# Simulation of a Quench Event in the Upgraded High-Luminosity LHC Main Dipole Circuit Including the 11 T $Nb_3Sn$ Dipole Magnets

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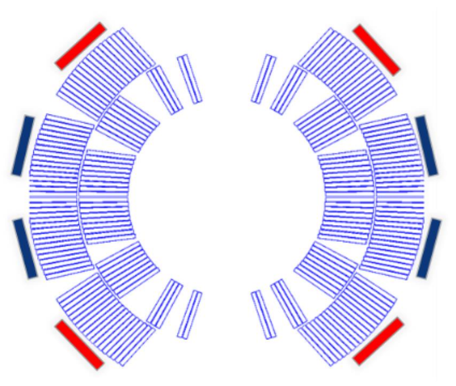
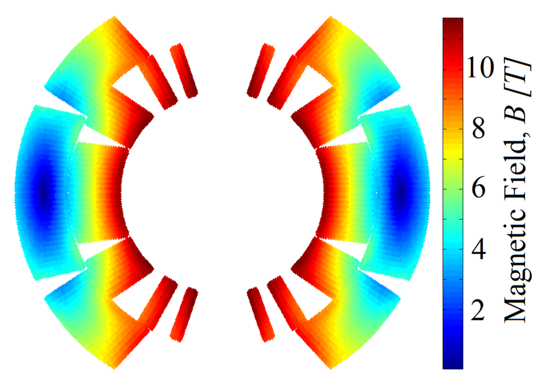
## Introduction

**11 T Double-aperture dipole magnet (MBH)**



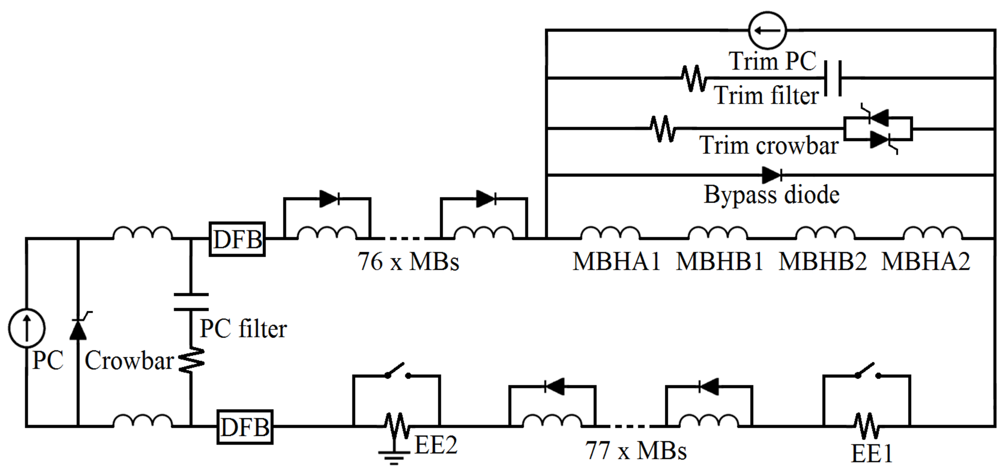
Baseline quench heater strips configuration




Simulated magnetic field map

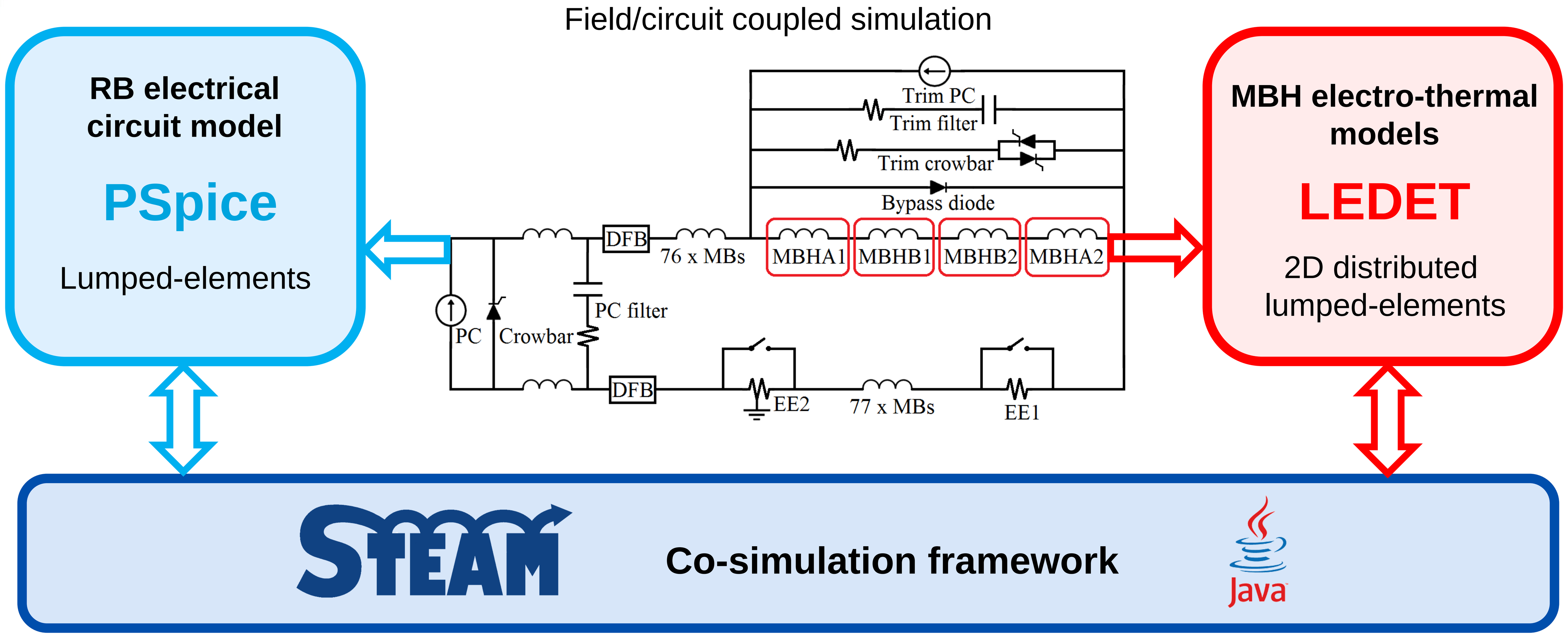
Two out of eight main dipole circuits will be reconfigured in the coming LHC upgrade by replacing one standard 14.3 m long, Nb-Ti based, 8.3 T dipole magnet by two 5.3 m long, $Nb_3Sn$ based, 11.2 T magnets (MBH). The modified dipole circuits will contain 153 Nb-Ti magnets and two MBH magnets, connected to an additional trim power converter. These modifications imply a number of challenges from the point of view of the circuit integrity, operation and quench protection. The simulation of this complex non-linear system addresses a multi-physics and multi-scale problem with interdependences among the subsystems.

**Upgraded RB circuit**




## System Modeling

Field/circuit coupled simulation



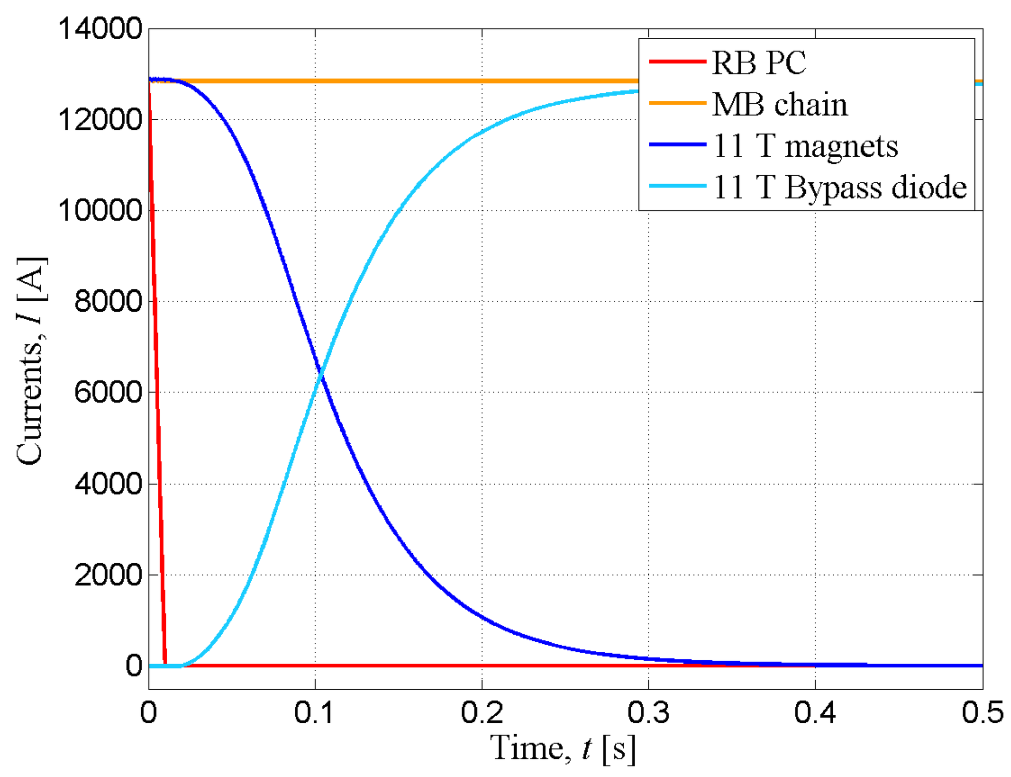

## Simulation Scenarios

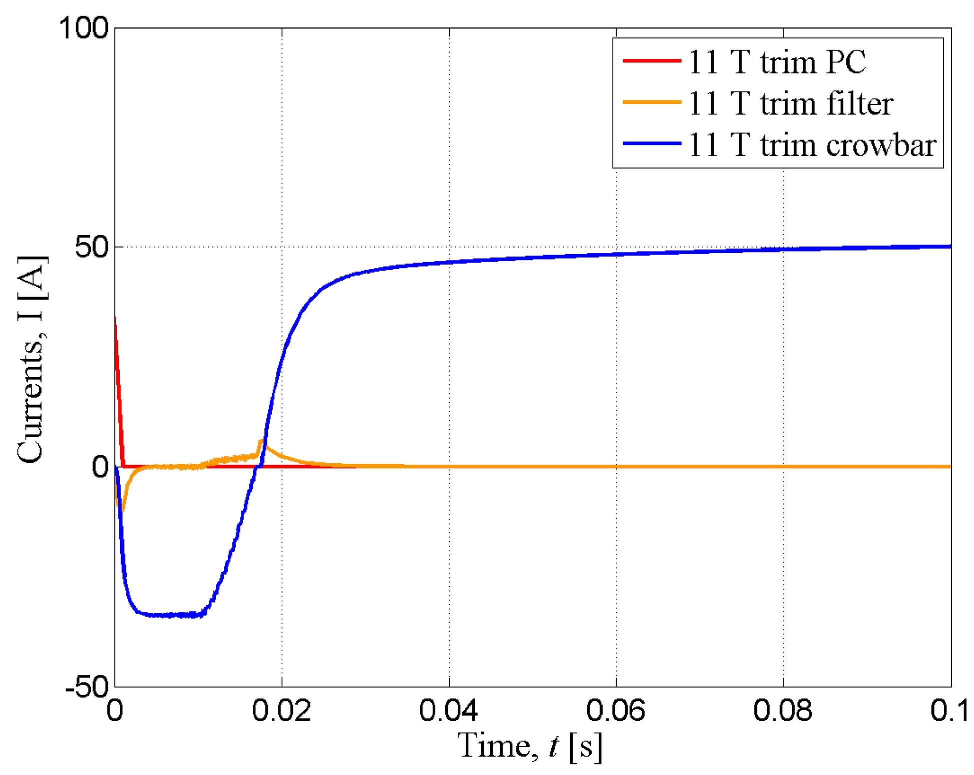
**Parameters and Operating Conditions**

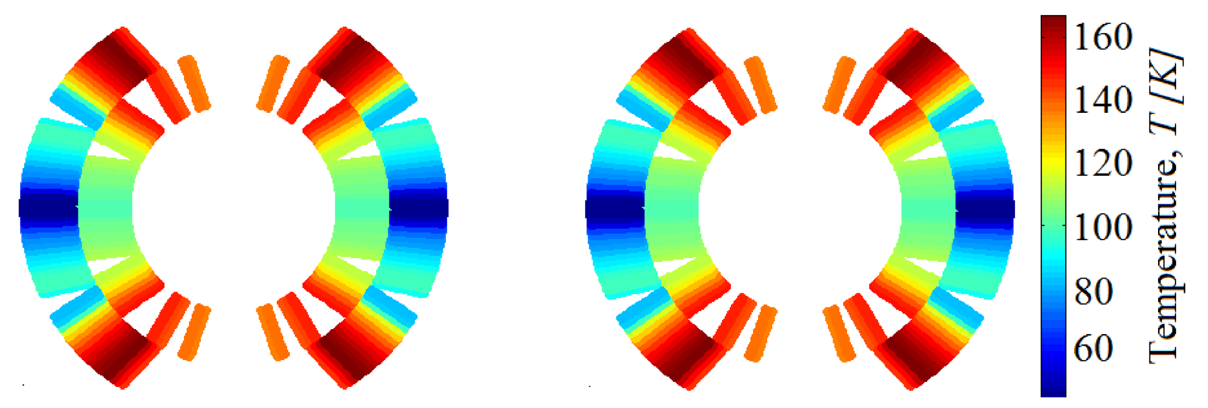
| Parameter | Unit | At plateau | At ramp-up |
|---|---|---|---|
| RB PC current | kA | 12.85 | 6 |
| RB PC ramp-up rate | A/s | 0 | 10 |
| Trim PC current | A | 34 | - 250 |
| Quench detection time | ms | 3 | 27 |
| Quench validation time | ms | 10 | |
| Quench heater supply triggering time | ms | 1 | |
| Trim crowbar resistance | mΩ | 100 | |
| Opening voltage of the MBH bypass diode | V | 6 | |

## Co-Simulation Results

### Quench in a MBH magnet and FPA at current plateau



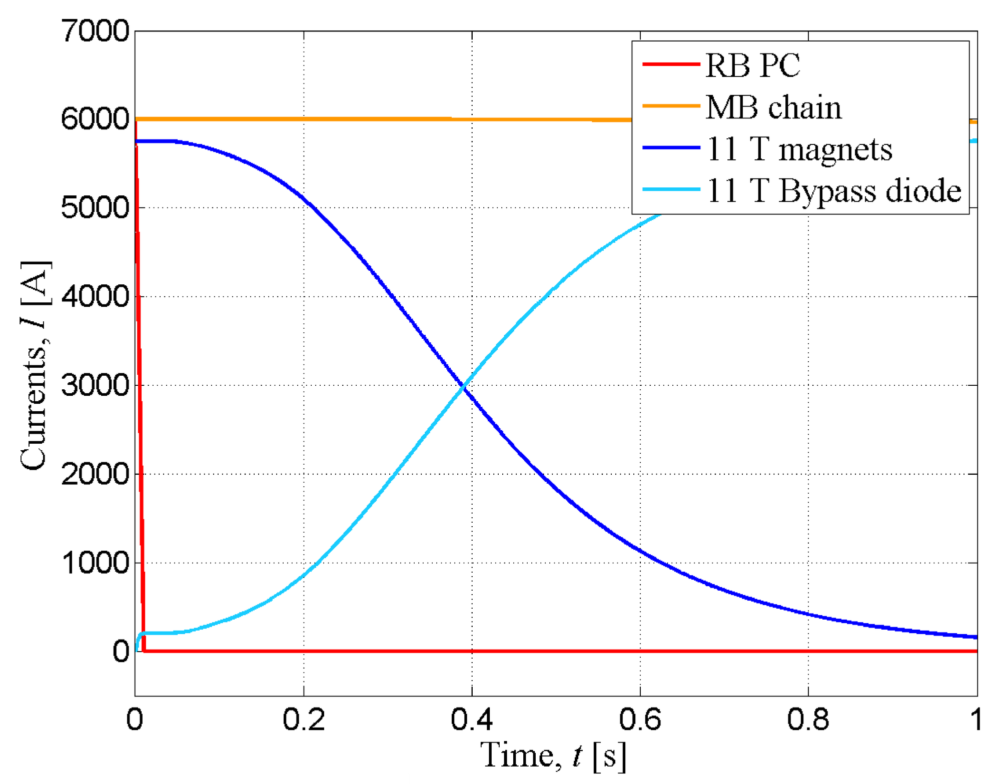



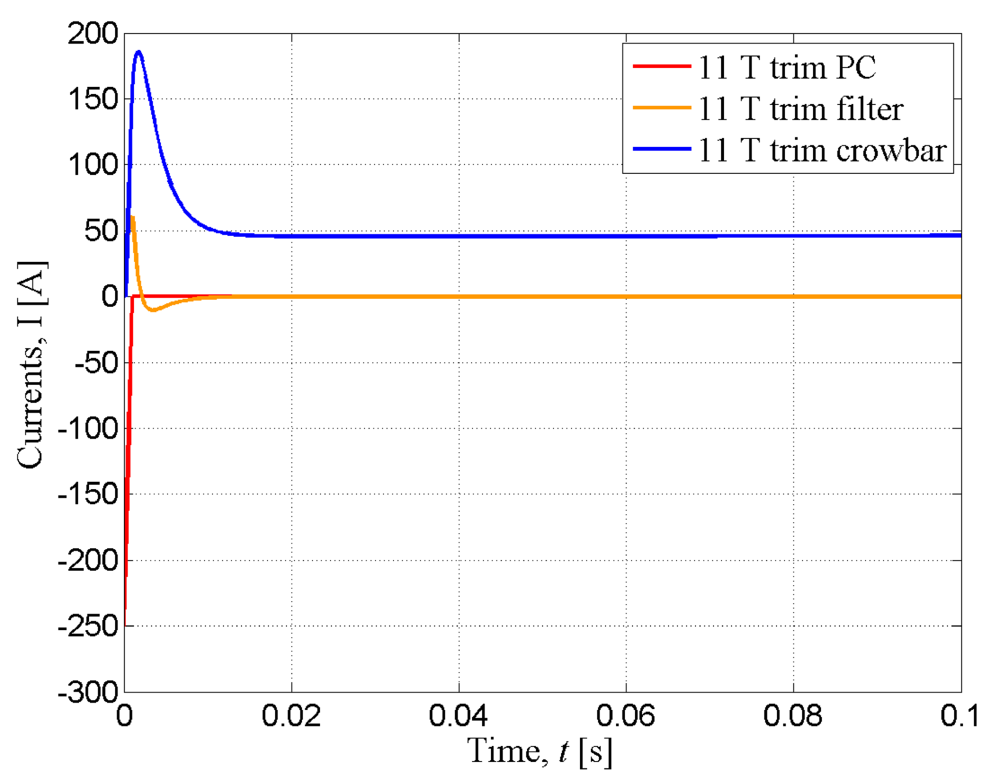




Peak temperature distribution due to the action of QH's

Calculated initial hot-spot temperature under adiabatic conditions: 326 K

### Quench in a MBH magnet and FPA at current ramp-up




## Conclusions

- The electro-thermal behavior during a quench event and the mutual influences between the quenched magnet and the electrical circuit have been analysed using the STEAM co-simulation framework.
- The results show a safe fast power abort of the system in the event of a quench in one of the MBH magnets. The 180 A peak current in the MBH trim circuit is below the design limit of 250 A. The hot-spot temperature in the MBH magnets reaches 326 K, which is below the maximum allowed peak of 350 K.
- These results support the validation of the correct functioning of the reconfigured RB circuit.

## Outlook

The STEAM framework, together with the models presented, will be used to study other aspects of the upgraded RB circuit, such as:

- Magnet and circuit behavior in case of a quench in an adjacent MB magnet to the MBH assembly.
- Power abort of the 11 T trim PC without a general FPA of the main circuit.
- Influence of electromagnetic waves on the functioning of the Quench Detection System.

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