Beam Dump System

Guangrui Li

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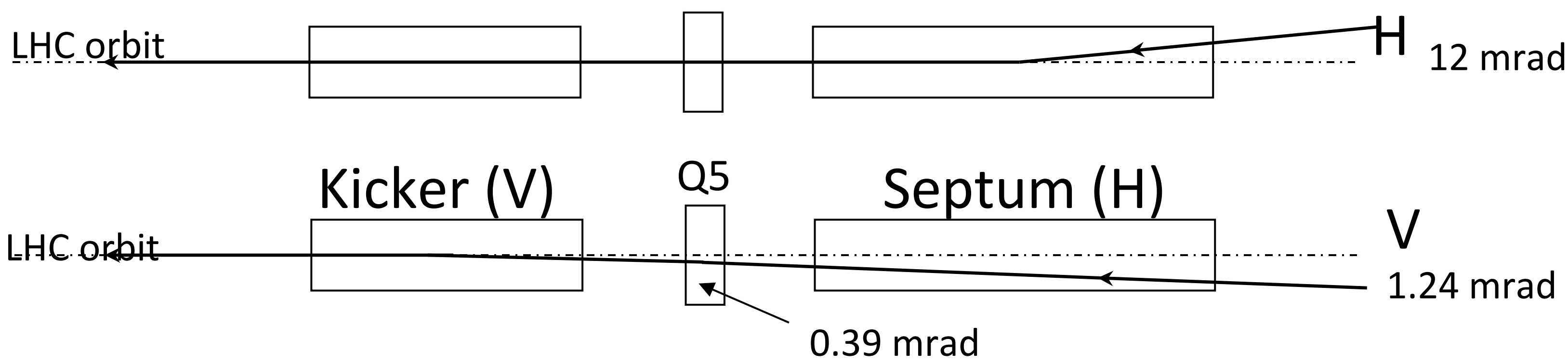
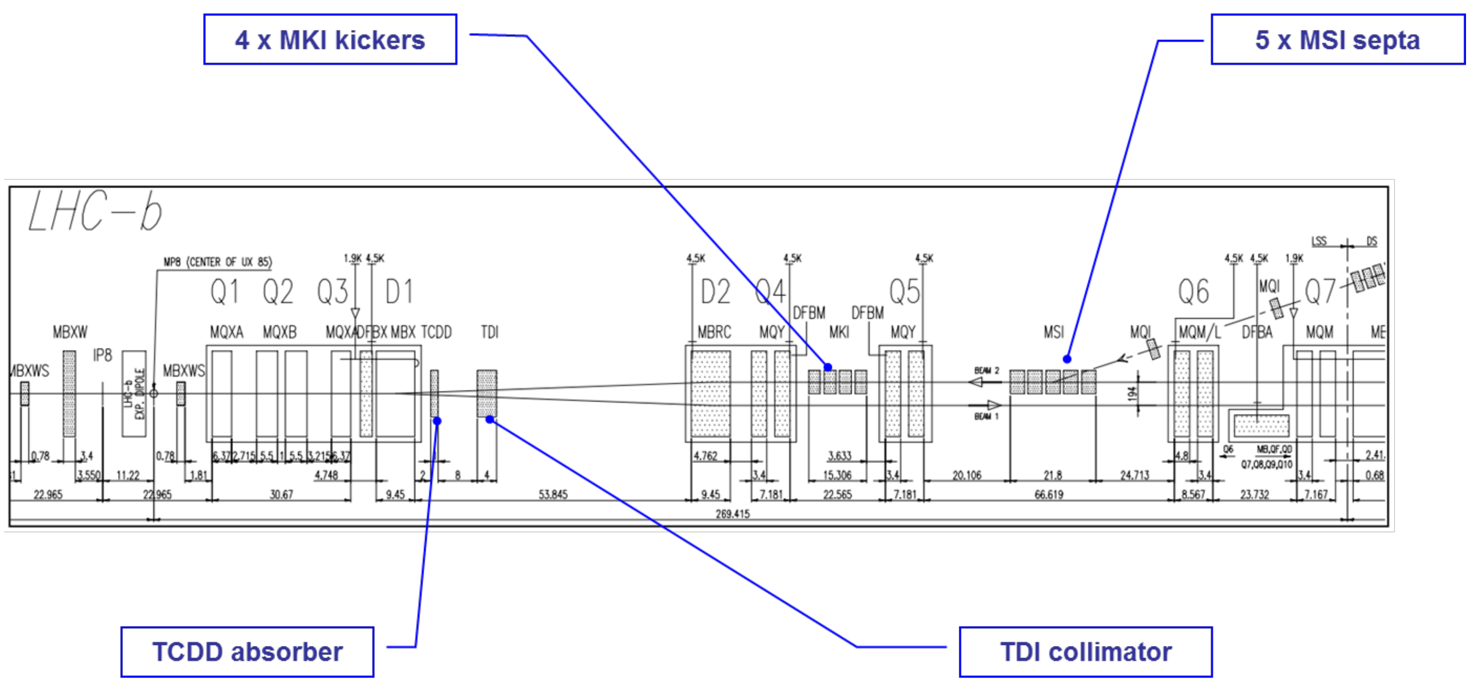
Outline

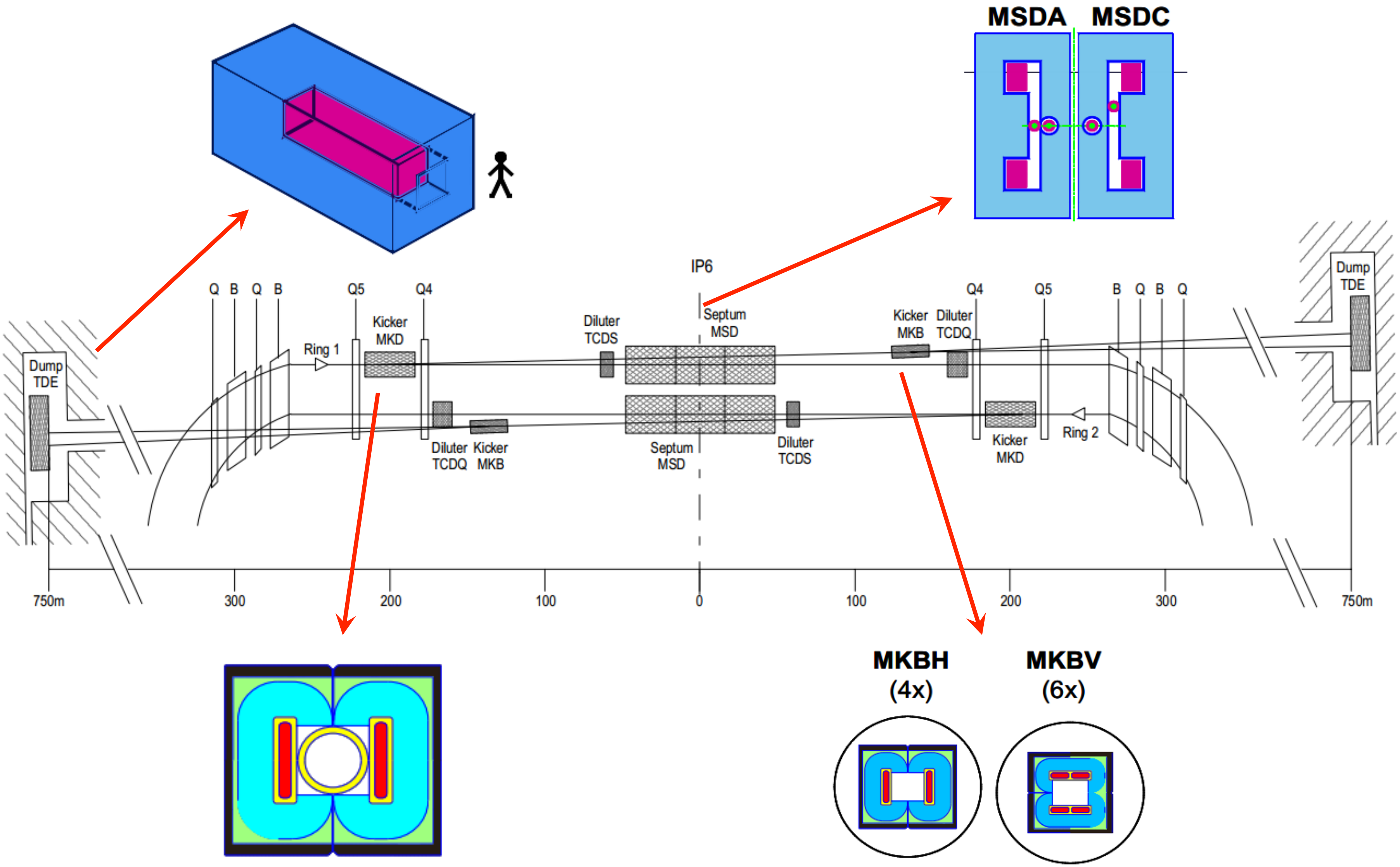
- Brief review of injection and extraction system
- LHC beam dump system design
    - Energy deposition
    - Thermal analysis
    - Off-normal operating
- Upgrade to SppC/FCC

Brief review of LHC injection system



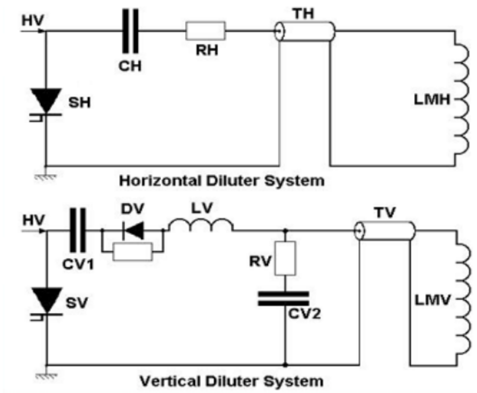


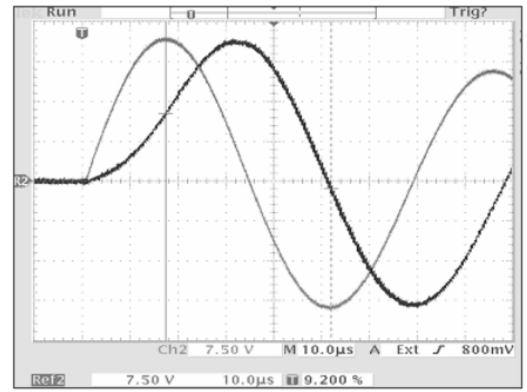
Brief review of LHC extraction system

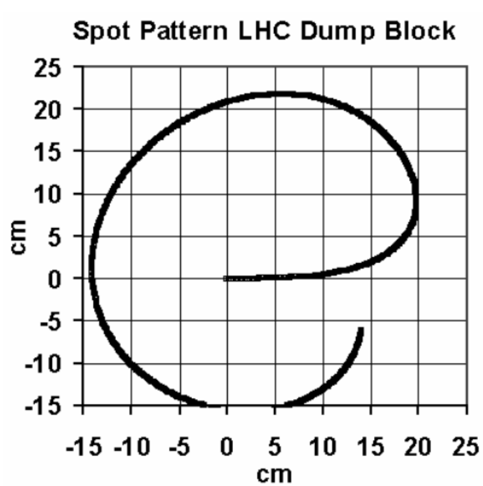


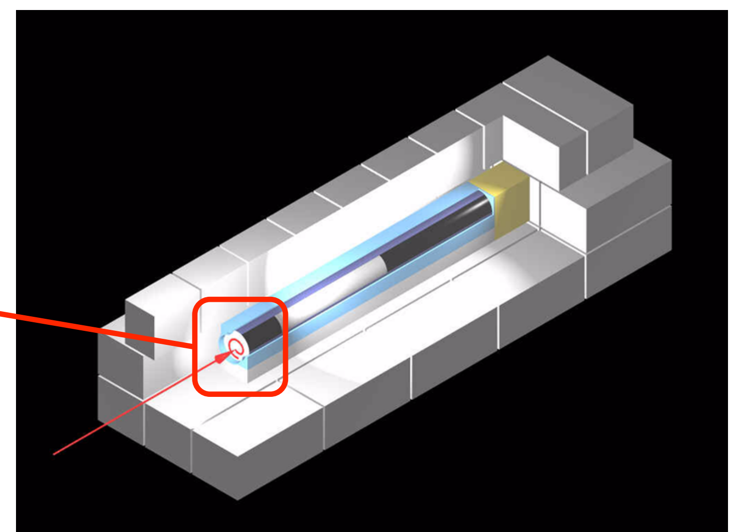
Brief review of LHC extraction system

- Fast-Pulsed Dilution Magnets(MKB)



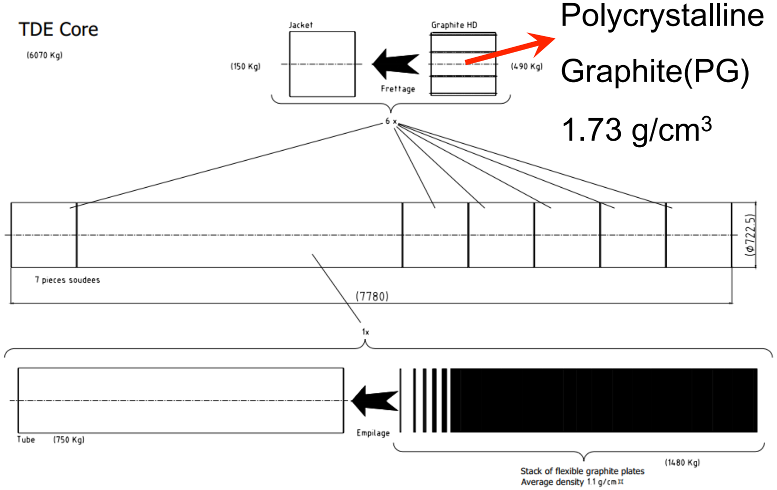






Brief review of LHC extraction system

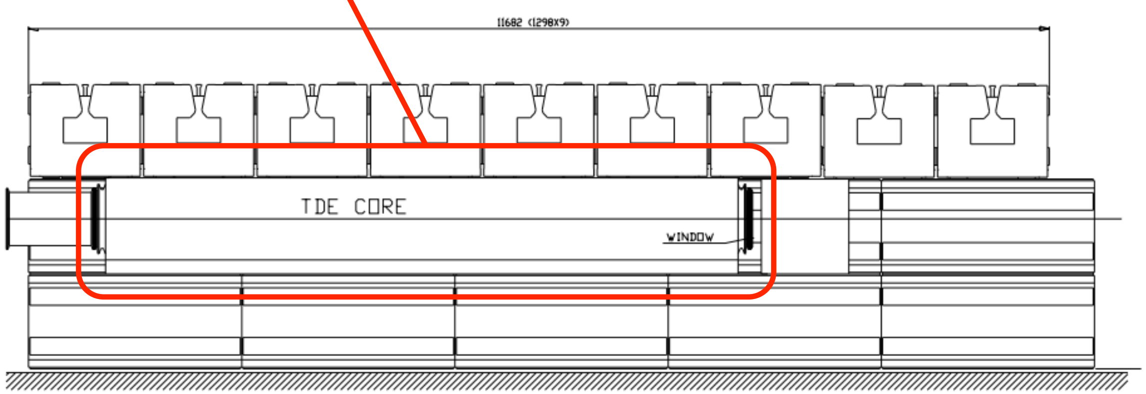
Beam Dump Absorber Block TDE

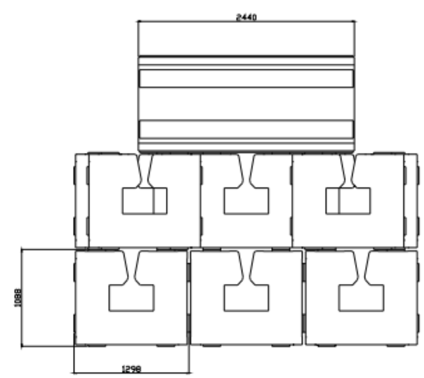


Polycrystalline Graphite(PG)

1.73 g/cm^3

- 4.7×10^{14} ppb, 2×10^{4} beam at 7 TeV during 20 years
- 80% energy(428MJ) is absorbed every dump
- Optimized design to avoid thermal and mechanical degradation
- ~900 tons radiation shielding blocks
- Filling the dump with an inert gas permanently to avoid graphite from fire





Dump system design

- Related areas
  - Particle shower simulation
  - Heat transfer analyses
  - Structural deformation and stress analyses
  - Other cascade simulations
- The design should define
  - Some critical parameters
  - Optimal choice of materials
  - Size and alignment of various components
  - Type and performance of cooling systems
  - Rules of beam abort repetition
  - Safety precautions

LHC beam dump system design

- Energy deposition

Maximum proton momentum	7.0	TeV/c
Beam size (Gaussian σ_h=σ_v)	0.95	mm
Number of protons per bunch	1.7	$\cdot 10^{11}$
Number of bunches	2835	
Bunch duration	0.25	ns
Bunch spacing	25.0	ns
Beam intensity (protons)	4.8	$\cdot 10^{14}$
Overall beam abort time	86	μs
Stored beam energy	540	MJ

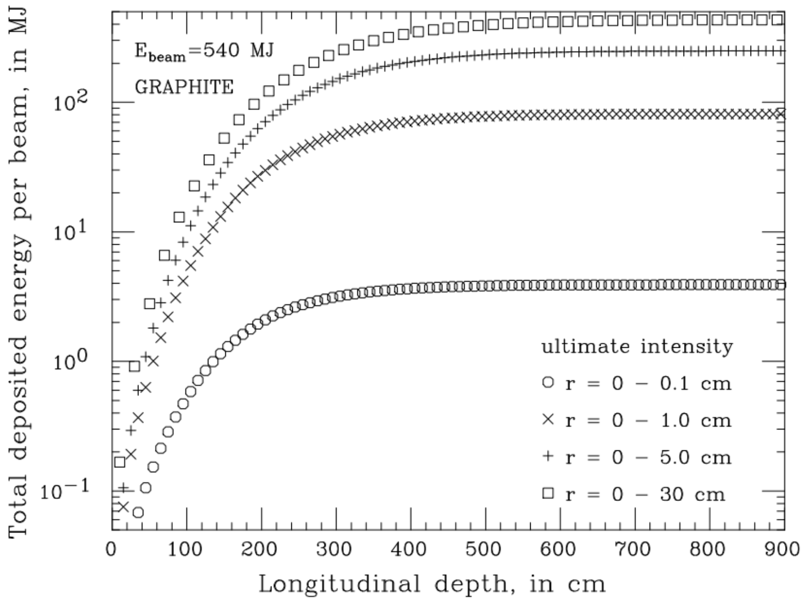


Figure 1: Cumulative distribution of total energy deposited within different radii in the graphite block, normalised to maximum beam intensity, as a function of longitudinal depth.

- 80%(428 MJ) energy is absorbed for 30 cm radius and 700 cm depth

LHC beam dump system design

- Energy deposition distribution(one proton)

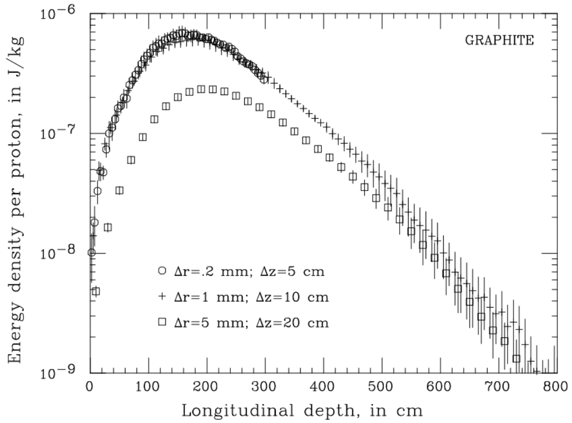


Figure 2a: Longitudinal distributions of energy density deposited per proton, on axis of a graphite block, within 0.2, 1 and 5 mm radius.

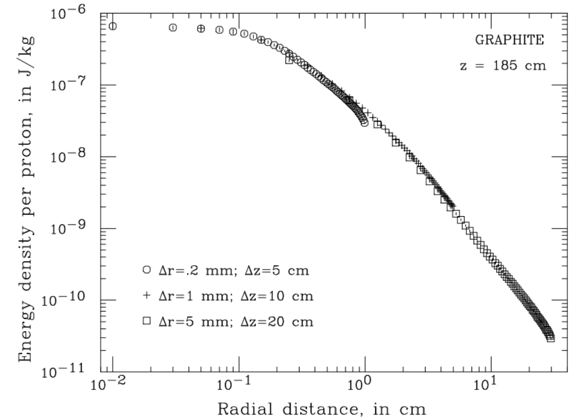


Figure 3a: Radial distribution of energy density deposited per proton, at the longitudinal maximum in graphite, obtained with 3 different energy-scoring meshes.

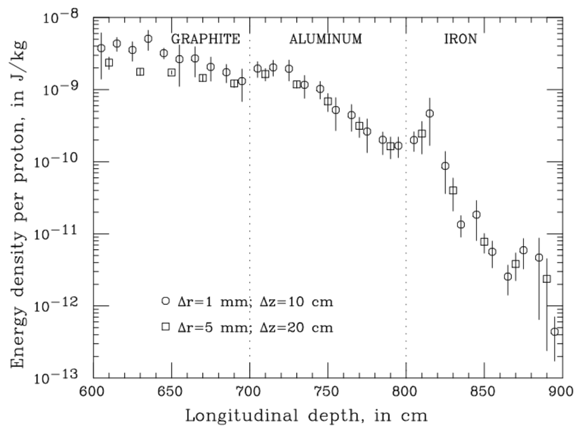


Figure 2b: Longitudinal distribution of energy density deposited per proton on beam axis, in downstream region of graphite (600-700 cm), aluminium (700-800 cm) and iron (800-900 cm).

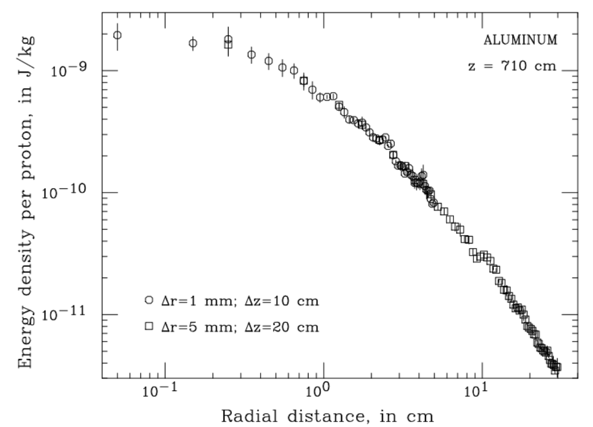
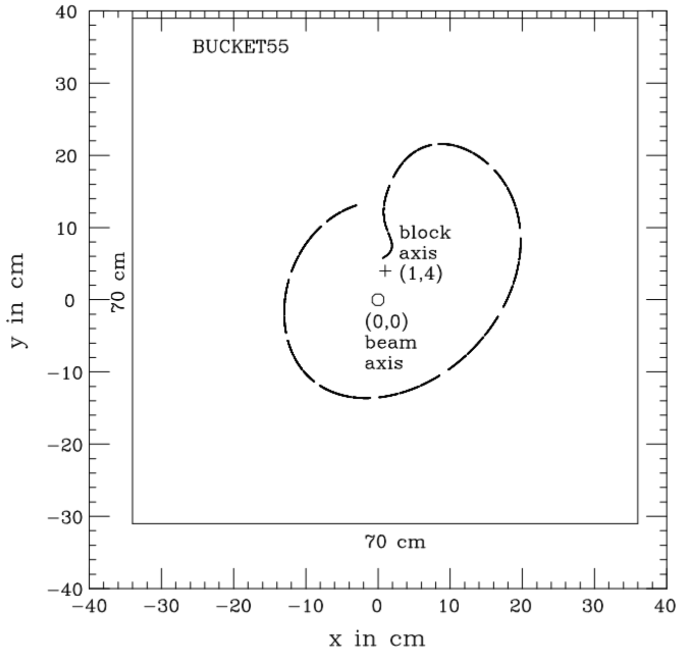
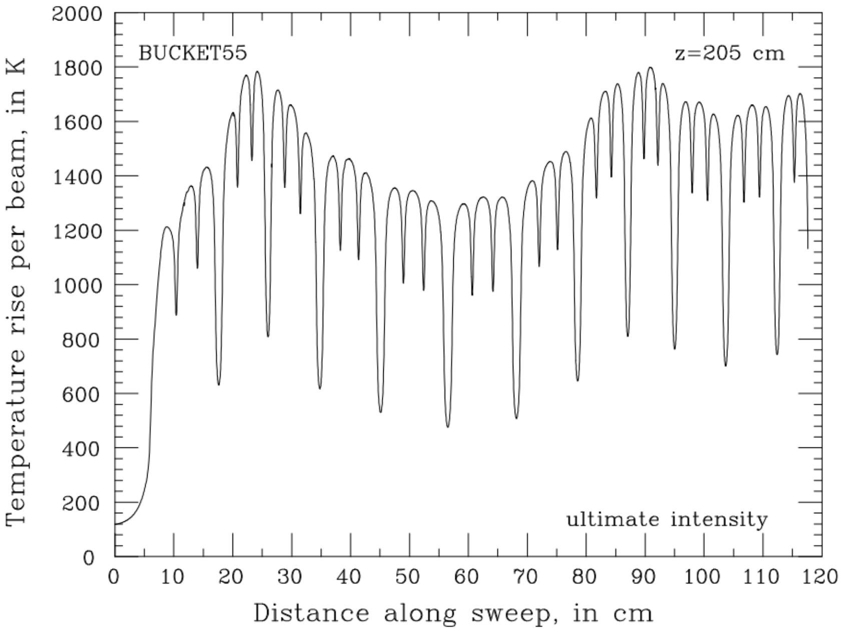


Figure 3c: Radial distribution of energy density deposited per proton, at the front of downstream Al absorber (710 cm depth).

LHC beam dump system design

- Energy deposition with sweep





- Direct MC simulation is too time consuming, the energy deposition is achieved by superimposing the distribution of single proton
- Temperature rise is estimated by resolving the equation

$$n_p\, d = H(\Delta T) = \int_{T_o}^{T_o+\Delta T} dT\, \rho\, c_v(T)$$

LHC beam dump system design

- Thermal analysis

		Graphite (C)	Aluminium (Al)	Iron (Fe)
Density	[g·cm^{-3}]	**1.85**	2.70	7.88
Inelastic hadron interaction length	[cm]	37.3	35.4	15.1
Radiation length	[cm]	21.2	8.83	1.73
Specific heat (at 20°C)	[J·g^{-1}·K^{-1}]	0.65	0.90	0.48
Thermal conductivity (at 20°C)	[W·cm^{-1}·K^{-1}]	0.90	1.80	0.52
Maximum safe temperature	[°C]	2500	150	
Melting (vaporisation) point	[°C]	(5000)	660	1540

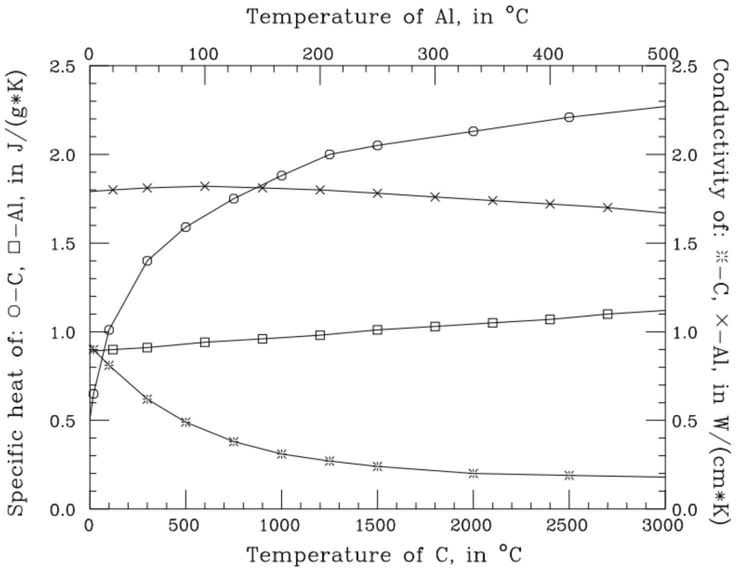
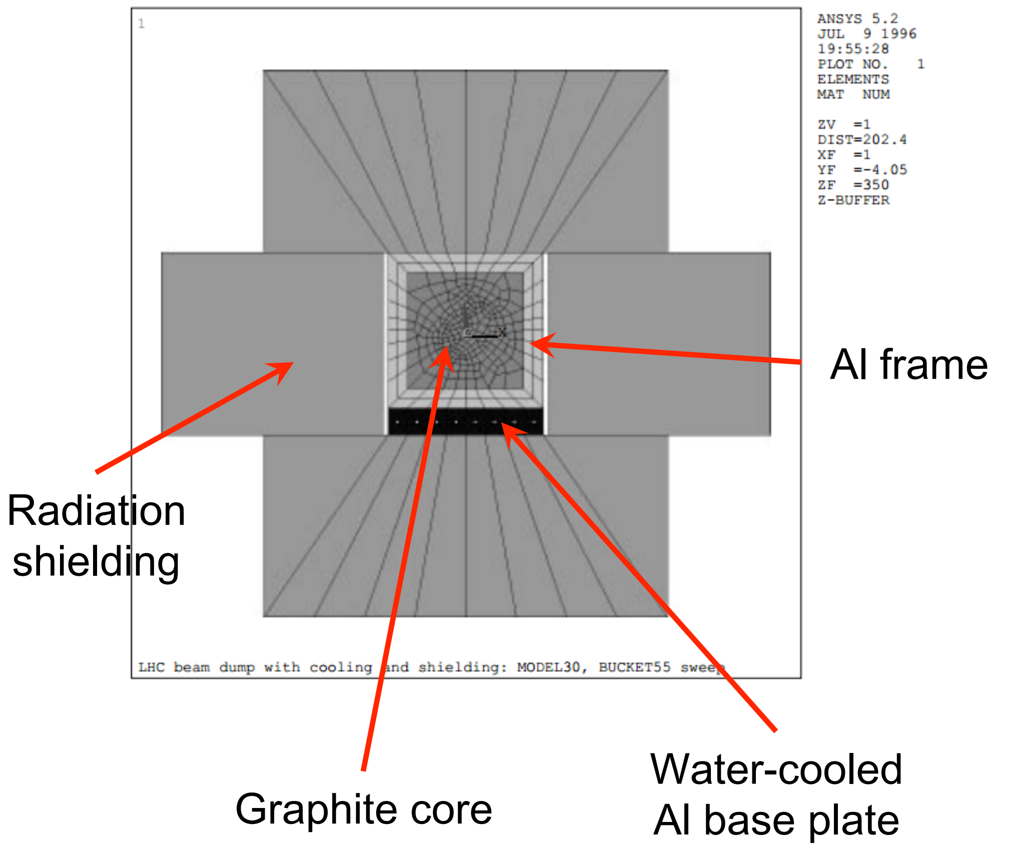


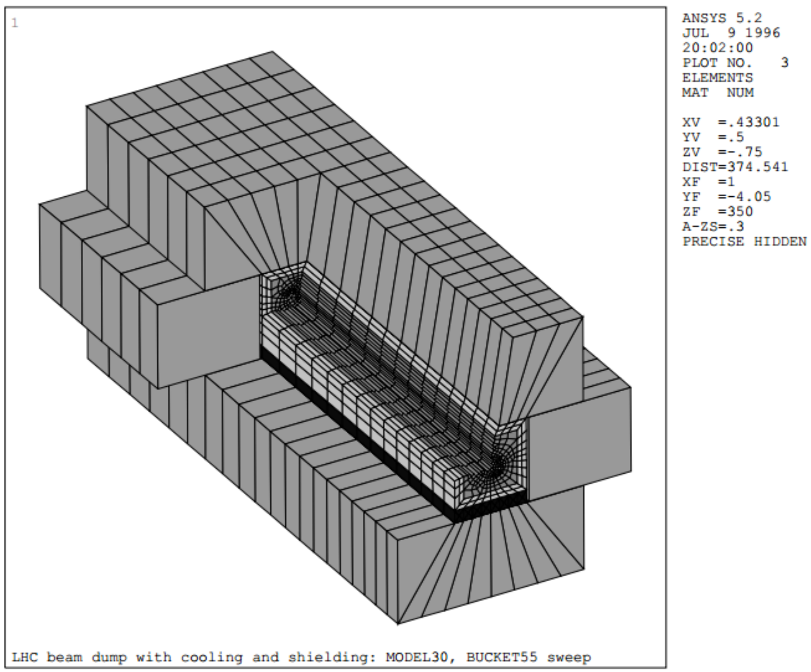
Figure 1: Thermal properties (specific heat and conductivity) of the graphite and aluminium, as a function of temperature, assumed for this study.

- Time-dependent nonlinear thermal analysis
- Nonlinear is due to larger temperature range
- Long transient state of heat transfer, beam impact(<0.1ms), cooling process(a few hours)

LHC beam dump system design

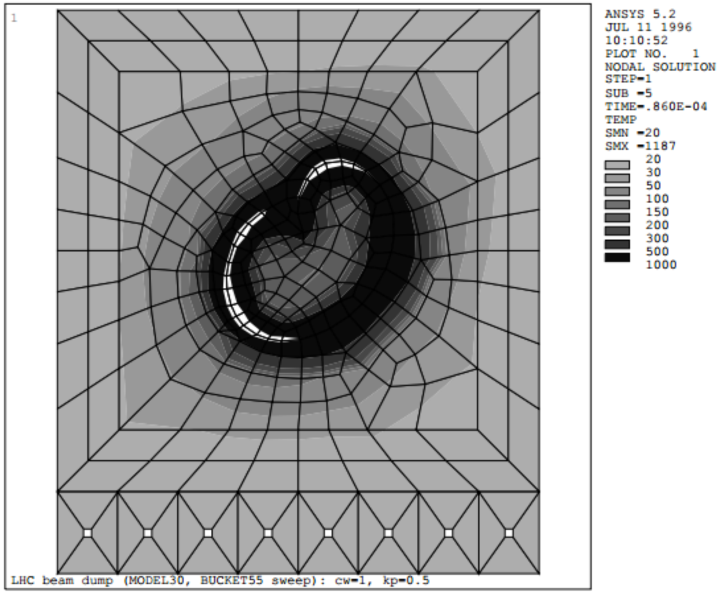
- Finite element model

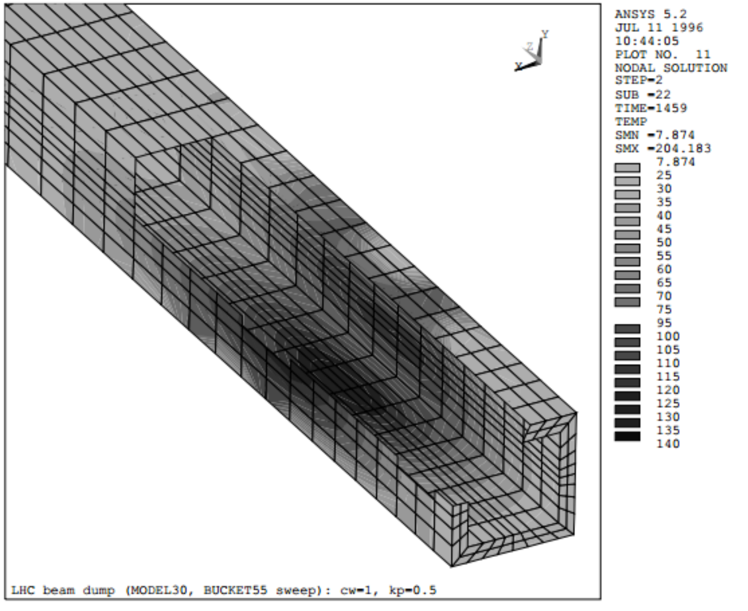




LHC beam dump system design

- Temperature rise in graphite and Al frame





- Maximum temperature rise below 1200 ℃ in graphite
- Maximum temperature rise below 150 ℃ in Al frame

LHC beam dump system design

- Temperature rise in graphite and Al frame

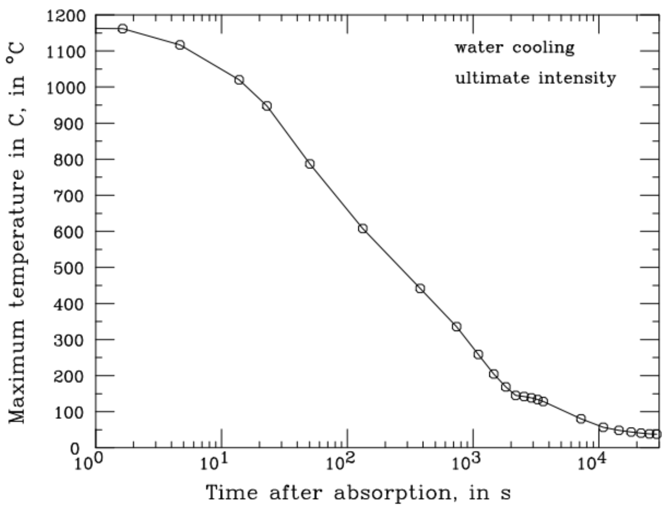


Figure 4a: Time evolution of maximum graphite temperature. Assumed conditions: BUCKET55 sweep, ultimate intensity, imperfect thermal contact, water cooling.

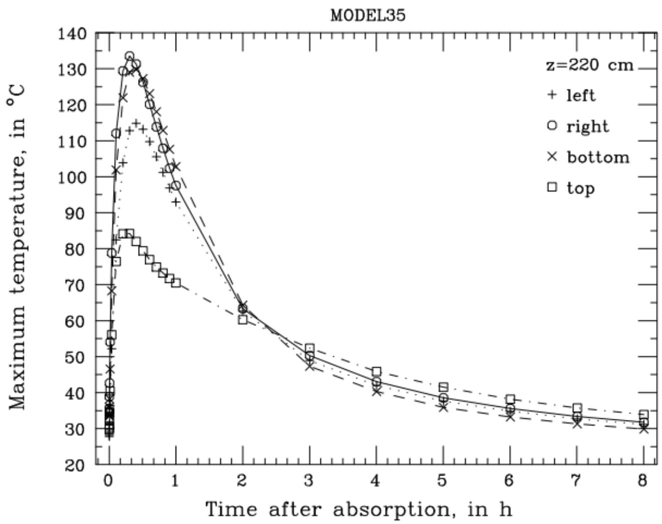
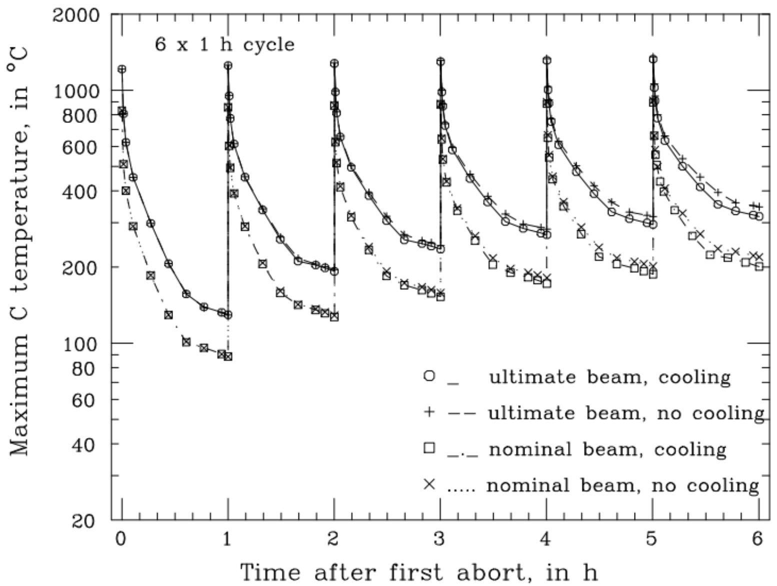


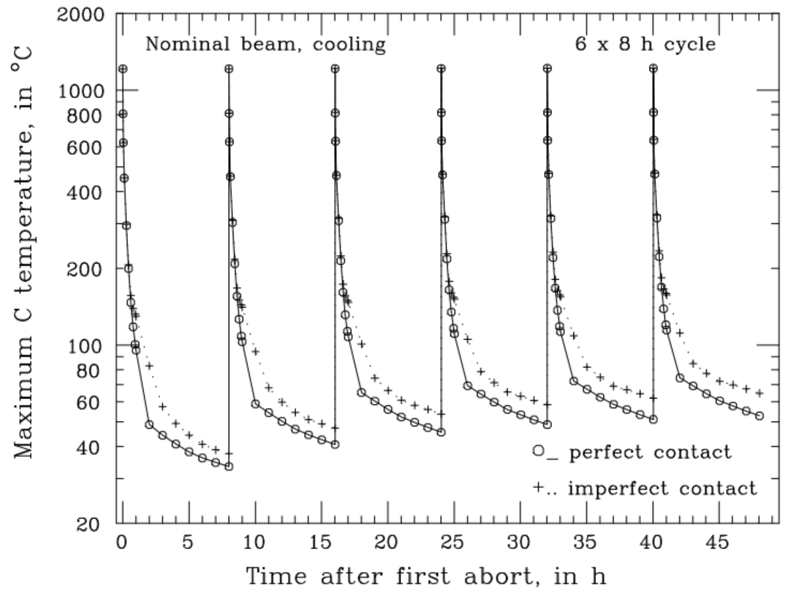
Figure 4b: Time evolution of the temperatures on the right, left, bottom and top edges of the graphite block, at depth of the longitudinal maximum (220 cm). Assumed conditions: BUCKET55 sweep, ultimate intensity, imperfect thermal contact, water cooling.

- Several seconds are required to cool the hottest region below 1000 ℃
  (No cooling system is effective in such a short time)
- More than 3h are necessary to bring temperature below 50 ℃

LHC beam dump system design

- Repetitive beam aborts

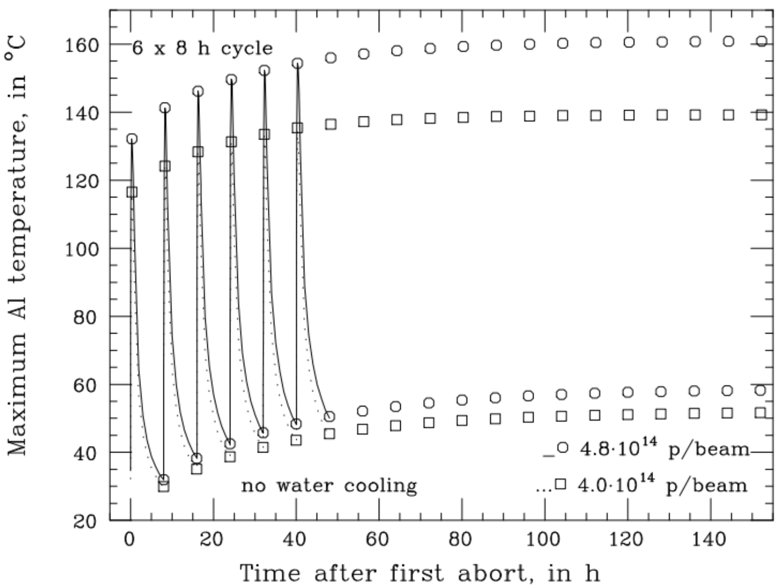


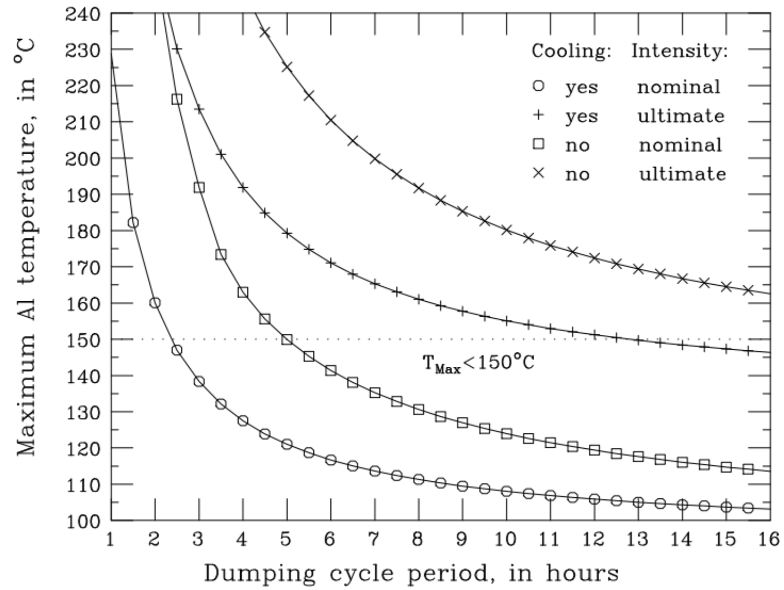


- At nominal intensity, beam can seemingly be dumped without cooling for periods longer than 3 h
- No practical cooling system can prepare the dump 7 TeV beam at ultimate or nominal intensity as frequently as once per hour
- After 6 cycles, the thermal steady state is almost reached in graphite, the situation is different in Al frame

LHC beam dump system design

- Repetitive beam aborts

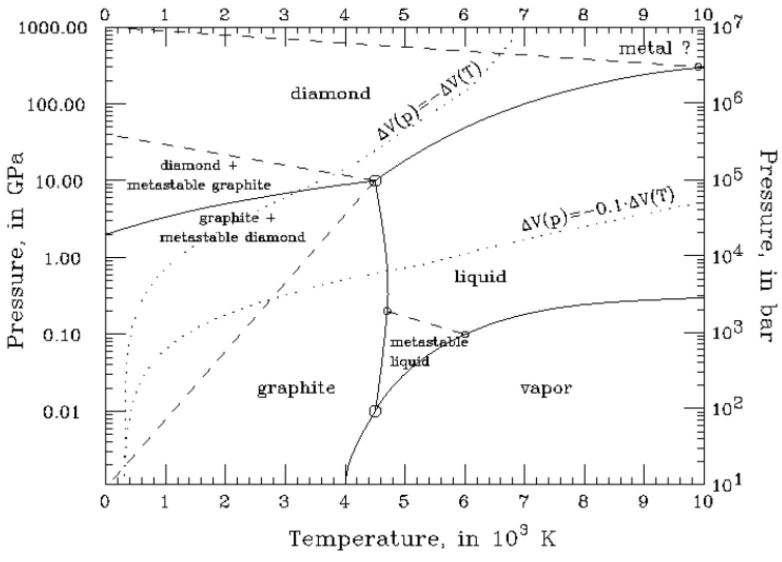


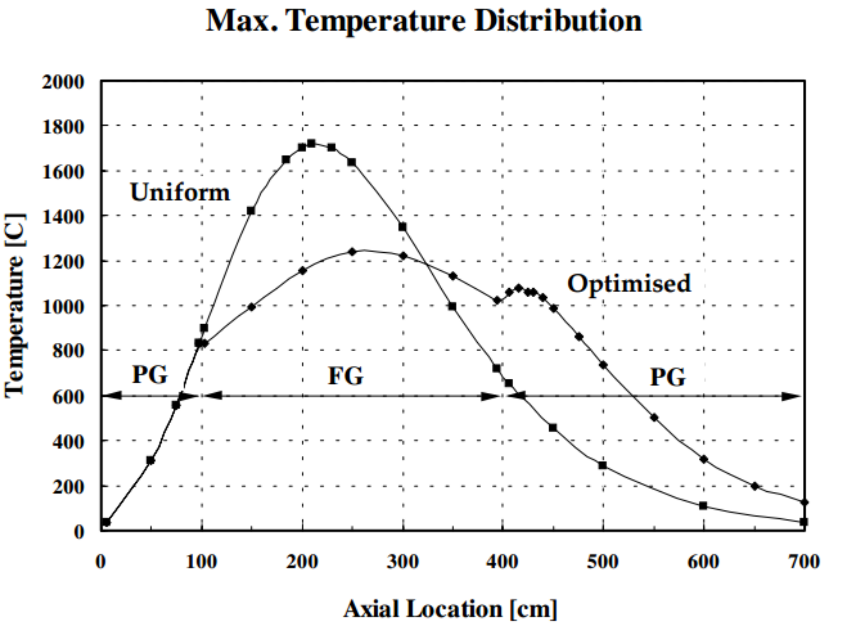


- In order not to exceed 150 °C in Al frame, the period should be longer than 2.5 h at nominal intensity and longer than 12.5 h at ultimate intensity
- Without cooling, the period should multiplied by at least a factor 2

LHC beam dump system design

- Off-normal operating condition



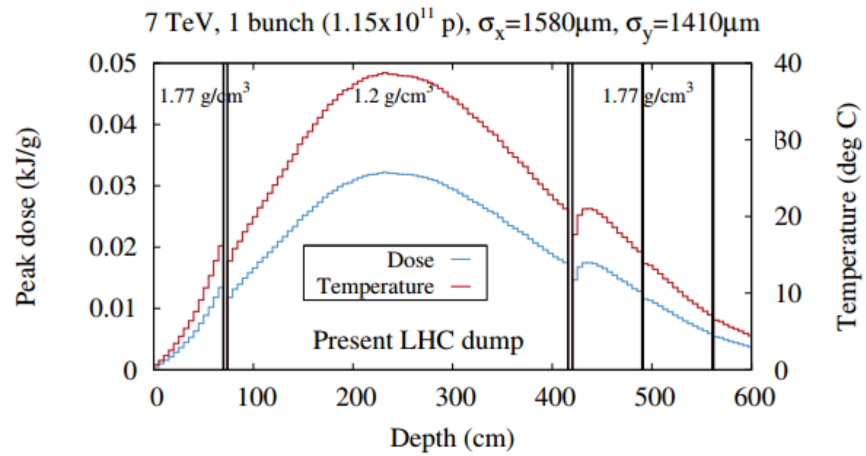


- Abnormal dilution(most dangerous!), may cause core perforation and structural break-down
- Loss of vacuum, oxidation begins on graphite at 450 ℃, on flexible graphite at 550 ℃

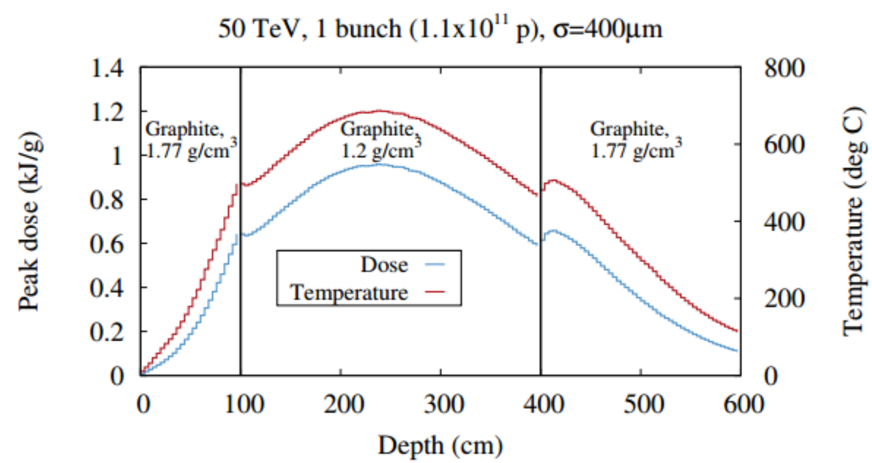
LHC beam dump system design

- Upgrade to SppC/FCC

Parameter	LHC	SSC	SPPC	FCC	Unit
Injection energy	0.45	1.0	2.0	3.3	TeV
Injection rigidity	1504	3339	6674	11010	T·m
Final energy	7.0	20	35.6	50	TeV
Final rigidity	23352	66714	118556	166785	T·m
Bunches	2808	17100	5835	10600	
Bunch population	1.15e11	7.3e9	2e11	1e11	
Total beam energy	0.362	0.405	6.6	8.5	GJ

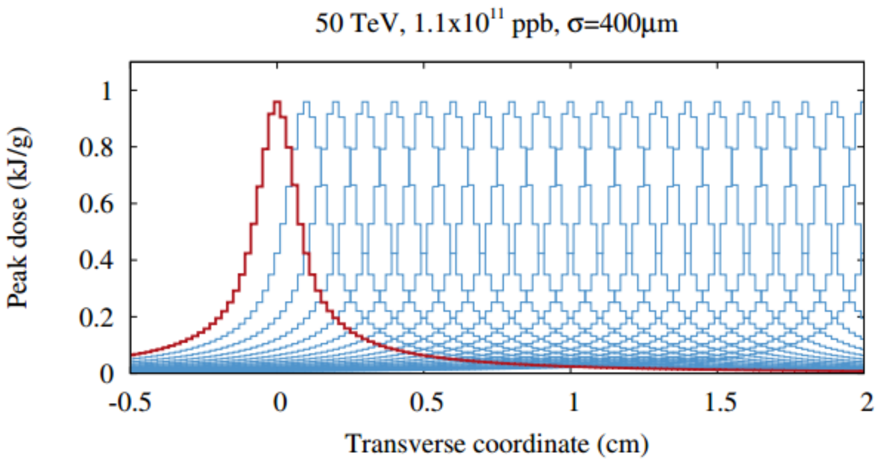


- Peak energy density increases by a factor ~30
- Entire dump needs to be longer to sufficiently absorb showers

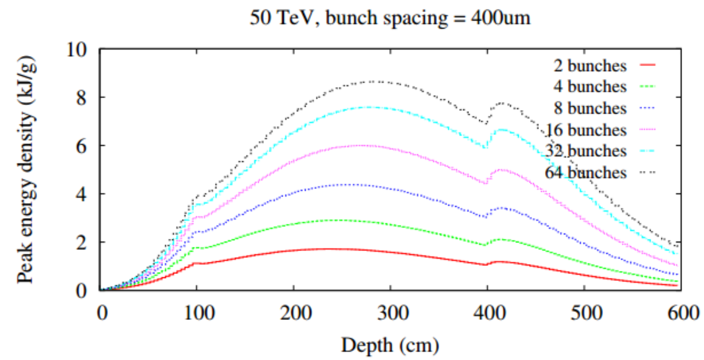


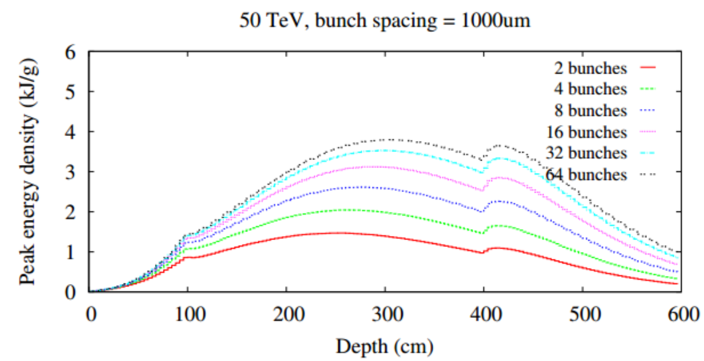
LHC beam dump system design

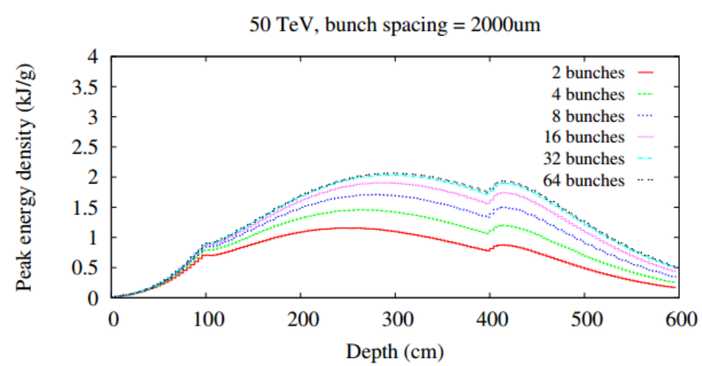
- Upgrade to SppC/FCC



- Linear sweep to estimate peak energy density
- Distance of 2 mm between bunches should keep peak temperature below 2000 ℃
- For 10600 bunches, the sweep length would be 21.2 m







Summary

- The performance of dump system is important for the running mode of whole system
- Dump design involves many different subjects, collaboration is necessary
- Upgrading LHC's dump system for SppC/FCC seems feasible, but need more careful and elaborated study

Thanks !