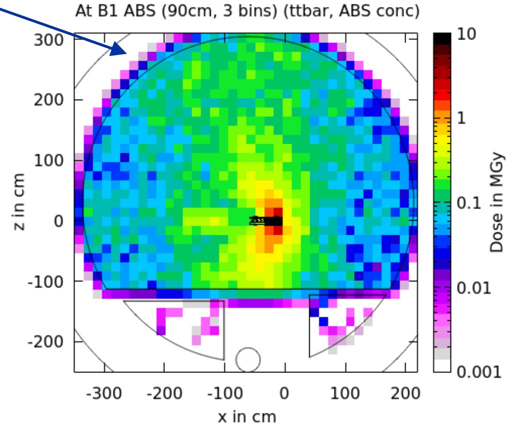


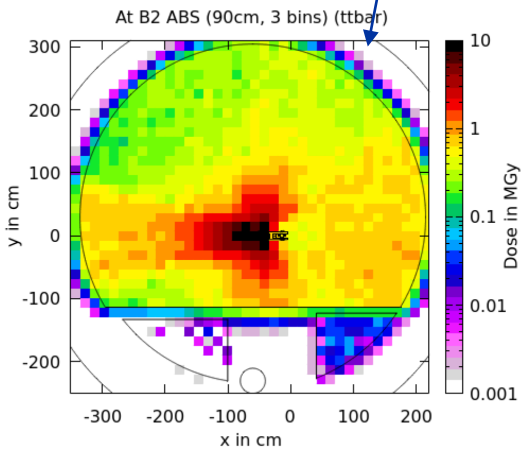
Significant dose reduction due to shielding around absorbers.

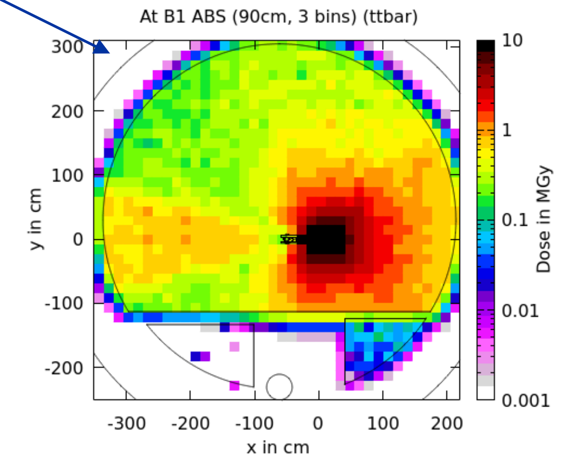
The additional shielding works **well** in the **horizontal plane**, but **more shielding** would be required **vertically**.





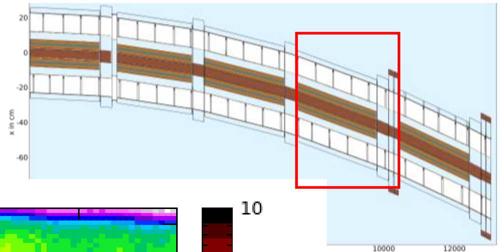




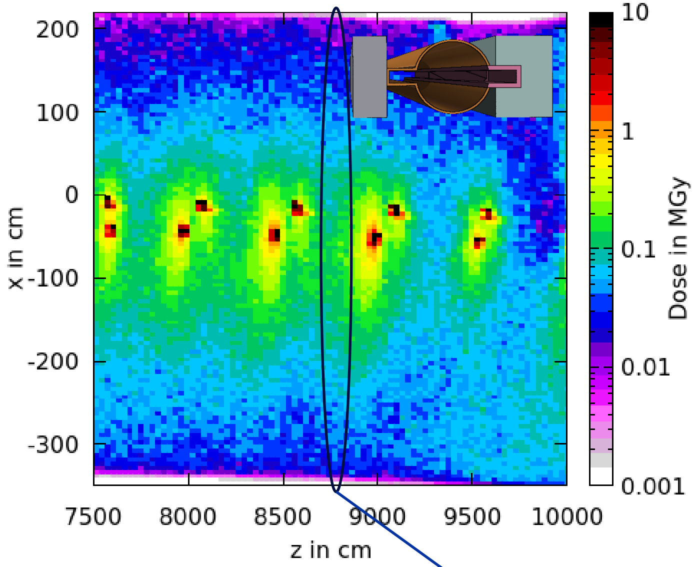


The dose levels are given for 10^7s of operation

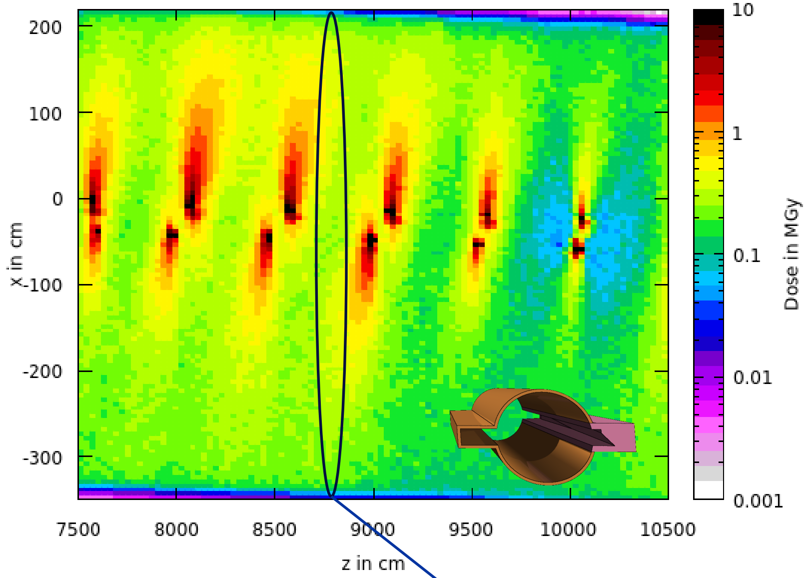
Dose levels with added concept. shield.



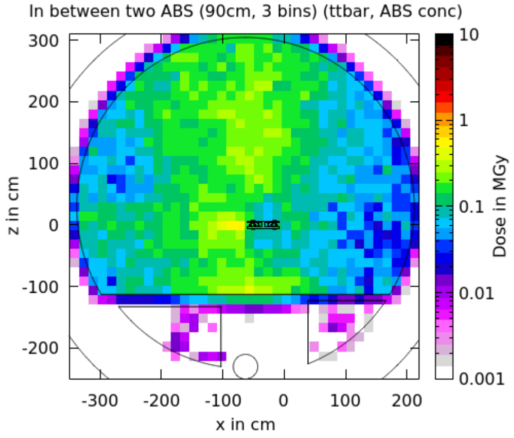
Conc. shield ttbar



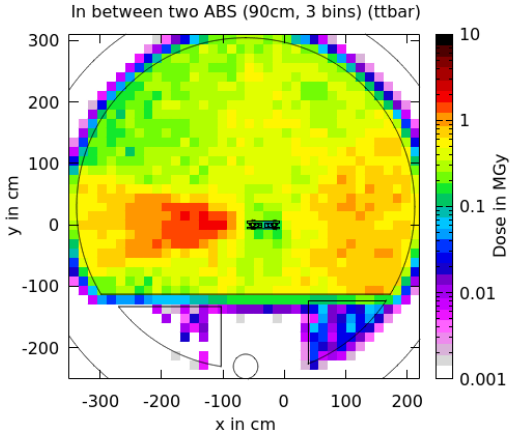
ttbar



The conceptual shielding leads to a **significant reduction** in the dose levels.

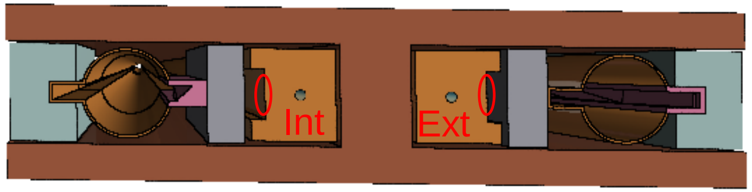


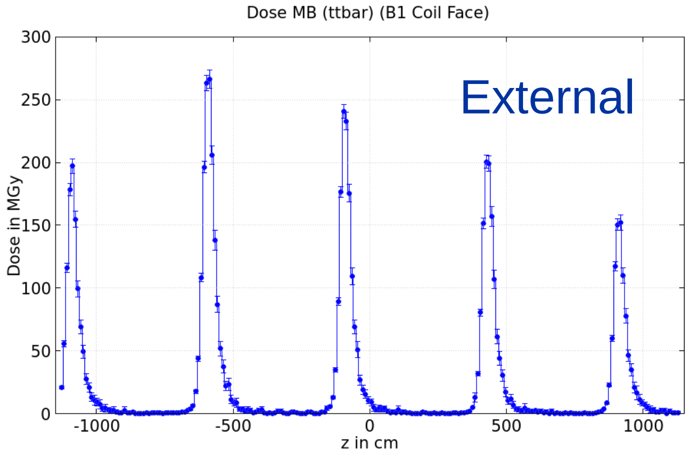
Still, a more efficient shielding is needed to achieve sustainable dose levels for operating the machine several years.



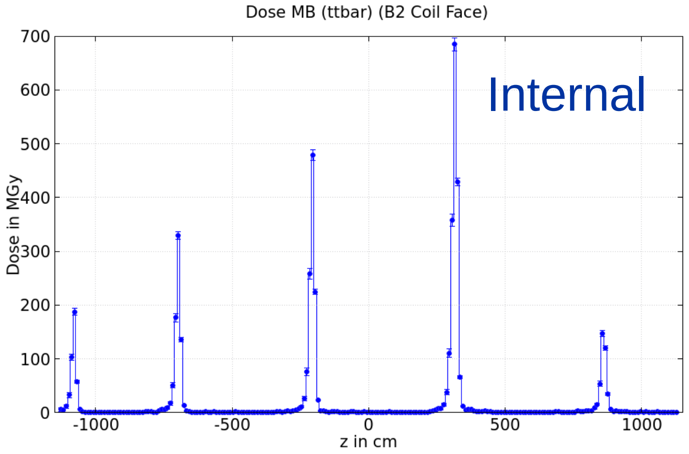
The dose levels are given for 10^7s of operation

Dose on the MB busbars – ttbar



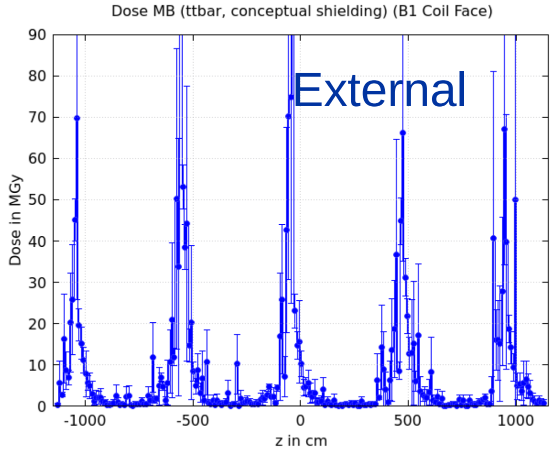


Absorber

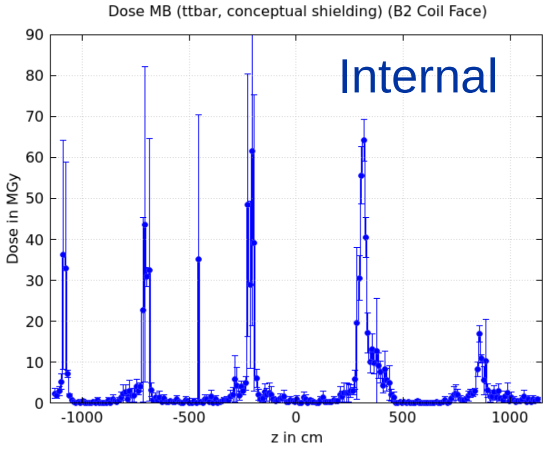


Coils protectable with a block of lead?

Dose is reduced by a few factors but not enough to use organic insulation material.
Due to space constraints, it is difficult to use more material between the vacuum chamber and the busbars.



Conceptual shield.



The results for the conceptual shielding do not provide a definitive number yet, as the statistical error is still too large! It still allows for a first estimate.

The dose levels are given for 10^7s of operation

Conclusion

- Using the basic absorber layout, the observed dose levels in the tunnel and on the dipole busbars are too high to withstand operation of several years. This is valid for the ttbar mode as well as for the Higgs operation mode.

- A conceptual additional shielding has been tested leading to a significant reduction in the dose levels. However, a more refined shielding concept needs to be developed to fulfill all the requirements acceptable dose levels for systems in the tunnel.

- Need to study the possible integration of the shielding with TE/MSC and TE/VSC (including the need of extra supports, active cooling, access to the vacuum chamber for NEG coating and bake out etc.)

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