The LHC Beam Loss Measurement System

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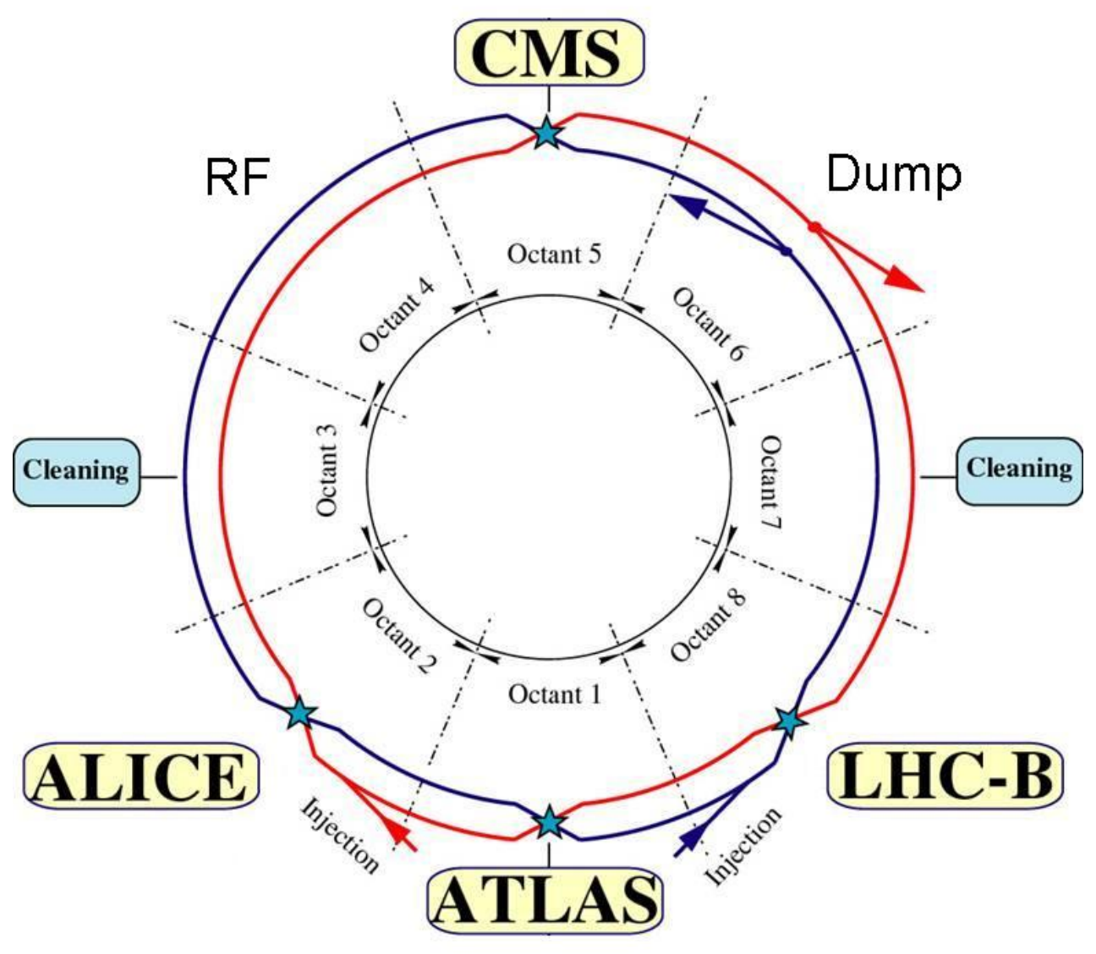
Abstract: *An unprecedented amount of energy will be stored in the circulating beams of LHC. The loss of even a very small fraction of a beam may induce a quench in the superconducting magnets or cause physical damage to machine components. A fast (one turn) loss of $3\cdot10^{-9}$ and a constant loss of $3\cdot10^{-12}$ times the nominal beam intensity can quench a dipole magnet. A fast loss of $3\cdot10^{-6}$ times nominal beam intensity can damage a magnet. The stored energy in the LHC beam is a factor of 200 (or more) higher than in existing hadron machines with superconducting magnets (HERA, TEVATRON, RHIC), while the quench levels of the LHC magnets are a factor of about 5 to 20 lower than the quench levels of these machines. To comply with these requirements the detectors, ionization chambers (BLMI) and secondary emission monitors (BLMS) are designed very reliable with a large operational range. Several stages of the acquisition chain are doubled and frequent functionality tests are automatically executed. The failure probabilities of single components were identified and optimized. First measurements show the large dynamic range of the system.*

LHC and it's BLM System



- **Circumference:** 26.7 km
- **Injection energy:** 450 GeV
- **Top energy:** 7 TeV in two counter rotating beams
- **~ 350 MJ** stored energy per beam
  (can melt 500 kg of copper)
- **~ 11 GJ** stored energy in the magnet system
- **~ $3x10^{14}$** protons per beam
- Superconducting magnets
- Magnetic field **8.3 T** (**1.9 K**)
- Factor 4 − 20 more sensitive to beam losses compared to existing hadron machines

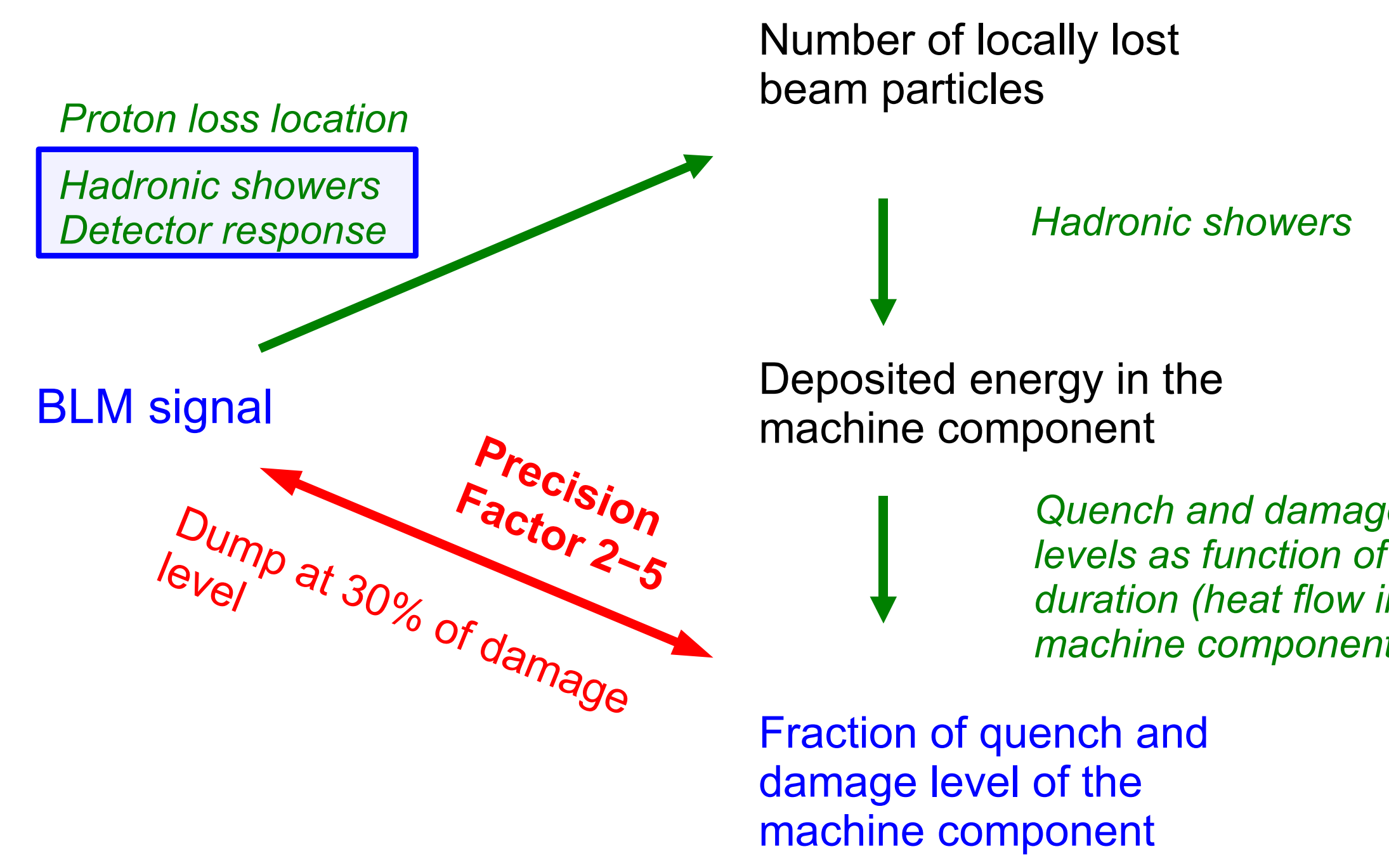
↳ **Quench Risk** ➡ **BLM System**

Purpose:
- Machine protection against damage of equipment and magnet quench
- Localization of beam losses and identification of loss mechanism
- Machine setup and studies

Location:
- BLMI mounted outside of cryostat (transverse tail of hadronic showers), six around each quadrupole, special locations (high dose rates) BLMS

Challenges:
- Reliability (tolerable failure rate 10^{-7} per hour per channel)
- Large dynamic range (10^8, pA – mA) achieved with BLMI + BLMS

Calibration of the BLM System



Proton loss location

Hadronic showers
Detector response

Number of locally lost beam particles

Hadronic showers

BLM signal

Precision Factor 2~5

Dump at 30% of damage level

Deposited energy in the machine component

Quench and damage levels as function of loss duration (heat flow in machine component)

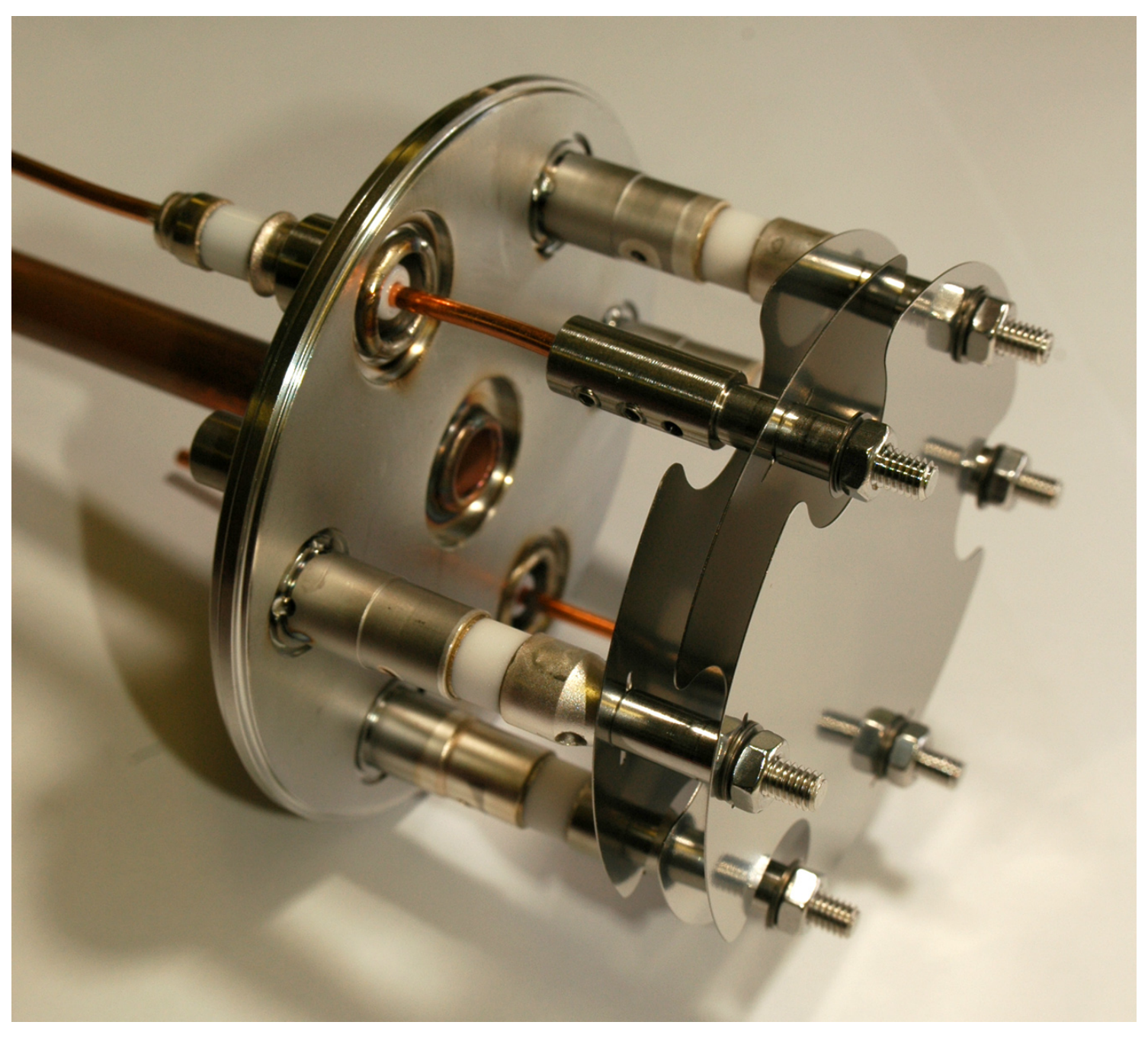
Fraction of quench and damage level of the machine component

Dump threshold values :
- Machine component
- Loss location
- Detector position
- Beam energy
- Loss duration

➡ *Simulations performed*

▭ *Presented in this poster*

Detectors

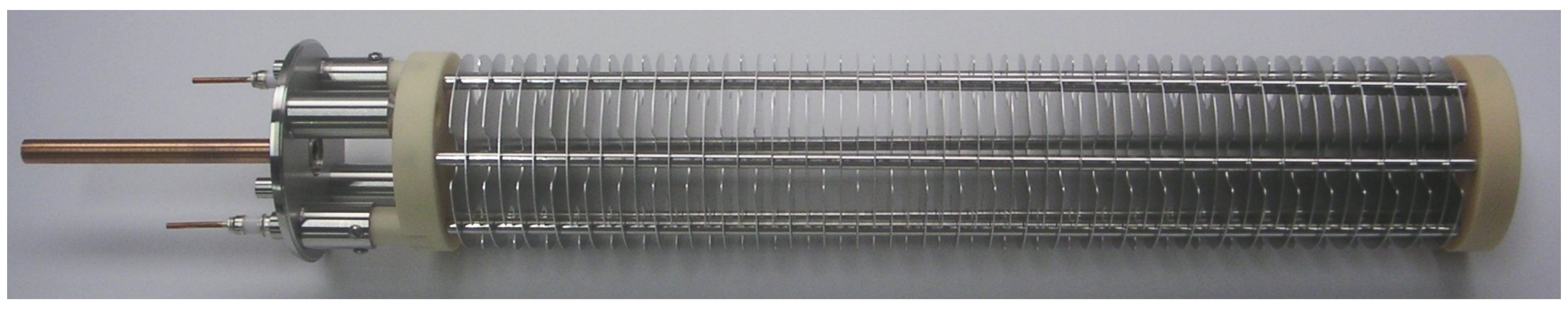


Secondary Emission Monitor (SEM) design:

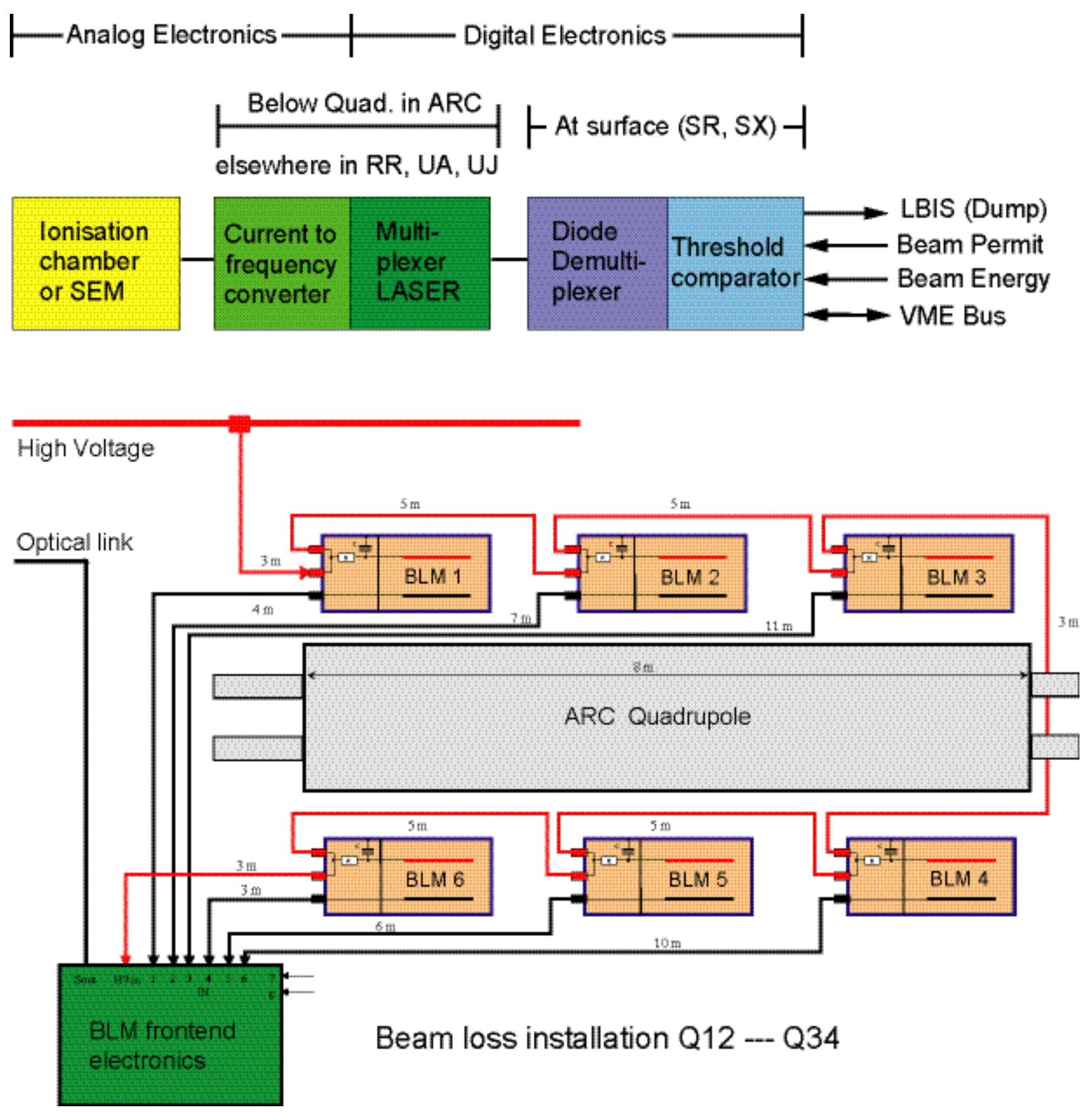
Diameter = 8.9 cm
3 Ti electrodes (1 signal electrode), 0.25 mm
NEG pumping stripe (300 cm^2)
Length: 10 cm
pressure: ≤ 10^{-7} bar
Bias voltage: 1500 V

Ionization chamber design:

Diameter = 8.9 cm
Length: 60 cm
Volume: 1.5 litre
60 Al disks, 0.5 mm
Gas: N_2 (1.1 bar)
Bias voltage: 1500 V
Gain difference to SEM: ~ 3 10^4



Readout and Reliability



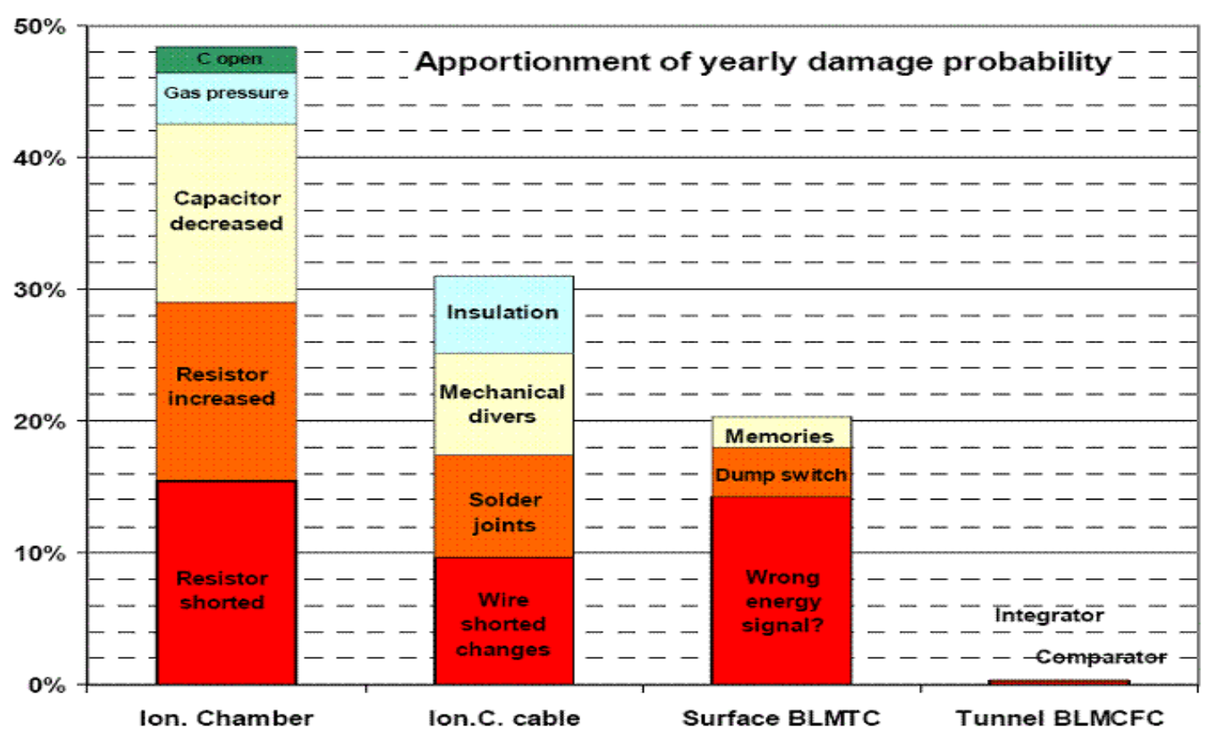
Schematic view of the signal transmission chain and the BLM installation around one arc quadrupole

Probability of damage to magnet due to not detecting a dangerous loss, required: 10^{-3} per year (SIL3)

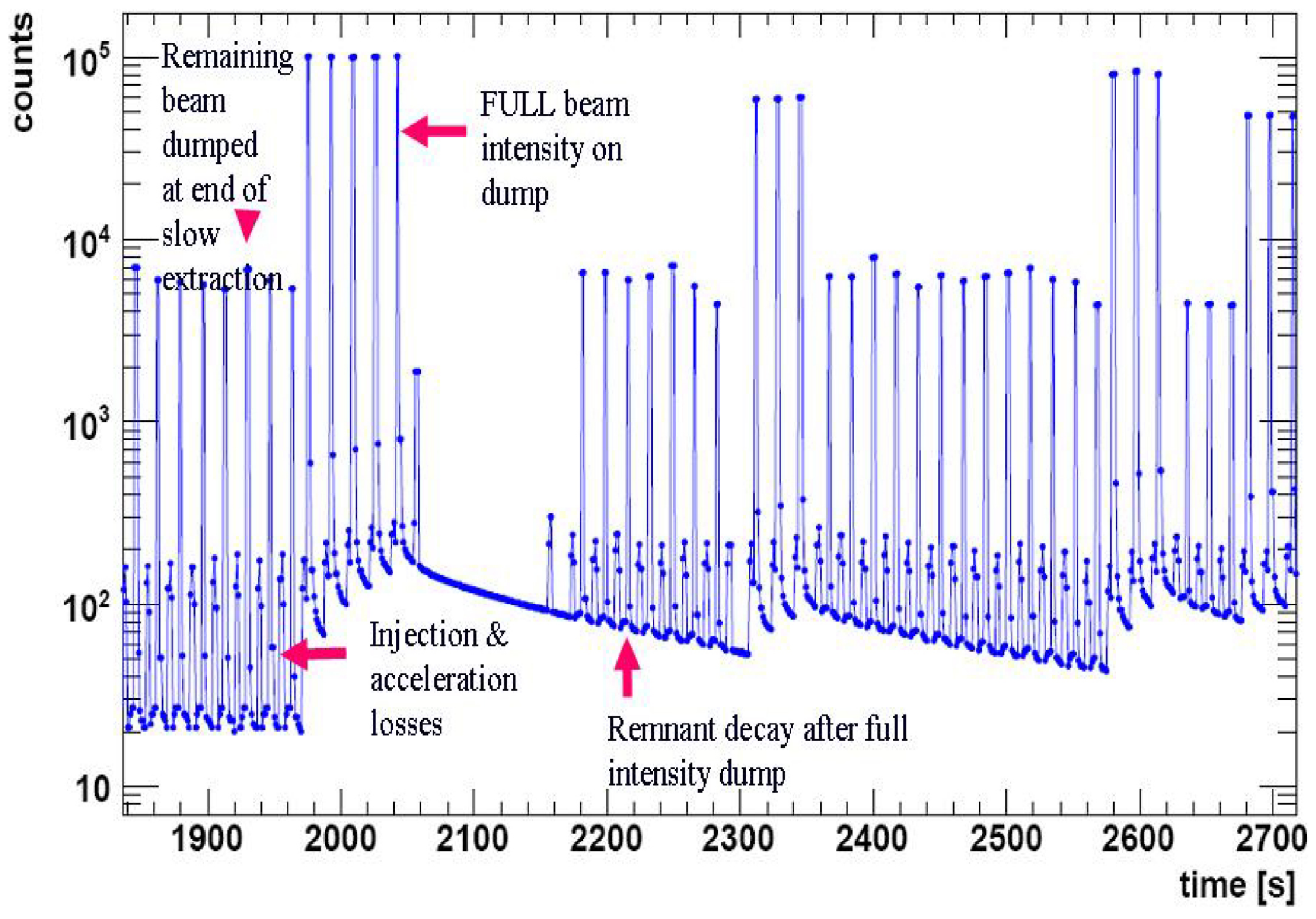
Calculated unavailability: 5 10^{-6} per channel (satisfies SIL3 for 100 dangerous losses per year)

Less than 20 false dumps per year required (SIL2), 10-17 false dumps per year calculated

Relative probability of a system component being responsible for a damage to a LHC magnet in the case of a loss



System Test SPS Beam Dump



Loss measurements (integrated over 1.3 s) as function of time at the SPS beam dump

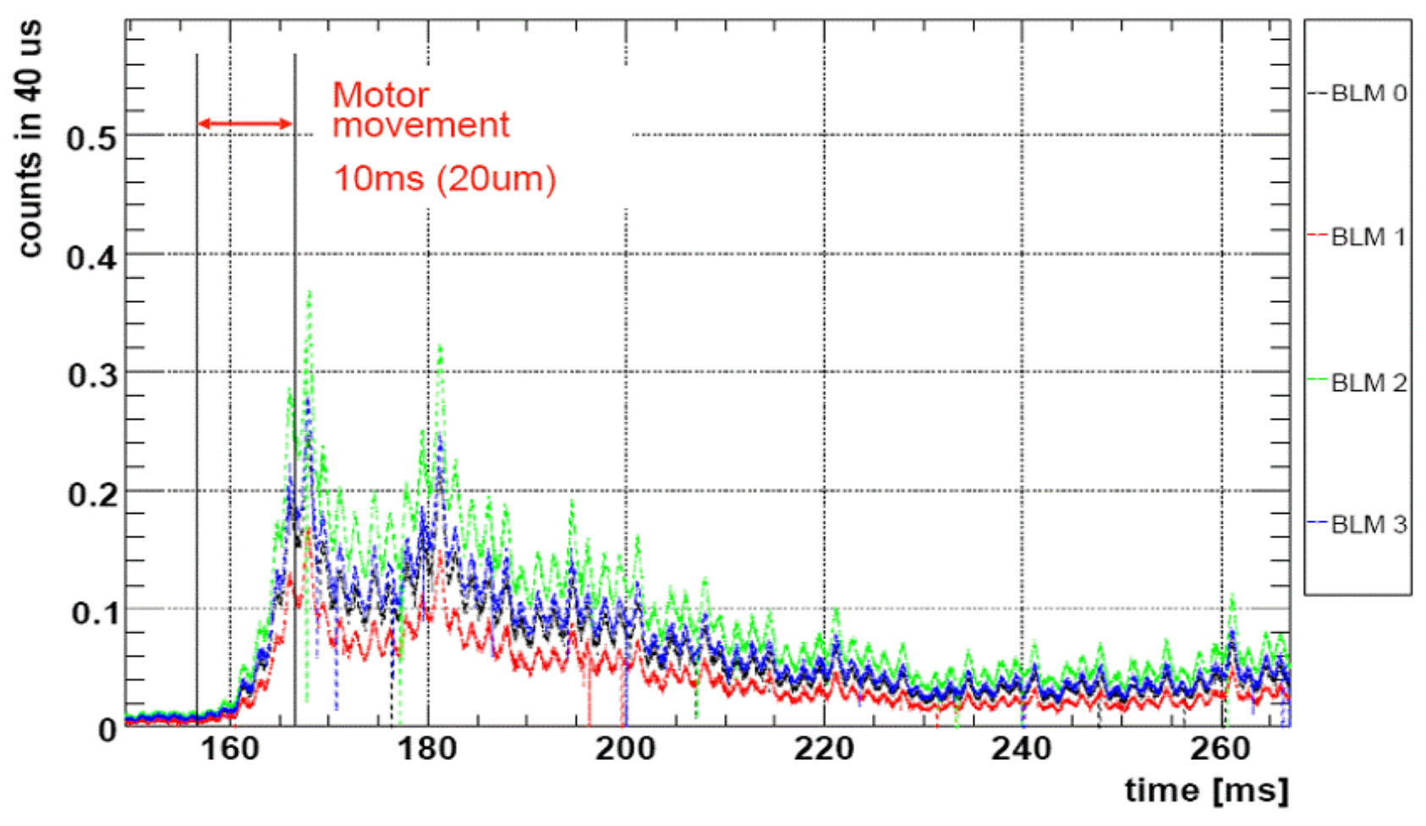
Test results of the BLM system (ionization chamber) over a large dynamic range with a pulsed beam at the SPS beam dump:

At 1900 seconds: evolution of the radiation at the dump under nominal fixed target operation.

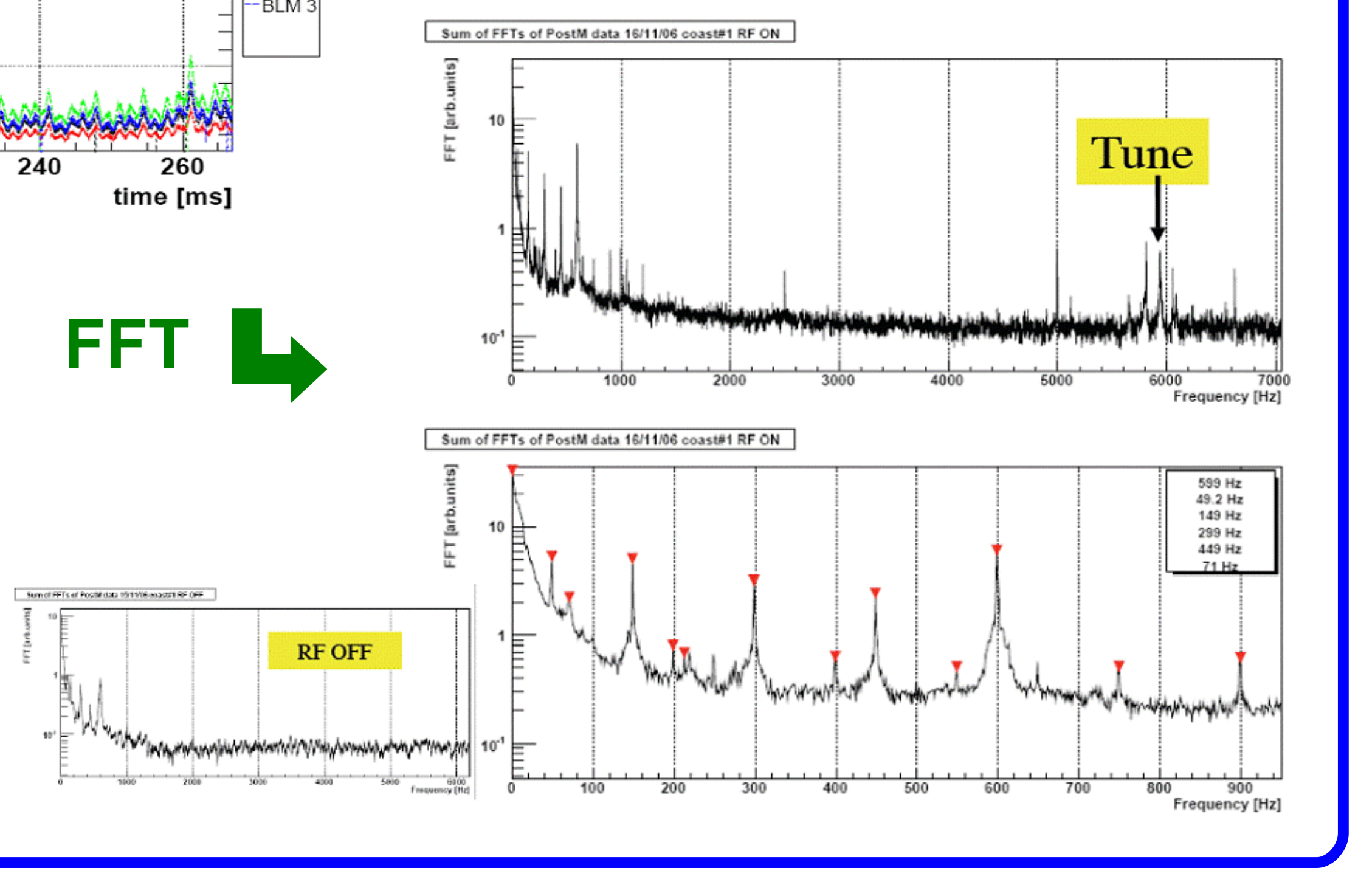
At 2050 seconds: full beam is dumped intentionally, showing immediately an increase in the remnant radiation level which is steadily decaying with time.

Illustration of radiation measurement over 4 orders of magnitude.

System Test SPS Collimator



Beam loss at an LHC prototype collimator installed in the SPS. Signal vs time after a collimator movement of 20 µs (corresponding to 10 ms)



Fast Fourier Transformation (FFT) of the BLM signal caused by the collimator movement (20 µs) of bunched and unbunched ("RF OFF") beam. Blow-up of the lower frequencies in the bunched beam case.

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