CERN

WP12 - MAGNETS & MACHINE PROTECTION
Status Report

- 12.1 POWERING, PROTECTION ARCHITECTURE FOR HIGH FIELD CIRCUITS

- 12.2 CONCEPT, ARCHITECTURE OF MACHINE PROTECTION & INTERLOCKS

- 12.3 HTS MAGNET PROTECTION

12.1 POWERING, PROTECTION ARCHITECTURE FOR HIGH FIELD CIRCUITS

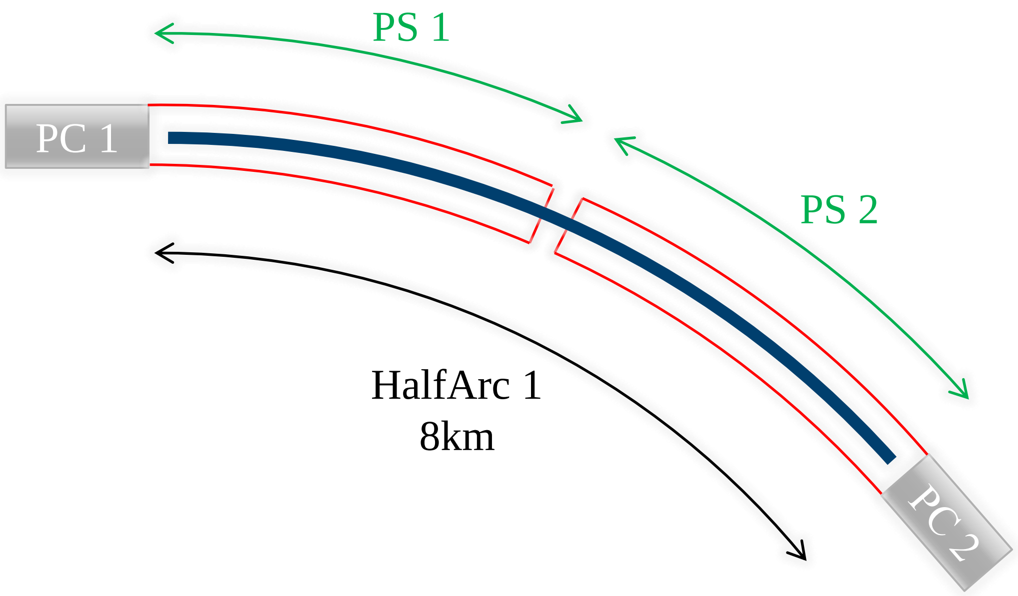
- Objectives: Propose architectures and technologies for the protection of high field circuits.

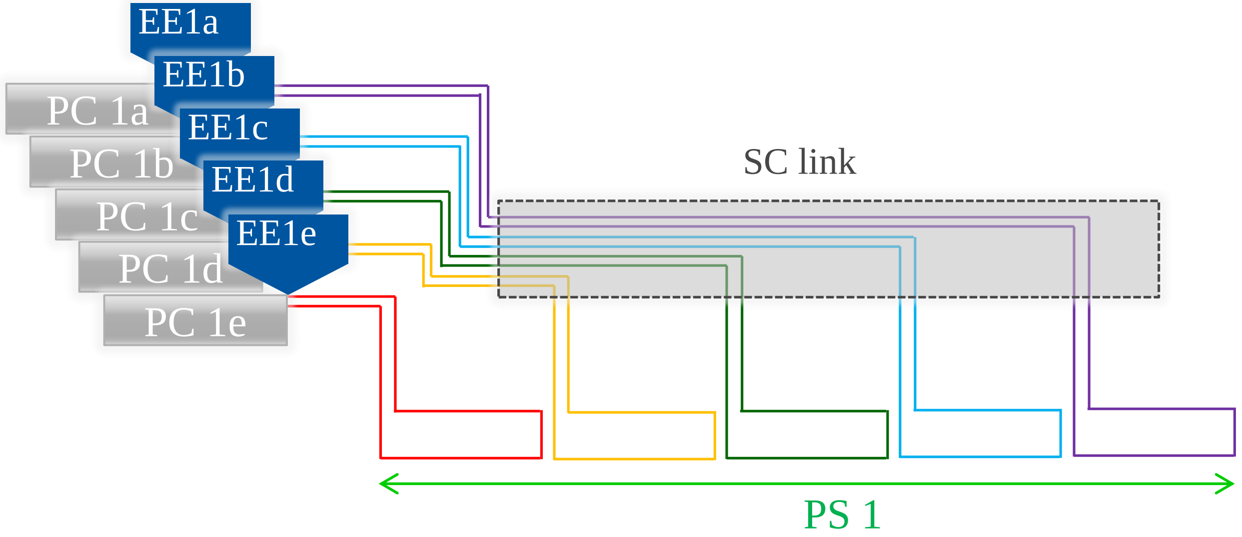
- **Quench detection/protection of the main ring (LTS) magnets.**
- Task 1: Analyse the LHC concept in view of removing electronics form the accelerator tunnel and centralizing them in underground infrastructures or preferably to surface infrastructures.
- **Energy extraction of all high current and high energy circuits.**
- Task 1: Extrapolate existing technologies and systems for the new requirements and propose circuit layout configurations compatible with FCC scale.
- Task 2: Propose new concept for energy dump system, optimising energy recovery.
- **Local magnet protection system(s)**
- Task 1: Analyse the existing magnet protection technologies and evaluate applicability of alternative technologies like Coupling-Loss Induced Quench (CLIQ). Optimisation of the system, implementation at the design stage of the magnets. Report on feasibility based on HL-LHC experience, specify potential implications for subdivision of magnet coils,
- Task 2: Evaluate the existing LHC magnet diode bypass assembly and propose required diode parameters in connection with the powering architecture of the magnets.

Studies of the layout of main dipole circuits

EuroCirCol
A key to New Physics

Proposal for FCC Powering Sectors (PS)





Study of possible circuit layouts to reduce the stored energy and limit the voltage to ground during the fast power abort

CLIQ studies for FCC cos-theta coil

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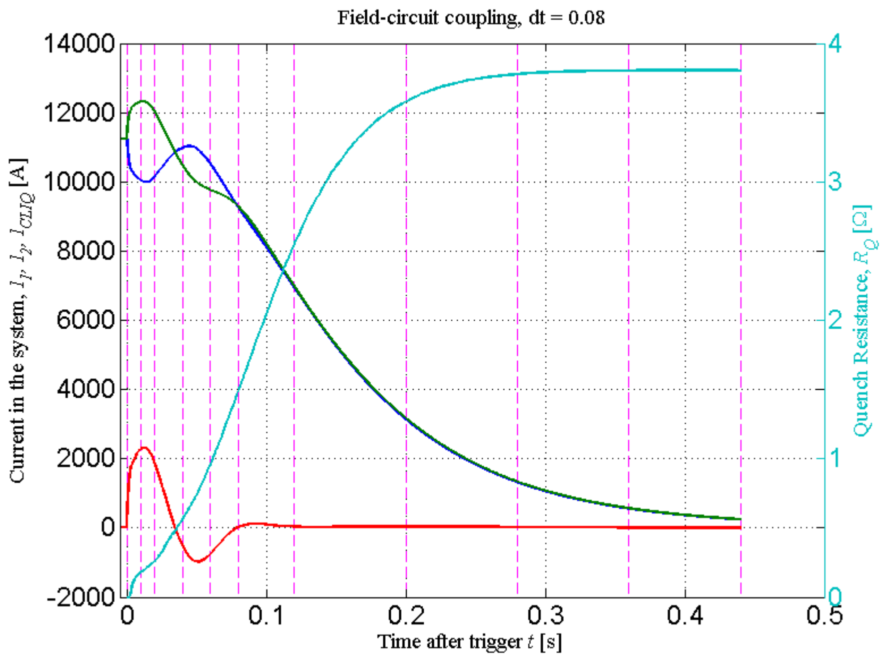
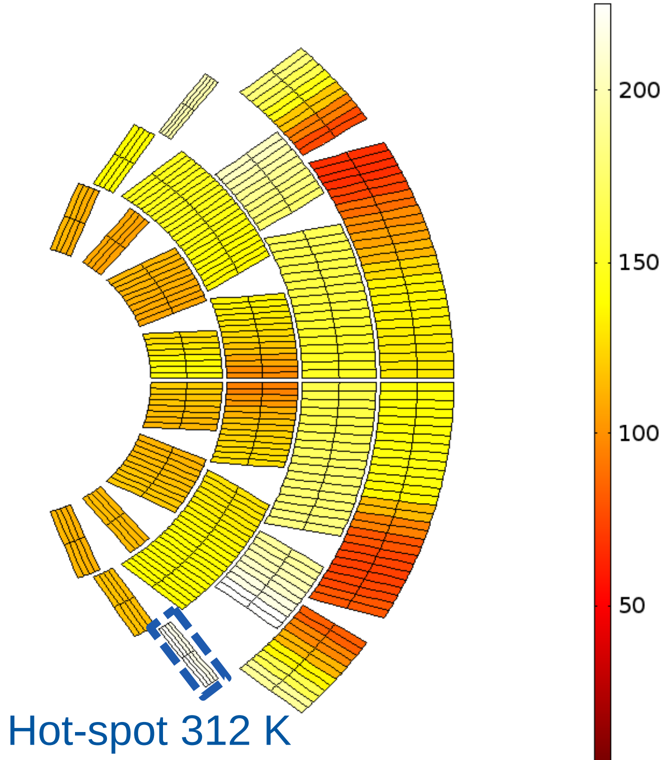
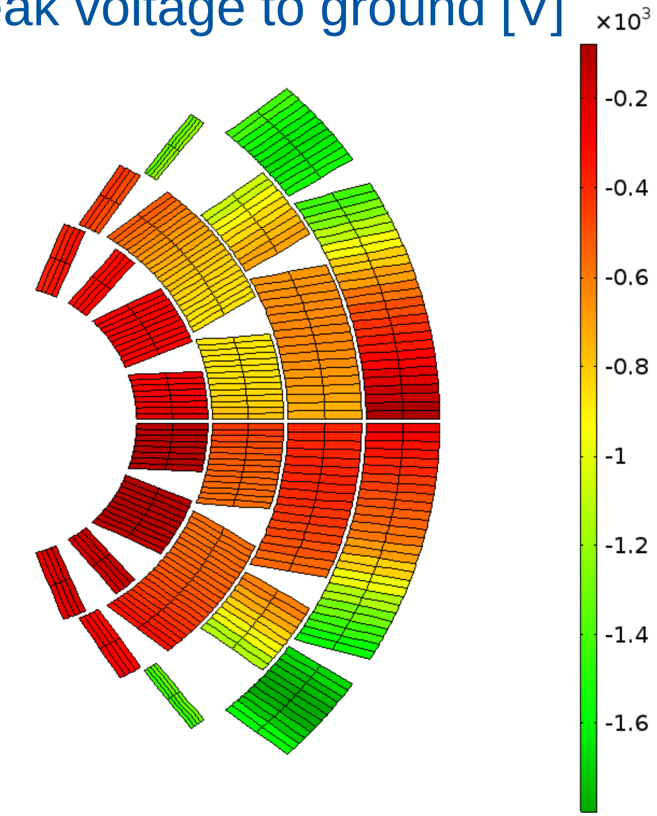
Current [A] and resistance [Ω]



Temperature [K]



Peak voltage to ground [V]



Outcome: temperature gradients and voltage to ground need to be mitigated possibly acting on the magnet design

Simulation tools and the STEAM

STEAM is providing tools for coupled protection studies: *protection of a chain of magnets*

Circuit protection

- Energy extraction
- Voltage to ground

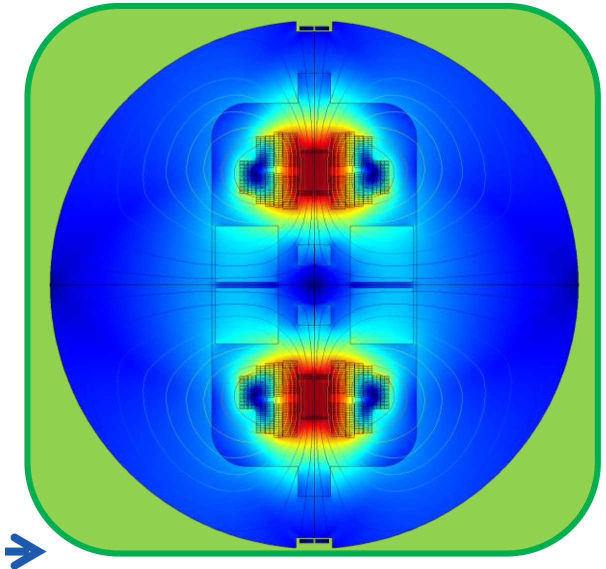
CLIQ technology

Magnet protection

- Hot-spot temperature
- Voltage to ground

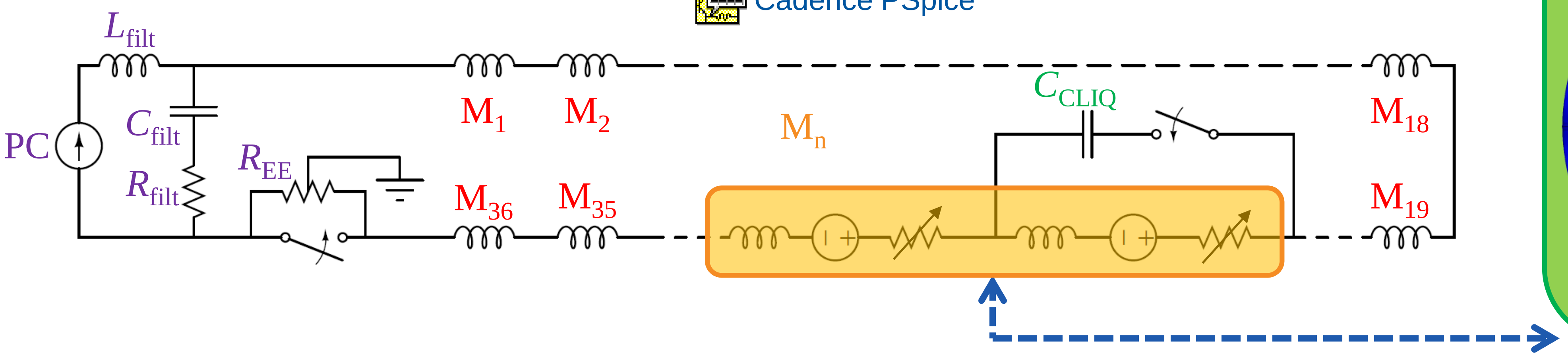
Common coil field model

COMSOL



FCC circuit model

Cadence PSpice



12.2 CONCEPT, ARCHITECTURE OF MACHINE PROTECTION & INTERLOCKS

- Objectives: Develop the architecture of the machine protection and interlock system for a larger accelerator scale as compared to LHC.

- Task 1: The study of these new options of architecture must be linked to the machine availability concepts.
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- Task 2: Based on the outcome of the task 1, review LHC concepts and propose new architecture of protection systems to assure machine component protection and optimised availability.

Beam Impact & Machine Protection of the FCC-hh

Execution time for a beam dump

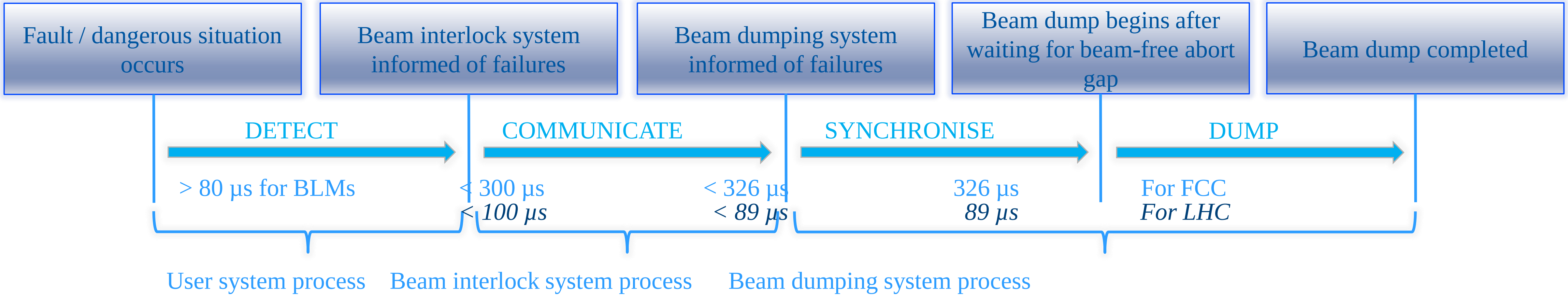


Figure after [B. Todd, PhD thesis, 2006]

- LHC Machine Protection System
  - After failure detection, about 3 turns' time is needed to dump the full beam completely.
- **For FCC, the time needed is most likely similar in terms of 'number of turns'**
  - **which is about 1 ms.**
  - ***but will depend on how many abort gaps & beam dump systems we have (open point).***

Beam Impact & Machine Protection of the FCC-hh

Top critical equipment failure modes (to be continued)

Name	Failure scenario	Magnet length	Nominal field	Nominal deflection or focusing strength	Beta-function at magnet	Required time constant of field decay	Comment
Separation dipole 'D1' in IRA / IRG	Powering failure of all the 4 MBXA magnets	12.5 m	4.27 T	0.00032 rad	25 km (left) 61 km (right)	> 33 s	Less critical
Separation dipole 'D1' in IRA / IRG	Quench of 1 magnet	12.5 m	4.27 T	0.00032 rad	61 km (right)	> 100 ms	Need to be careful
Low-β triplet quadrupoles	Quench of 1 magnet (MQXC.3RA)	30.81 m	86 T/m	0.000514 m^{-2}	77 km	> 139 ms	Need to be careful
Main dipole	Quench of 1 magnet	14.3 m	15.92 T	0.001366 rad	335 m (max.)	> 55 ms	Less critical
Main quadrupole	Quench of 1 magnet	6.29 m	357 T/m	0.00214 m^{-2}	350 m (max.)	> 8.6 ms	Less critical
Warm dipole in collimation insertion	Powering failure of MBW.A6R3.B1	9.09 m	1.45 T	0.000079 rad	718 m	> 0.27 s	Less critical
Warm quadrupole in collimation insertion	Powering failure of MQWA.D4R3.B1	8.31 m	29 T/m	0.000174 m^{-2}	1068 m	> 0.023 s	Less critical

- The minimum time constant of field decay is determined such that beam position is displaced less than 1.5 σ and tune change is less than 0.01, within 2 ms after magnet failure.
- Other failure scenarios (RF, UFOs, etc) that could result in very fast beam losses are being studied.

Beam Impact & Machine Protection of the FCC-hh

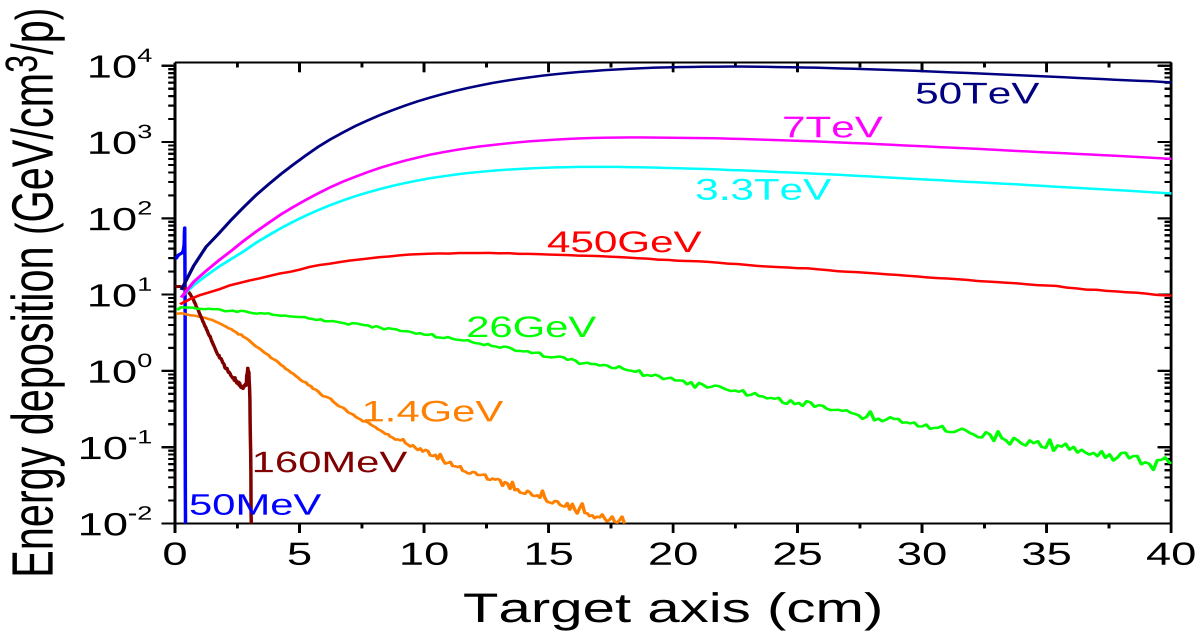
Time constant of beam loss

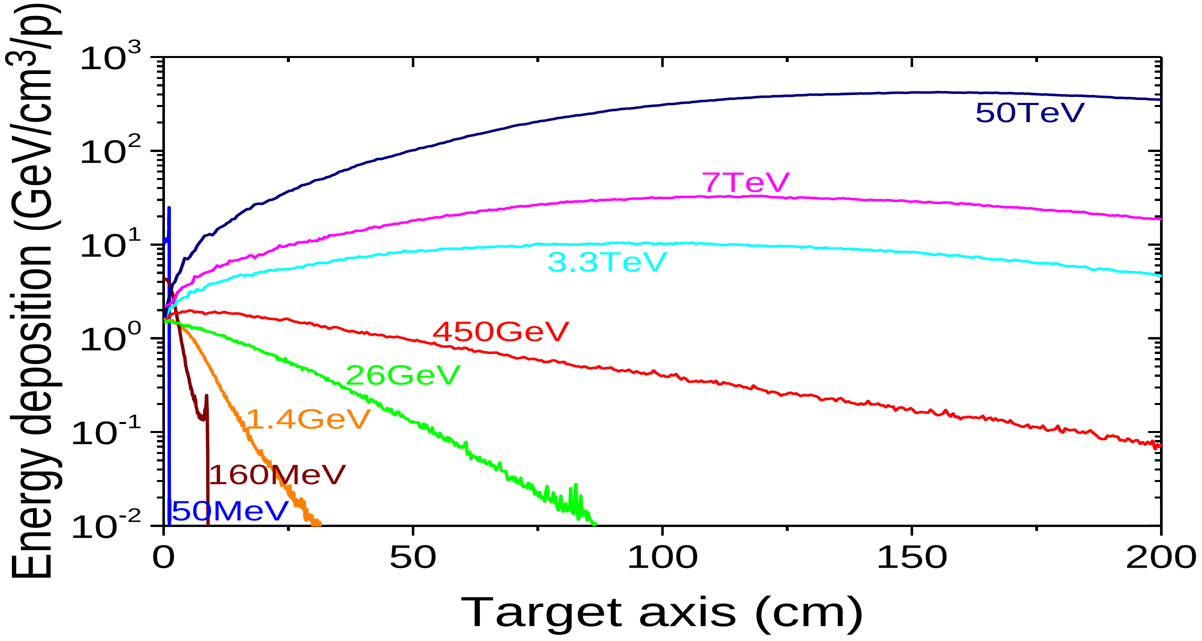
Beam lifetime	Beam power into environment		Scenario	Strategy
	LHC	FCC		
100 h	1 kW	23 kW	Optimum operating conditions	(Possible) upgrade of the collimation system after some years of operating experience
10 h	10 kW	236 kW	Acceptable operating conditions (expected during early operation)	Operation acceptable, collimators must absorb large fraction of beam energy
12 min	500 kW	11806 KW	Particular operating conditions (during change of optics, tuning, collimator aperture setting, etc)	Operation only possible for short time (~ 10 second), collimators must be very efficient
1 s	362 MW	8500 MW	Fast beam loss (standard equipment failures)	Detection of failure, beam must be dumped rapidly
A few ms (multi turns)	~100 GW	~ TW	**Very fast beam loss** (fast equipment failures, e.g., magnet powering failures or quenches)	Detection of failure or beam losses, beam dump as fast as possible
1 turn	4 TW	26 TW	Single-passage beam loss (failures at injection or during beam dump, potential damage of equipment)	Beam dump not possible, passive protection relies on collimators, absorbers (sacrificial materials)

Table after [R. Schmidt, et al., 29th ICFA Advanced Beam Dynamics Workshop, 2003]

Beam Impact & Machine Protection of the FCC-hh

Energy deposition studies





Energy deposition of proton in typical materials (Left: copper, Right: graphite)

- Beam size $\sigma_{x,y} = 0.2$ mm, beam energy from 50 MeV to **50 TeV**.
- For each energy, another two typical beam sizes were studied, in addition to 0.2 mm.
- **The integral study provides a reference for quick assessment of beam impacts on 'targets' in FCC-hh and its injector chain.**

Spare slides

Protection of FCC magnets and circuits

At the magnet level: *design for protectability*

- CLIQ protection system
- Quench-heaters protection system
- Hybrid systems +

At the circuit level: *machine integration of magnets*

- Study of the possible layouts of main dipole circuits

THE STEAM As a provider of simulation tools