Design studies for the FCC-hh beam dump

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(CERN)

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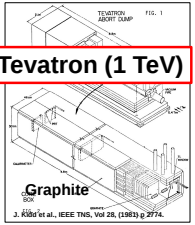
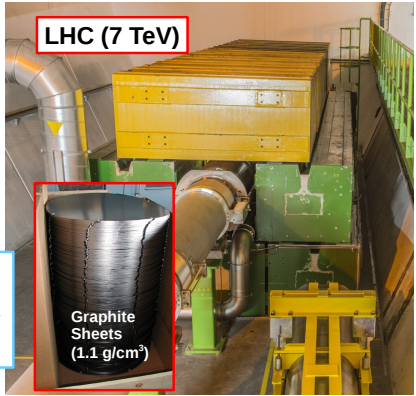
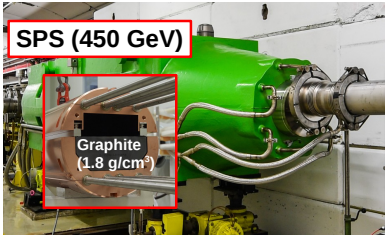
Introduction

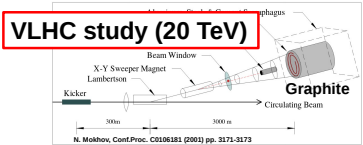
- **Graphite - the natural choice for high-energy proton dumps**







Graphite:
+ low Z and density
+ high thermal shock resistance
+ high melting point



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  - **Dilution requirements** for safely absorbing FCC beams in a **LHC-like Graphite dump**
  - Consequences of **irregular beam aborts** → mitigation with **low-density Carbon foams/powders**?

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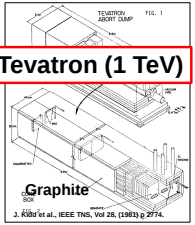

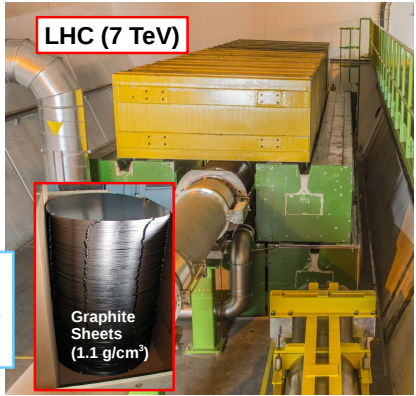

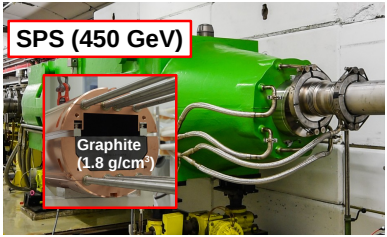

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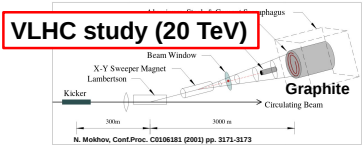

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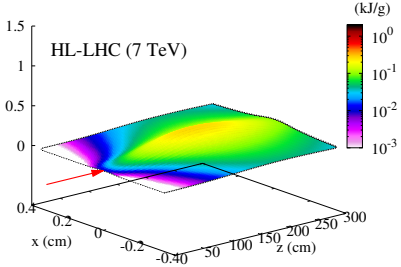
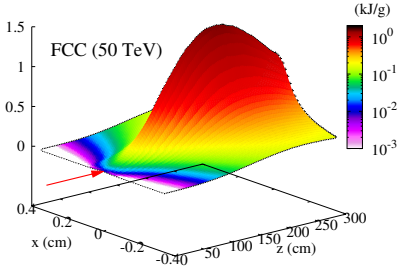
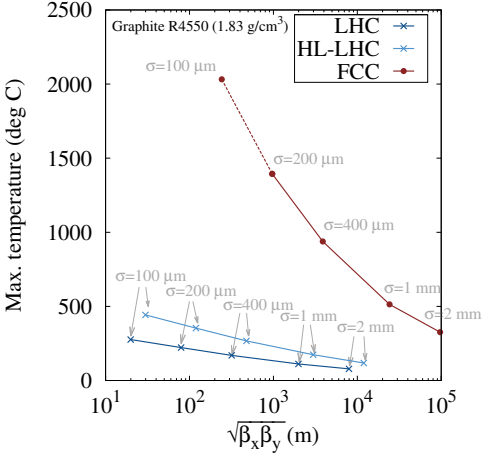
(HL-)LHC vs FCC: single proton bunch on Graphite





	LHC	HL-LHC	FCC
E (TeV)	7	7	50
ϵ_n (μm·rad)	3.75	2.5	2.2
ppb ($\times 10^{11}$)	1.15	2.2	1.0



1 proton bunch,
Graphite (1.8 g/cm^3)

Even with large β:

- O(few) bunches can induce critical stresses
- O(10s) bunches can provoke phase transition

(if all on the same spot)

Figures on the left: dose in 3 m long Graphite (1.83 g/cm3) for one nominal proton bunch (σ =400 μm) - HL-LHC (top) and FCC (bottom).

Max. energy density/temp. by single bunch → spot size

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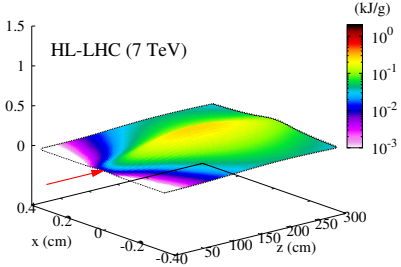

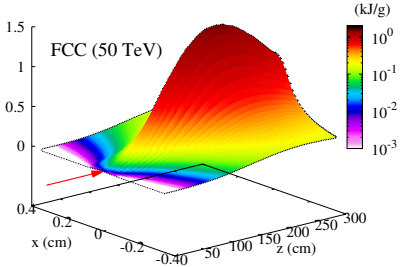

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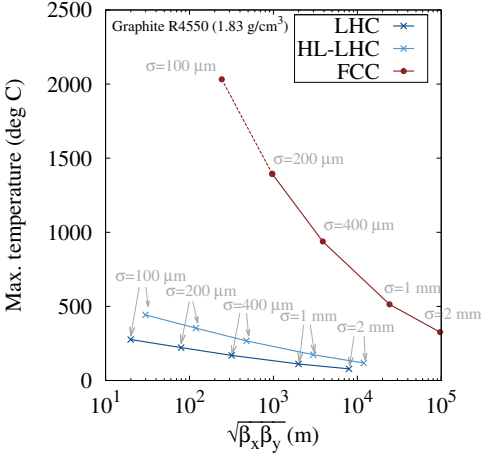

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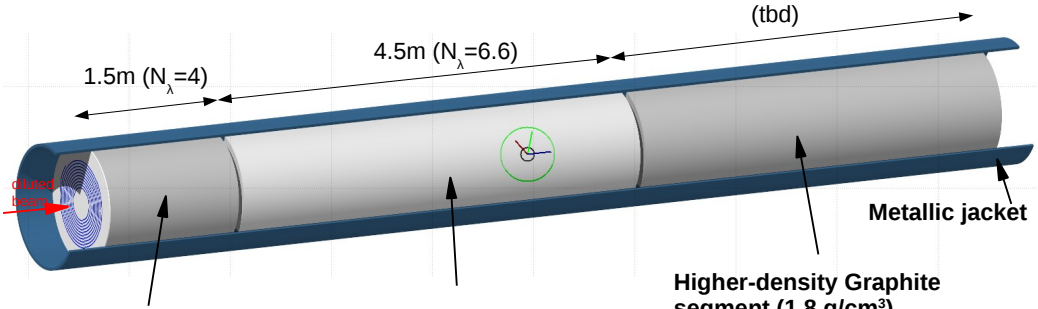
FCC-hh dump concept (LHC-like Graphite dump)



Higher-density Graphite segment (1.8 g/cm^3)

Higher material density at upstream end gives rise to a steeper shower build-up and hence reduces the overall dump length
Note: the presence of the higher-density graphite has only a small effect on the maximum energy density in the low-density segment if the beam is diluted across the dump face

Low-density Graphite segment (1.0 g/cm^3)

Lower material density in the region of the shower maximum reduces the max. energy density and temperature

Higher-density Graphite segment (1.8 g/cm^3)
+ possibly other materials (tbd)

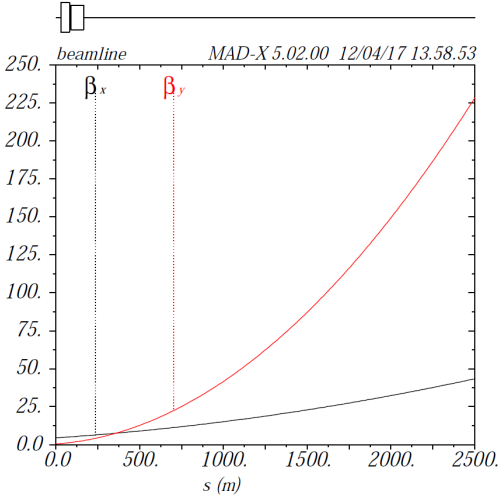
Higher material density gives rise to better attenuation of the longitudinal shower tails and hence reduces the dump length

Total core length expected < 10-12m

Core radius depends on sweep pattern (+ a certain margin to jacket)

FCC-hh: optics parameters+bunch spot sizes at the dump

Distance dilution kickers - dump: ~2.5 km



⇒ *see talk of F. Burkart for details.*

- **Optics parameters at dump:**

β_x	β_y	D_x	D_y
45 km	240 km	0.13 m	2.7 m

- **25 nsec beam (10600 bunches):**

$\varepsilon_{x,y}$	I_b	σ_x^*	σ_y^*
2.2 μm·rad	1×10^{11}	1.36 mm	3.15 mm

- **5 nsec beam (53000 bunches):**

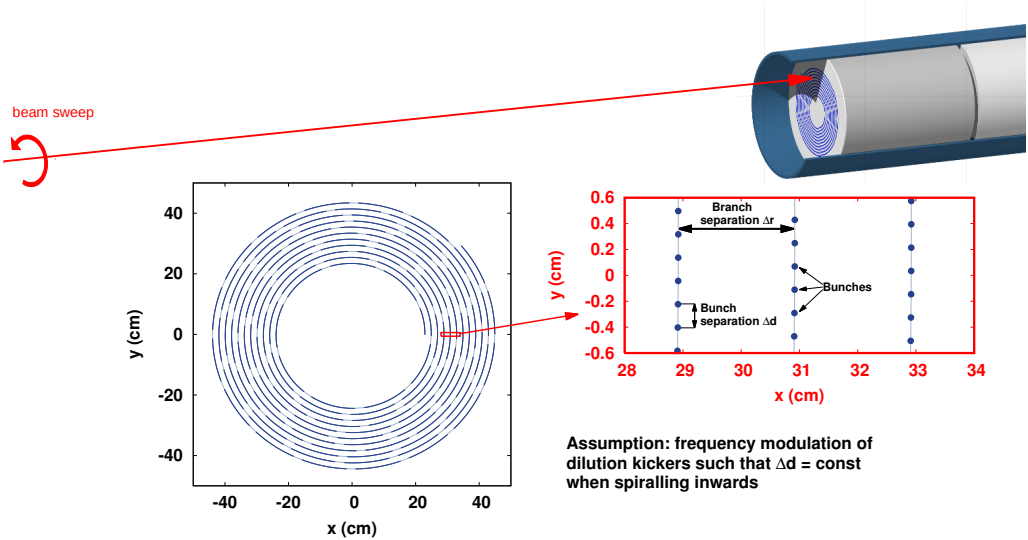
$\varepsilon_{x,y}$	I_b	σ_x^*	σ_y^*
0.44 μm·rad	0.2×10^{11}	0.61 mm	1.41 mm

Note:

- The large β-functions at the dump **do not relax much dilution requirements** (the optics is mainly motivated by the available kicker aperture)

* *Without dispersion contribution.*

FCC-hh: spiral dilution pattern



Assumption: frequency modulation of dilution kickers such that Δd = const when spiralling inwards

Tentatively assumed filling scheme for 25 nsec: Trains of 80b separated by 425 nsec gaps (5 nsec: trains of 400b separated by 425 nsec).

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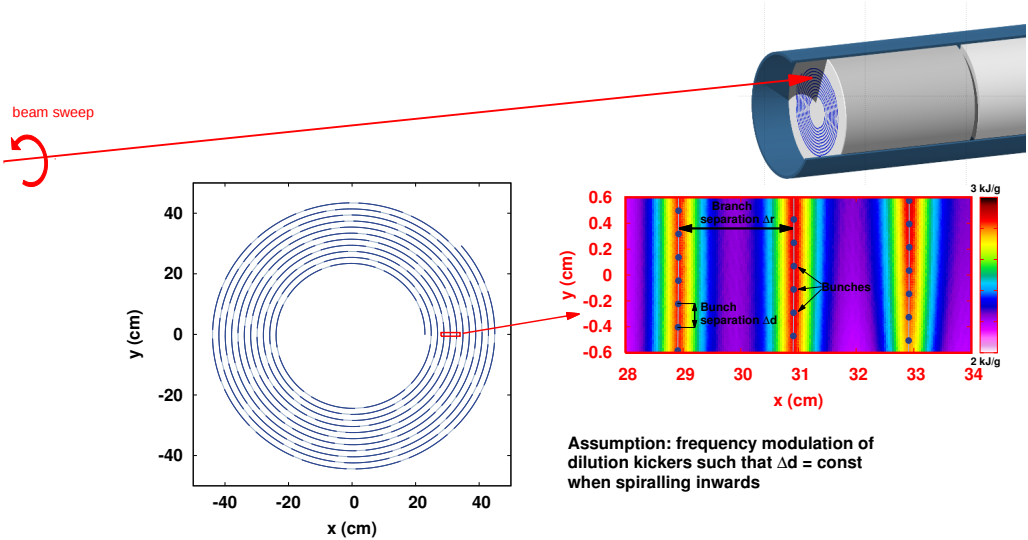

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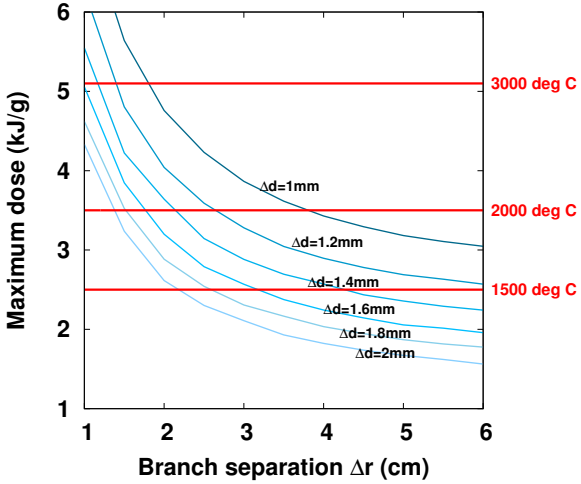
Maximum dose in low-density Graphite segment for 25 nsec beams:



(all values in adiabatic limit)

Set of baseline parameters:

- Bunch separation Δd: **1.8 mm** *(5 nsec: 1.8/5=0.36 mm)*

$\Rightarrow$ Sweep path length: **23.8 m** *(LHC: 1.2 m)*

- Branch separation Δr: **20 mm**
- Pattern outer radius: **45.1 cm**

(all results shown in the following are for this sweep pattern)

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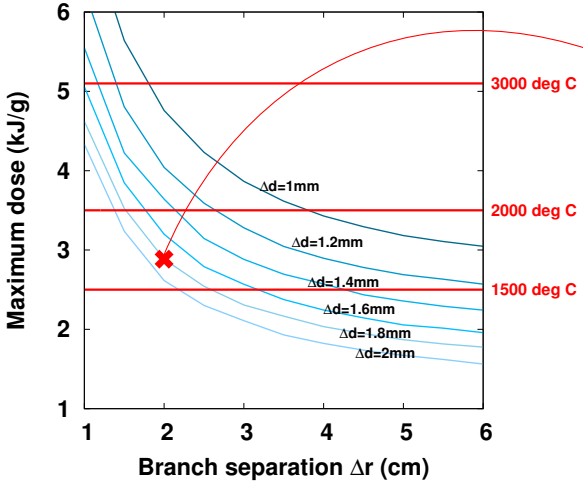

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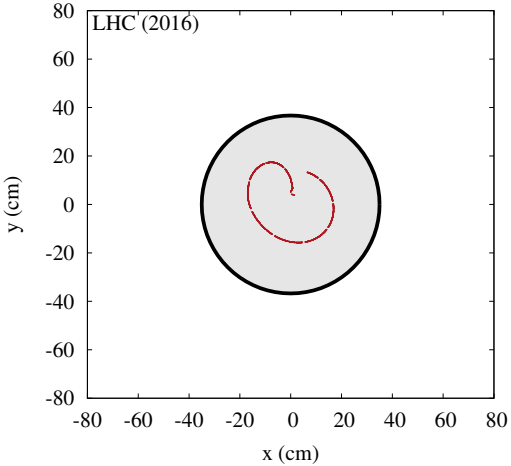
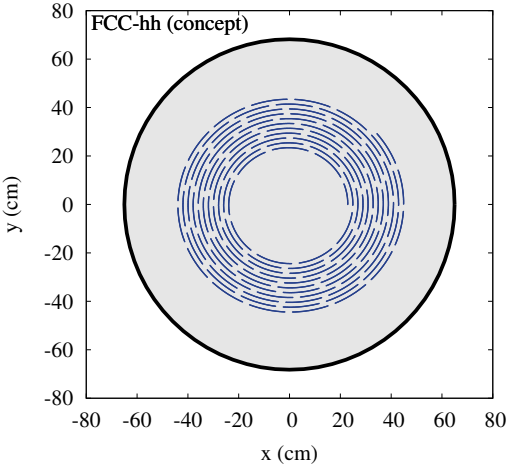
LHC vs FCC-hh: sweep pattern and dump radius

- **LHC (core radius = 35 cm):**



- **FCC-hh (core radius $\sim$ 60-70 cm):**



LHC vs FCC-hh: transverse dose distribution

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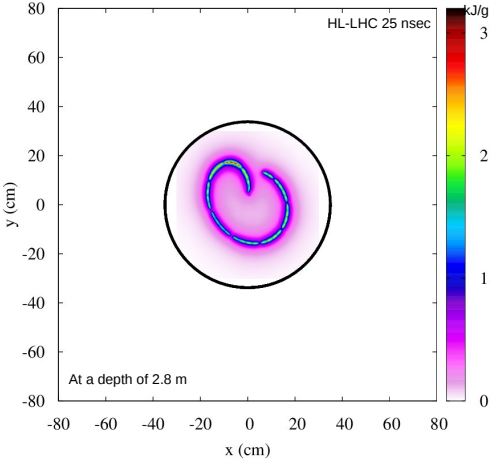

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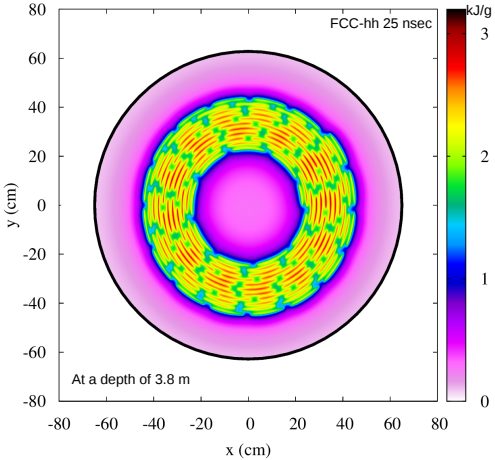
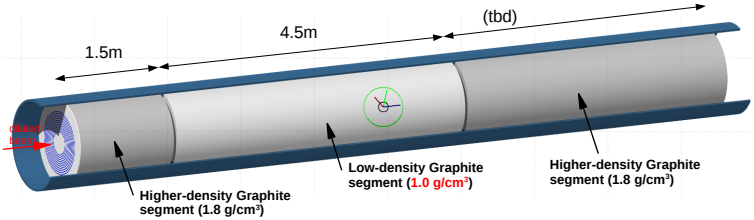
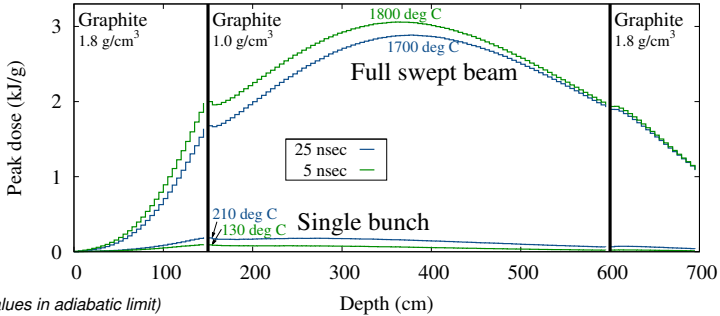


FCC-hh: longitudinal peak dose profile (5 & 25 nsec)





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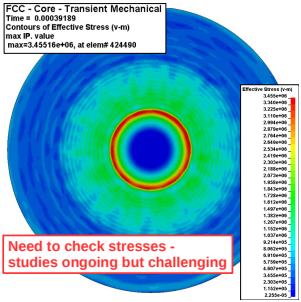
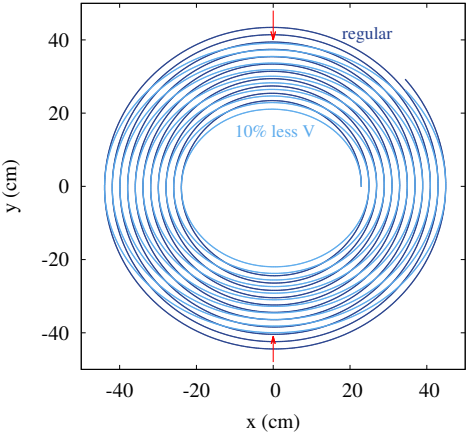
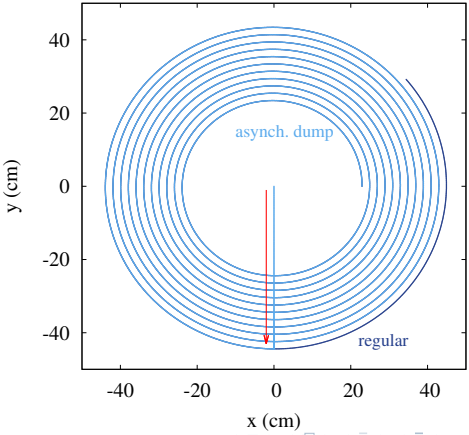


Failure cases: distortion of dilution pattern

- **Dilution failure:**
  - **10% less dilution** in vertical plane (dilution system highly segmented)



- **Asynchronous beam dump:**
  - Beam extracted while **dilution kickers still raising**



FCC-hh: energy deposition in dump in failure cases (25 nsec)

- **Latent heat:**
  ~**8.7 kJ/g** [1]
- **Melting:**
  ~**17 kJ/g** [1]

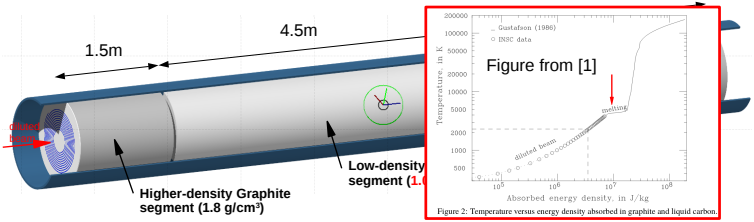
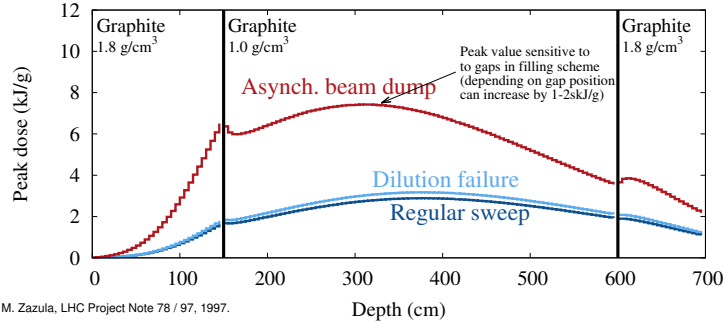
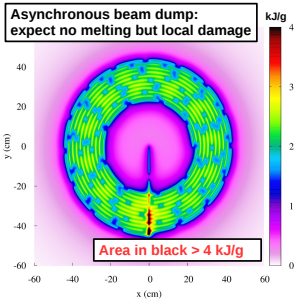


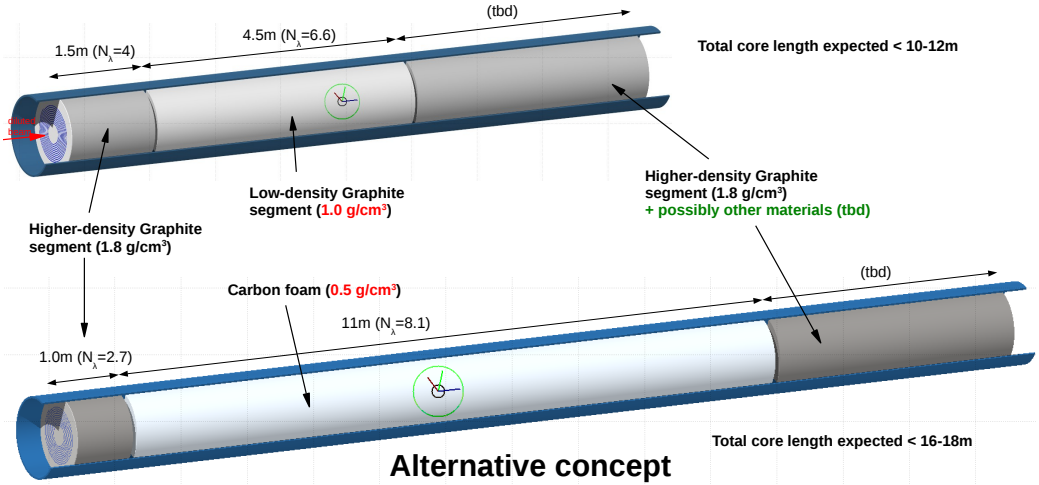
Figure 2: Temperature versus energy density absorbed in graphite and liquid carbon.



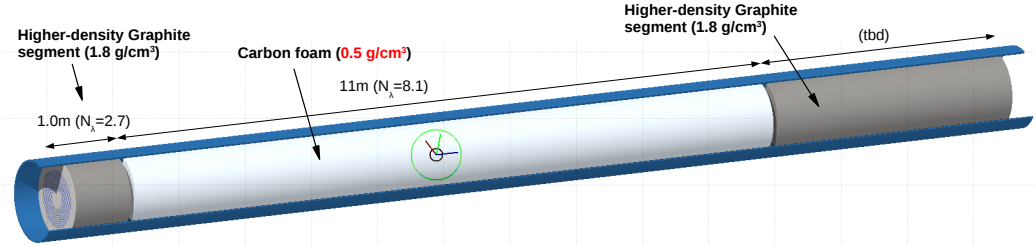


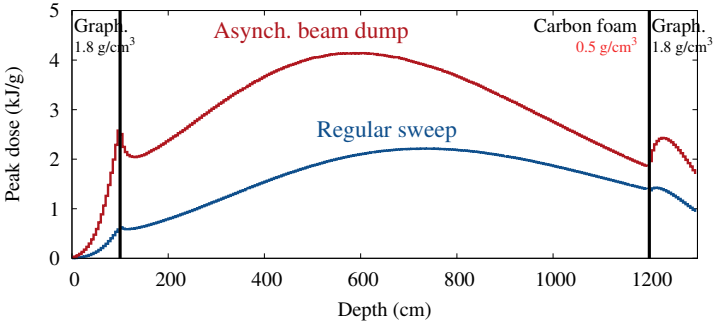
[1] Jan M. Zazula, LHC Project Note 78 / 97, 1997.

FCC-hh alternative dump concept: lower material density



FCC-hh alternative dump concept: energy deposition





- Peak dose reduction wrt baseline concept:
  - Regular sweep: **-25%**
  - Asynch. dump: **-45%**
- **Further material testing & characterisation required** (needed to assess stresses etc.)

Conclusion and outlook

- **Baseline Graphite dump for FCC-hh (LHC-like flexible Graphite with 1g/cm^3):**
  - Approximate dimensions:
    - $\Rightarrow$ **radius of 60-70 cm**, **length of 10–12 m**
  - Simulations of the thermo-mechanical response for regular sweep ongoing
  - Dump will suffer local damage in case of **asynchronous beam dump**
    - $\Rightarrow$ might require dump exchange - remote handling desirable
    - $\Rightarrow$ mitigation measures under consideration, e.g.
      - $*$ anti-damped dilution spiral (to be assessed by kicker experts)
      - $*$ delay extraction and allow for 1σ oscillation of O(100) bunches
- **Alternative directions:**
  - Employ lower-density **Carbon foams** (or even **Carbon powder**) with densities $\leq 0.5\,\mathrm{g/cm^3}$
    - $\Rightarrow$ reduces shower-induced energy densities
    - $\Rightarrow$ dump length still expected to stay below 20 m
  - Foams already exist but **material characterisation and testing** required to assess their response to beam impact - they have never been used in high-energy proton BIDs or dumps