Magnet powering system and beam dump requests

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Outline

- ➔ Magnet Powering for the LHC and SPS-LHC Transfer lines
  - See also ‘Introduction to Magnet Powering and Protection’ by R.Denz
- ➔ Powering of electrical circuits with normal conducting magnets
- ➔ Powering of electrical circuits with superconducting magnets
- ➔ Timescales for a beam dump by the interlock systems in case of different powering failures – Can we dump before beam losses occur?
- ➔ Fast Magnet Current Change Monitors providing additional protection
- ➔ Protection against combined failures

Magnet powering for superconducting and normal conducting magnets

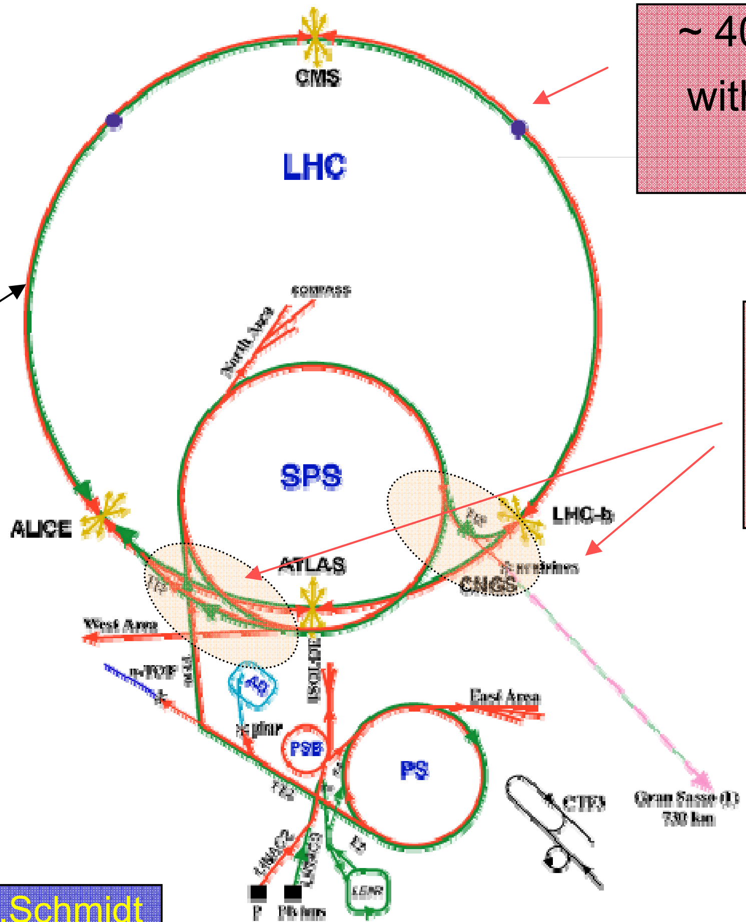
➔ Machine protection of the LHC starts already with its pre-injectors and the transfer lines

➔ Magnet powering and interlock systems in the SPS, transfer lines and the LHC are more or less identical

~ 40 electrical circuits with 150 nc magnets in the LHC

~ 25 electrical circuits with 800 nc magnets in SPS extractions lines & CNGS

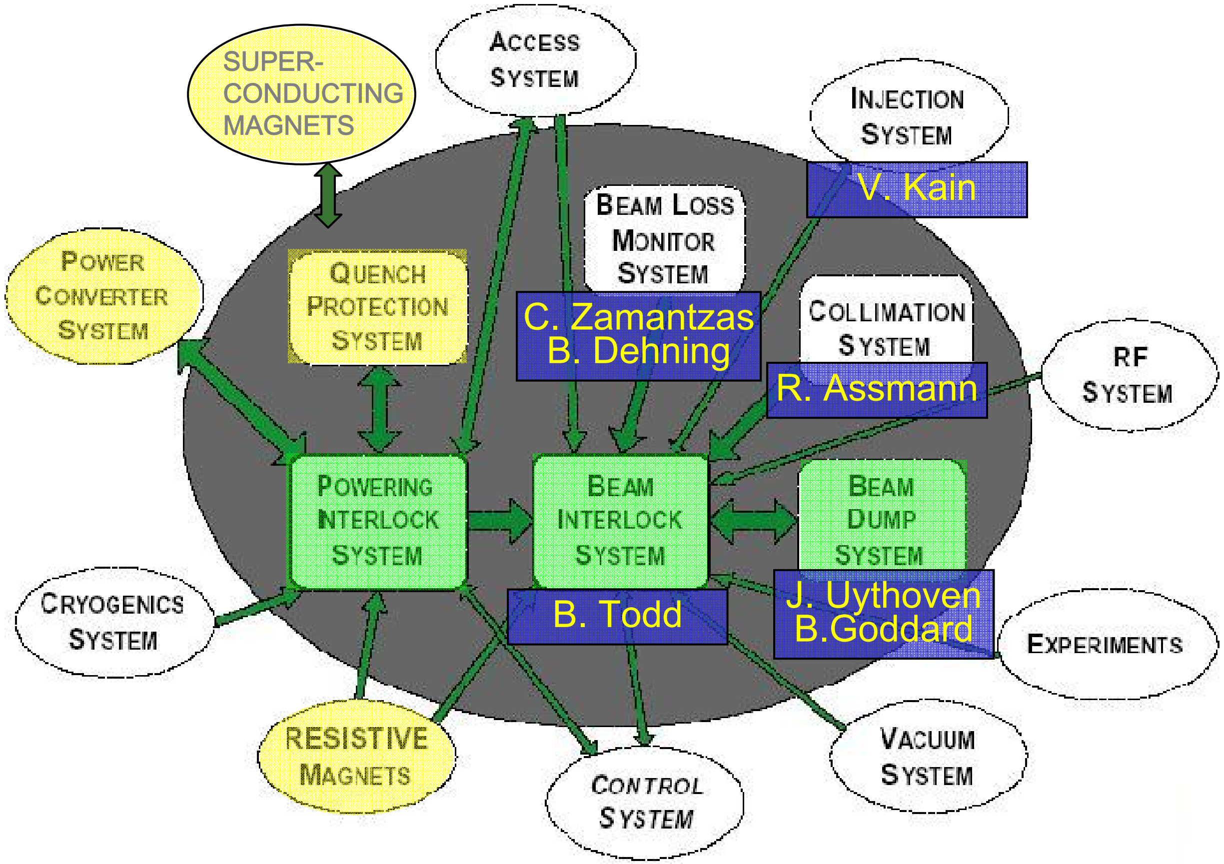
~1600 electrical circuits with 10 000 sc magnets in the LHC



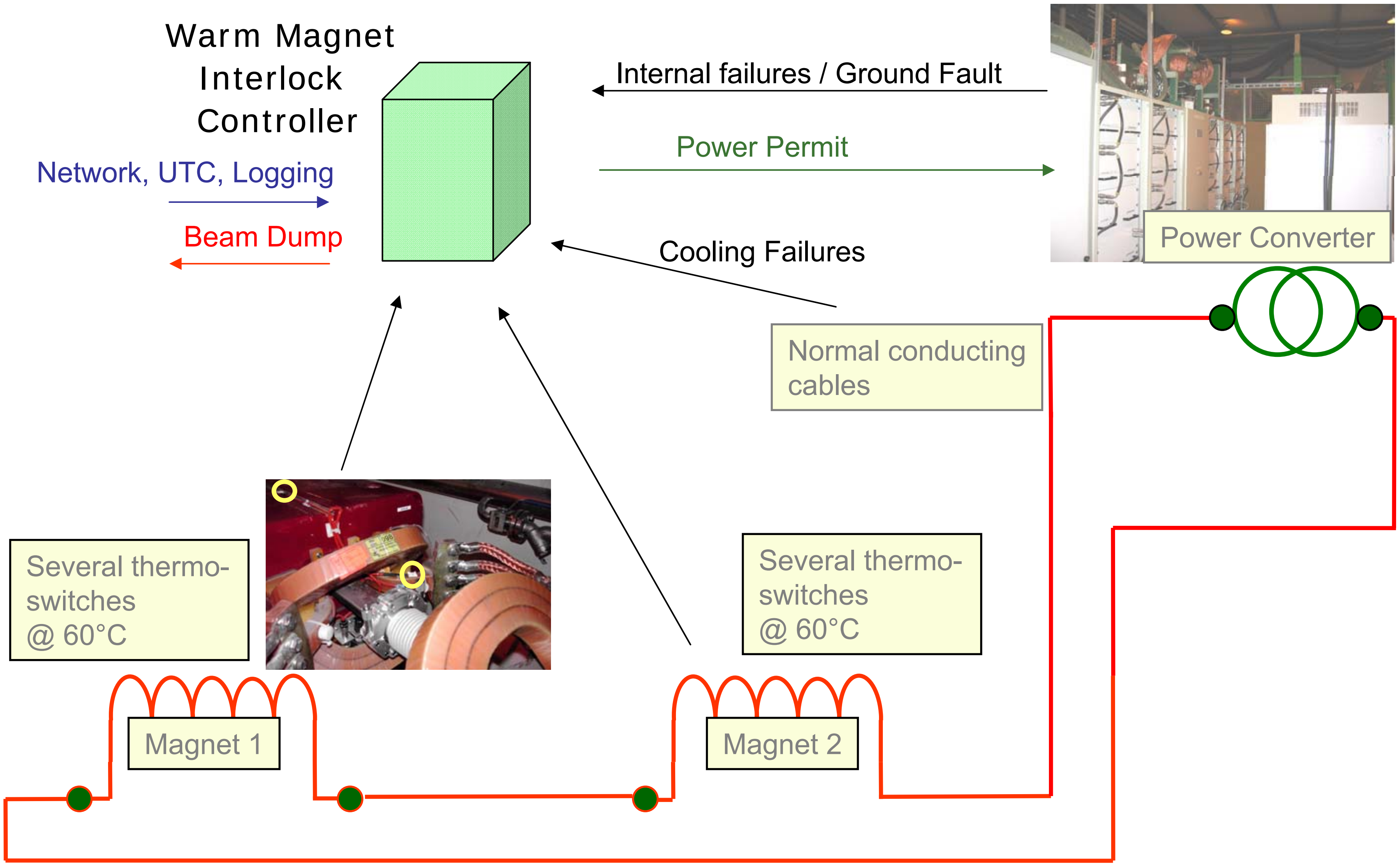
see also: Talks of R. Denz and R.Schmidt

➔ Magnet powering system will account for a considerable fraction of beam dump requests due to (e.g. beam induced) magnet quenches, power converter failures, mains failures, etc..

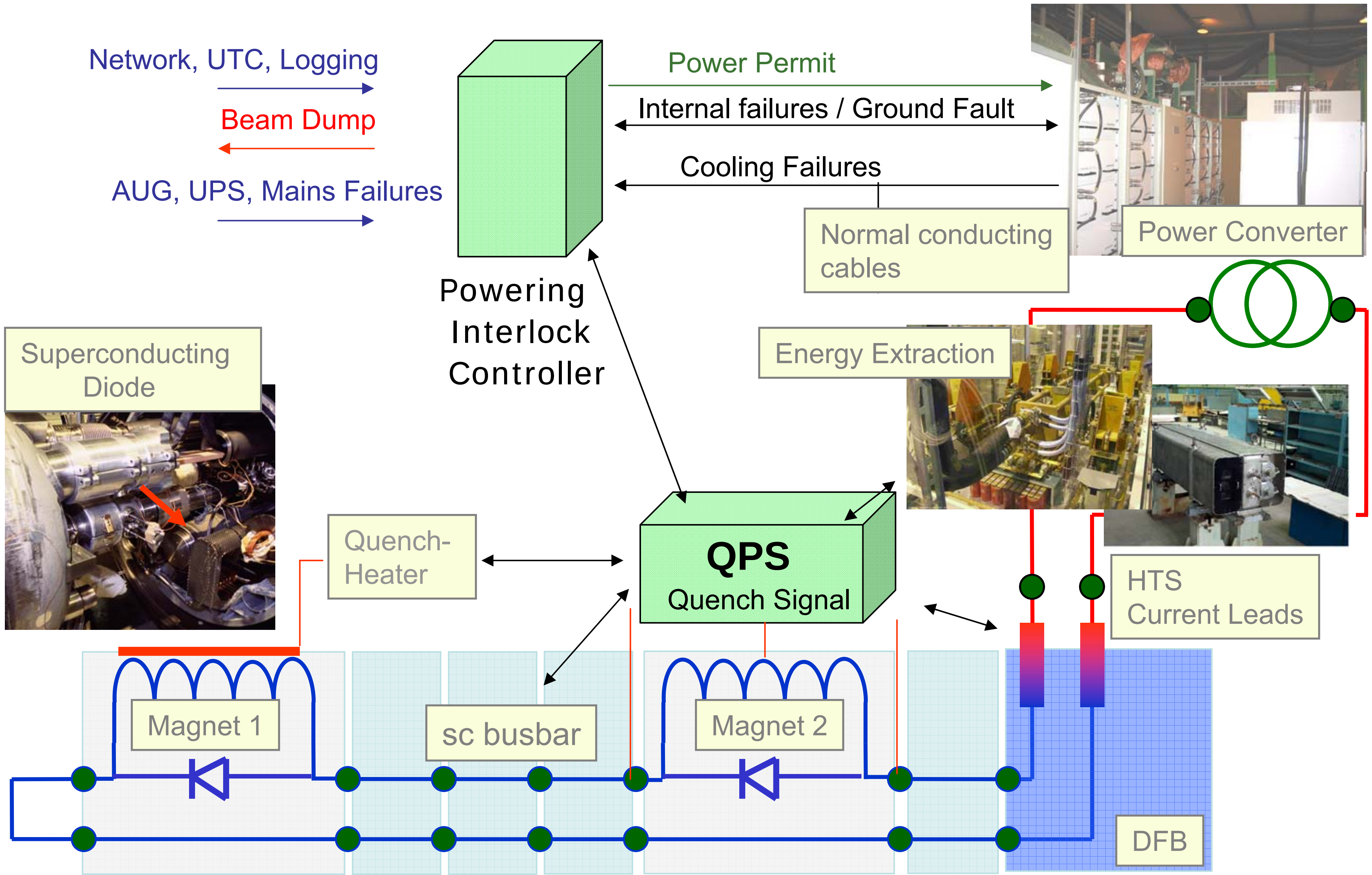
➔ Due to its complexity and the requirement of flexibility (not all powering failures require beam dumps), the powering interlock systems are separated from the beam interlock system



Protection mechanisms for normal conducting magnets / circuits



Protection mechanisms for superconducting magnets / circuits



Powering Interlocks for sc and nc magnets

Powering Interlock Controller (PIC)

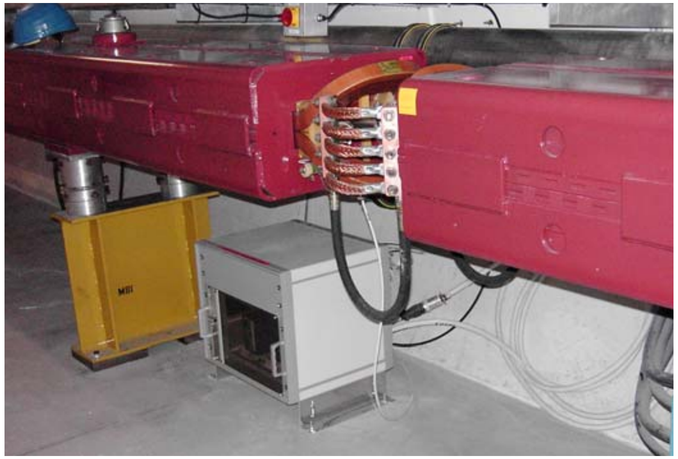
Protect electrical circuits with super conducting magnets (LHC)

HW Interfaces with quench protection system, converters, emergency stop, UPS

PLC Siemens S7-400

Real-Time (Response time ~5 msec)

Typical Powering Failures: Quenches, internal converter or cooling failures



Warm Magnet Interlock Controller (WIC)

Protect electrical circuits with normal conducting magnets (TI8/TI2, CNGS, LEIR, LHC, SPS, etc…)

HW Interfaces with Magnets (Thermo-Switches) and power converters

PLC Siemens S7-300

Real-Time (Response time ~ sec)

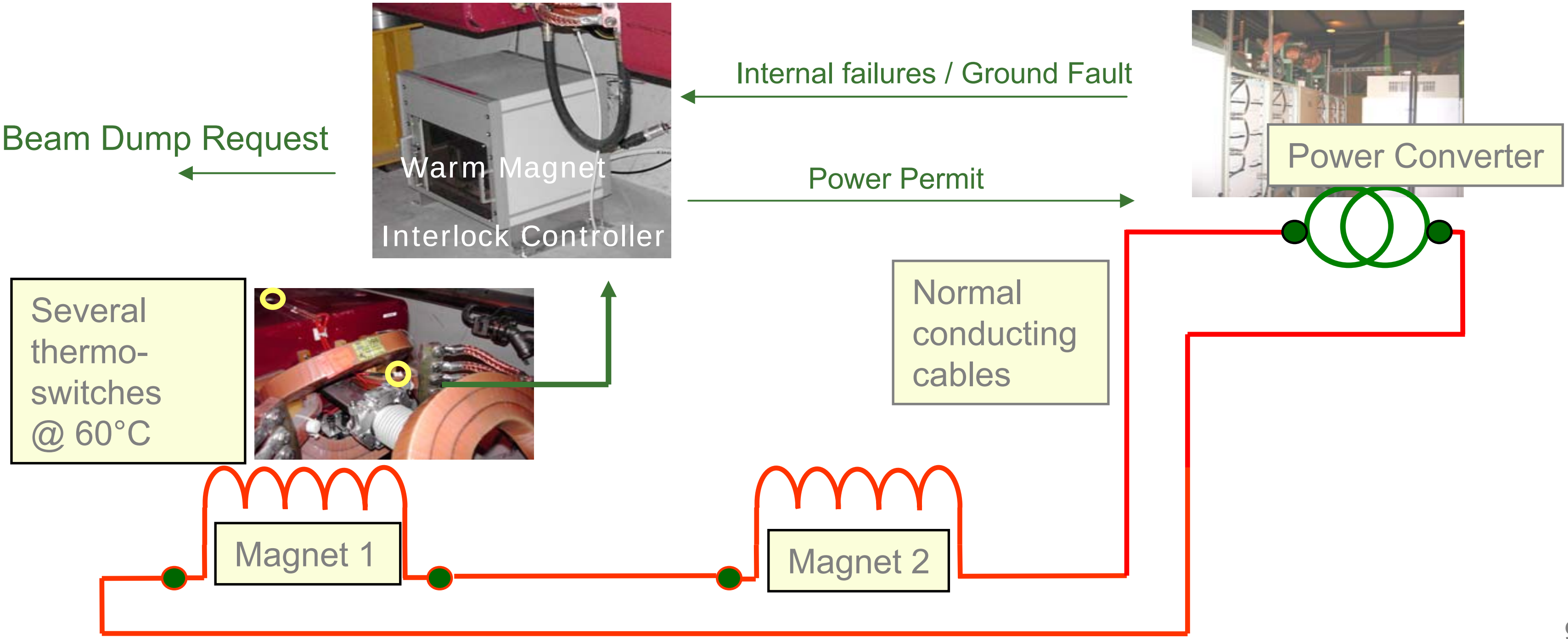
Typical Powering Failures: Magnet overheating, internal converter failure

- Prior task is the protection of powering equipment (magnets, busbars, current leads, cables,…) -> ms reaction time sufficient
- Collect protection signals from the powering equipment and issue the beam dump requests if necessary
- Up to 4 protection signals/circuit or magnet are exchanged using hardwired current loops -> No safety critical function via SW
- Simple, robust, fails safe and quasi-redundant signal transmission (Safety, Reliability, Availability) see also: Talks of B.Todd and R. Filippini
- Not influenced by EMC (successfully tested to highest level of the norm)

- For most failure cases, the issued beam dump request provide redundancy to BLM's, as the fault is transmitted to the Beam Dumping System before beam losses occur
- For some failure cases, the issued beam dump request will not be fast enough and other monitors (BLM etc) need to trigger the beam dump
- But, for single turn failures the BLM system can not prevent damage (TT40 incident end of last year)

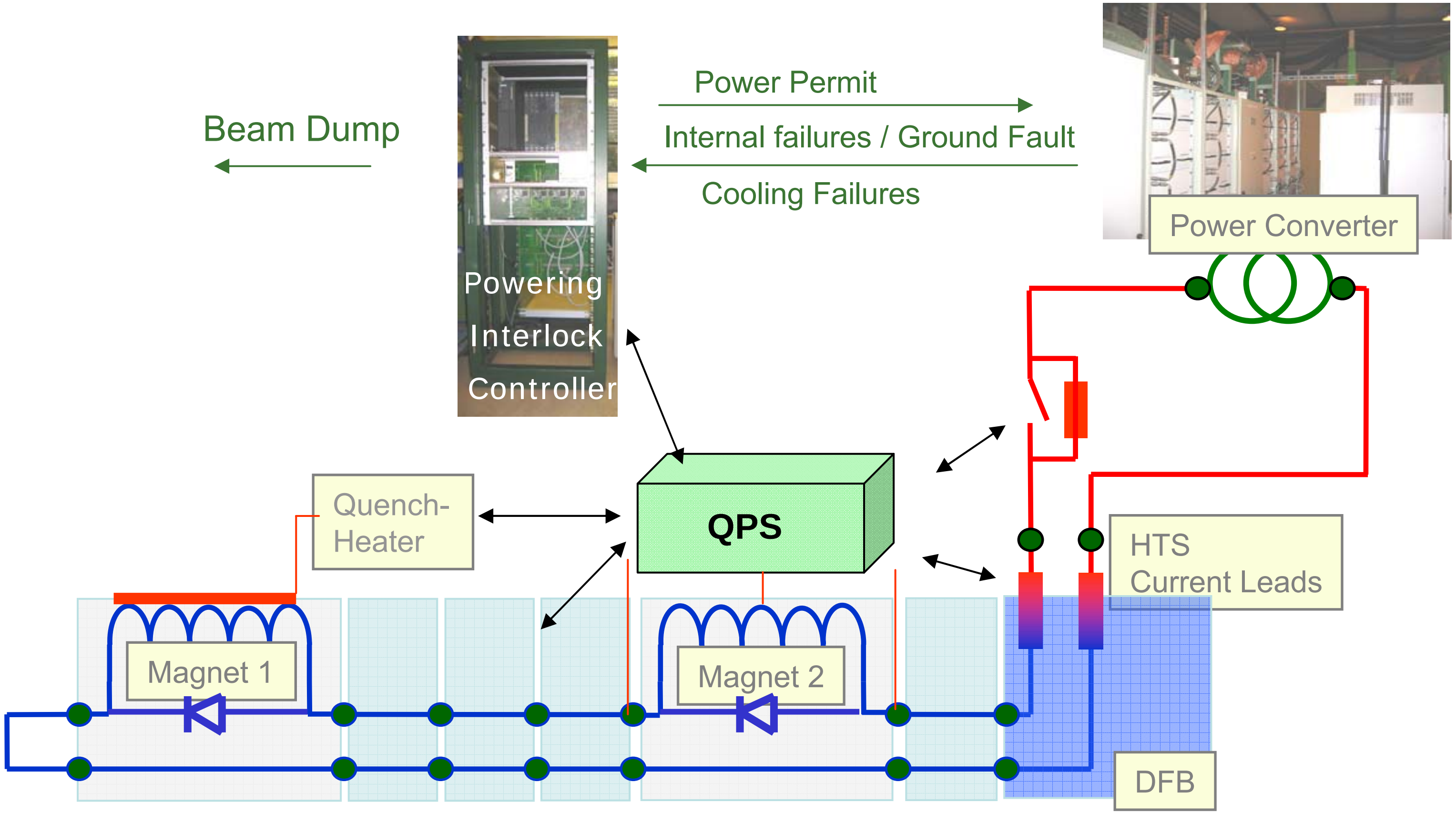
Failure case #1: Overheating of a normal-conducting magnet

- ➔ Overheating of magnet due to e.g. cooling failure
- ➔ Up to 6 thermo-switches on the magnet -> Signal to the interlock controller
- ➔ Controller will first switch off the beam
- ➔ After an additional delay of 1 sec the converter is stopped, to avoid a decaying magnetic field as long as beam is present
- ➔ One of the reasons of the beam incident in TT40 was that a PLC switched off the power converter first, and only then inhibited extraction of beam

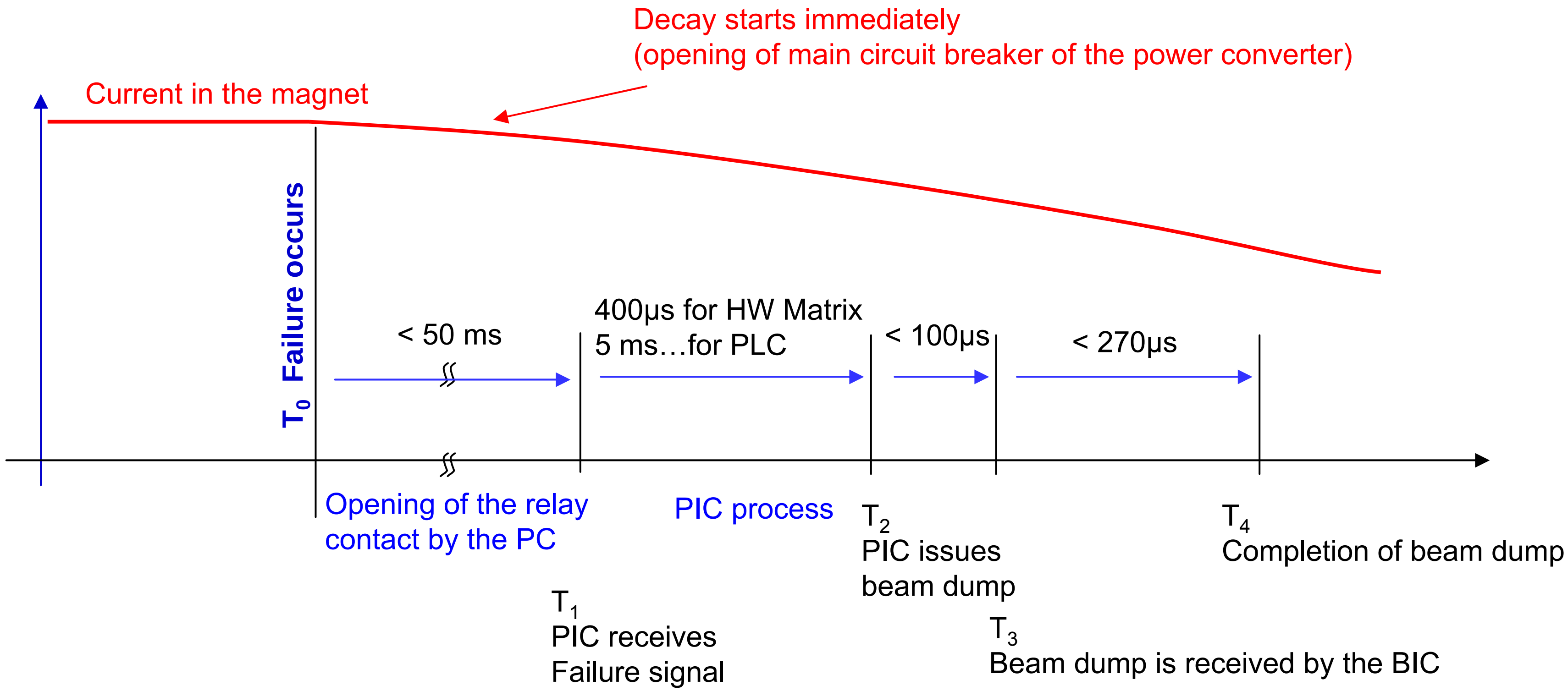


Failure case #2: Internal Failures of the power converter

- ➔ Power converter detects internal failure, switches immediately OFF and informs powering interlock (e.g. direct opening of the main circuit breaker)
- ➔ Upon reception, the interlock controller immediately triggers a beam dump (HW Matrix in parallel to PLC process to minimize delays), but magnetic field is already decaying!



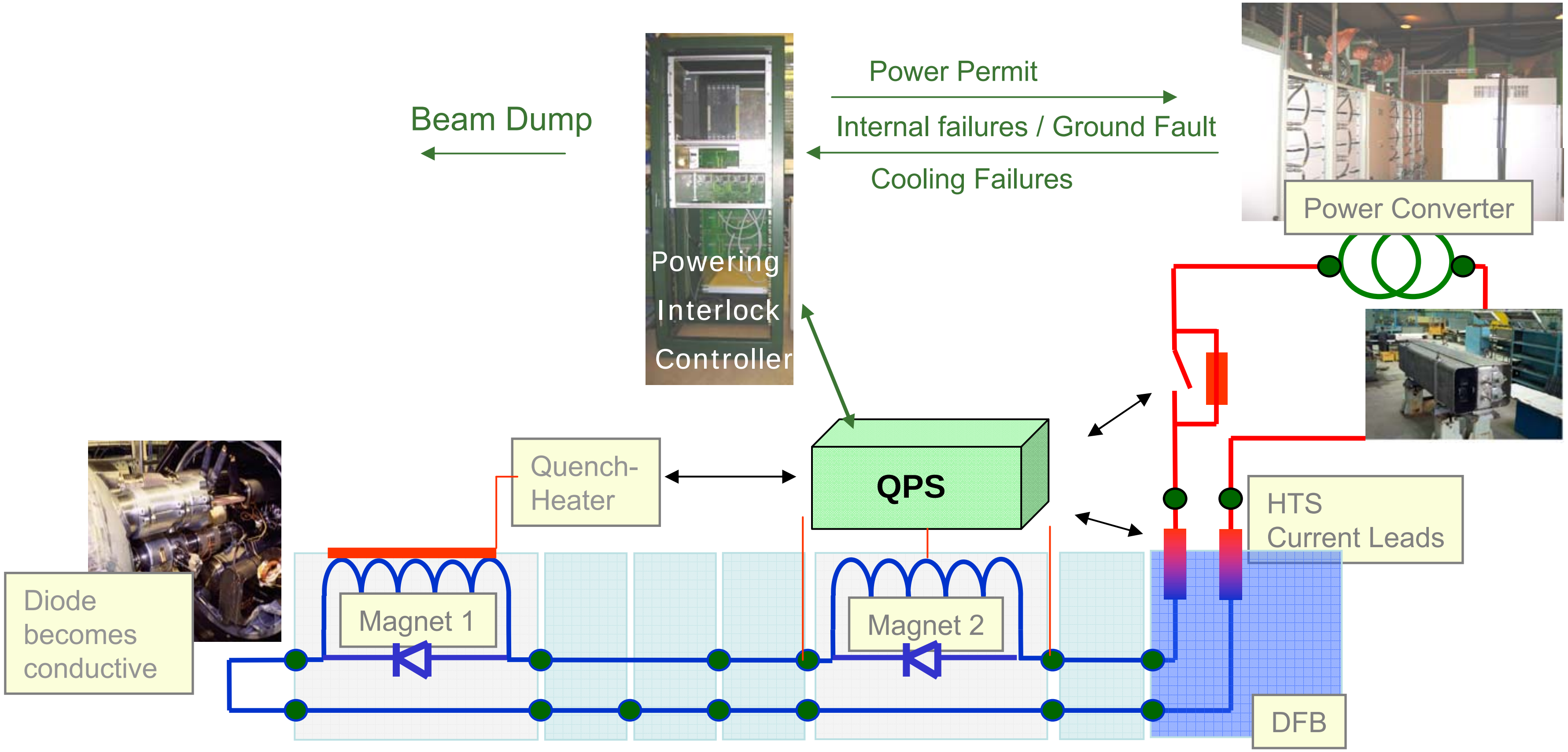
Failure case #2: Internal Failures of the power converter



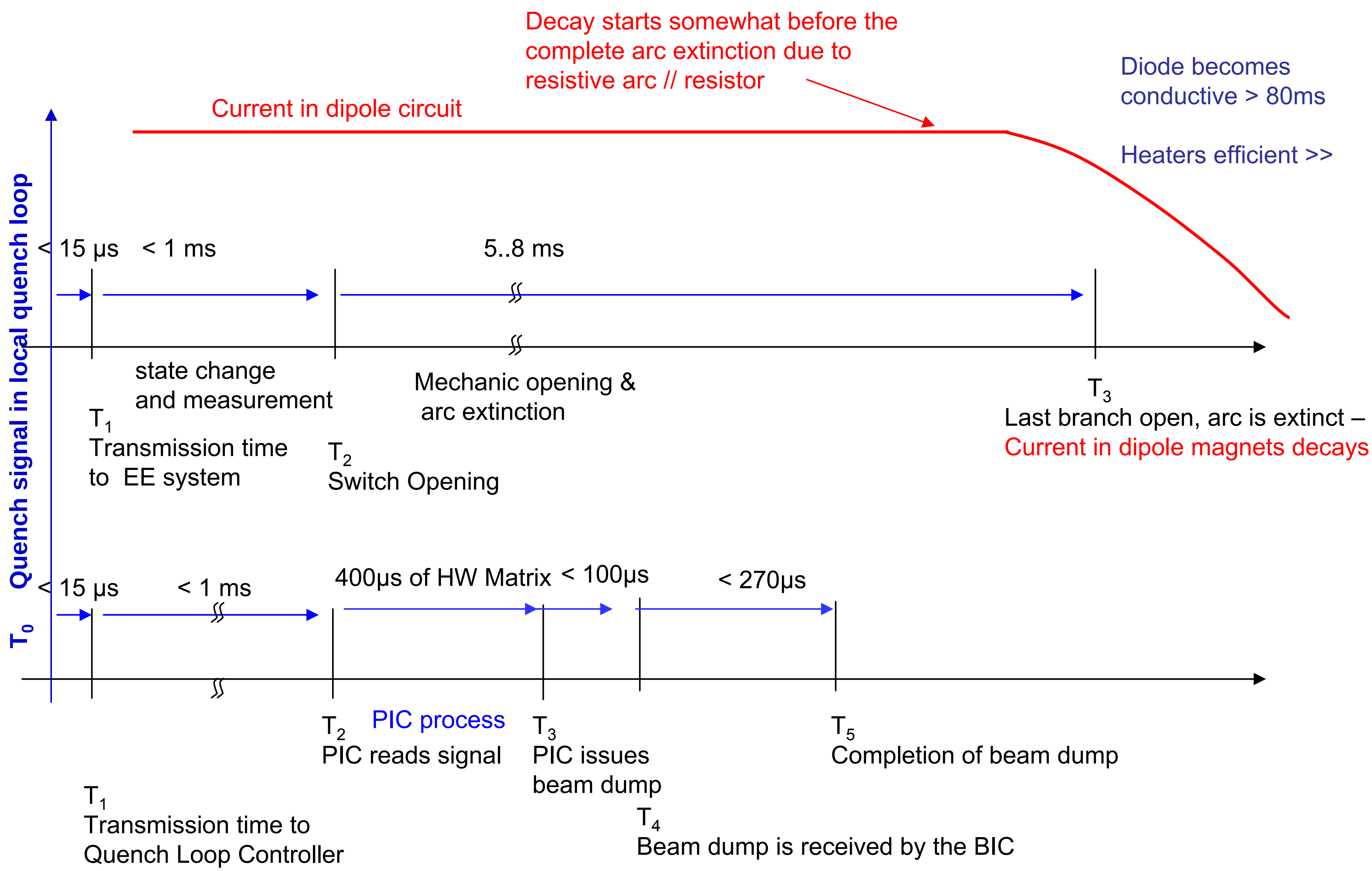
- ➔ Delay due to signal transmission via a relay contact
- ➔ T>> (for sc magnets, but NOT for nc magnets), converter output filter and eddy currents limit the field decay and relax the detection

Failure case #3: Quench of a superconducting magnet

- ➔ Quenching of sc magnet due to e.g. beam losses
- ➔ Quench detection by the QPS system   Talk of R. Denz
- ➔ Transmission of quench signal, firing of heaters and activation of EE system
- ➔ Current decay only upon complete opening of EE switch, diode will become conductive much later



Failure case #3: Quench of a superconducting magnet



➔ Powering Interlock system requests a beam dump before the current in the dipole magnet starts decaying (all other magnets even less time critical)

Failure case #4: Powering failure in magnets with effects on the beam very shortly after the failure

- For superconducting magnets, the large natural time constant relaxes the required detection time
- For a number of normal conducting magnets (T ~ sec) such as septas and separation dipoles, current changes of 5*10E-4 can be hazardous and beams have to be dumped in < 1ms
- Very fast losses occur (due to the quickly decaying field)
- Present powering interlock system provides NO redundancy to BLMs

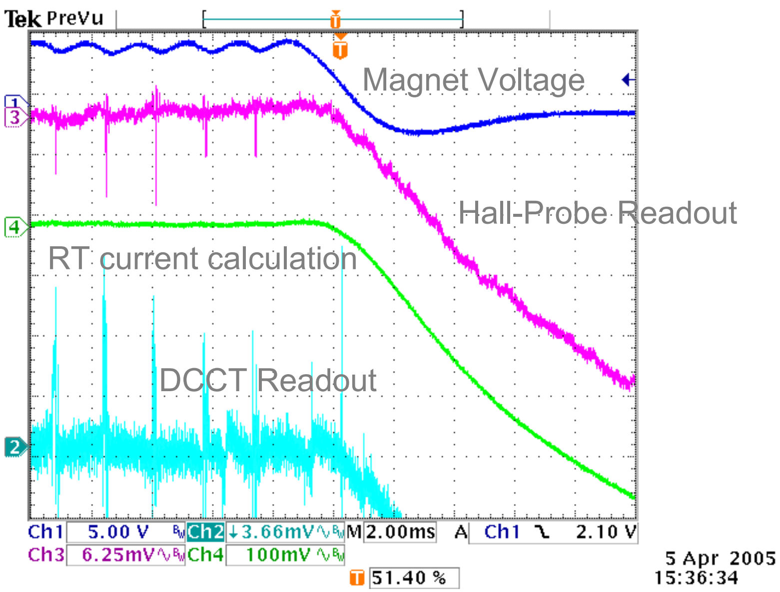
- Idea of a Fast Magnet Current Change Monitor, initially developed at DESY and recently successfully tested for the SPS extraction septa and the LHC separation dipole D1

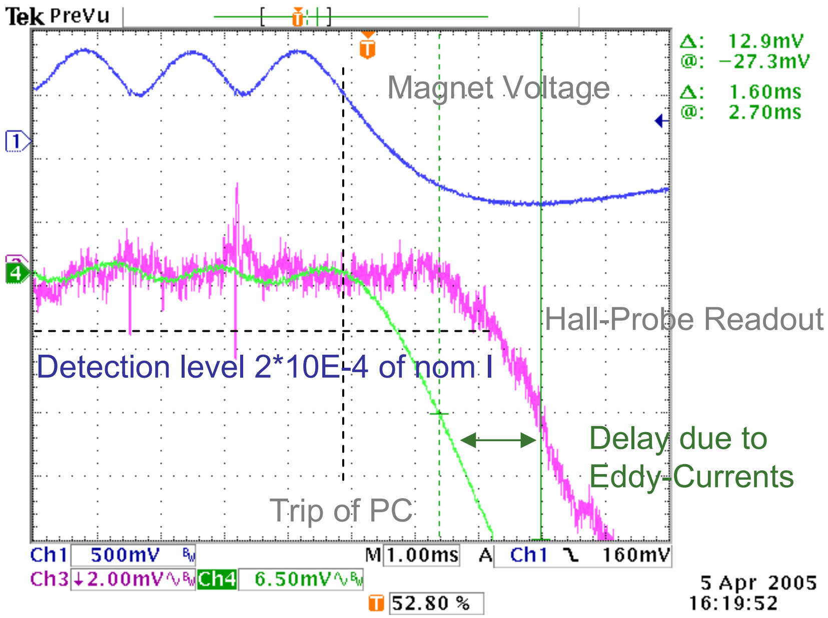
With courtesy of M. Werner

Failure case #4: Powering failure in magnets with large effects on the beam

- ➔ Measurement of fast current changes (typical for powering failures), instead of absolute values
- ➔ Based on measurements of the magnet voltage rather than a DCCT readout
- ➔ RT calculation of the current based on a model of the circuit impedance

Example of measurements during a shut down of a nc separation dipole (D1):





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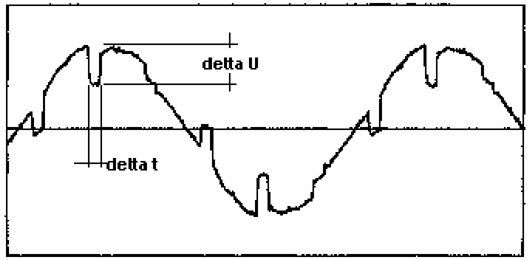
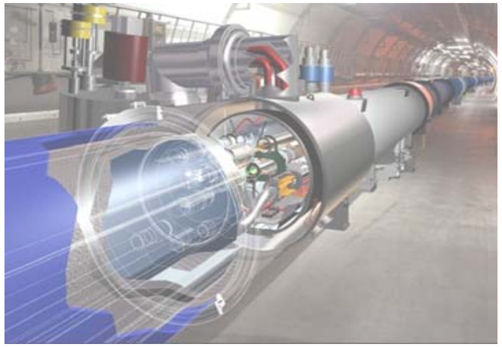
Combined failures

- Failures of the mains supply could affect not only single circuits, but a complete machine sector
- Lightnings or brown outs, but also emergency stops could trip the complete powering system of a machine sector (small tolerances for thyristor converters)
- No direct beam dumps are generated by the electrical distribution system for the time being
- Fast Magnet Current Change Monitor would be the first device to detect such a failure
- Simulations for combined failures in progress, but most insertions are covered by a FMCCM





Conclusions and Outlook

- ➔ Beam dump requests from the powering interlock systems provide redundancy to e.g. BLM for most of the powering failure scenarios
- ➔ Due to the limited response time of the powering interlock system, one has to rely on BLMs and collimators for some special failure cases
- ➔ Whenever possible, delays are minimized (HW Matrix in parallel to the PLC, fast relays,...) to dump the beam before any beam lossess occur
- ➔ Additional systems are studied for protection of critical normal conducting circuits and pulsing magnets
- ➔ Combined failures as e.g. due to thunderstorms and mains losses could equally be captured using such additional protection measures