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# Radiation Load Studies for the FCC-ee Positron Source: AMD and Positron Linac

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FCCee Injector Studies Mini-Workshop
(25/11/2022)

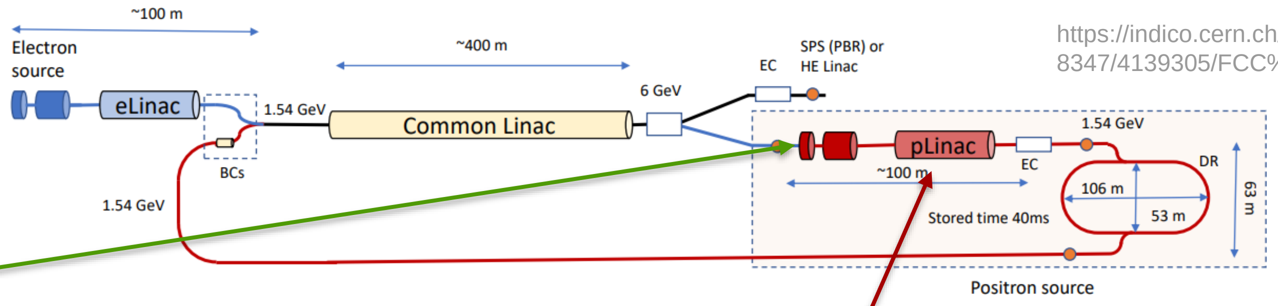
Acknowledgments to I. Chaikovska, P. Craievich, M. Schär, Y. Zhao,…

CERN SY STI FLUKA TU WIEN

# Agenda

1. Geometry
2. Beam Parameters
3. AMD
4. Positron Linac
5. Outlook & Conclusion

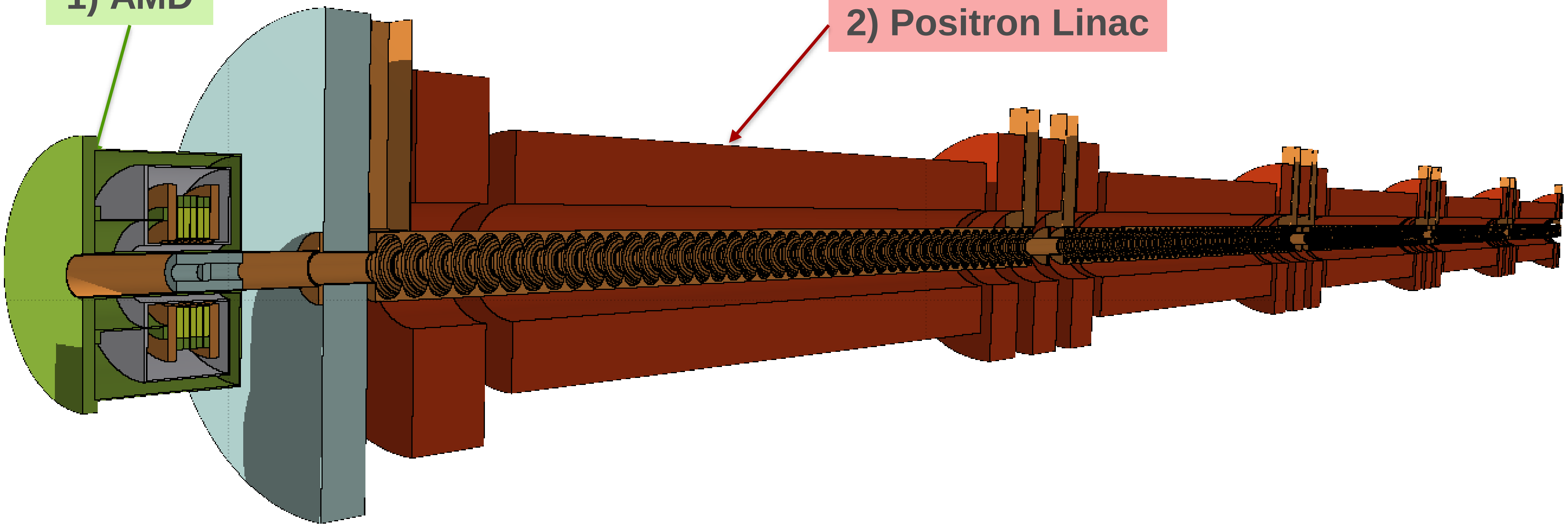
# Geometry



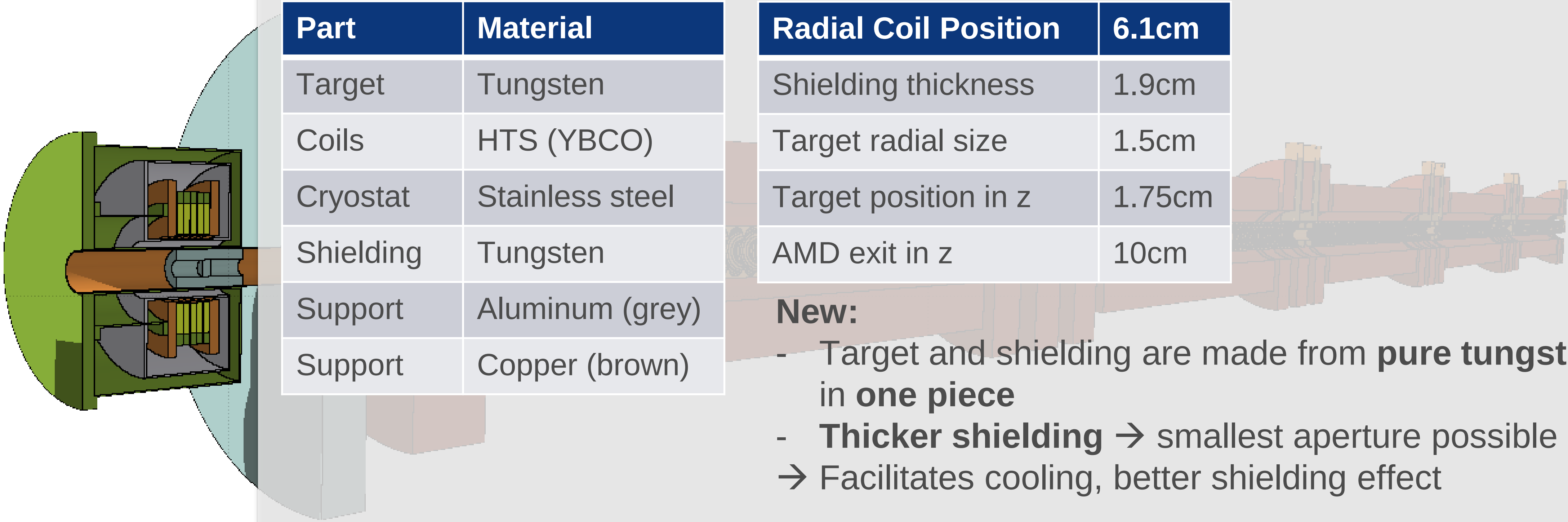
https://indico.cern.ch/event/1133621/contributions/4756873/attachments/2418347/4139305/FCC%20injector%20schematic%20layout%2031032022.pdf

**1) AMD**

**2) Positron Linac**



# Geometry – Adiabatic Matching Device (AMD)



| Part | Material |
|---|---|
| Target | Tungsten |
| Coils | HTS (YBCO) |
| Cryostat | Stainless steel |
| Shielding | Tungsten |
| Support | Aluminum (grey) |
| Support | Copper (brown) |

| Radial Coil Position | 6.1cm |
|---|---|
| Shielding thickness | 1.9cm |
| Target radial size | 1.5cm |
| Target position in z | 1.75cm |
| AMD exit in z | 10cm |

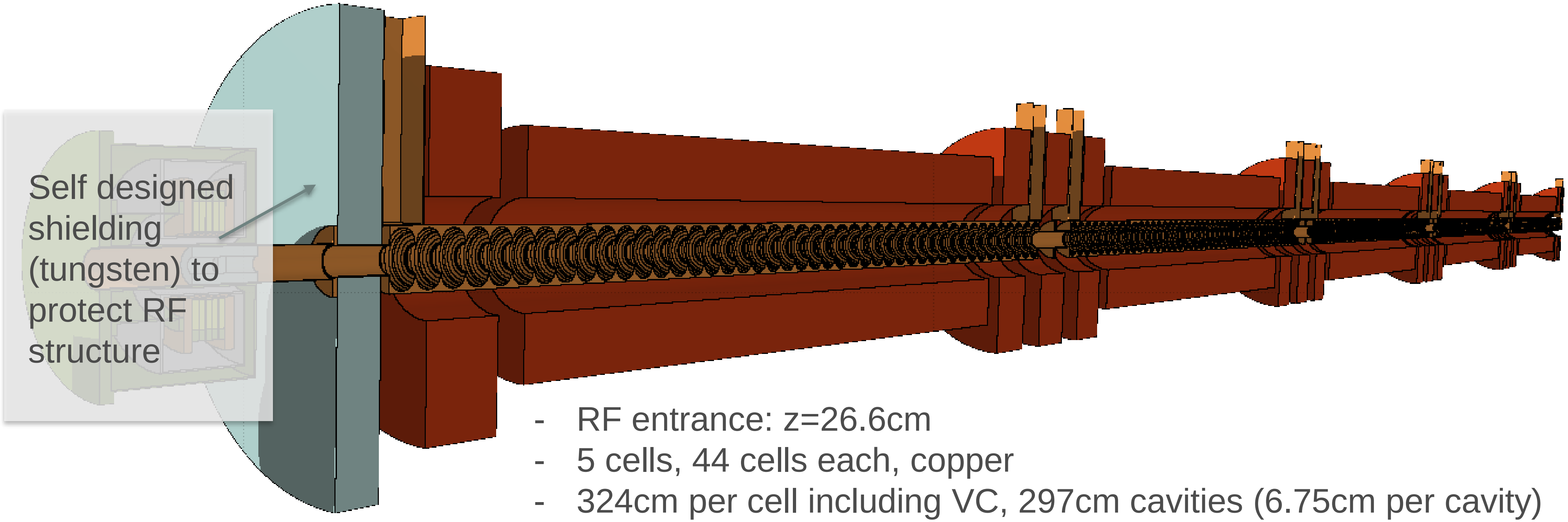
**New:**

- Target and shielding are made from **pure tungsten** and in **one piece**
- **Thicker shielding** → smallest aperture possible chosen

→ Facilitates cooling, better shielding effect

- Corrected magnetic field

# Geometry – Positron Linac



Self designed shielding (tungsten) to protect RF structure

- RF entrance: z=26.6cm
- 5 cells, 44 cells each, copper
- 324cm per cell including VC, 297cm cavities (6.75cm per cavity)
- Constant magnetic field of 0.5T in cavities
- Aperture: 3cm, up to r=7cm

- Solenoids: 13cm aperture → what will be in-between cavities and solenoids?
- Concept of one long solenoid, 3 shorter ones
- Copper with density taking in account the water cooling channels

# Parameters for the FCC-ee positron target

| **Electron drive beam** | **6GeV** |
|---|---|
| Beam size | 0.5mm RMS |
| Repetition rate | 200Hz |
| Bunches per pulse | 2 |
| Bunch intensity (filling) | 3.47E10 (5.56nC) |
| Bunch intensity (top up) | 3.47E9 |
| Beam Power | 13.34kW |
| Target length | $5X_0$=17.5mm |

**Filling time of collider:**

**Old** (FCC-Week 2022)
2.4% filling from scratch
97.6% at top-up with 10% bunch charge

**New**
100% filling with full bunch charge

**Current time scheme:** needed for reliable dose and DPA values (no difference between filling and top-up)

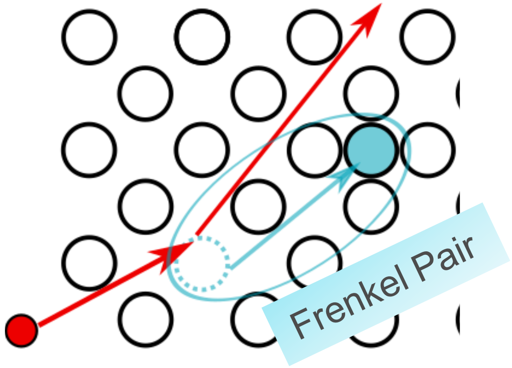
2bunches*200Hz*3600s*24h*185days*0.804(duty factor)*3.47E10e-/bunch*0.5

⚠ **e- on target per year: 8.9E19e-/year** ⚠

# Measured quantities

- **Instantaneous effects**
  - **Total deposited power (in W):** Determines the heat load on the elements
  - **Power density (in mW/cm$^3$):** Quenching of SC if it is too high

- **Long term radiation effects**
  - **Dose (in MGy):** Deterioration of (organic) materials
  - **Displacement per atom (DPA):** Structural damage of inorganic materials; Dimensionless number proportional to the number of Frenkel pairs



# Adiabatic Matching Device Target

# Power on different AMD elements

| | 13.34kW | 3.43kW | →x3.9 |
|---|---|---|---|
| Target | 3100W | 869W | →x3.5 |
| Shielding | 1040W | 209W | →x4.9 |
| Coils (1-5) | 0.6-2.9W | 0.27-1.25W | |

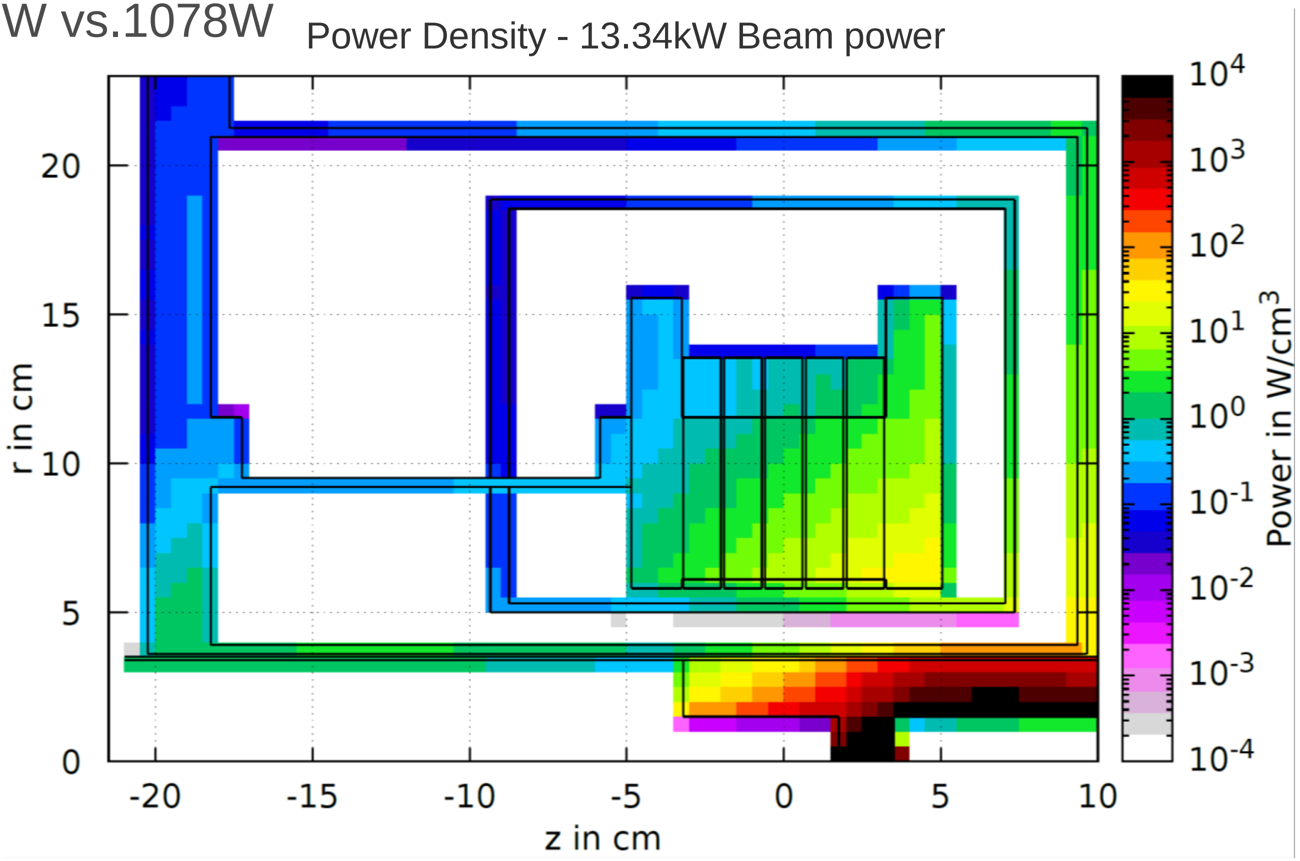
4140W vs.1078W
**x3.8**

Smaller target, less increase (x3.5)
bigger shielding, more increase (x4.9)

↓

Sum increases proportional (x3.9) to beam power (x3.9)

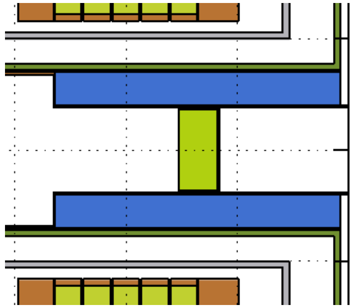
→ Slightly different distribution but total power stays similar


Power Density - 13.34kW Beam power

# Close up on the target

**Old**

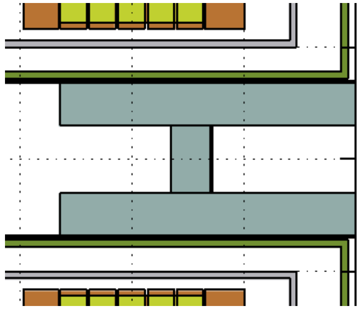
(FCC-Week 2022)

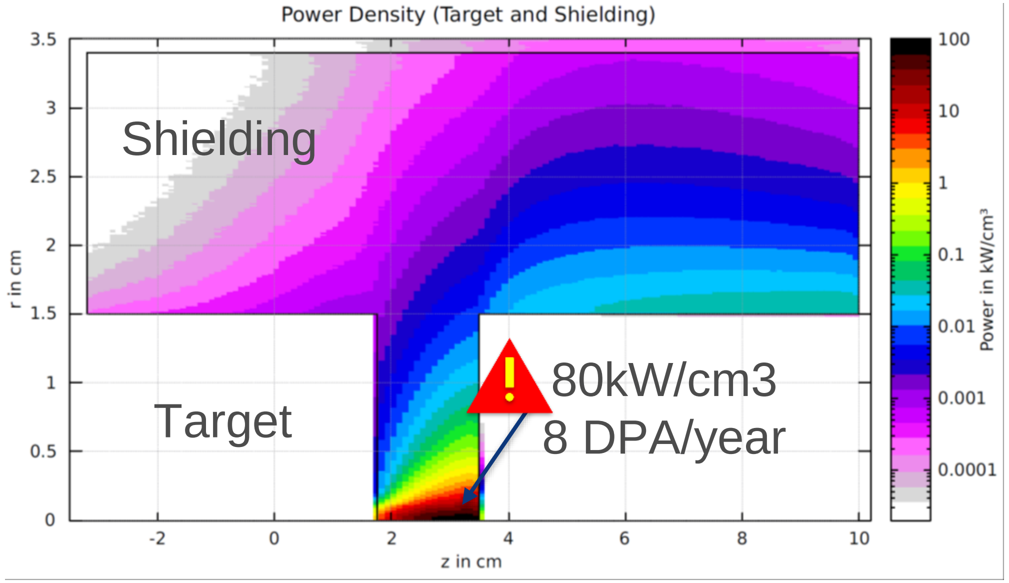


Shielding and target in one piece
Pure tungsten

Shielding: 1.5cm → 2cm
Aperture: 2cm →1.5cm

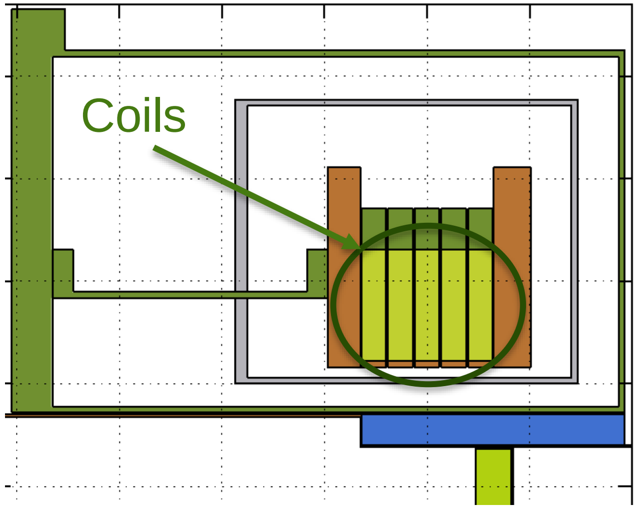
**New**

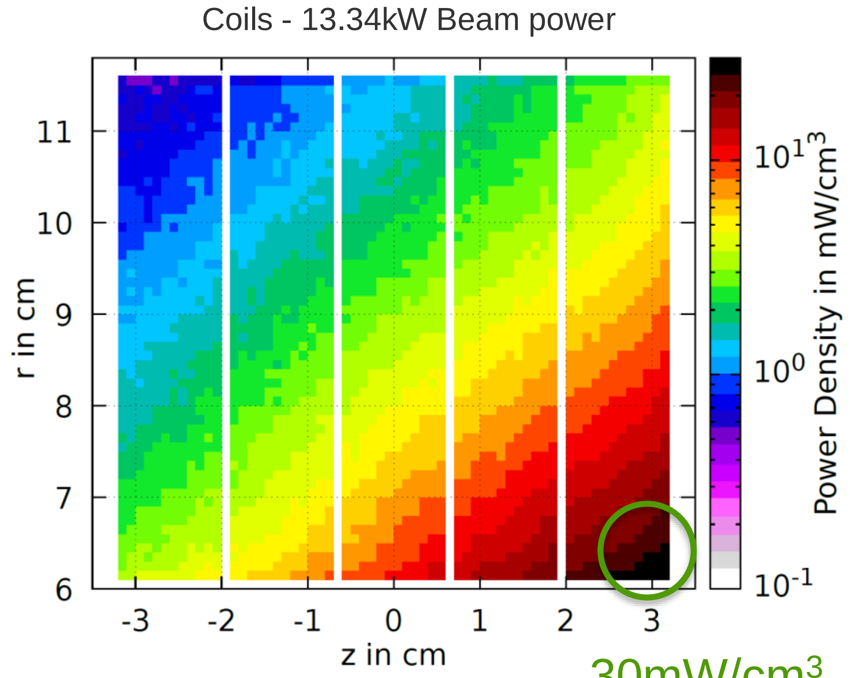




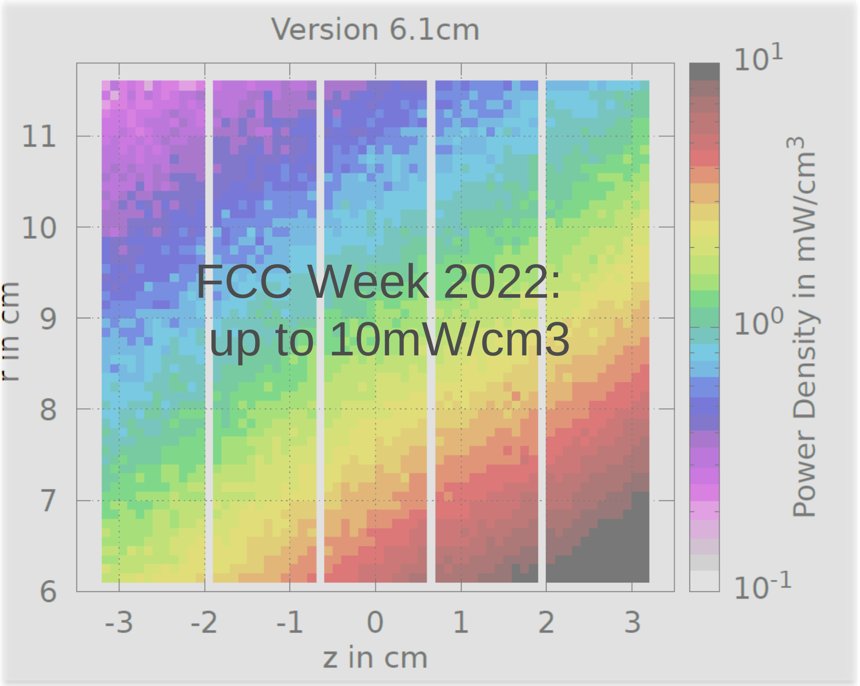
80kW/cm3
8 DPA/year

# Power density on coils





30mW/cm$^3$

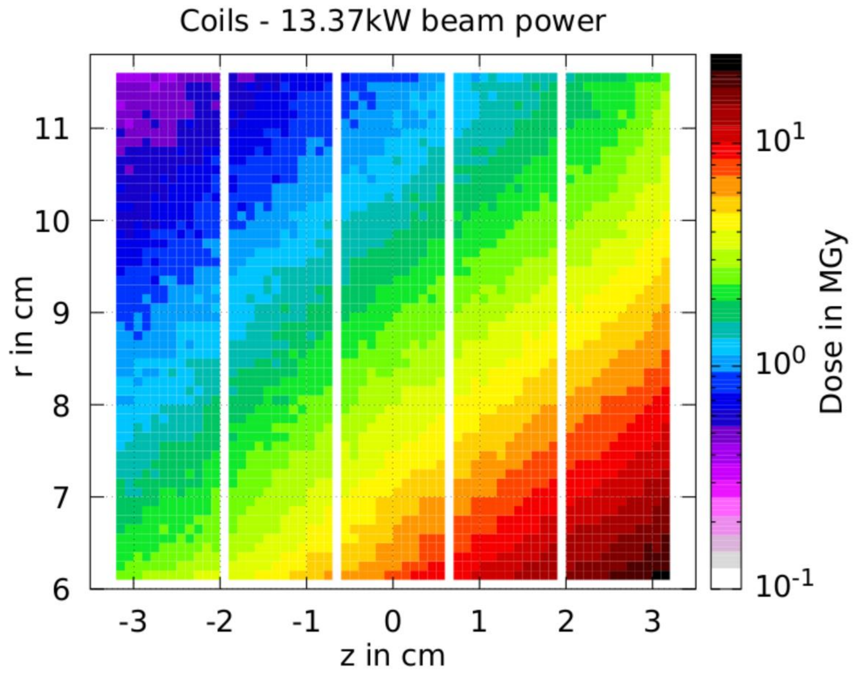


FCC Week 2022:
up to 10mW/cm3

Should be safe considering HTS coils
+ strong gradient is favourable as well

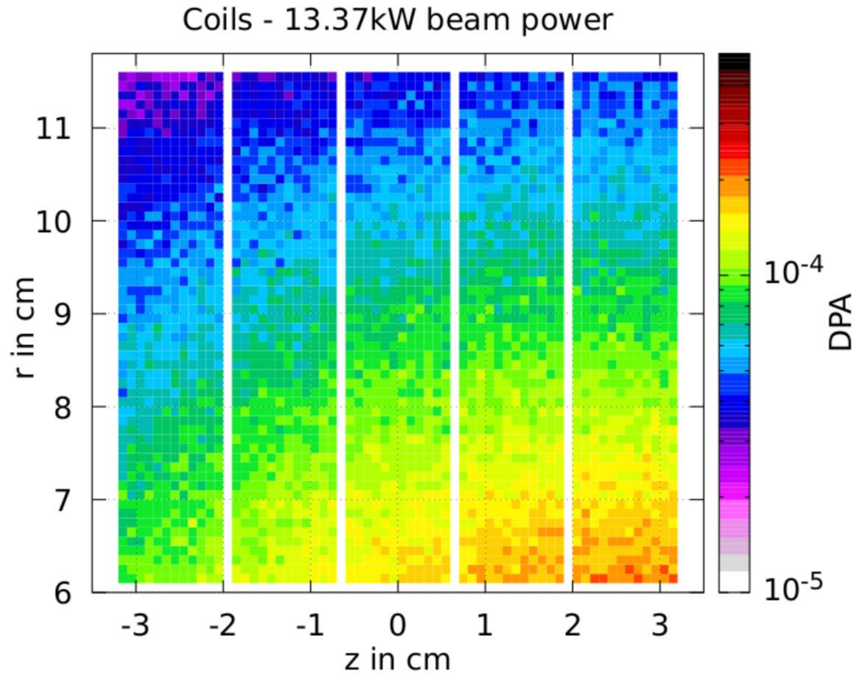
Values **~3x higher** than in old design due to 4x higher beam power.
Power density does <u>not scale directly</u>, due to **thicker shielding** protecting the coils better and a **target** position further **downstream**.

# Long-term radiation effects per year of Z operation on coils



Up to **22MGy/year**

Dose and DPA values must be investigated if they can be considered as safe

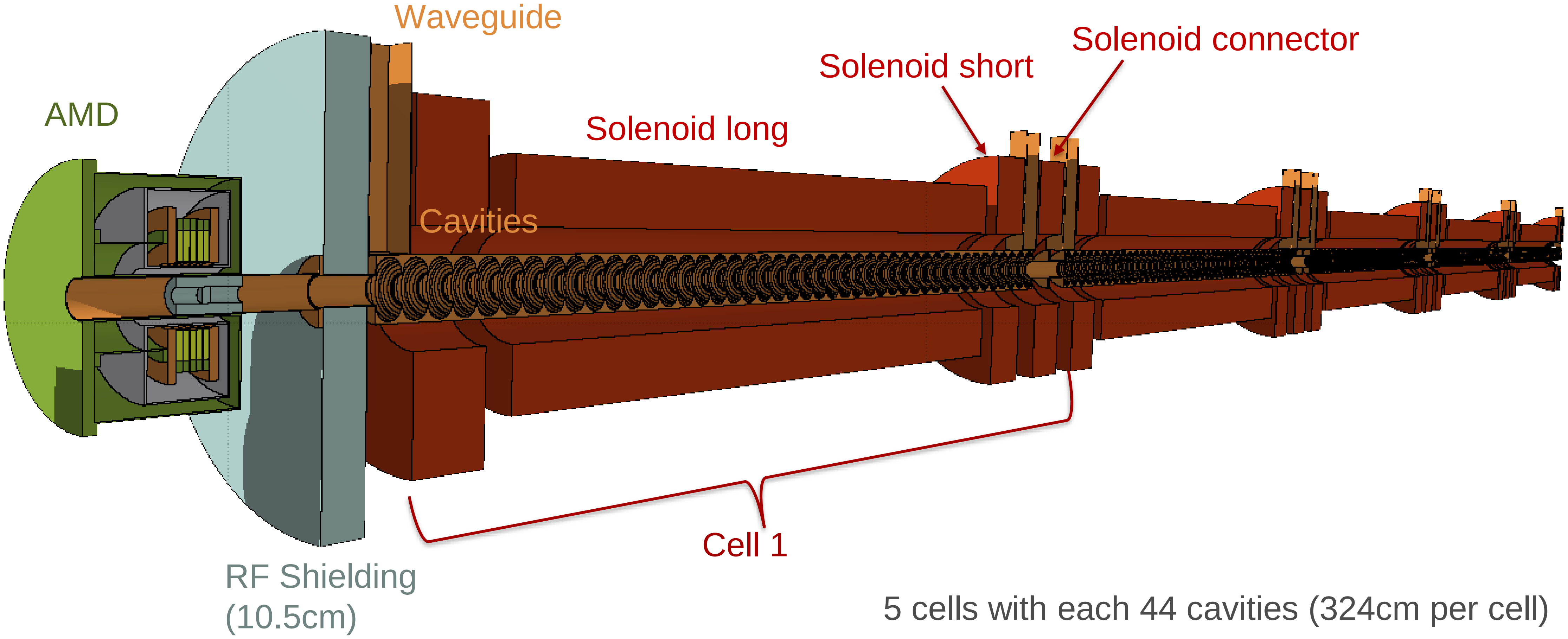


Up to **2E-4 DPA/year**

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

# Positron Linac

# Geometry reminder

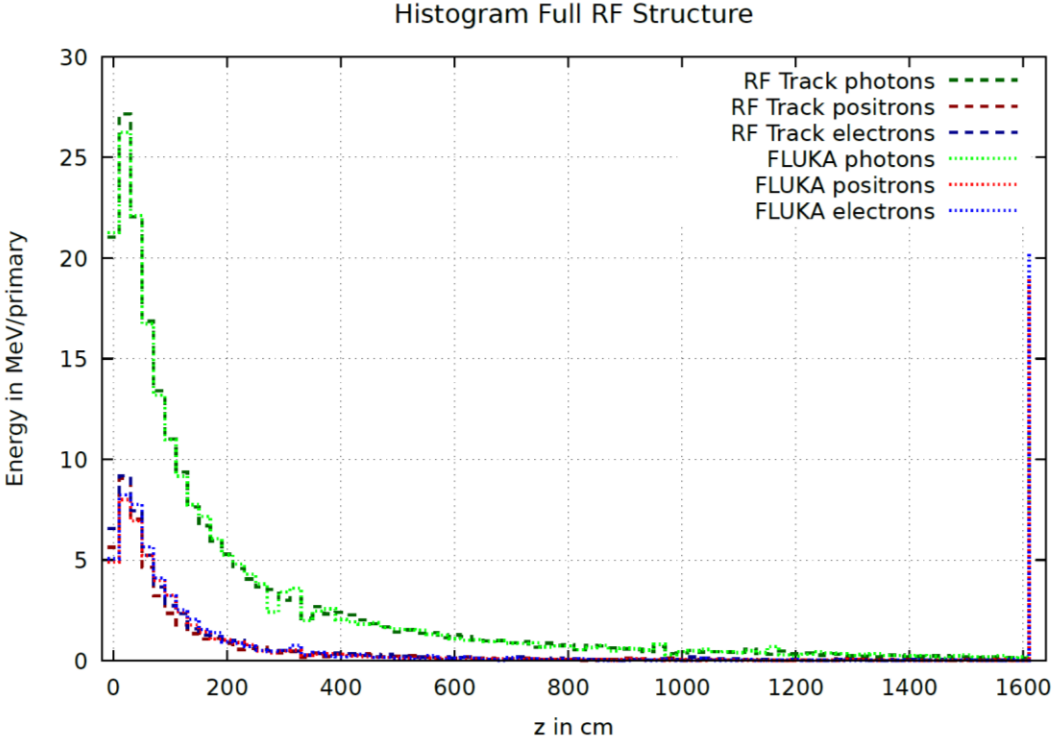


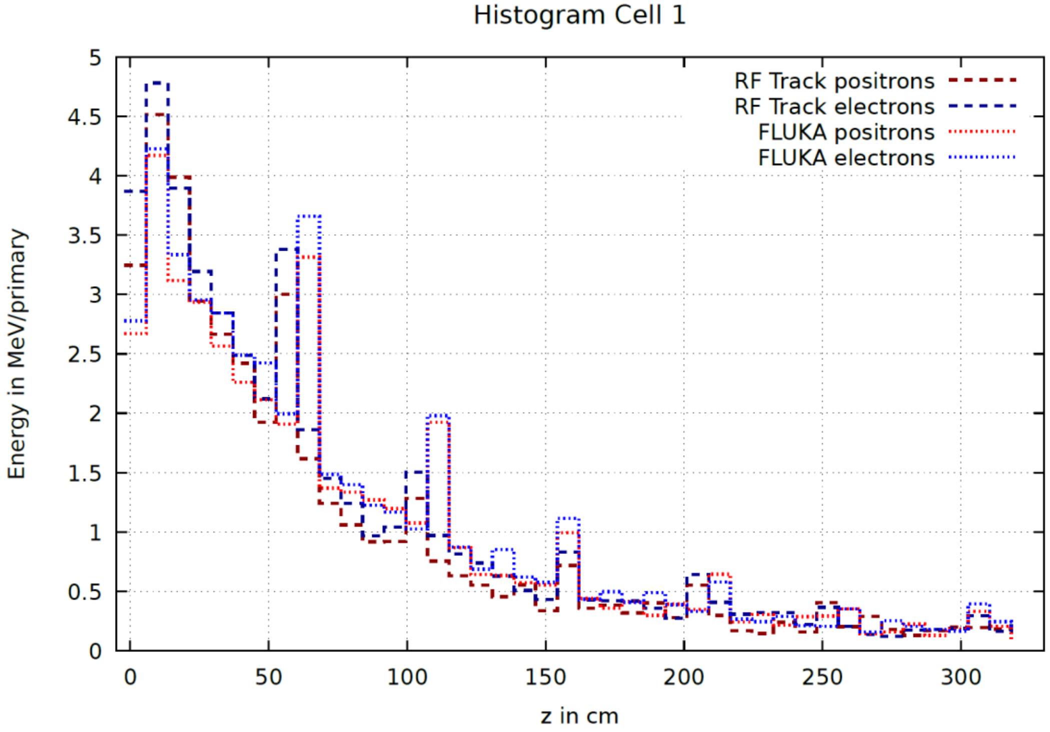
5 cells with each 44 cavities (324cm per cell)

# Power **loss** on aperture in positron linac

Thanks to **Y. Zhao** for the RF Track values

As soon as particle leaves vacuum and touches a cavity/VC it is dumped, and its properties are stored





Good agreement in data means that FLUKA simulations should be sufficient for energy deposition studies, even with only a constant magnetic field of 0.5T and no electrical field.

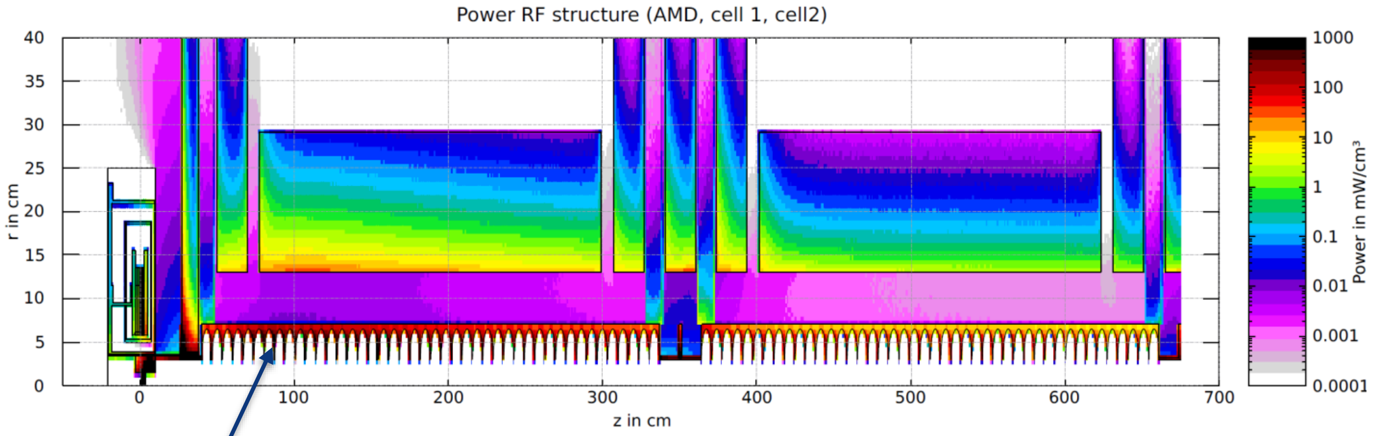
# Power **loss** on aperture in positron linac

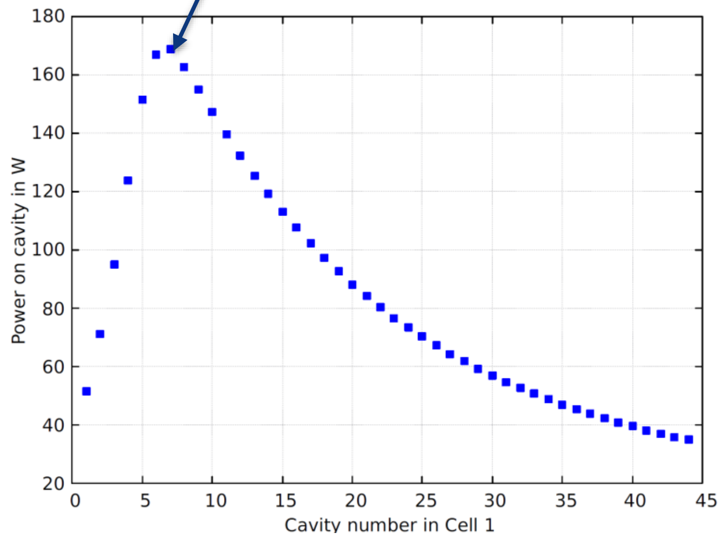
| | Electrons | | Positrons | | Photons | | TOTAL | |
|---|---|---|---|---|---|---|---|---|
| | **RF Track** | **Fluka** | **RF Track** | **Fluka** | **RF Track** | **Fluka** | **RF Track** | **Fluka** |
| **Total** | 1154W | 1126W | 1037W | 1061W | 4830W | 4822W | 7021W | 7015W |
| **Cell 1** | 1015W | 1026W | 913W | 967W | 3722W | 3721W | 5650W | 5721W |
| **Cell 2** | 85W | 71W | 79.5W | 62.8W | 631W | 607W | 796W | 741W |
| **Cell 3** | 24W | 16W | 23.5W | 19.7W | 265W | 261W | 313W | 297W |
| **Cell 4** | 21.2W | 9.1W | 12.8W | 6.6W | 140W | 148W | 174W | 163W |
| **Cell 5** | 8.8W | 3.4W | 7.9W | 4.1W | 71W | 83W | 88W | 90W |

**Values are generally in good agreement**
Thanks to **Y. Zhao** for the RF Track values!

Impact on the aperture ≠ energy deposition

# Power **deposition** on different elements of the positron linac





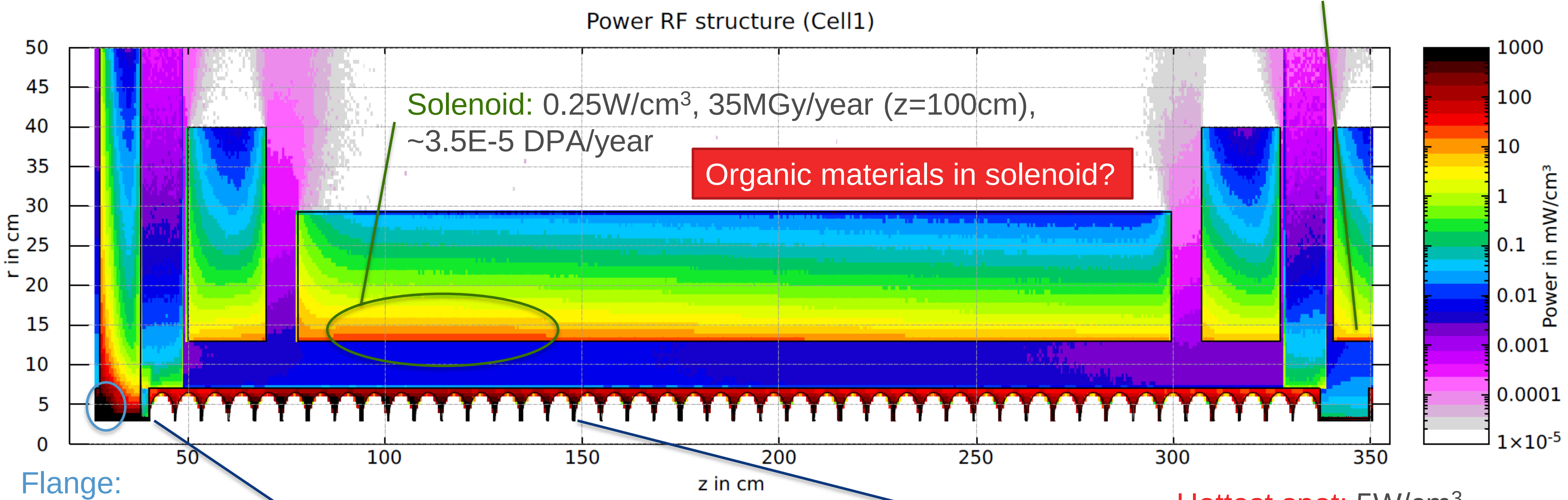
| | **13.34kW** |
|---|---|
| Shield RF | 1049W |
| Flange AMD/RF | 132W |
| Flanges cells | 43W-3.6W |
| SOL short | 68W*-3.6W |
| SOL long | 607W-12.66W |
| SOL connect | 53W-4.3W |

* Highest value in first short solenoid of cell 2

- First cell most impacted: up to **170W(!)** absorbed by cavity
- Cell 2 up to 20W per cavity
- Shielding protects positron linac solenoids, but not the cavities
- If cavities need more protection, elaborate shielding scheme must be elaborated

# Close up to first cell

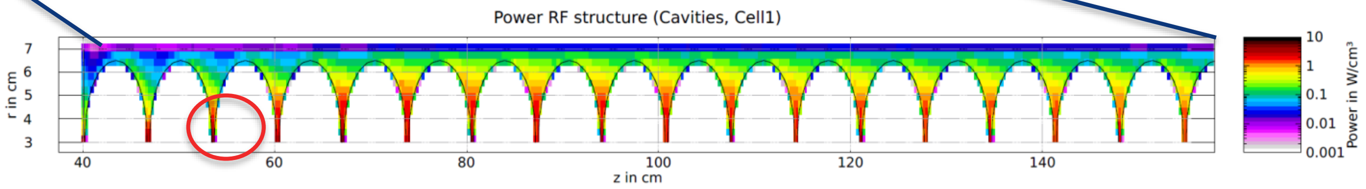
Solenoid: 65MGy/year – shielding?



Solenoid: 0.25W/cm$^3$, 35MGy/year (z=100cm), ~3.5E-5 DPA/year

Organic materials in solenoid?

Flange:
3.8W/cm$^3$,
2800MGy,
1E-3 DPA



Hottest spot: 5W/cm$^3$, 3500MGy, 1.2E-3 DPA

Which numbers are acceptable?

# Summary

- **AMD & Target:**
  - Coils: power density is below critical values, DPA and dose must be understood if they are acceptable
  - Target: 13.34kW beam power leads to critically high heat load and DPA ➔ solution pending
- **Positron Linac:**
  - Power loss: FLUKA results align well with RFTrack
  - Cavities: highly impacted by particles from the inside, so shielding is not possible.
  - Solenoids: Protected by large tungsten shielding in front of positron linac. In case of organic material and/or SC solenoid, dose values are too high.
  - What power deposition values and DPA levels can the cavities withstand?

# Any questions?

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