

# Radiation Load Studies for the FCC-ee Positron Source with a SC Matching Device

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Acknowledgments to B. Auchmann, I. Chaikovska, J. Kosse, Y. Zhao,...

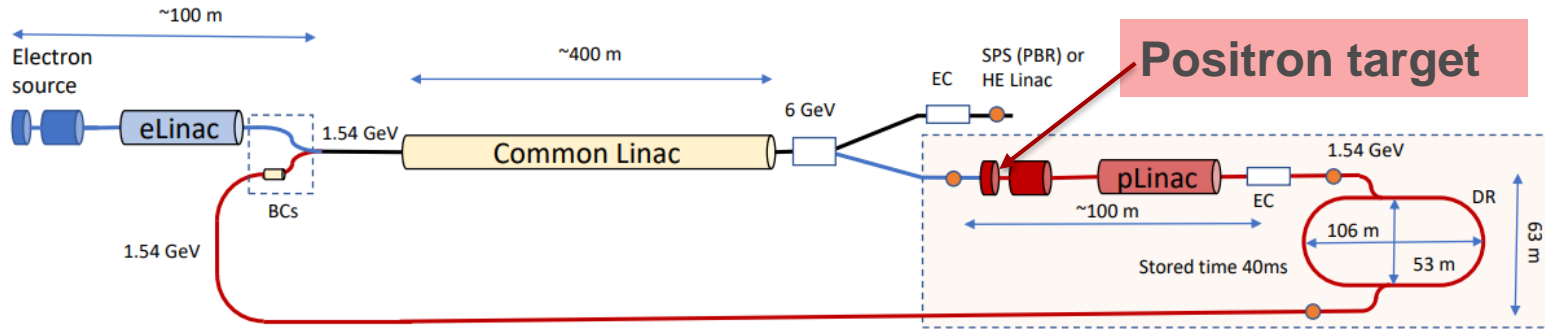


# Agenda

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1. Motivation
2. Layout & Parameters
3. Instantaneous Effects
4. Long Term Radiation Effects
5. Outlook & Conclusion

# Concept and layout

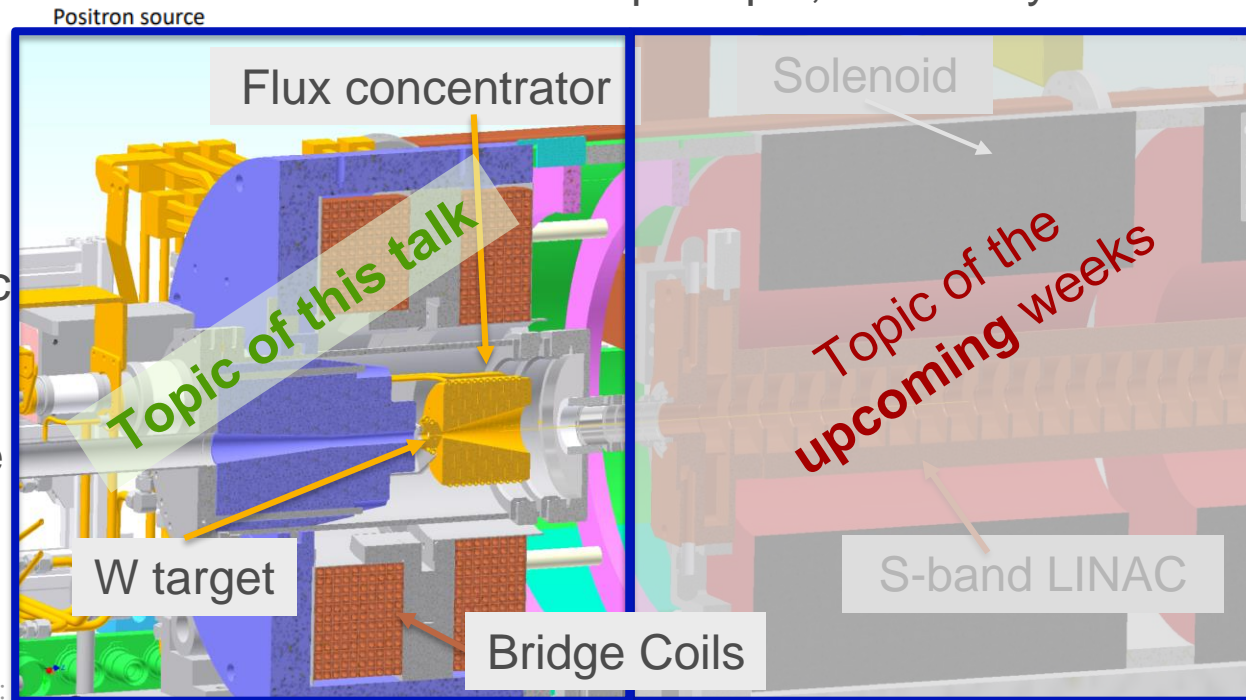


**SuperKEKB Positron Source:**  
Same principle, similar layout

FCC-ee Injector Design Coordination meeting 08:  
<https://indico.cern.ch/event/1133621/contributions/4756873/attachments/2418347/4139305/FCC%20injector%20schematic%20layout%2031032022.pdf>

## FCC-ee:

- **Superconducting (HTS) matching device** considered as one of the design options, to achieve higher magnetic fields → higher positron yield
- Similar source will be implemented at PSI in the P<sup>3</sup> experiment first, before it will be implemented in FCC-ee
- **Goal** of the simulations: are the radiation levels on the target and the **superconducting coils feasible**? Any unexpected **showstoppers**?



FCC Week 2021 (I. Chaikovska):  
[https://indico.cern.ch/event/995850/contributions/4413337/attachments/2273779/3862159/FCCweek2021\\_positrons30062021.pdf](https://indico.cern.ch/event/995850/contributions/4413337/attachments/2273779/3862159/FCCweek2021_positrons30062021.pdf)

# Physical background – 2 underlying principles

## 1. Bremsstrahlung

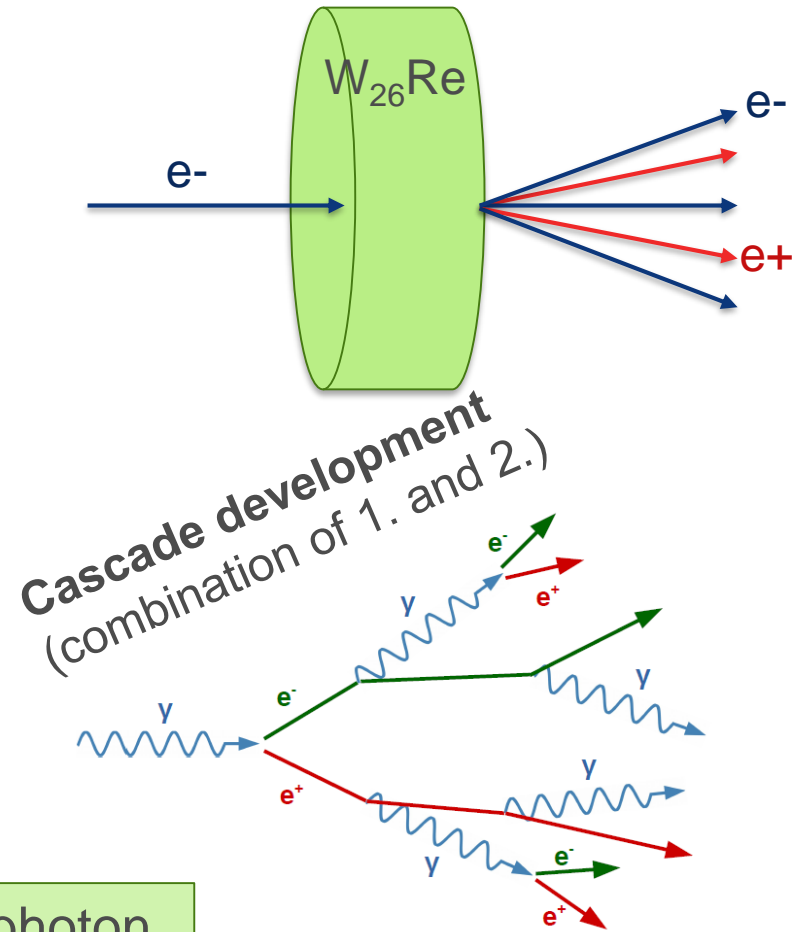
A charged particle that is slowing down emits electromagnetic radiation (a photon)  $\rightarrow$   $e^-$  is deviated in nucleus of atom

## 2. Pair production

In the field of a nucleus, a photon can produce an electron-positron pair, if its energy is  $>1.022\text{MeV}$  (combined rest energy of an electron and positron)

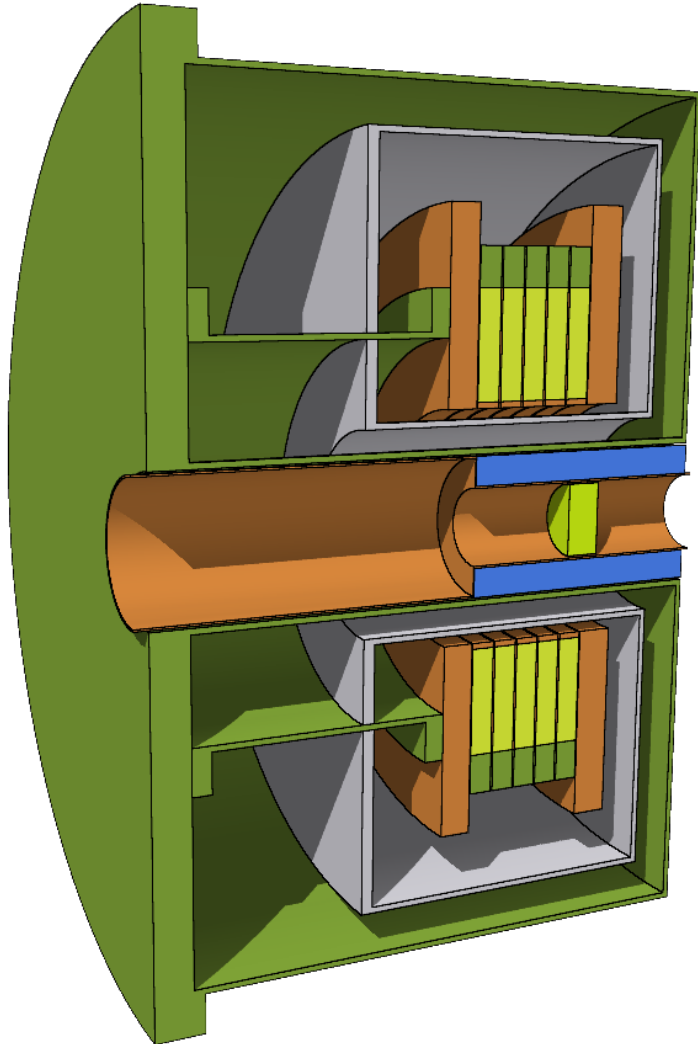
This process scales as  $\sigma \propto Z^2 \rightarrow$  high  $Z$  material favourable for positron target where a high positron yield should be achieved.

6GeV incoming  $e^-$  beam  $\rightarrow$  bremsstrahlung produces photon  $\rightarrow$  photon undergoes pair production  $\rightarrow e^-$  and  $e^+$  (and photons) leave the target



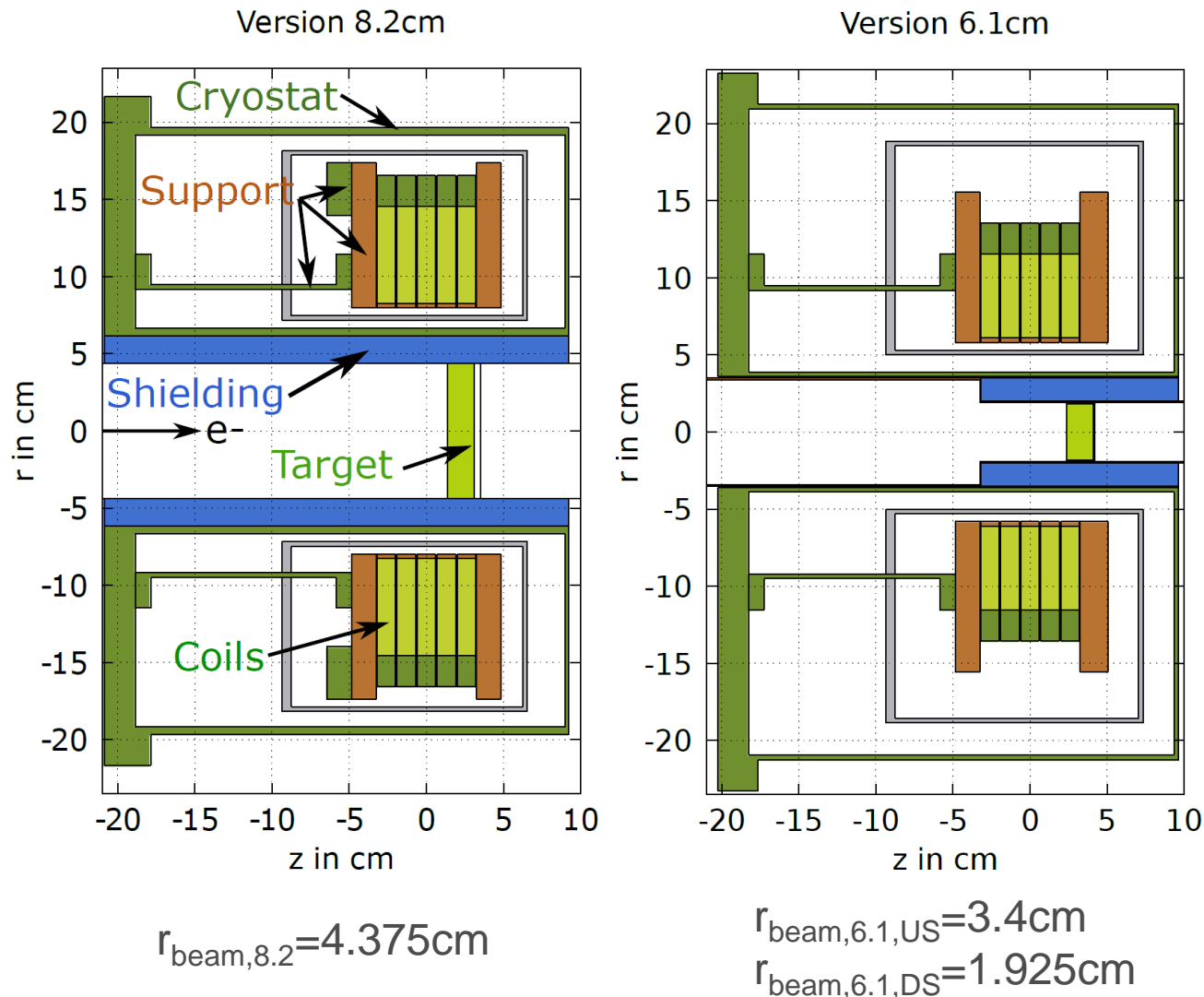
[https://indico.cern.ch/event/817601/attachments/1876118/3107117/25\\_07\\_2019\\_acceleratorbeamlossesl.pdf](https://indico.cern.ch/event/817601/attachments/1876118/3107117/25_07_2019_acceleratorbeamlossesl.pdf)

# Geometry overview



- Two (slightly) different geometries studied
  - Version 6.1 identical to the  $P^3$  positron source geometry, apart from the shielding
  - At FCC-ee a slightly larger geometry can be used, which is tested in Version 8.2
- Similar components, but different radial and longitudinal positions

# Geometry – technical details



Radial Coil Position	8.2cm	6.1cm
Shielding thickness	1.8cm	1.4cm
Target radial size	4.4cm	1.8cm
Target position in z	3.1cm	2cm

Part	Material
Target	W-26Re
Coils	HTS (YBCO)
Cryostat	Stainless steel
Shielding	Inermet180®
Support	Aluminum (grey)
Support	Copper (brown)

# Parameters for the FCC-ee positron target

- **Instantaneous effects**

- **Total deposited power (in W)**

- Determines the heat load on the elements

- **Power density (in mW/cm<sup>3</sup>)**

- Quenching of SC if it is too high

- **Long term radiation effects**

- **Dose (in MGy)**

- Deterioration of the material, especially organic materials

- **Displacement per atom (DPA)**

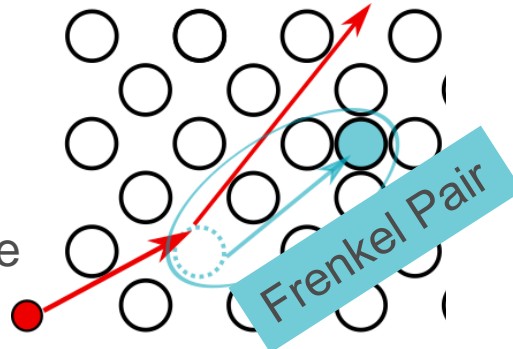
- Structural damage of inorganic materials
    - Dimensionless number proportional to the number of Frenkel pairs

Electron drive beam	6GeV
Beam size	0.5mm RMS
Repetition rate	200Hz
Bunches per pulse	2
e- charge per bunch	1.43nC
Beam Power	3.43kW
Target length	$5X_0=17.5\text{mm}$

**Filling scheme of collider:**

2.4% filling from scratch

97.6% at top-up injection with lower bunch charge



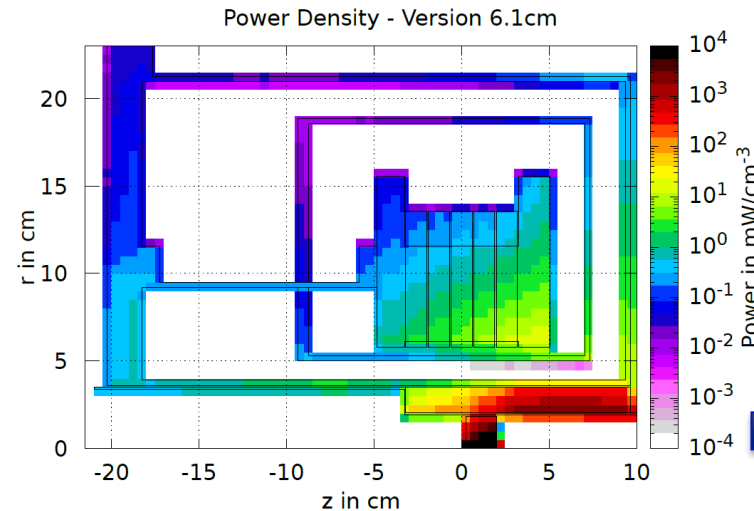
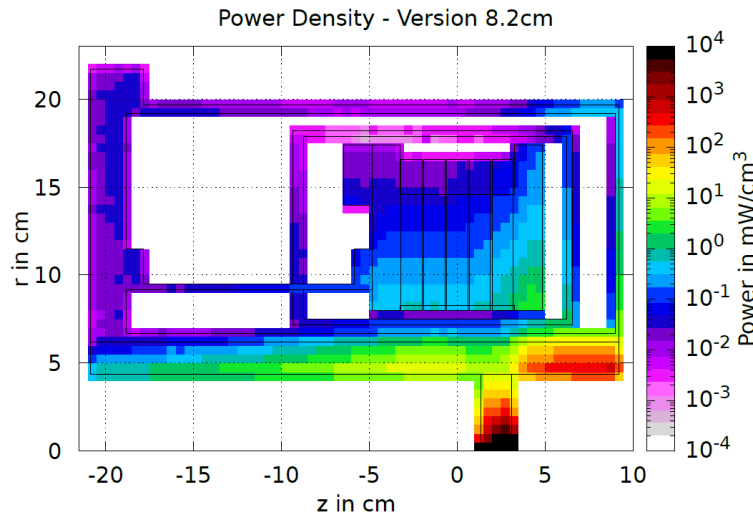
**“Top-up injection”:**

e-/e+ are constantly lost in collider ring, so collider is constantly refilled with particles (not possible/needed for hadron machines)

# Power on different elements

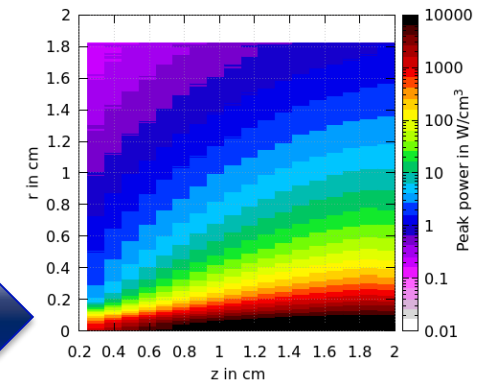
- Around 25% of e- beam power (3.43kW) are dissipated in the **target**
  - Higher heat load for V8.2, due to bigger radial size → self induced shielding effect
- **Shielding** stronger impacted due to position closer to the beam in V6.1
  - Thermo-mechanical studies needed Stationary target not excluded
- **Total:** around 2.3-2.5kW (3.43kW beam power) escaping the geometry → impacting RF? Shielding needed?
- Of the 2.3-2.5kW escaping power, 1.98kW is carried by electrons and photons

	V8.2	V6.1
Target	906W	869W
Shielding	69W	209W
Cryostat and coil support	3.3W	11.8W
Coils (1-5)	0.09-0.18W	0.27-1.25W
<b>Total</b>	<b>980W</b>	<b>1126W</b>

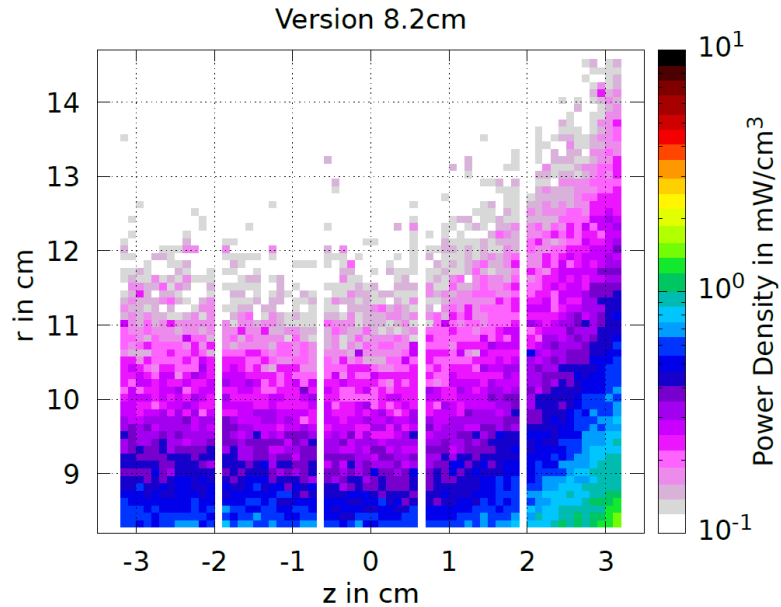


Up to 21kW/cm<sup>3</sup> at target exit face  
(values are similar for both cases)

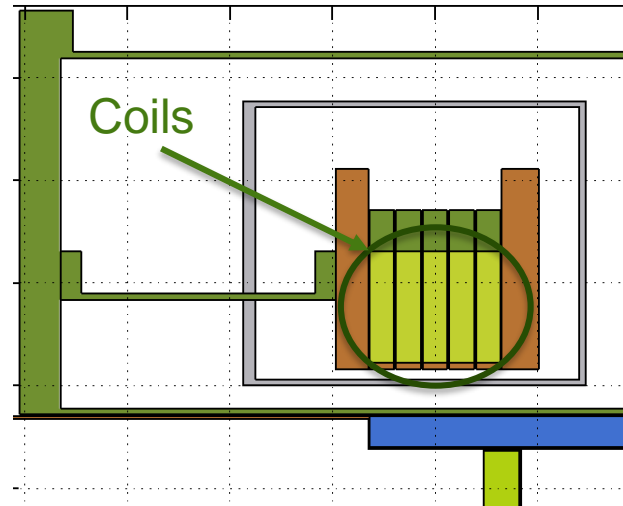
Zoom on target



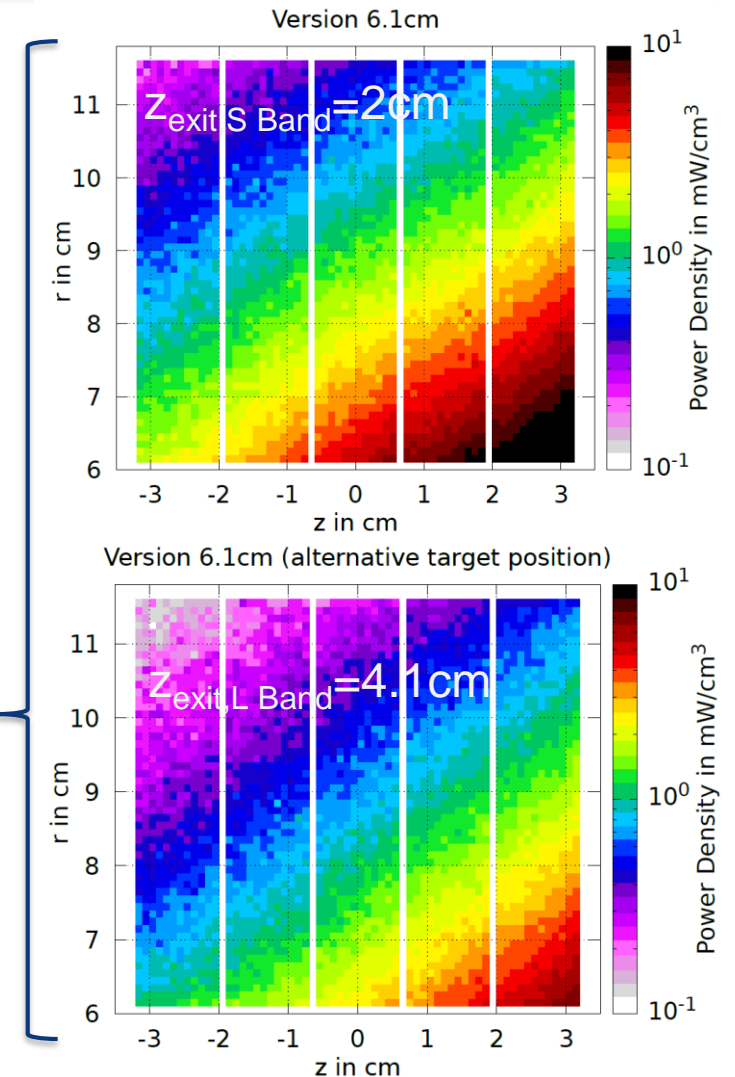
# Power density on coils



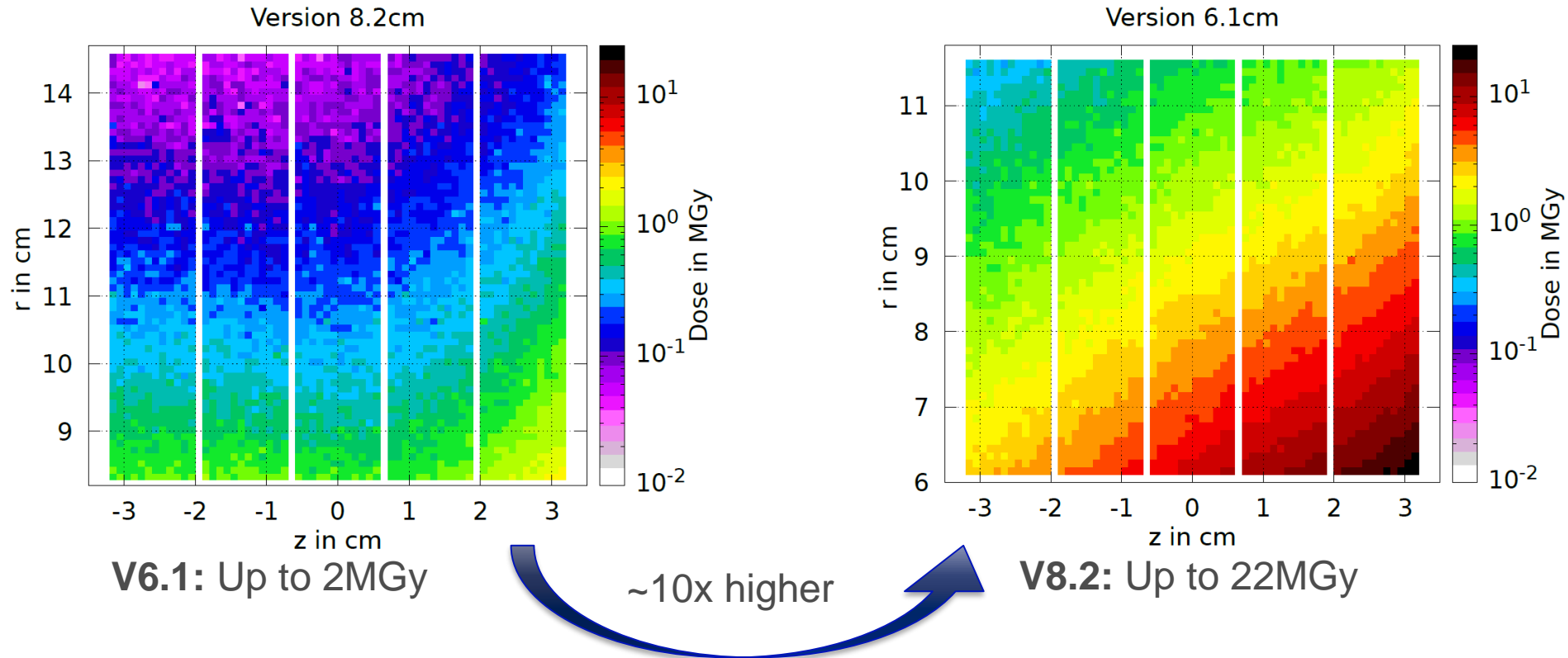
- Position further outside reduces the deposited power by an order of magnitude
- Gradient of deposited power per coil is strong  $\rightarrow$  favorable for heat transport  $\rightarrow$  considered safe



Target position matters  $\rightarrow$  must be taken in account for the decision for the following RF structure (L Band or S Band)



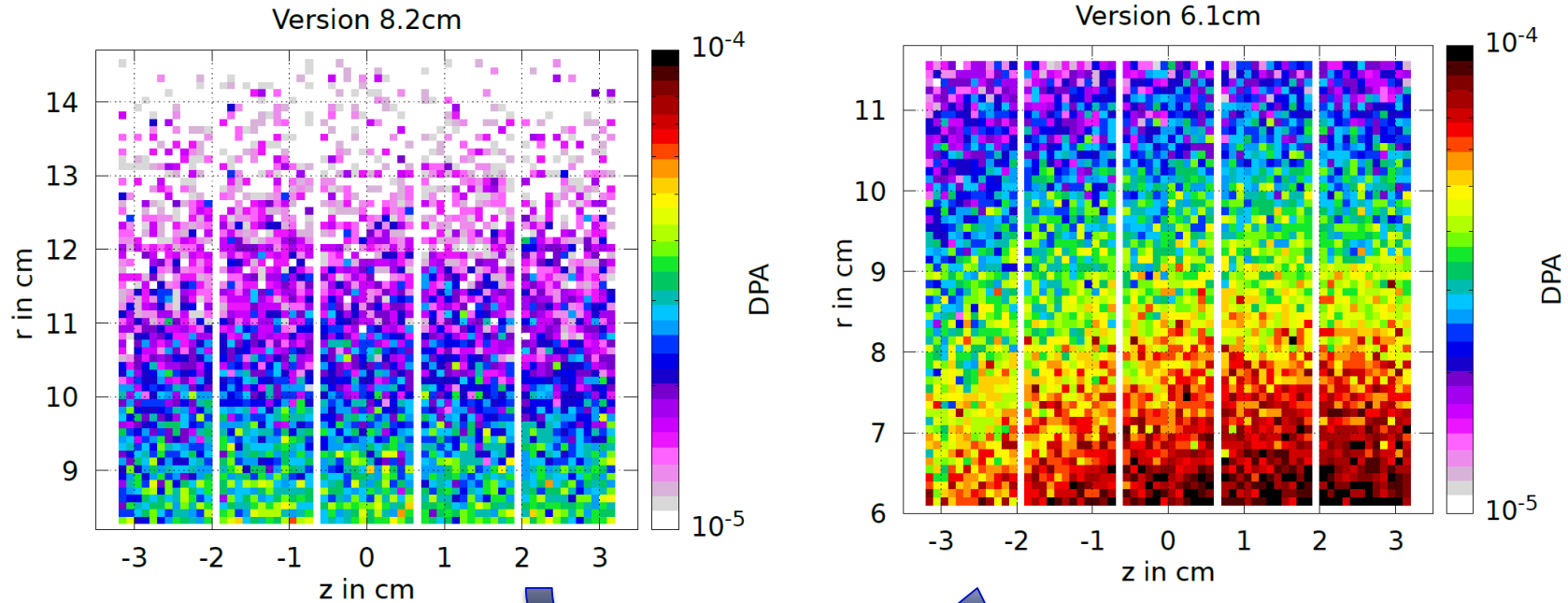
# Dose per year of z operation on coils



**Remark:** long term radiation effects (dose, DPA) are given for one year of Z operation. Conservative assumption is that values will be  $\sim 10\times$  higher for operational time of FCC-ee.

# DPA on coils and target per year of Z operation

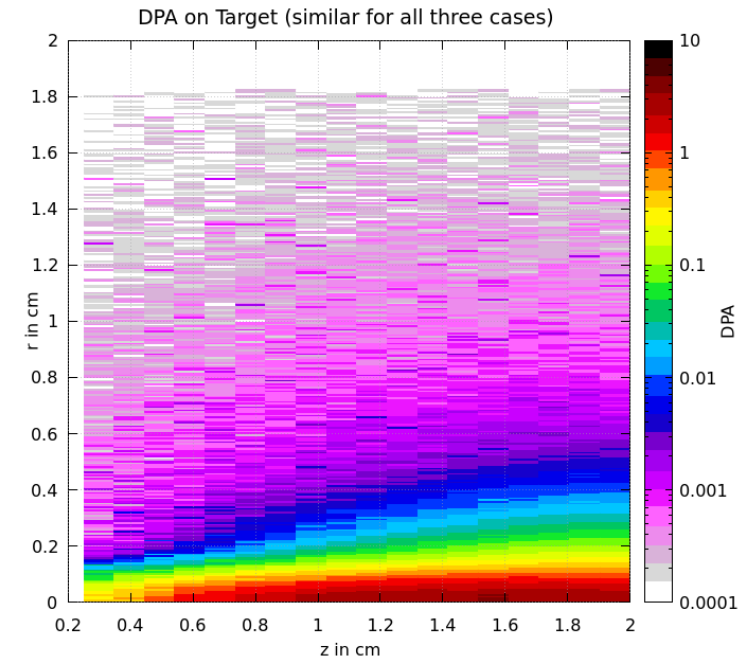
## COILS



~5x higher

Up to  $1\text{E-}4$  DPA per year  $\rightarrow$  full operational time:  $\sim 1\text{E-}3$  DPA

## TARGET



Up to 3DPA/year on target  $\rightarrow$  high value considering em. beam

# Limits for total ionizing dose & DPA

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## ■ Dose:

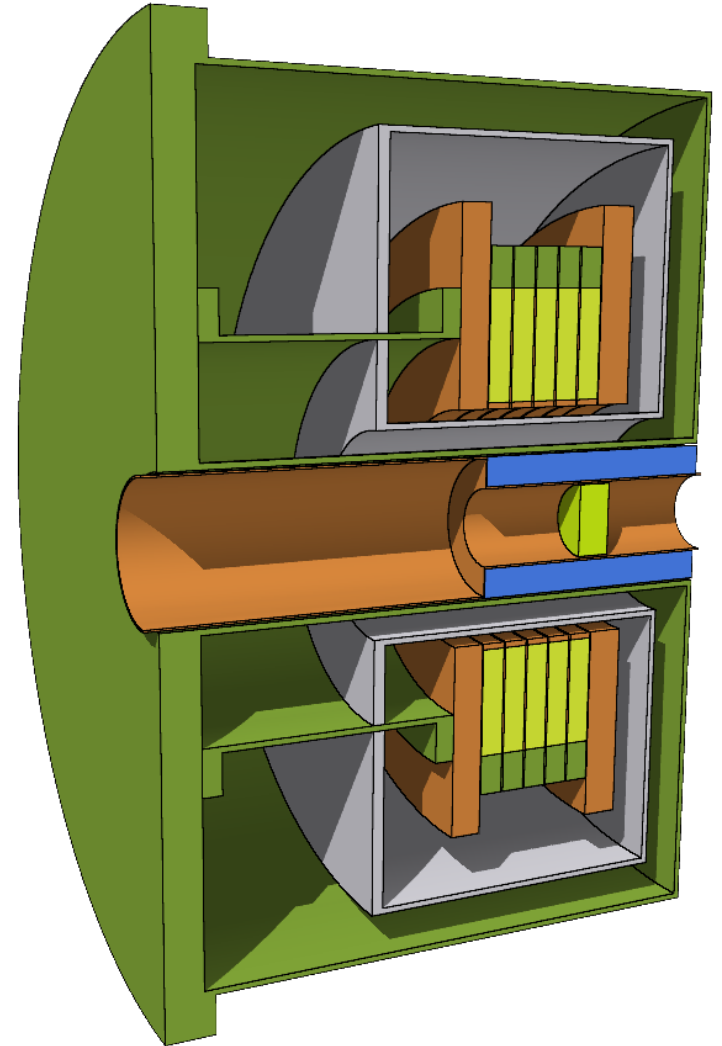
- Limits in low temperature superconductors (Nb<sub>3</sub>Sn, NbTi,...): ~30MGy → due to organic insulation, not SC itself
- HTS coils do not have organic insulation
- High temperature SC in literature: many papers on displacement damage (neutron irradiation), but not much on ionizing dose (gamma irradiation)
- Shall one propose gamma irradiation tests of HTS coils within FCC/CHART?

## ■ DPA:

- High values despite an electron beam
- Not negligible anymore for the coils over full lifetime if coil aperture is at 6.1cm (10<sup>-3</sup>DPA) → further shielding studies ongoing

# Summary

- So far, **no showstoppers** found that prevent a superconducting matching device
- Still work to do, to **optimize** the situation
  - Target position along z matters
  - **Coil position** and **shielding thickness** optimization ongoing
  - **Find limits** for the dose of high temperature SC
- **Outlook:** Energy deposition in RF structure downstream and evaluation if mask is needed



# Any questions?

