Challenges of high-power beam dumps – general considerations on beamstrahlung absorbers

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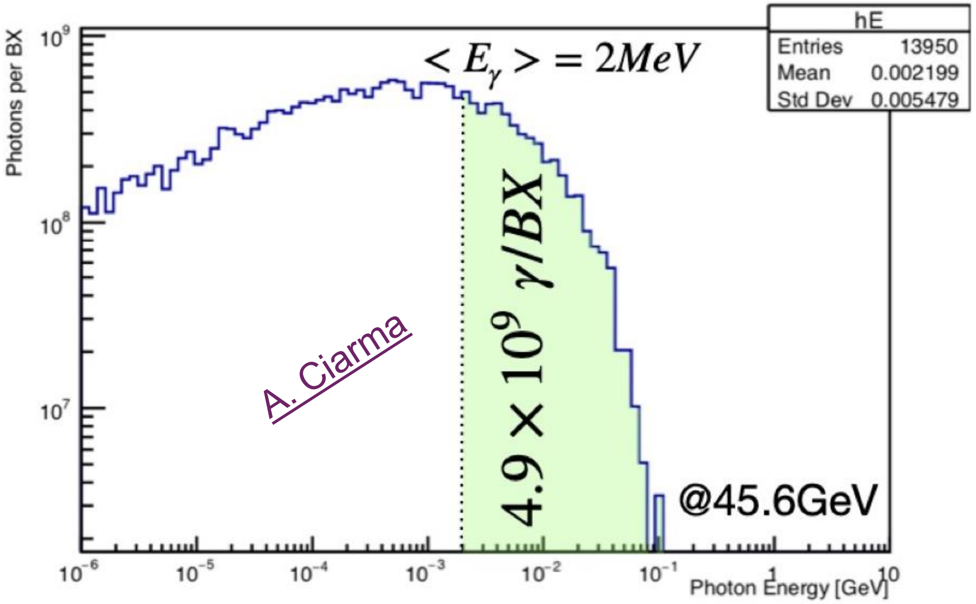
Setting the scene / requirements

- A **significant fluence of photons is generated at the IPs** in the very forward direction by different mechanisms (beamstrahlung, radiative Bhabha, etc.)
  - ±2 MeV average, extending up to 100 MeV
  - Almost **O(400 kW)** in few cm²



- To be absorbed reliably and safely

Beam energy	Radiation Power	Interacting Power
45.6 GeV	387 kW	1.8 kW
182.5 GeV	89 kW	0.4 kW

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- Interesting of **monitoring the incoming photon fluence for physics**

Setting the scene / requirements

With 4 IPs, we would need 8 dumps, each of them of 0.5 MW class

This is a big challenge for a beam intercepting device and monitoring

What type of challenges need to be faced?

- Must be able to withstand operation and accident scenarios & protect delicate equipment
- "Last line of defence" against component damage
- Dependable components, whose failure often leads to long period of downtime
- Radioactive components in an accelerator complex (cool down, ALARA)

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INTERCEPTING THE BEAMS

From targets to absorbers, beam-intercepting devices are vital to CERN's accelerator complex.

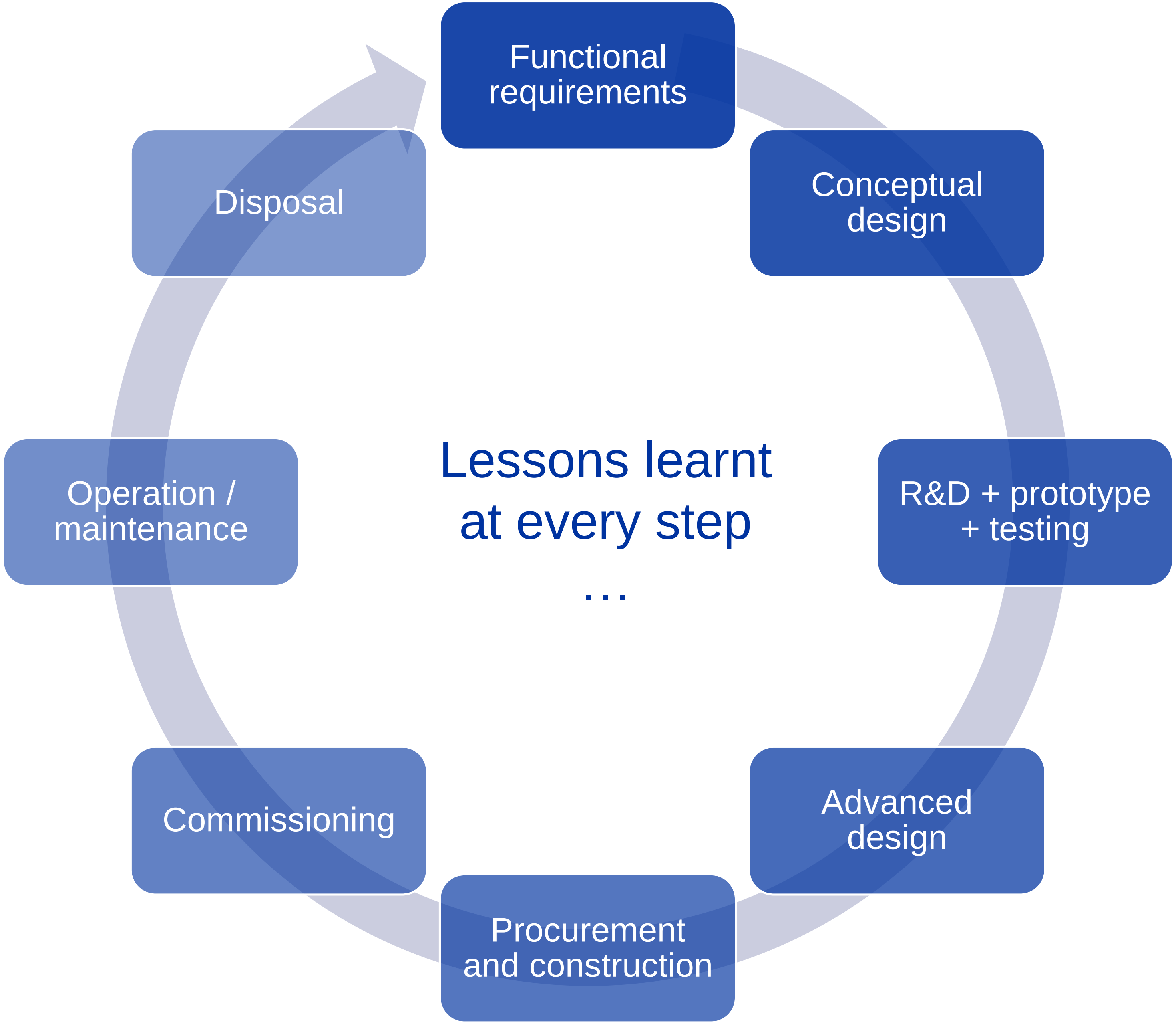
https://cerncourier.com/a/intercepting-the-beams/

What type of challenges need to be faced?

- Ultra High Vacuum requirements (if internal)
- High energy and power densities (several kW/cm^3)
- High average deposited power (hundreds of kW)
- Radiation damage and TID (hence shielding) in neighbouring areas
- Impedance optimisation
- Several independent units to be installed in the complex

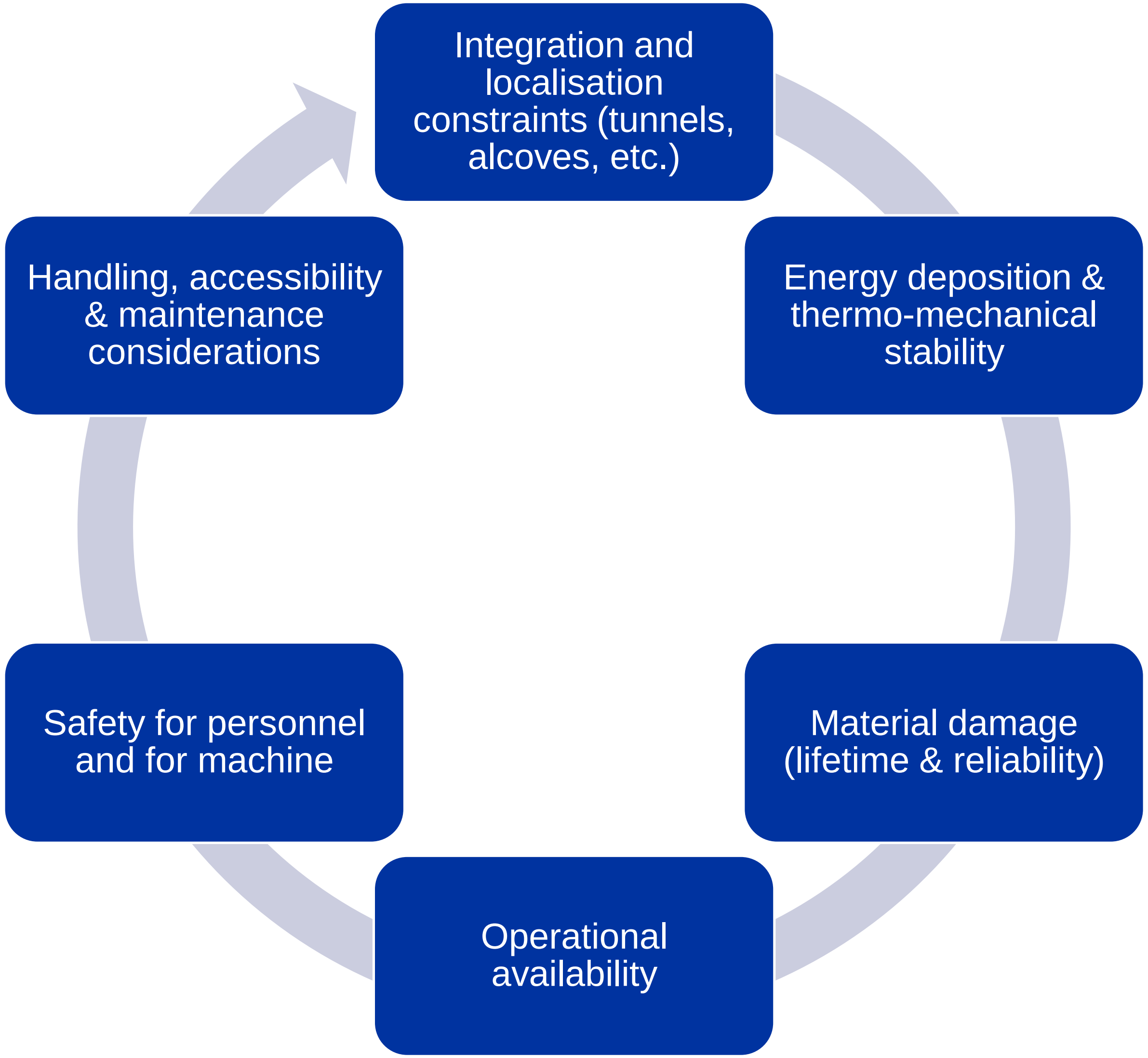
BIDs lifecycle

Lifecycle for the successful construction & operation of BIDs/Target Systems



Boundary conditions & constraints

Design is a complex and iterative process, which must satisfy multiple requirements with – in most cases – incomplete data to start with



Internal vs. external dumps

- Dumps are designed to withstand **all potential beam scenarios**, **safety devices** for machine components
- They can be located **internally** or **externally** to the machine vacuum depending on the geometry and external requirements
- Internal dumps have the extra challenge of having to comply with the **strict UHV requirements** despite the high T (& strict **impedance requirements**!)
- External dumps usually requires dedicated caverns or line components

Internal vs. external dumps

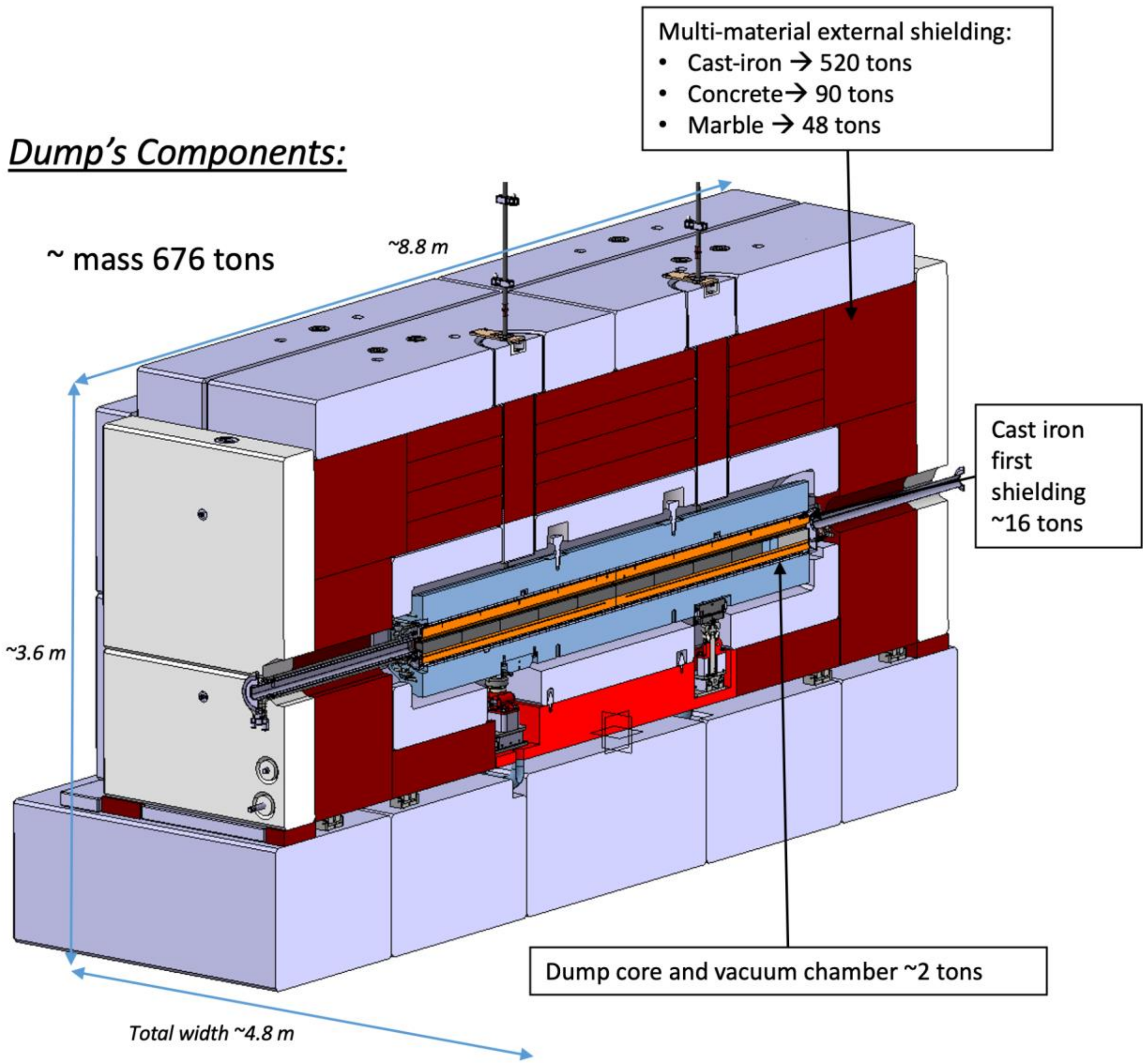
- Internal dumps
  - Extra challenge of having to comply with the strict UHV requirements despite the high T
  - Plus, highly radioactive devices in the middle of the accelerator
- External dumps
  - Usually requires dedicated caverns or line components (CE complexity)

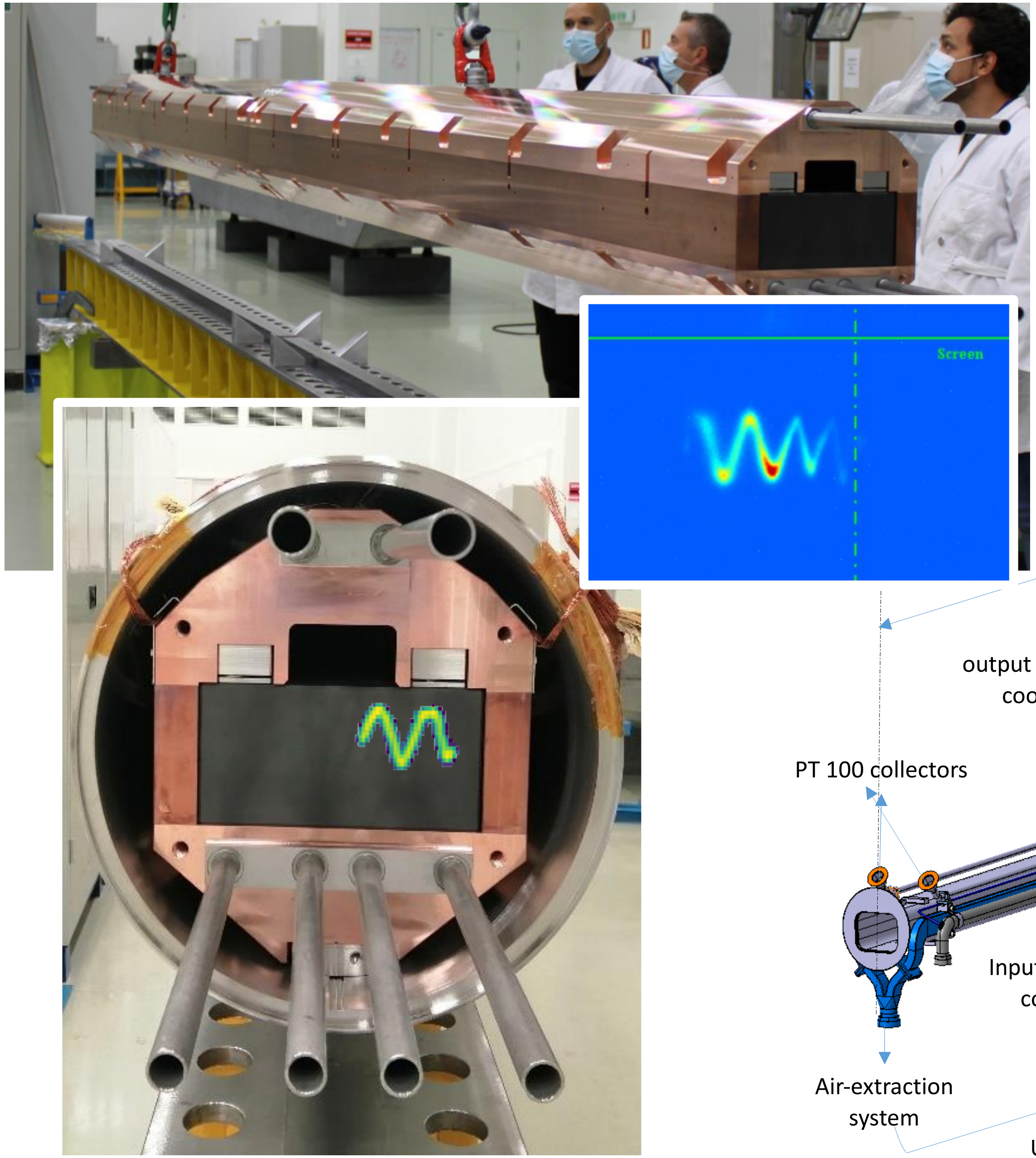

Pre-LS2 SPS internal dump

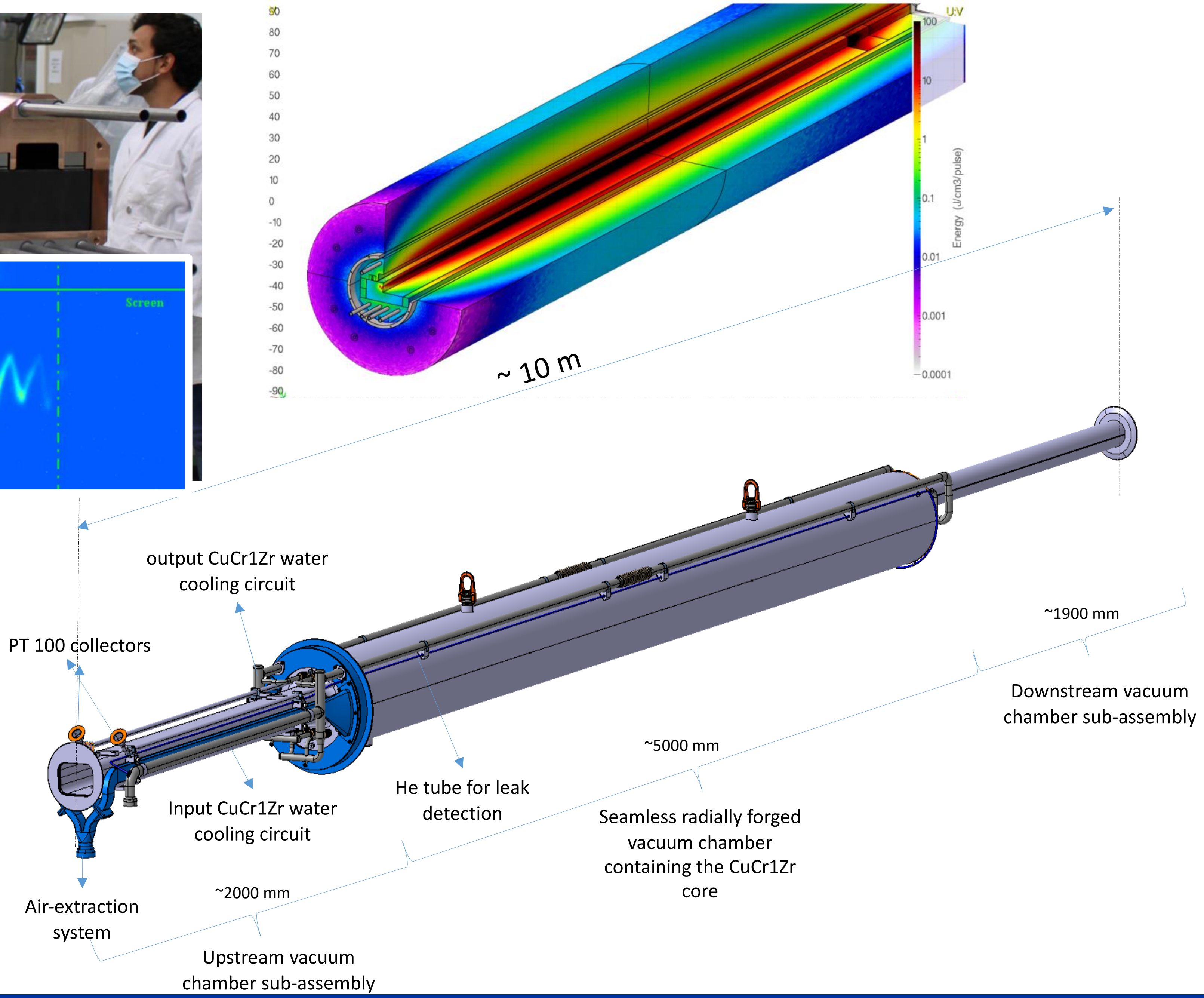

Pre-LS2 LHC external dump

SPS TIDVG5 (internal dump)

Designed for about 300 kW in the most demanding scenario





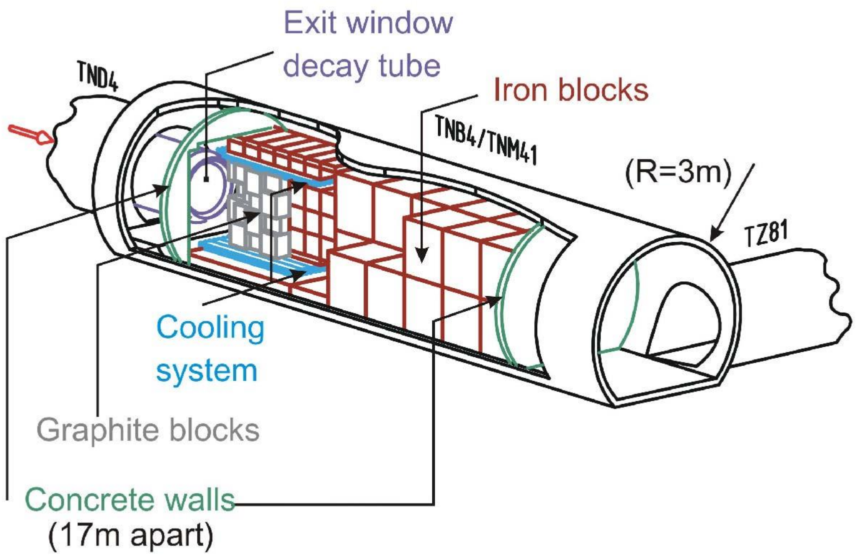


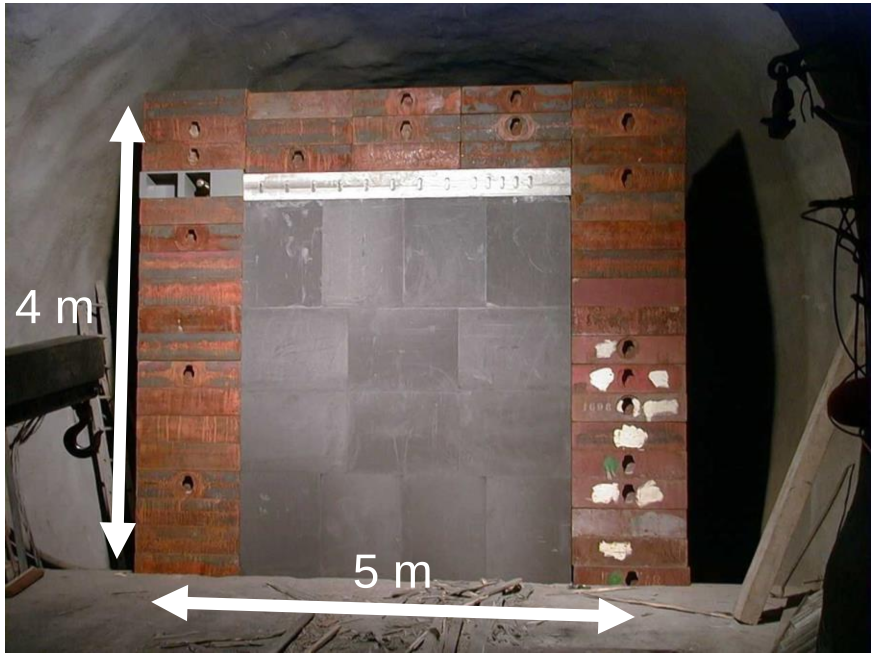
Energy (J/cm3/pulse)
~ 10 m
output CuCr1Zr water cooling circuit
PT 100 collectors
Input CuCr1Zr water cooling circuit
He tube for leak detection
Air-extraction system
~2000 mm
Upstream vacuum chamber sub-assembly
~5000 mm
Seamless radially forged vacuum chamber containing the CuCr1Zr core
~1900 mm
Downstream vacuum chamber sub-assembly


Bonfanti
BA5
BA6

Hadron absorbers for neutrino beams

- High average power absorbers exists also in neutrino beam lines, namely, to absorb the **large hadron fluence** and the **remaining proton beam**

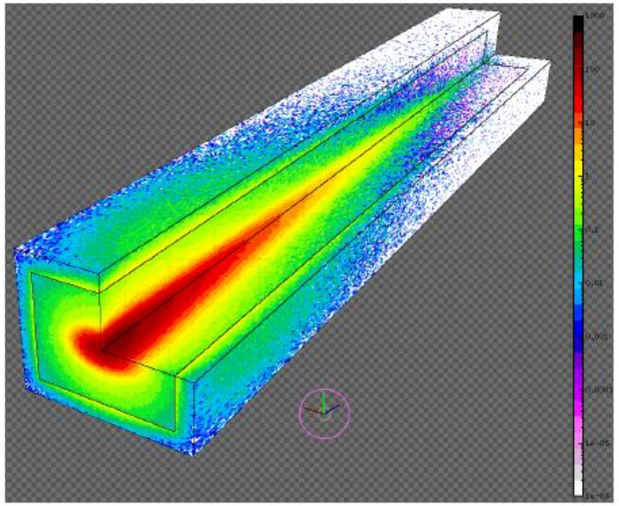




e.g. CNGS@CERN absorber

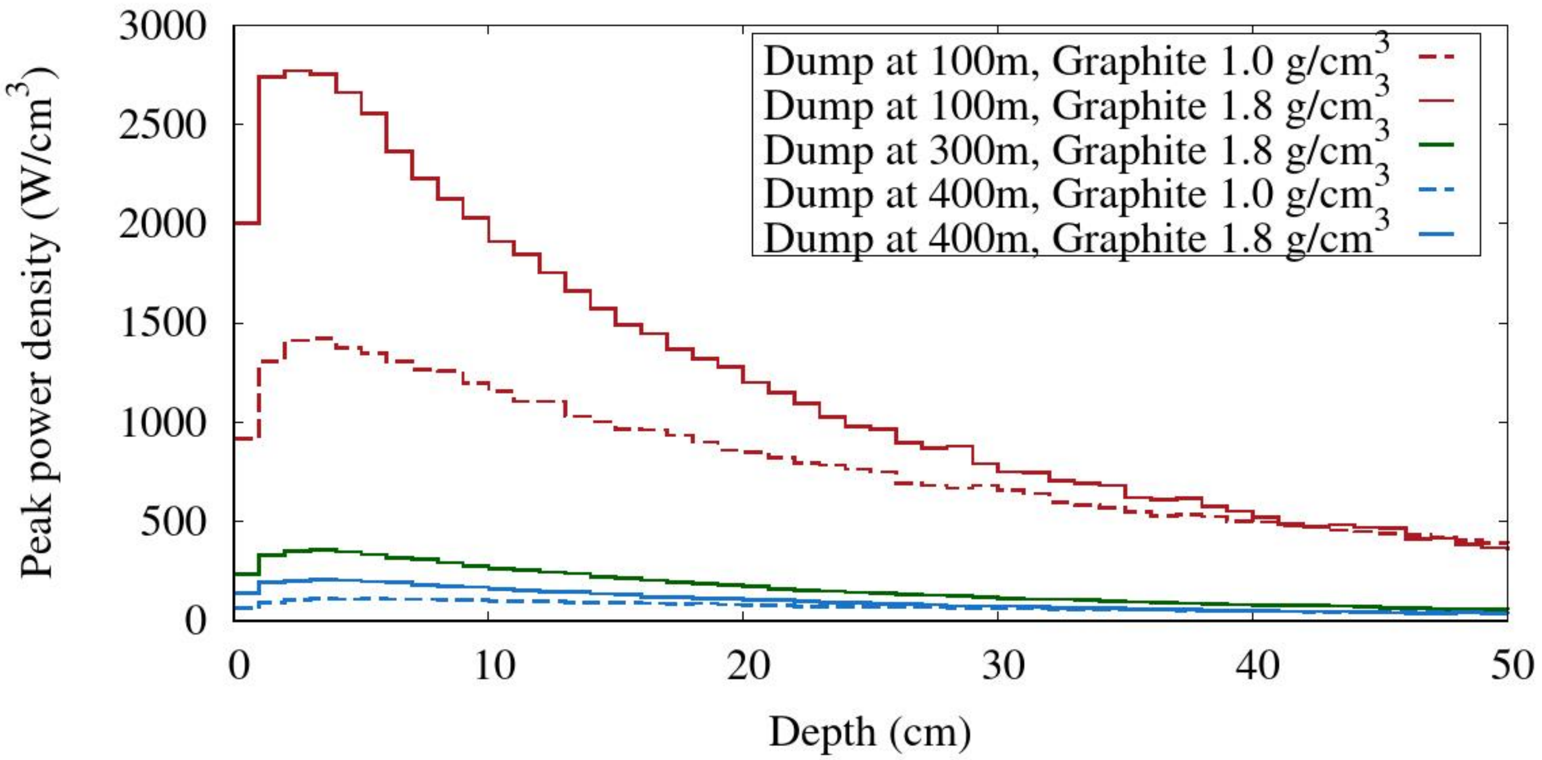
e.g. T2K absorber, courtesy T. Ishida (JPARC)

Power density in a tentative graphite core (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

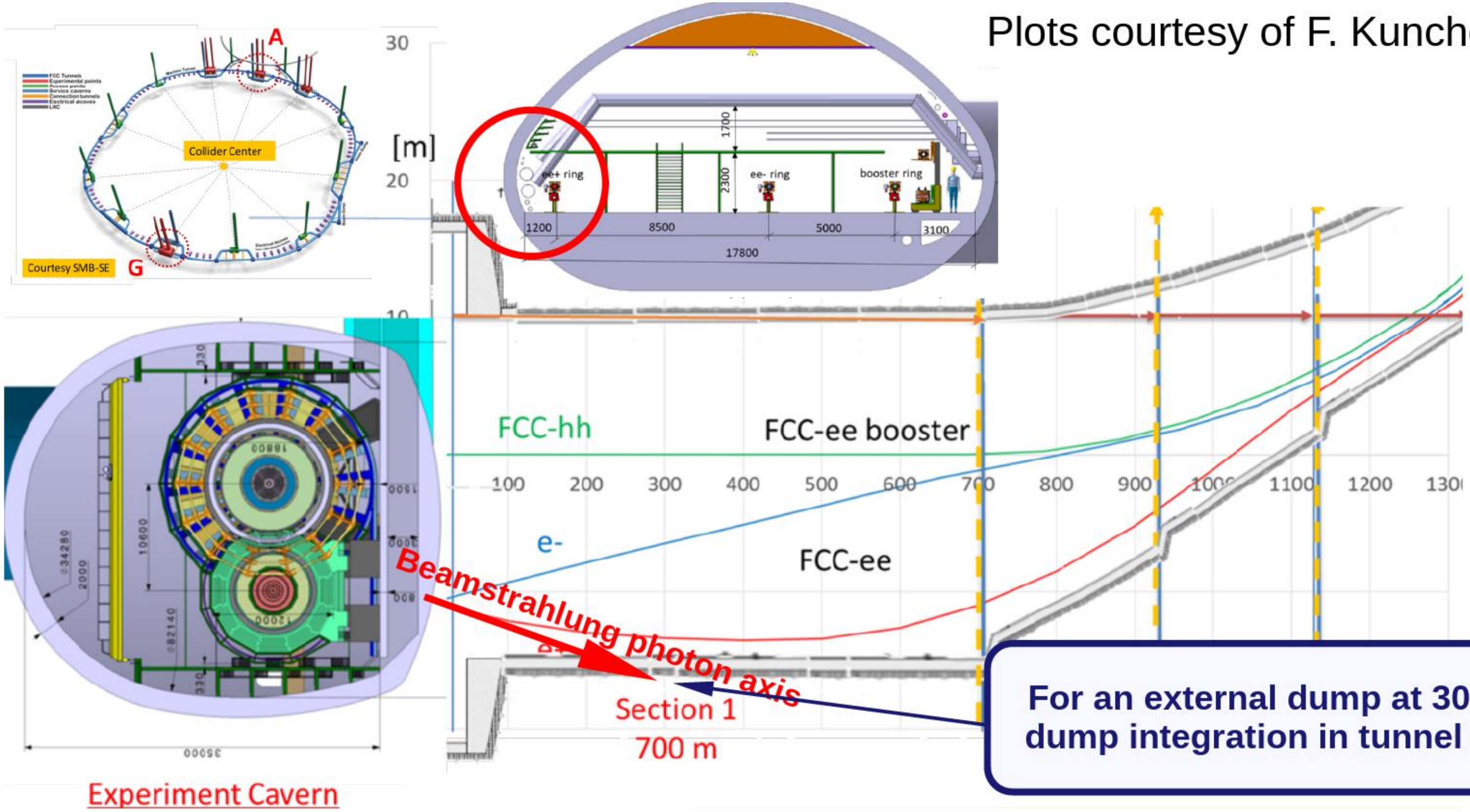
Typical HD and LD graphite densities for different distances from IP



Based on beamstrahlung distribution from A. Ciarma

Beamstrahlung dump integration in tunnel

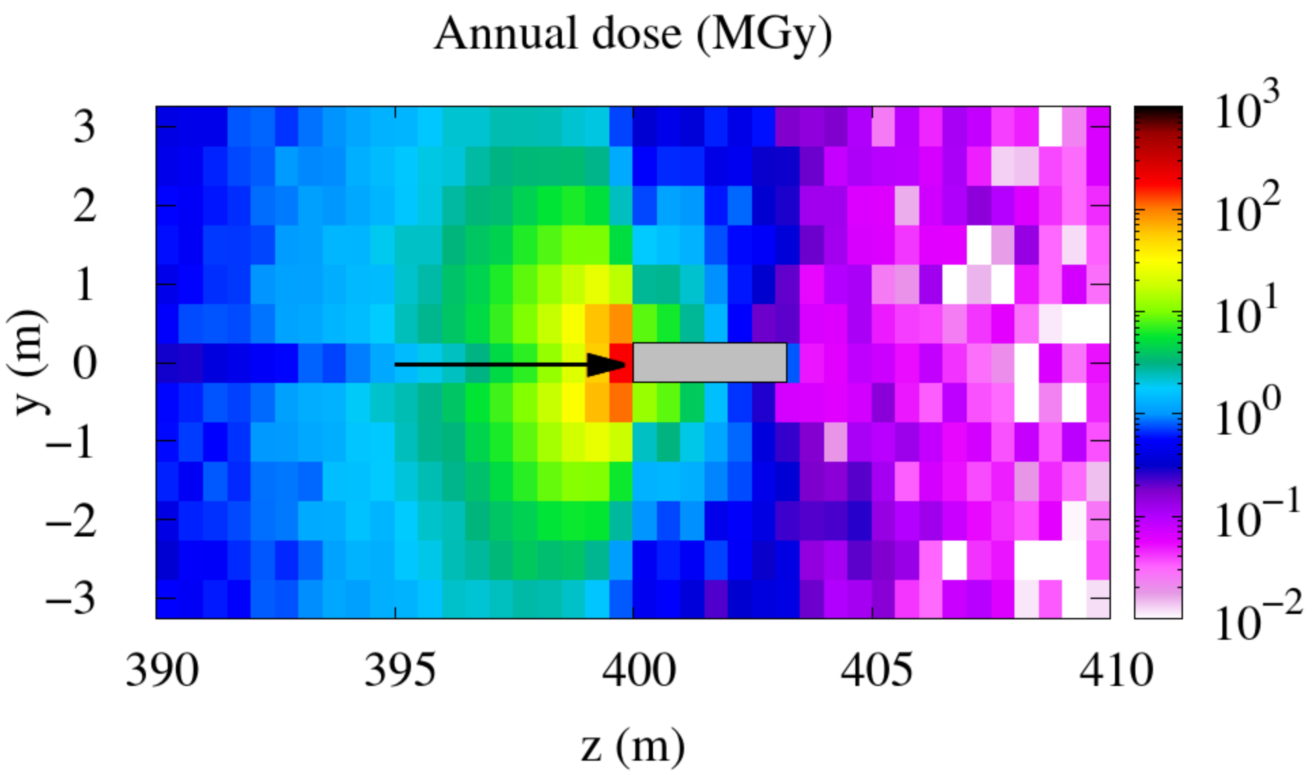
Plots courtesy of F. Kuncheva-Valchkova

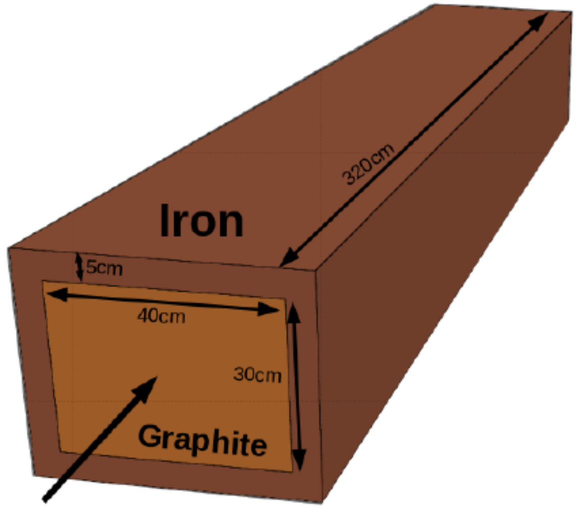


For an external dump at 300+ m from IP, dump integration in tunnel to be studied

Radiation environment around dump (Z pole)

Dose in the horizontal plane (vertically averaged within ±25cm) with simple toy model (w/o significant shielding):





⇒ **Backscattering from Graphite block is enourmous**

Neutrons are also produced due to the tail of higher energy photons

Options for the FCCee beamstrahlung absorber

- **Graphite** core (monolithic or tilted to dissipate energy) is a primary option given the robustness (but thermal conductance is not the best)
- **Water** absorber could also be a possibility (à-la ILC photon dump)
- **Liquid metal (e.g. Pb or PbBi)** could also be an opportunity for a very compact design (line of R&D joint with other activities at CERN)
- **Integration** constraints (example of questions):
  - **Can we put the dump at 300/400 m from the IP?**
  - **Vacuum line design – impacted, vacuum criteria?**
  - **Do we need a window, or can we move to a window-less absorber**?

Measuring beamstrahlung photons at FCCee

- Challenge: Measuring the **intensity**, **position** and **size** of high-power densities beamstrahlung photon beams

- Proposal: Use a **two-steps approach** with different diagnostics
  - **Fully characterising the photon beams at low power** using, e.g., scintillating screens and cameras (to be studied) that will only be inserted in the photon beam extraction line during **single bunch** or **few bunch** operation
  - Measure the transverse tails of beamstrahlung photon distribution using intercepting sensors (i.e., scintillators, gaseous detectors, pixel detectors..) or developing **fully non-invasive methods** (e.g., using ionisation or fluorescence of gas jets) that would be able to **withstand the full photon beam power**

- Studies priority to be clarified with project (and possibly launched if resources made available)

How to go ahead?

The definition of a working plan is essential for priorities & resources

1. Definition of the source and boundary conditions
2. Integration constraints and possibilities is a major boundary in the definition of the design parameter space
3. Beam monitoring opportunities
4. Early conceptual design for the assembly & cooling & R&D (!)

- **Lots of challenges ahead !**

Conclusions

- **Hundreds of kW of photons to be safely absorbed – and potentially measures – out of the FCCee IPs is a major challenge**
- Integration constraints must be carefully addressed and included in the conceptual design, as the potential primary boundary limitation
- It is a challenging multi-physics/dimensional problem, that needs attention & adequate resources to be properly assigned
- The BS dump/instrumentation line is a challenging part of the collider as well requiring a thorough study (that can only be started when resources are available)
- Lessons can be derived from other high-power absorbers built worldwide and at CERN

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