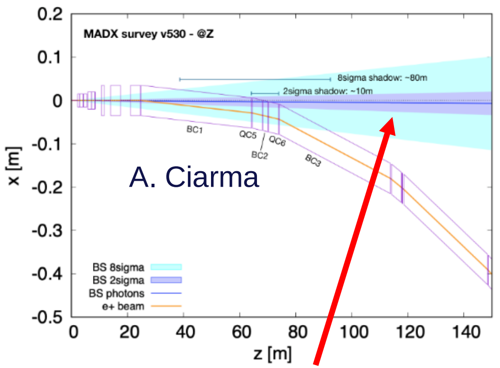
# BEAMSTRAHLUNG DUMP: RADIATION CHALLENGES

A. Lechner, A. Perillo Marcone, M. Calviani, M. Boscolo, A. Ciarma, H. Burkhardt, T. Lefevre, R. Garcia Alia, M. Widorski, F. Valchkova-Georgieva

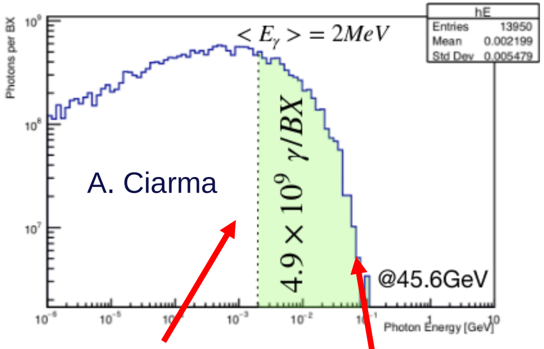
4th FCC MDI Workshop
(27/10/2022)

# Introduction




- Different processes in the experimental IRs give rise to an intense photon flux (almost) parallel to the outgoing beam
- The most important ones (in terms of photon power) are:
  - Synchrotron photon production in the **field** of the **counter-rotating beam** (**Beamstrahlung**) – **370 kW** (Z pole) – see talk of A. Ciarma this week
  - Synchrotron photon production in the **fringe field** of the **solenoid** and **anti-solenoid** – **77 kW** (Z pole) – see talk of K. Andre last week & H. Burkhardt at FCC week 2022
- These photons exit the vacuum chamber around the BC1 dipole
- **A high-power beam dump is needed to dispose of these photons** (accounting for all sources)
- The dump (and extraction line) must be compatible with all operation modes (Z … ttbar) and must allow for operational margins (steering etc.)

# Introduction - continued

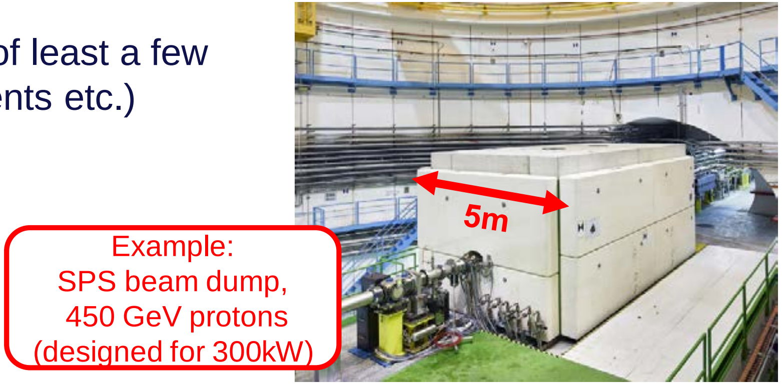



- A dump usually consists of a dump core + surrounding shielding, which must fulfill **essential requirements** like:
  - Dissipate the heat generated by the photons in the absorber
  - Limit radiation-induced effects / damage in other equipment
  - Limit exposure of personnel due to the induced radioactivity
  - Avoid contribution to beam-induced background in detector (backscattering)
- This presentation:
  - Outline some of the most important radiation-related challenges to be addressed
  - Present first (very preliminary) radiation studies with FLUKA* - for the moment, only Beamstrahlung photons@Z-pole were considered

**More detailed studies will be carried out by a PhD student who will start in early 2023 in SY/STI/BMI*

# Internal vs external dump

- The photons must exit the collider in a windowless Y chamber, followed by an extraction chamber which then leads to the dump
- The dump could in principle be **internal** or **external** to the collider – depends on the lateral separation between the circulating $e^+/e^-$ beam and the photon "beam"
  - Internal: the dump is part of the lattice (like the SPS dump) and houses the vacuum chamber of the circulating beam
  - External: the dump is placed next to the ring (but not necessarily in a dedicated dump cavern)
- An external dump requires a lateral separation of least a few meters (will depend on final shielding requirements etc.)

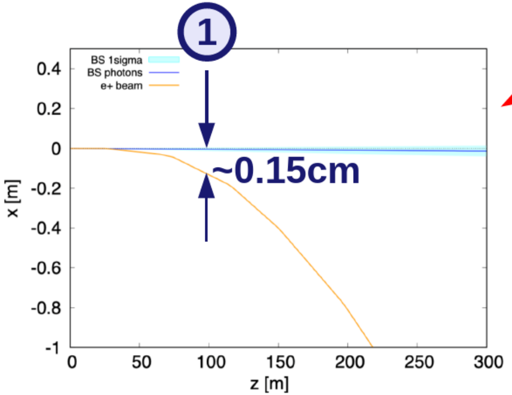


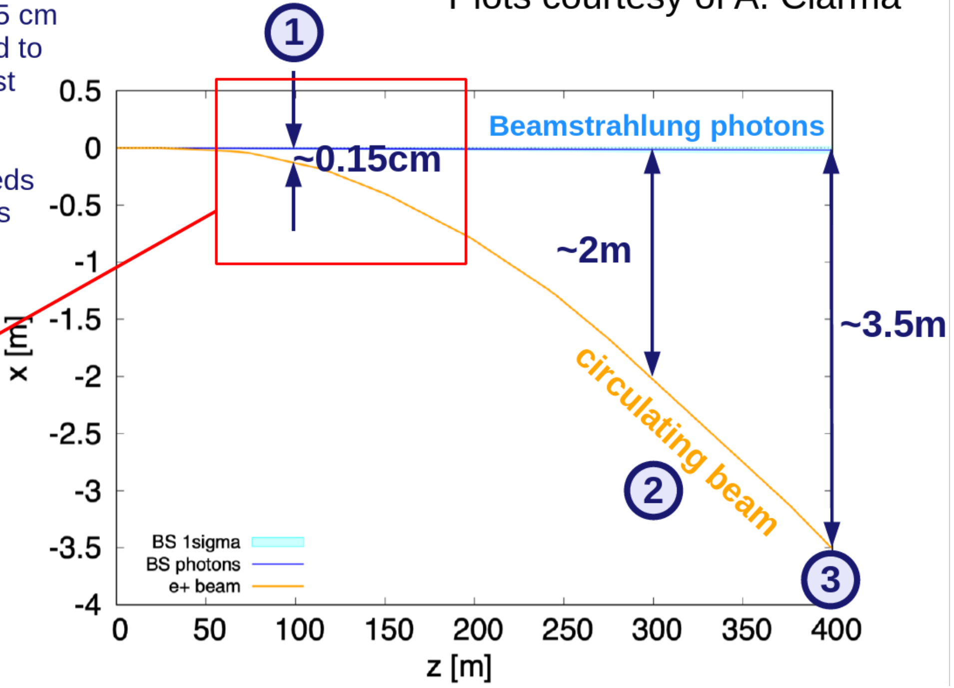
# Separation Beamstrahlung photons from beam

1. Around 100m from the IP the separation between photon beam axis and circulating beam is only 15 cm → if the dump would be placed here it would need to be integrated in the lattice and would need to host the chamber of the circulating beam

2. 3. In order to have an external beam dump one needs a minimum separation of ~meters → dump needs to be several hundred of meters from IP

Plots courtesy of A. Ciarma

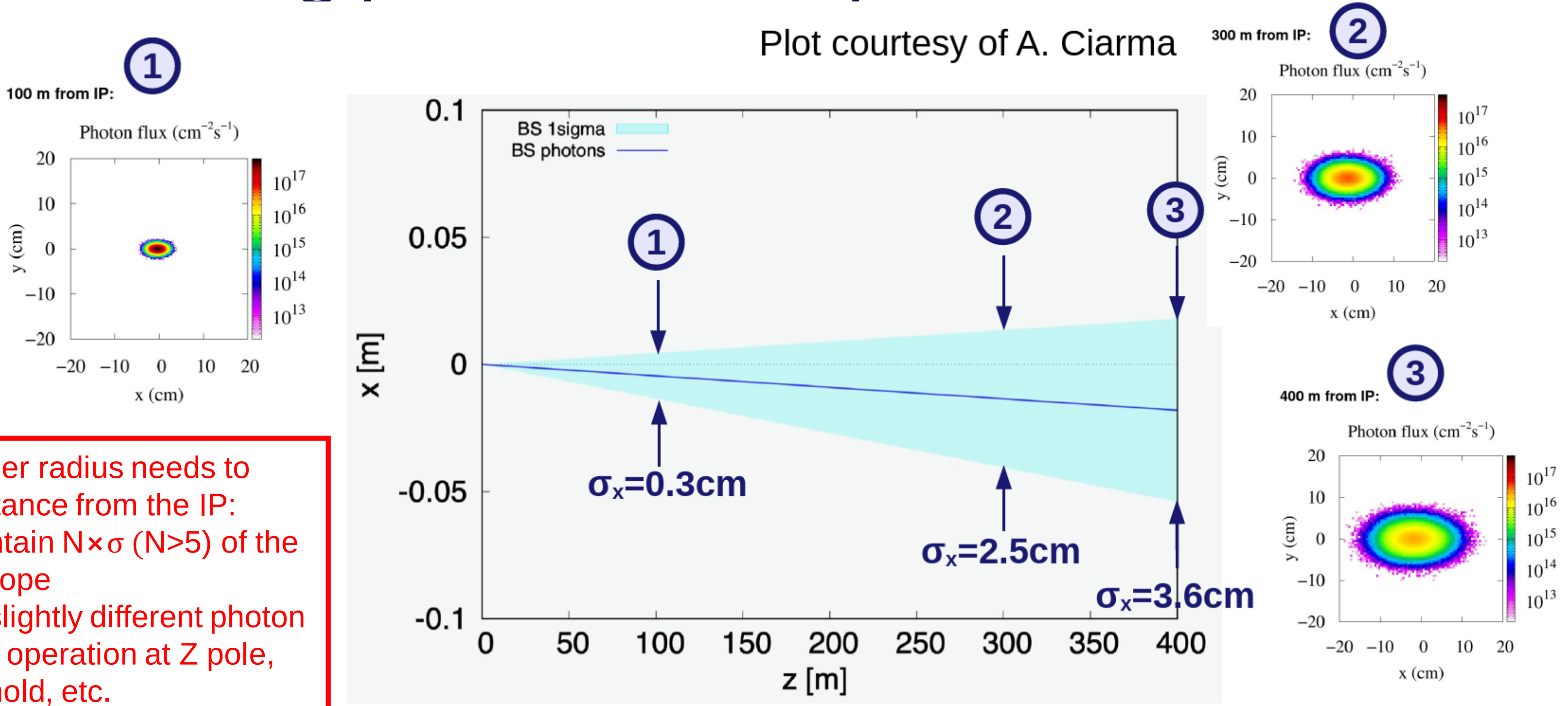



Similar picture applies for synchrotron photons from solenoid

# Beamstrahlung photon envelope

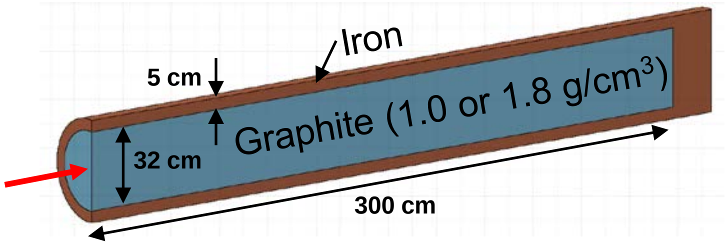
Plot courtesy of A. Ciarma




Extraction chamber radius needs to increase with distance from the IP:

- Needs to contain N×σ (N>5) of the photon envelope
- Account for slightly different photon directions for operation at Z pole, W+W- threshold, etc.
- Account for imperfections and operational margins

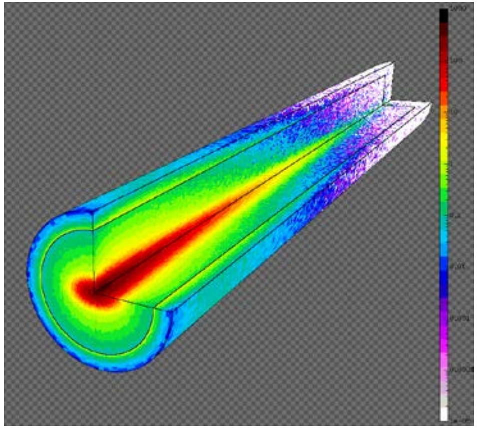
# Power deposition in dump core vs dump location




Disclaimer: this is just a *generic* **toy model** of the **dump core** in order to study the power deposition (this is not a proposal how the dump core should look like)

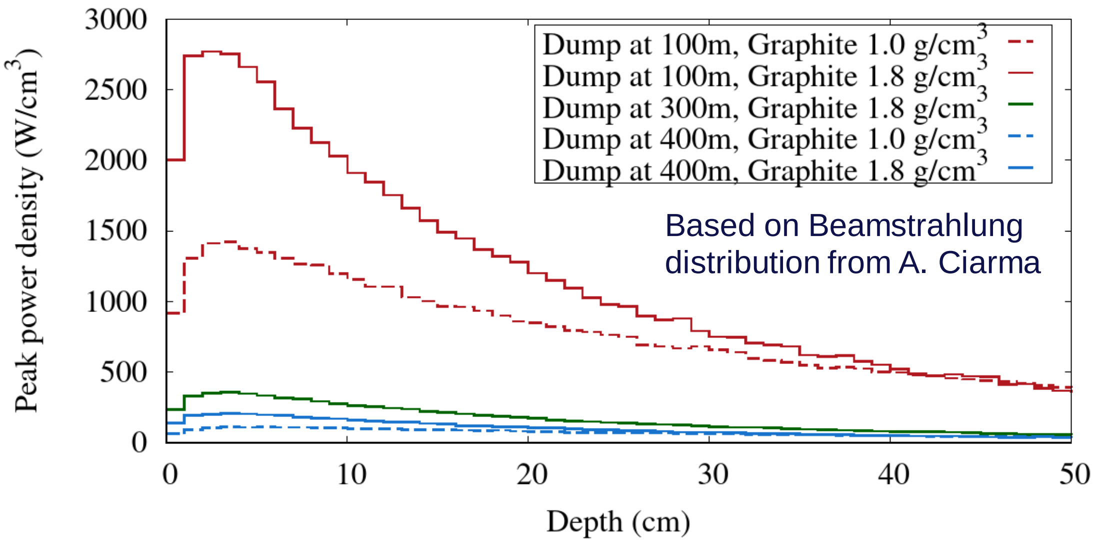
- **Dump absorber material:**
  - At this stage, different options may be possible, for example **liquid lead** – see talk of A. Perillo Marcone
- **Power deposition in dump vs dump location:**
  - Although the **absorber material is still undefined**, we performed first power deposition studies for a classical Graphite dump
  - We considered low-density (1.0 g/cm$^3$) and higher-density (1.8 g/cm$^3$) Graphite grades
  - Different dump locations were studied in order to get a first feeling about the order of magnitude (for the peak power density) – can provide some input for the dump placement

# Power deposition in dump (toy model) – Z pole



| kW/cm$^3$ | Graphite 1.0 g/cm$^3$ | Graphite 1.8 g/cm$^3$ |
|---|---|---|
| 100 m | 1.4 | 2.8 |
| 300 m | | 0.4 |
| 400 m | 0.1 | 0.2 |

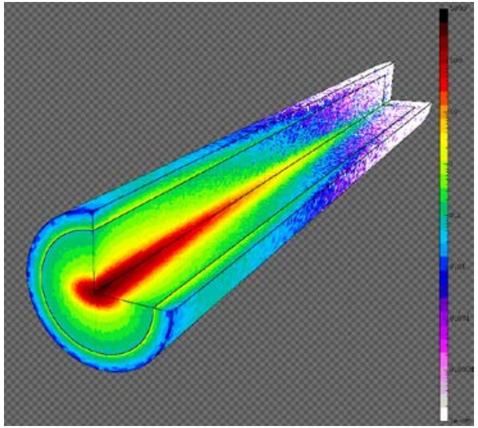
Figure shows peak power density for the first 50 cm of the dump:




Based on Beamstrahlung distribution from A. Ciarma

@100m from IP: O(kW/cm$^3$!) @300/400m from IP: O(few 100 W/cm$^3$)

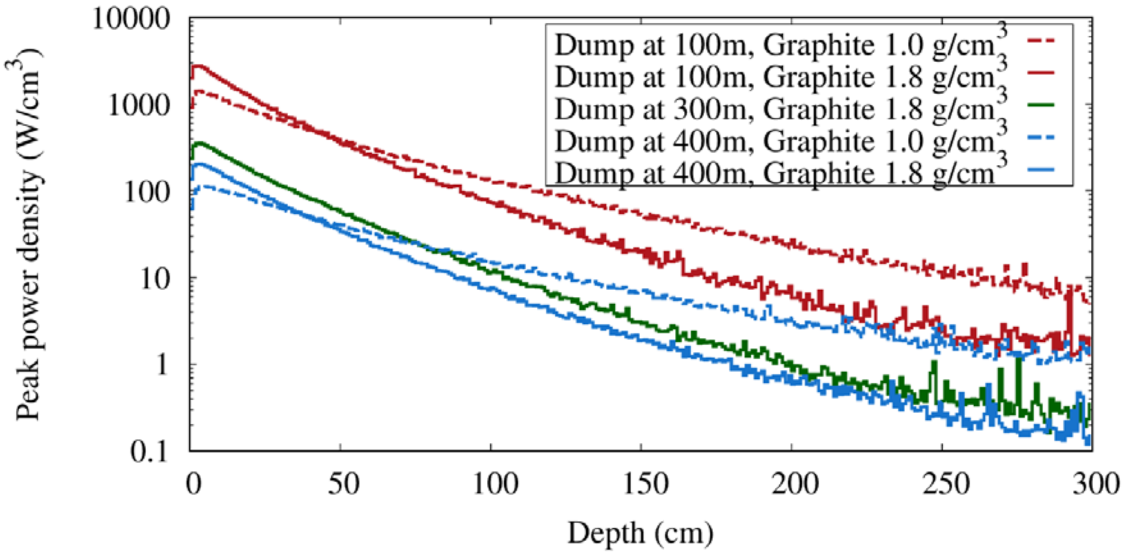
# Power deposition in dump (toy model) – Z pole



93% of the power is deposited in the first meter of the toy model dump

**In total, the dump absorbs >98% of the photon power**

Same figure as on previous page, but now showing the full dump length (log scale):




The dump core can likely be more compact than in the toy model (i.e. less than 3 meters), but the dimensions will depend on the actual absorber material choice

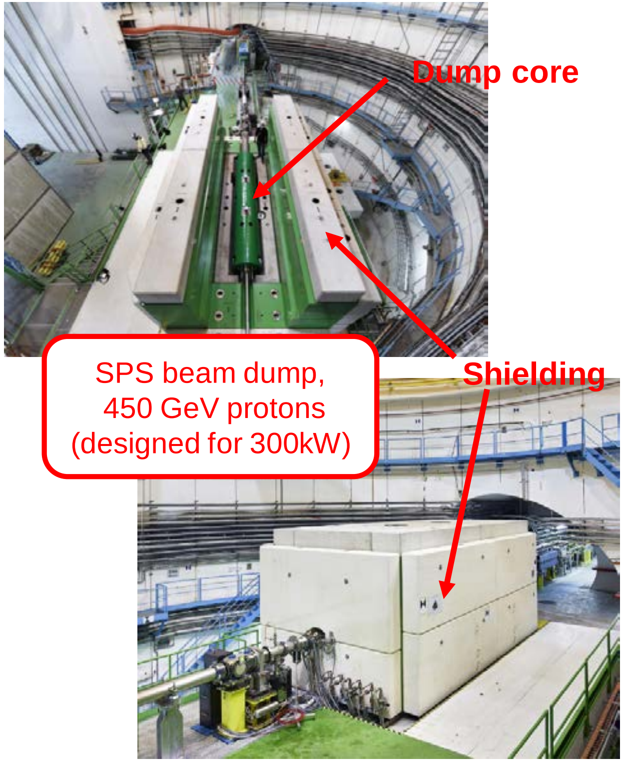
# Internal vs external dump – some remarks

- Internal dump at ~100 m from IP (part of the lattice):
  - The peak power density induced by the photons is extremely high (small spot size)
  - An enormous amount of power needs to be dissipated in the close vicinity of (or even inside) the vacuum chamber of the circulating beam (can lead to many problems, e.g. outgassing etc.)
  - The dump takes space in the lattice (between bends), which alters the IR layout
  - Not the preferred option
- External dump >400 m from IP (next to the ring):
  - A long and large extraction chamber is needed (integration?)
  - The dump core needs to be wider to contain the photon envelope - on the other hand the peak power density is lower due to the larger spot size
  - Extra civil engineering is possibly required to make space for the dump (see also the talk of F. Valchkova-Georgieva

# Shielding considerations

## Dump cores need to be shielded:

- The shielding shall mitigate **instantaneous** and **cumulative radiation effects** in **nearby equipment** and ensure **radiation protection** of **personnel** during shutdowns/technical stops
- **Equipment protection:**
  - The photon dump might be close to the e-/e+ ring and other equipment (cables, electronics)
  - Understanding the radiation fields around the dump is important for the dump integration → impact on other equipment?
- **Personnel protection:**
  - Hadron machines (e.g. SPS): shielding requirements often driven by personnel protection
  - Radionuclide production is still very much relevant for the FCC photon dump → radionuclide production by neutrons



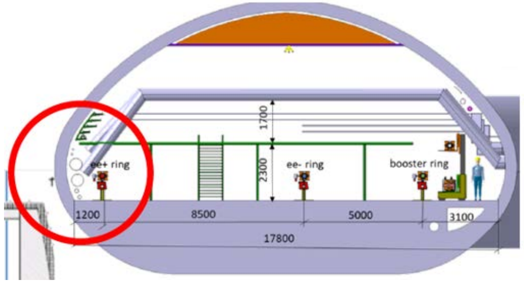
# Radiation hazards for equipment*/personnel

**Other than the dump itself*

**Effects of secondary radiation fields generated by the photons impacting on dump:**

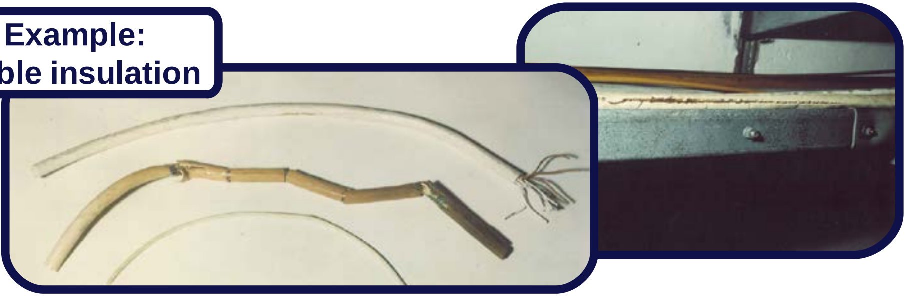
- The **accumulated ionizing dose** and **displacement damage** in equipment near the dump can affect the equipment lifetime (e.g. magnet coil insulation/spacers, cables, electronics etc.) ⇦ *Integrated over time*
- Prompt radiation can induce **single-event effects** in nearby electronics (e.g. power converters etc.), which can lead to premature beam aborts ⇦ *Instanta-neous*
- Production of **radionuclides** in the dump and in surrounding materials leads to the exposure of personnel in case of interventions in the area ⇦ *Integrated over time*
- Last but not least, secondary particles can **backscatter** into the **detector** region (likely not an issue if dump is far away) ⇦ *Instanta-neous*

The radiation environment created by the photons near the dump needs to be carefully studied → ***shielding considerations and distances to other equipment are essential for the dump integration***



# Long-term damage due to ionizing dose

**Example: cable insulation**



Acceptable values for cable insulation (LHC)*:
‘Standard’ cables up to **200 kGy (qualified up to 1 MGy)**
‘Rad-hard’ cables up to **2 MGy (qualified up to 10 MGy)**

*G. Lerner et al., *HL-LHC radiation level specifications on cables and R2E-R2M considerations*, https://indico.cern.ch/event/1043148/

**Example: Electronics**

Below **1 Gy!** commercial electronics can be considered insensitive to radiation

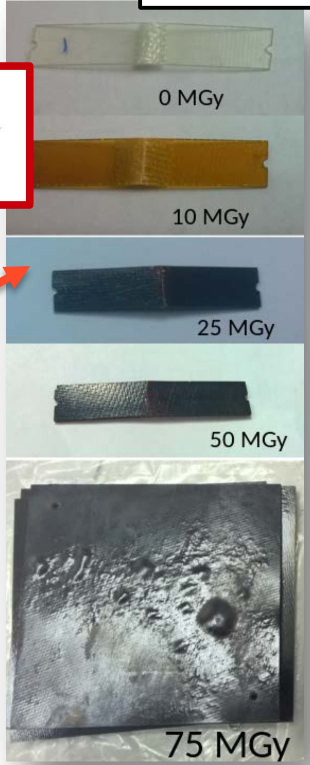
Above **10 kGy** electronic systems need to rely on radiation hardened components by design

*G. Lerner et al., *Radiation level specifications for HL-LHC*, EDMS No 2302154.

*P. Fessia et al.*

**Example: coil insulation**

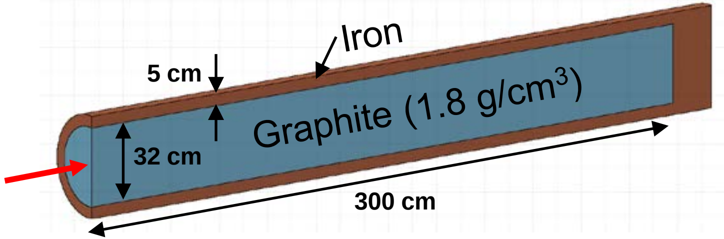
***Risk: loss of insulation between coil/ground or between coils***




Acceptable values for coil insulation (LHC):

From **few MGy** up to **30 MGy**

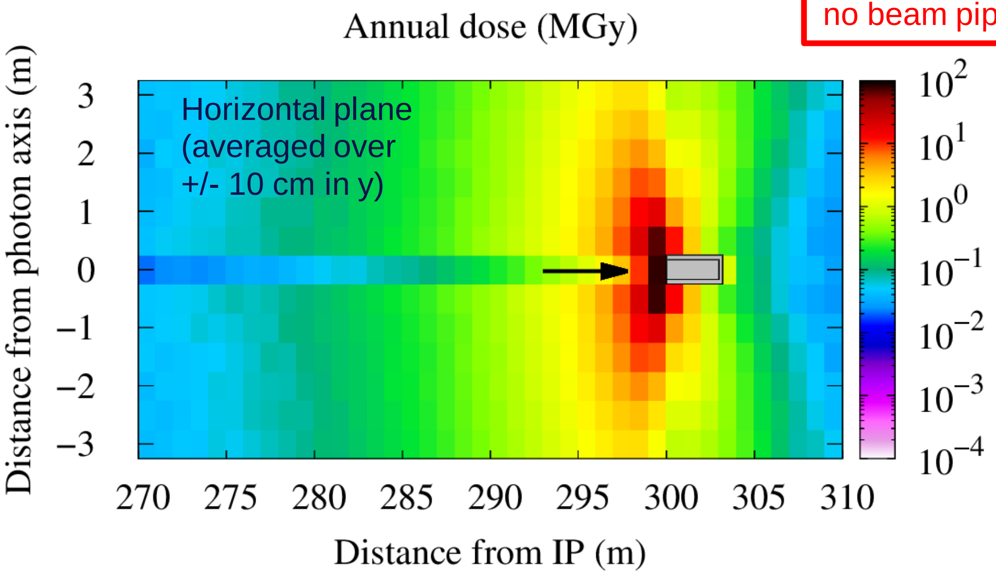
# Cumulative dose around dump (1 year at Z pole)




Disclaimer: this is just a *generic* **toy model** of the **dump core** in order to study the radiation fields (this is not a proposal how the dump core should look like)

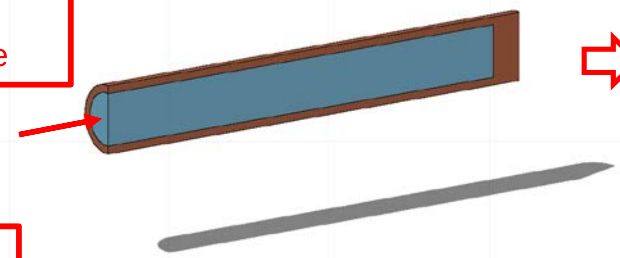
Assumptions for study:
- dump **@300 m** from IP (*but expect similar results for other distances*)
- 1E7 seconds of operation/year

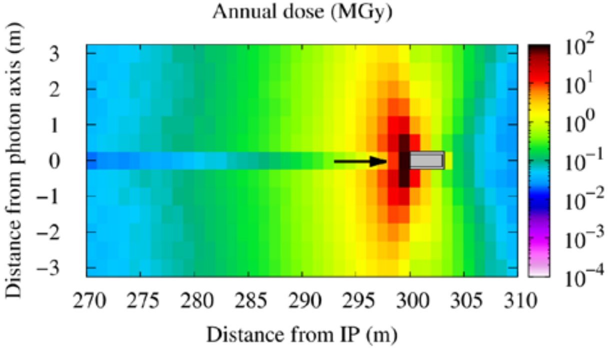
Only dump core, no shielding, no beam pipe

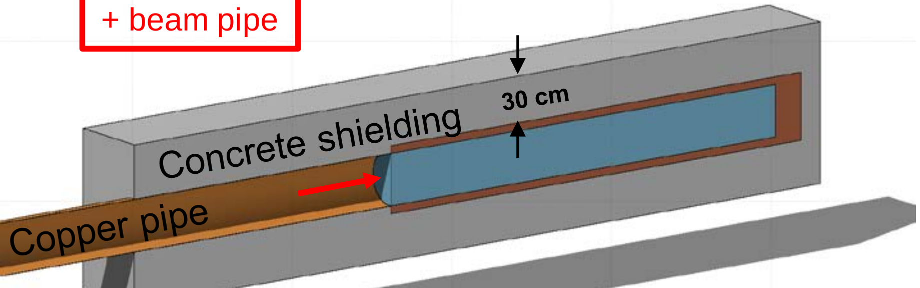


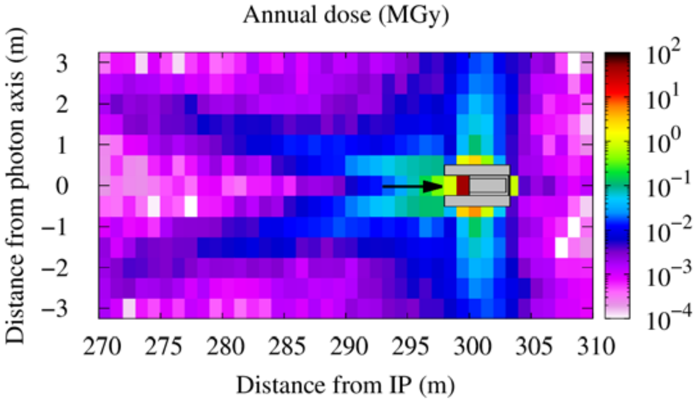

**Backscattering from dump core is enormous**
**→ many MGy/year in vicinity of dump core**

# Cumulative dose around dump (1 year at Z pole)



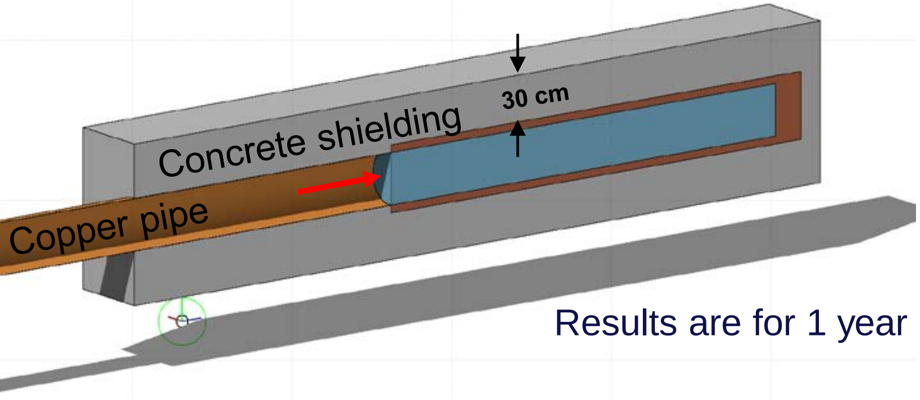



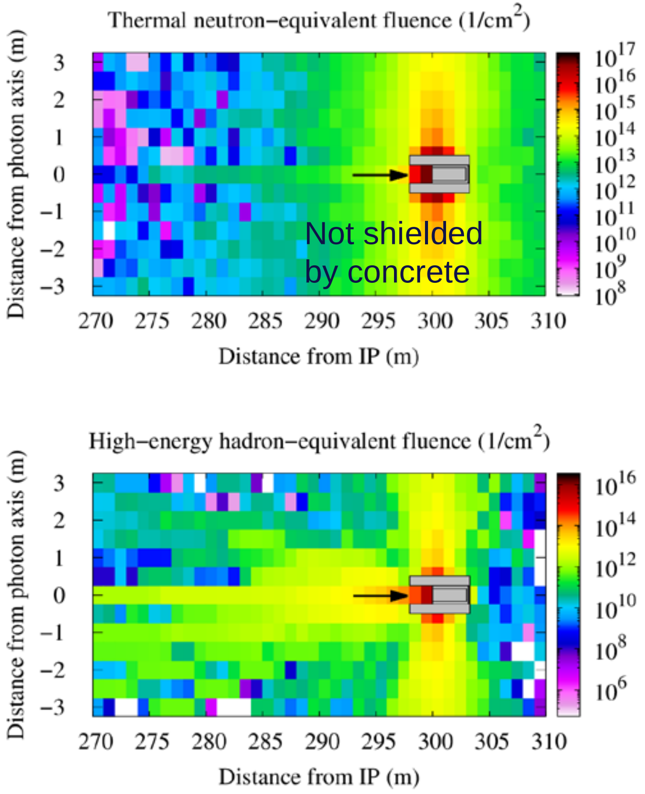




Ionizing dose to nearby equipment can be well reduced with few 10 cm of concrete, but location of sensitive equipment (e.g. electronics) still needs careful assessment

# Single event effects in nearby electronics

- Neutrons produced in photo-nuclear interactions
- Preliminary results show that thermal neutron and high-energy hadron equivalent fluences would be too high for any nearby electronics - *shielding or alternative locations for electronics (alcoves) need to be assessed*
- **Radiation effects in electronics are studied with in the CERN R2E project** (R. Garcia Alia et al.) – shall be involved early in the discussions

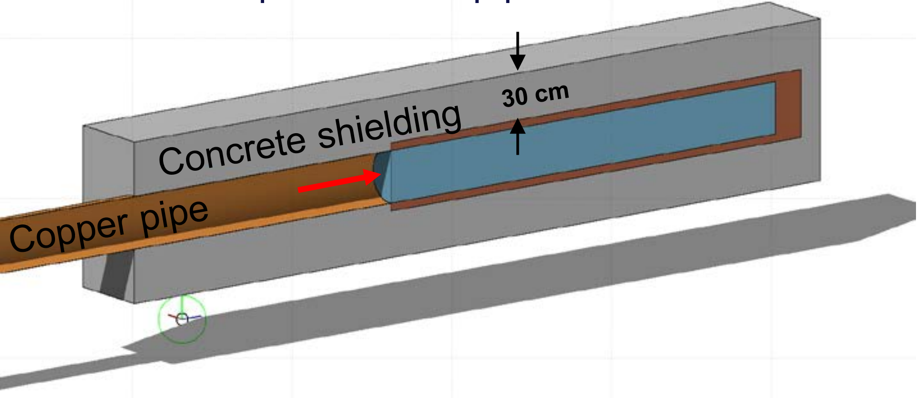



Results are for 1 year at Z pole

# Radiation protection (RP)

- Neutrons produced in photo-nuclear interactions also lead to a sizeable production of radioisotopes
- Likely, a 30 cm concrete shielding as assumed in our toy model is not enough - just to provide the order of magnitude for 1 year of Z operation ($10^7$ s):
  - 1 day of cooling: O(100 mSv/h) at contact outside of the shielding
  - 1 week of cooling: O(1 mSv/h) at contact outside of the shielding
- **Any RP assessment is under the responsibility of the CERN HSE-RP group** (FCC link person: M. Widorski) – RP considerations shall be included early in the discussions as the shielding requirements can impact the dump placement

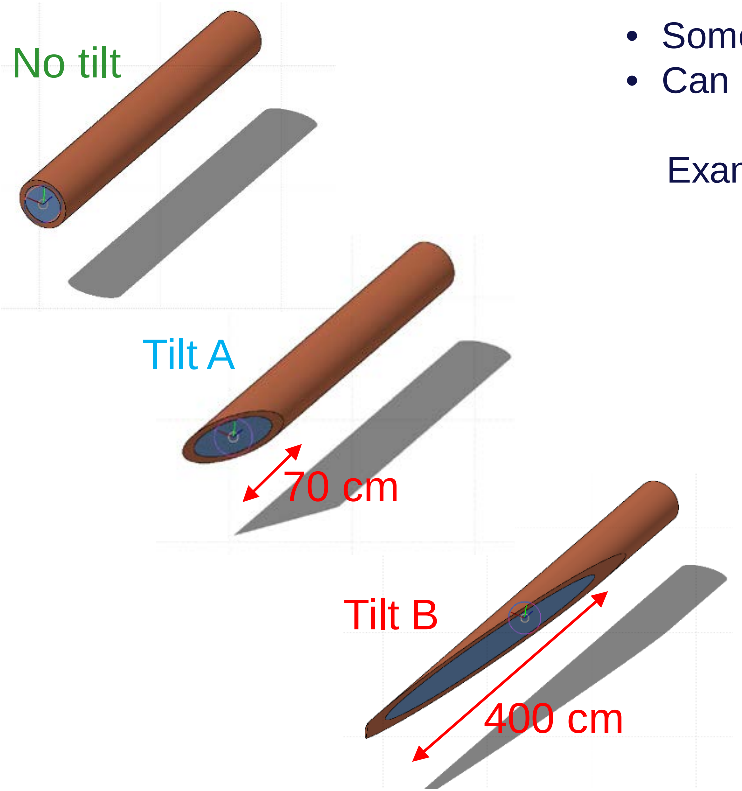


# Summary

- The photon dump poses significant challenges, both in terms of engineering (see also A. Perillo Marcone’s talk) and radiation fields → absorber material still to be defined
    - An internal dump would not be the preferred option (high power densities, enormous heat load in vicinity of circulating beam chamber) → better to have an external dump >400m from IP
- In terms of radiation shields, first studies were performed with a toy model (Graphite), indicating that particular attention has to be paid to electronics in the tunnel and radiation protection (dose to personnel during shutdowns)
- The next step would be to progress on the dump placement, under consideration of:
    - extraction chamber dimensions (considering all photon sources + tolerances + op margins)
    - extraction chamber integration
    - distances to other equipment and electronics
    - shielding requirements (equipment and personnel)
    - civil engineering implications

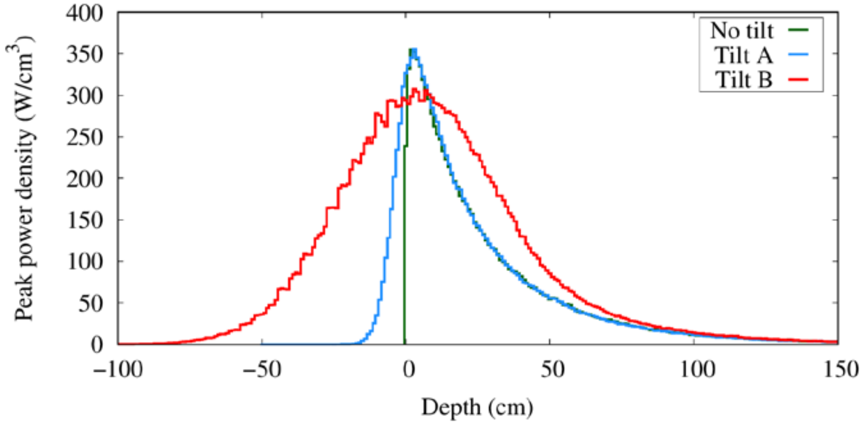
# Backup

# Power deposition in dump (toy model) – Z pole




- Some dumps have a **tilted front face** to reduce the power density
- Can it help here considering the large photon spot size?

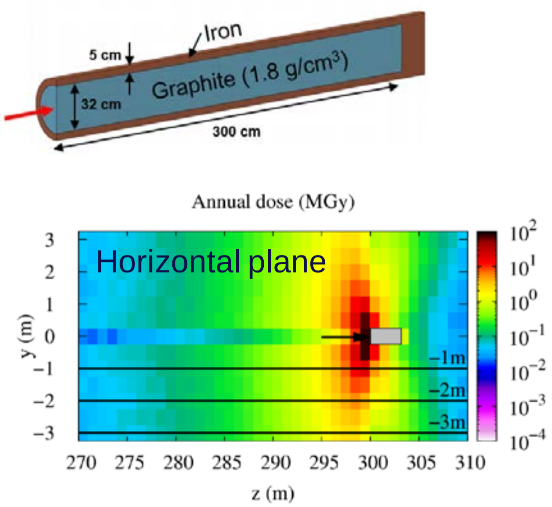
Example: dump at 300 m from IP (spot size already quite large):

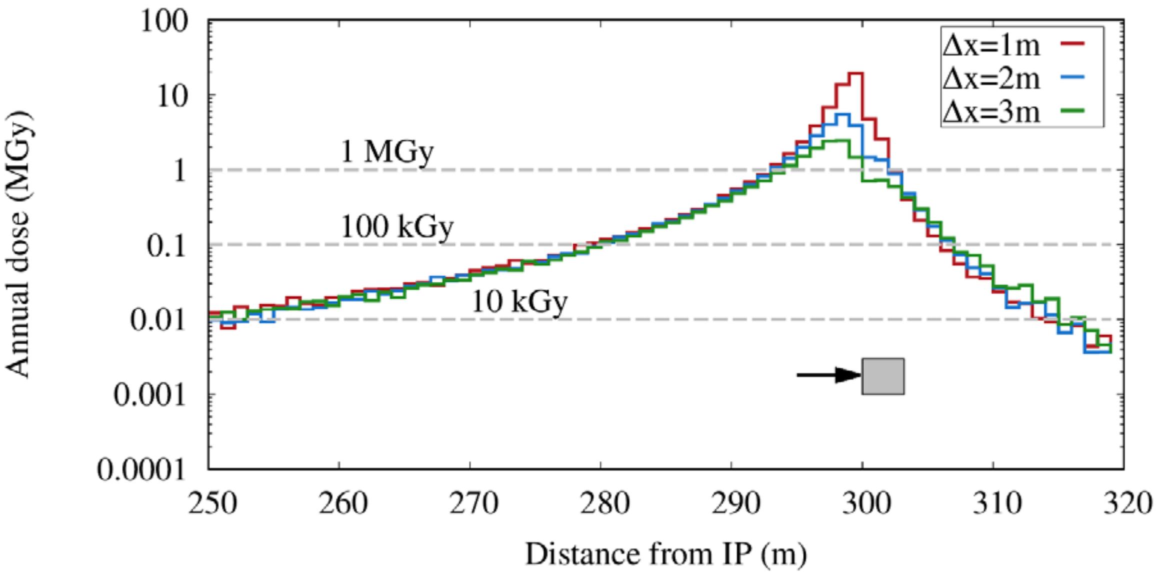



Marginal effect - the dump would need to be excessively long in order to achieve a sizeable reduction of the power density …

# Cumulative dose around dump (1 year at Z pole)

Only dump core,
no shielding, no beam pipe




Assumptions for study:

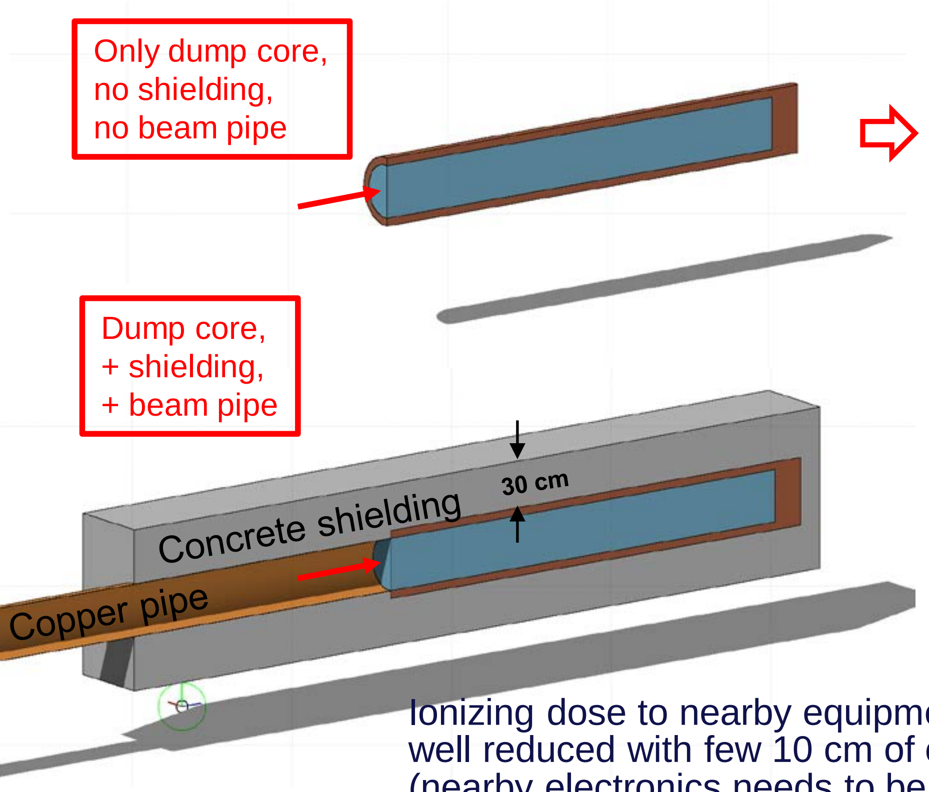
- dump @300 m from IP
- 1E7 seconds of operation/year

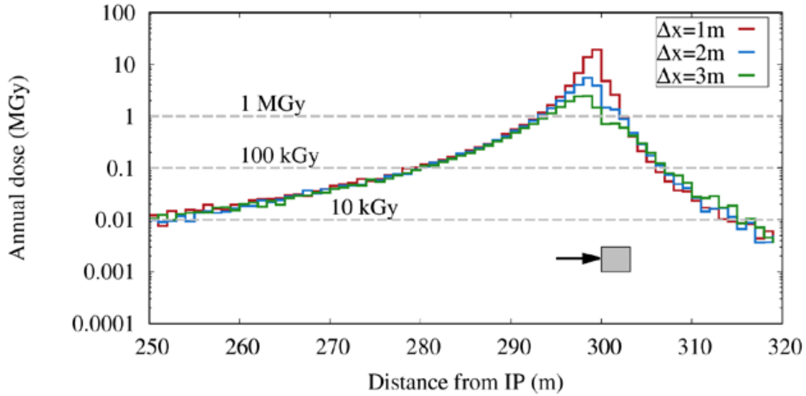
**At this location (300 m from IP), the beam line is only 2 m from dump**

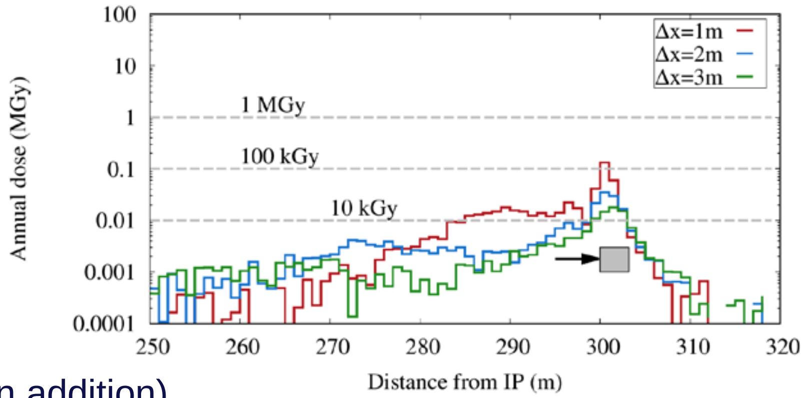
# Cumulative dose around dump (1 year at Z pole)

Only dump core,
no shielding,
no beam pipe

Dump core,
+ shielding,
+ beam pipe




Ionizing dose to nearby equipment can be well reduced with few 10 cm of concrete (nearby electronics needs to be shielded in addition)