Experience with BLMs

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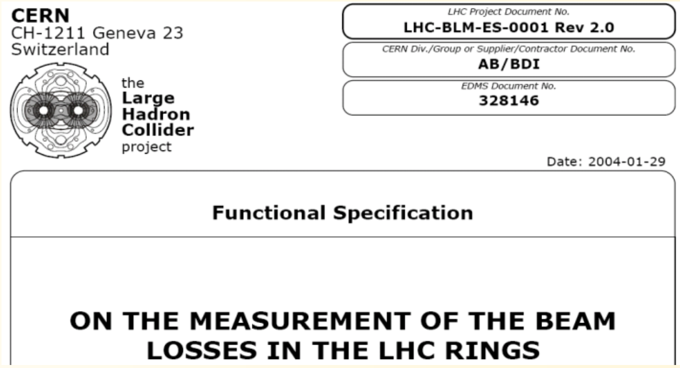
  - Firmware
  - With beam (delays)
  - Online (Sanity Check)
- Post mortem data
- Logging data

Beam Loss Monitor Specification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the Large Hadron Collider project

LHC Project Document No.
LHC-BLM-ES-0001 Rev 2.0

CERN Div./Group or Supplier/Contractor Document No.
AB/BDI

EDMS Document No.
328146

Date: 2004-01-29

Functional Specification

ON THE MEASUREMENT OF THE BEAM LOSSES IN THE LHC RINGS

5. USE OF THE BLM'S FOR MACHINE PROTECTION

The strategy for machine protection impacts on the BLM design in two ways, its time response and the reliability.

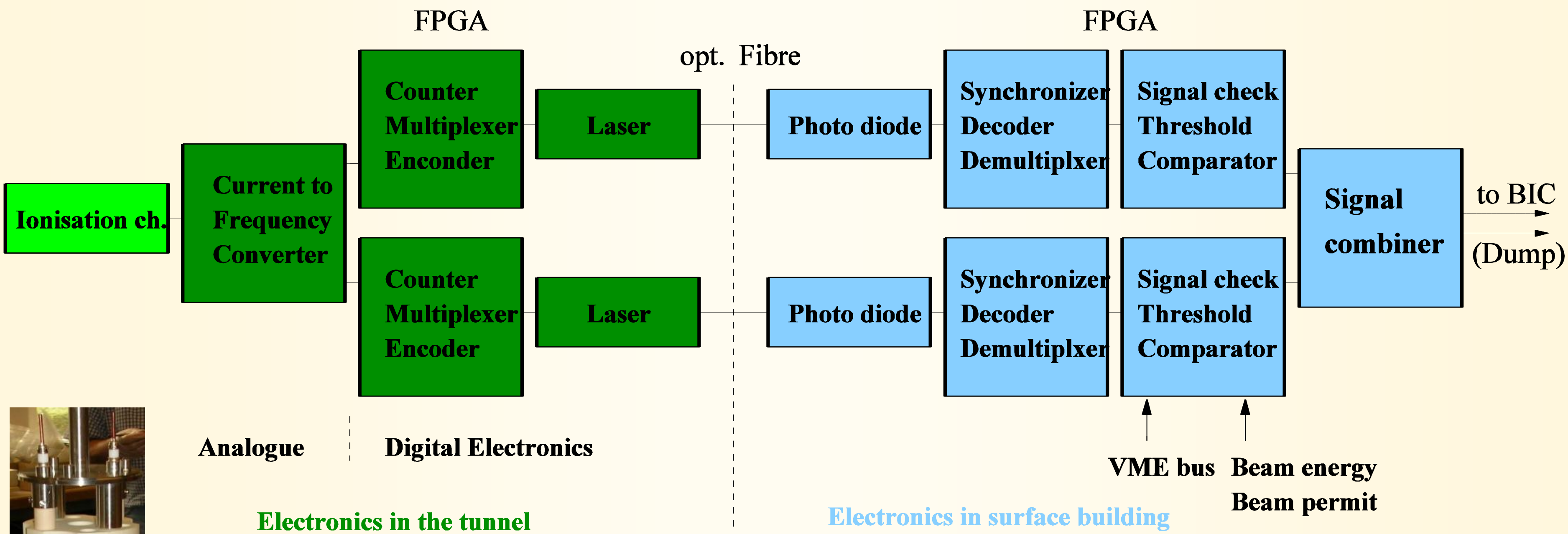
Protection of the machine from beam losses has two aspects:

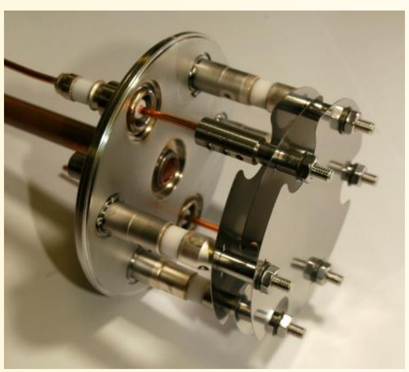
- protection against beam losses that could lead to damage of equipment,
- protection against beam losses that could lead to a quench of a magnet.

Since a repair of superconducting magnets would take several weeks, the protection against damage has highest priority and damages should be strictly avoided (**SIL 3, 1E-8 to 1E-7 1/h**).

In case of a quench, the quench protection system would prevent equipment damage. However, the beam would be lost and re-establishing operation would take several hours. Therefore the number of quenches should be minimized.

Beam Loss Measurement System Layouts

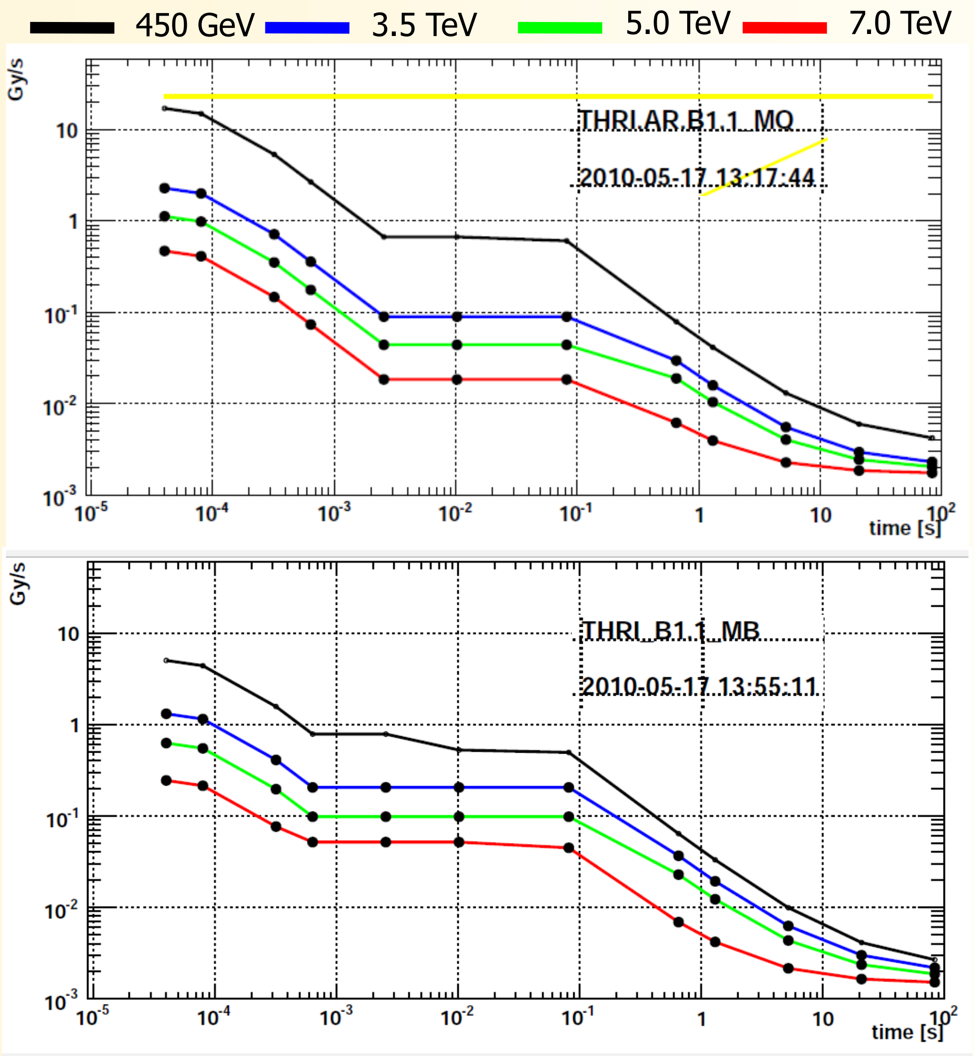




- Ionisation chamber
  - Function: observation and interlock
  - 3700 installed
  - Over 90 % connected to interlock/dump system
- Secondary emission detector
  - Function: observation
  - 300 installed

Quench and Damage Levels

Quadrupole and bending magnet thresholds

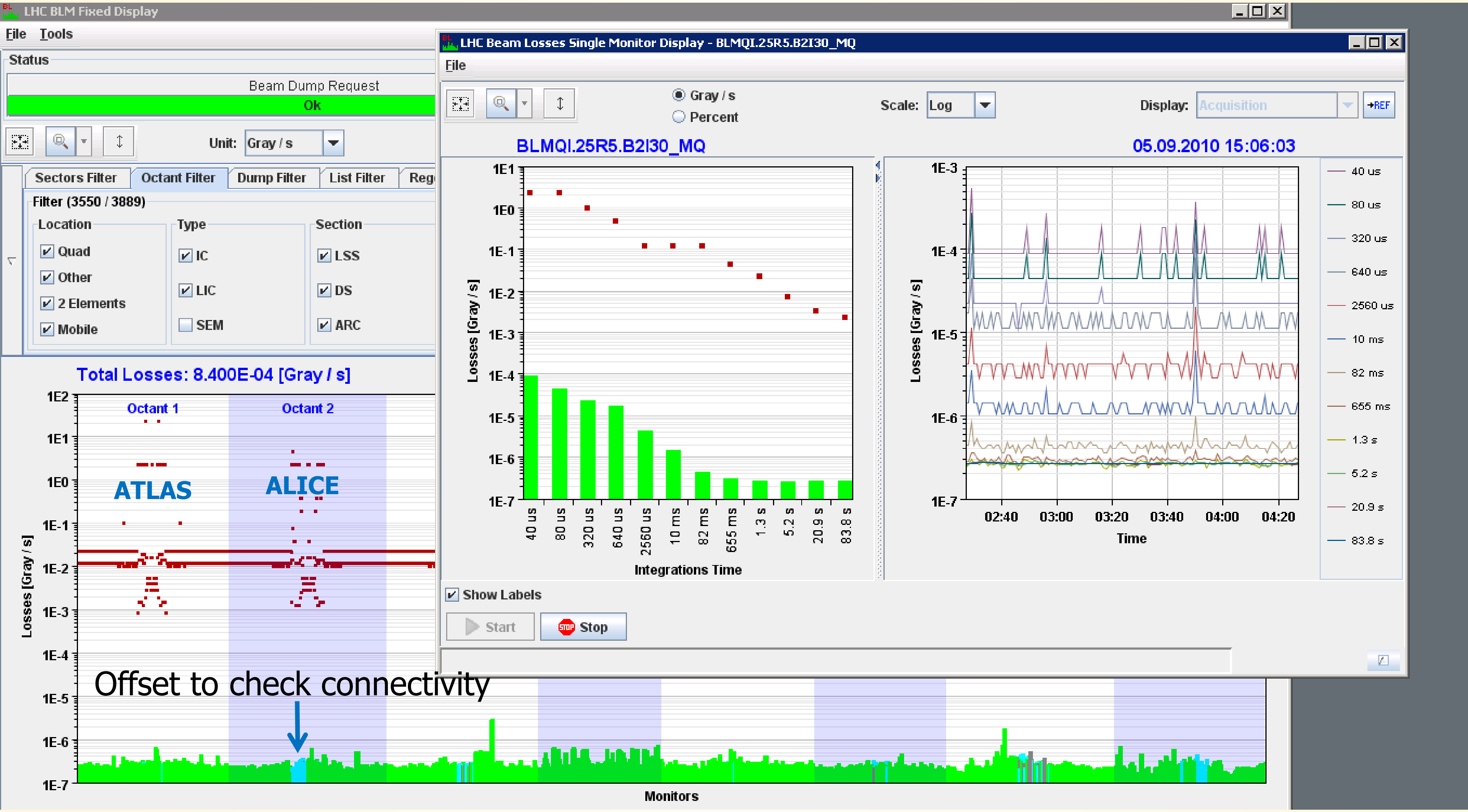


Specifications

- Time resolution ½ turn, 40 us
- Average calculation loss:
  - 12 values, 40 us to 83 s
- Max amplitude 23 Gy/s
- Min amplitude
  - 1E-4 Gy/s @ 40 us
  - 3E-7 Gy/s @ 1.3 s
- Dynamic
  - 2E5 @ 40 us
  - ~ 1E8 @ 1.3 s
- Damage level
  - 2000 Gy/s @ 1 ms
- All channels could be connected to the interlock system
- Thresholds
  - Loss duration dependent, 12 values
  - Energy dependent, 32 values
  - About 1.5 E6 thresholds

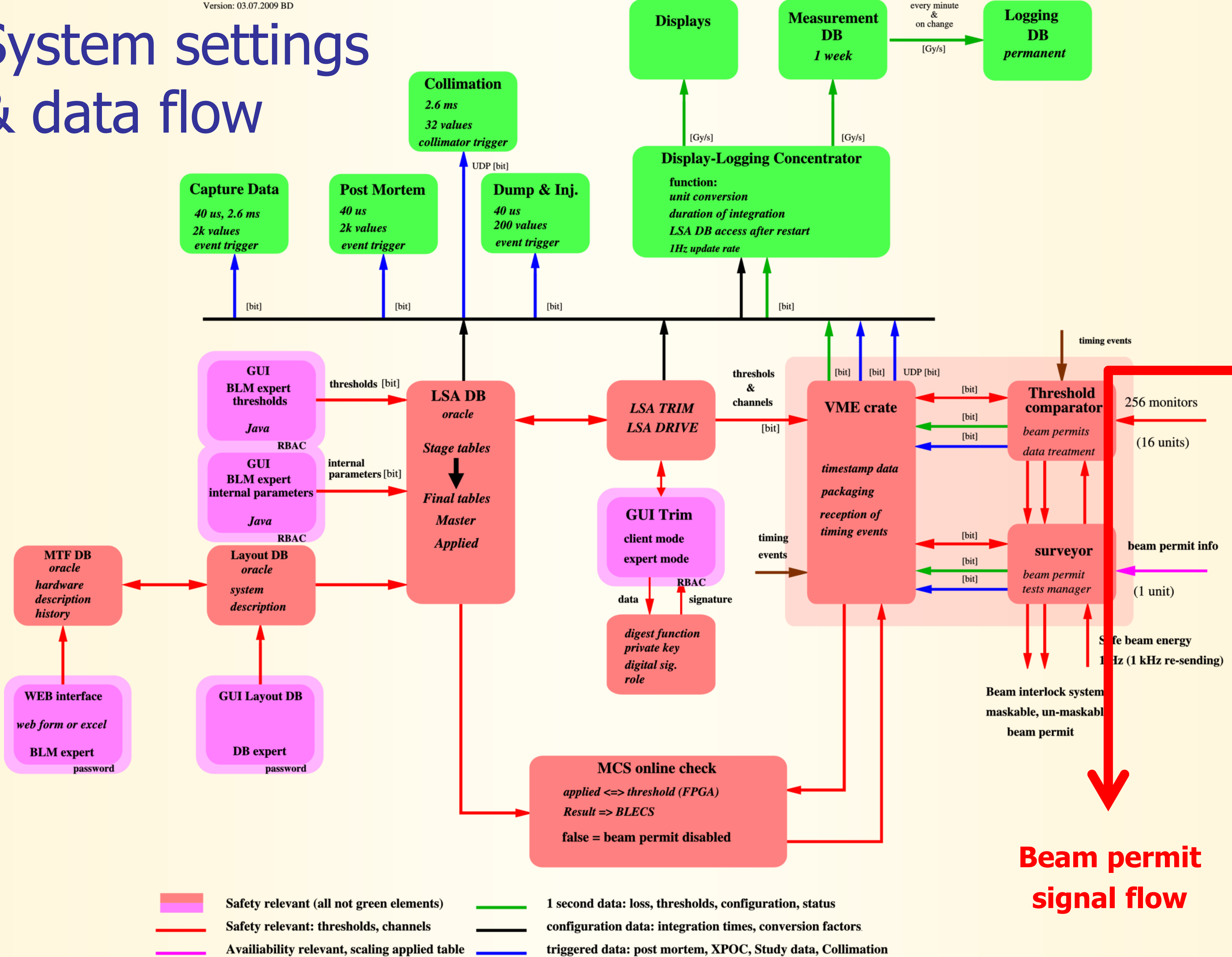
BLM Online Display

LHC @ 450 GeV



Version: 03.07.2009 BD

System settings & data flow



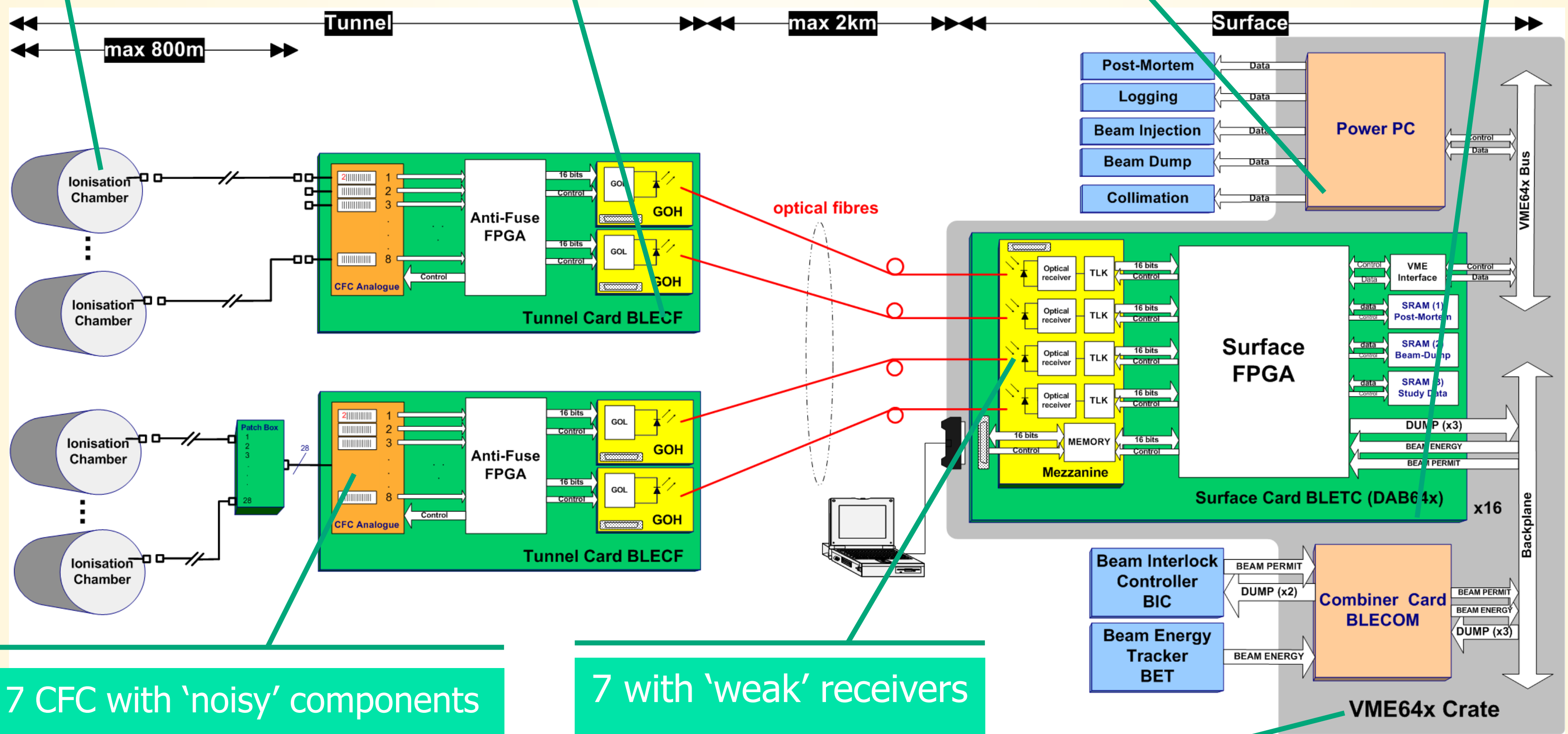
Overview of H/W Failures (since Feb. 2010)

9 IC with bad soldering (out of 3700)

9 GOH with low power
1 damaged connector
out of 1500

2 failed CPU RIO3 out of 25

2 with failed SRAM out of 350



7 CFC with 'noisy' components
2 cards with bad soldering
out of 359

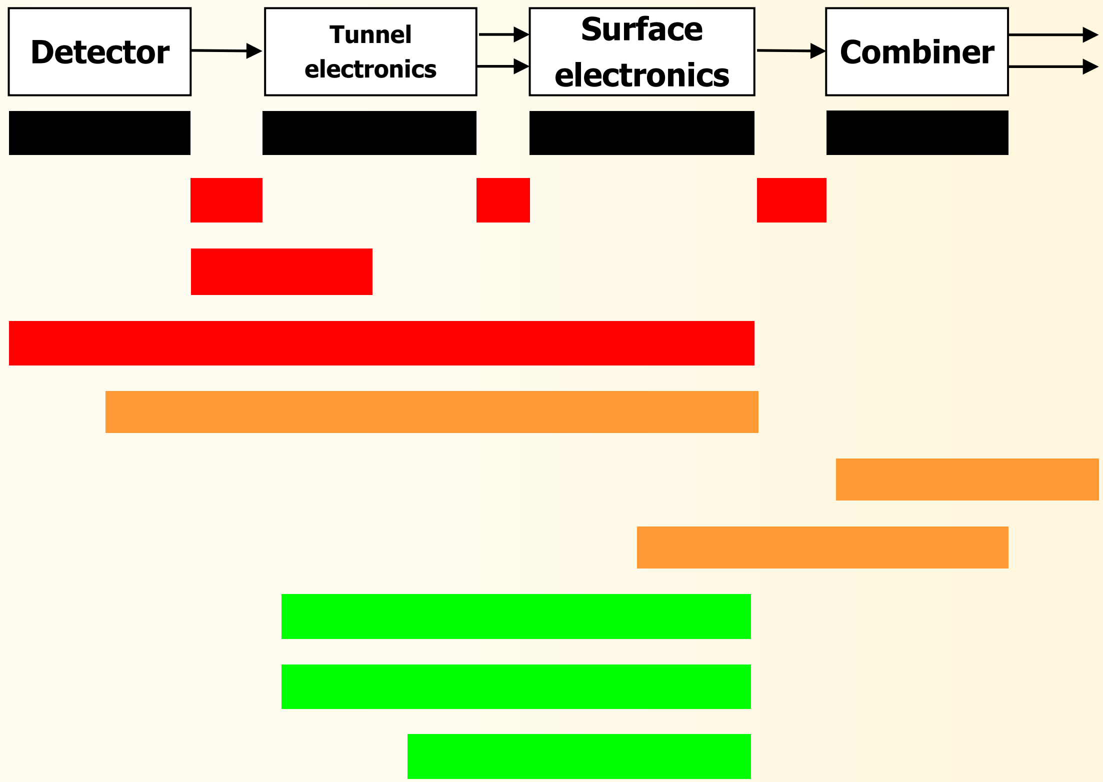
7 with 'weak' receivers out of 1500

1 VME Power Supply, out of 25

Number of failures regarded as manageable

Functional Tests Overview

PhD thesis G. Guaglio



Functional tests before installation

Barcode check

Current source test

Radioactive source test

HV modulation test

Beam inhibit lines tests

Threshold table data base comparison

Offset to check connectivity (10 pA test)

Double optical line comparison

System component identity check

Inspection frequency:

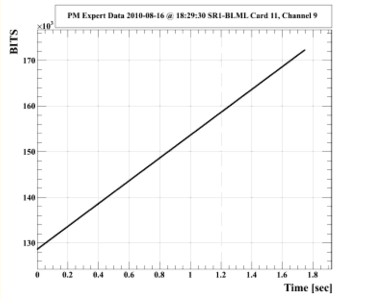
Reception   Installation and yearly maintenance   Before (each) fill   Parallel with beam

System Verification Tests
Surface Electronics Firmware Tests

Automatic on Vertical Slice Test system (before releasing new firmware)

Using front-end electronics emulator

- Lab tests
  - Exhaustive Threshold triggering tests [also in LHC done]
  - Optical Link Reception and Status tests
  - Linearity, impulse, and some predefined patterns of input signals check
- Beam tests
  - injected low intensity beams (pilot), debunched them and dumped with the operator switch.
  - closed one of the collimator jaw of a TCP at point 3 and injected 3 times pilot beam 1.

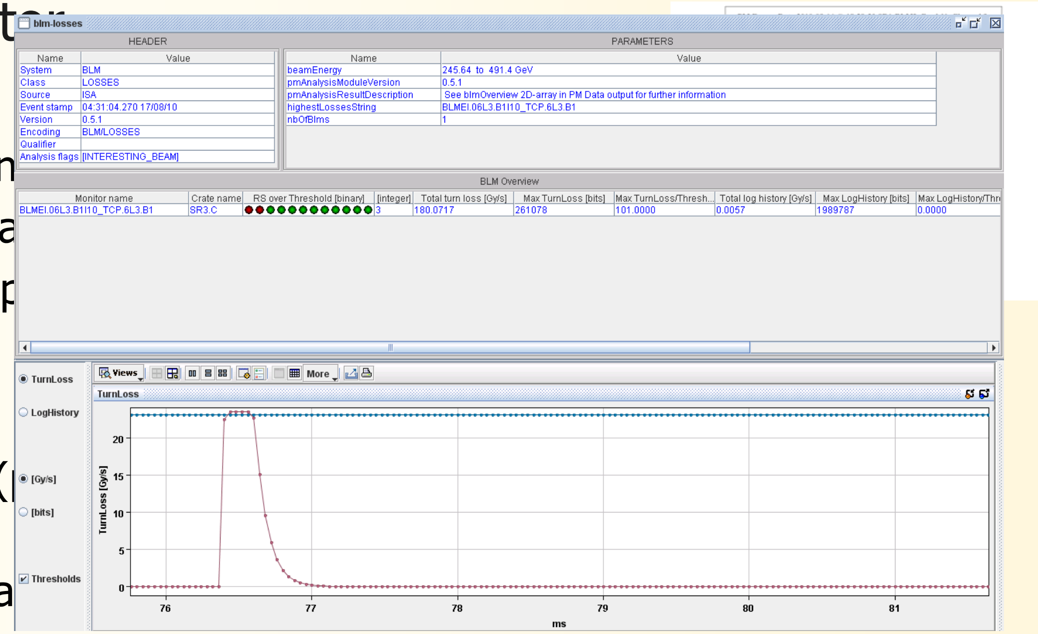


System Verification Tests
Surface Electronics Firmware Tests

Automatic on Vertical Slice Test system (before releasing new firmware)

Using front-end electronics emulator

Detector with filter, B. Holzer



times pilot beam 1.

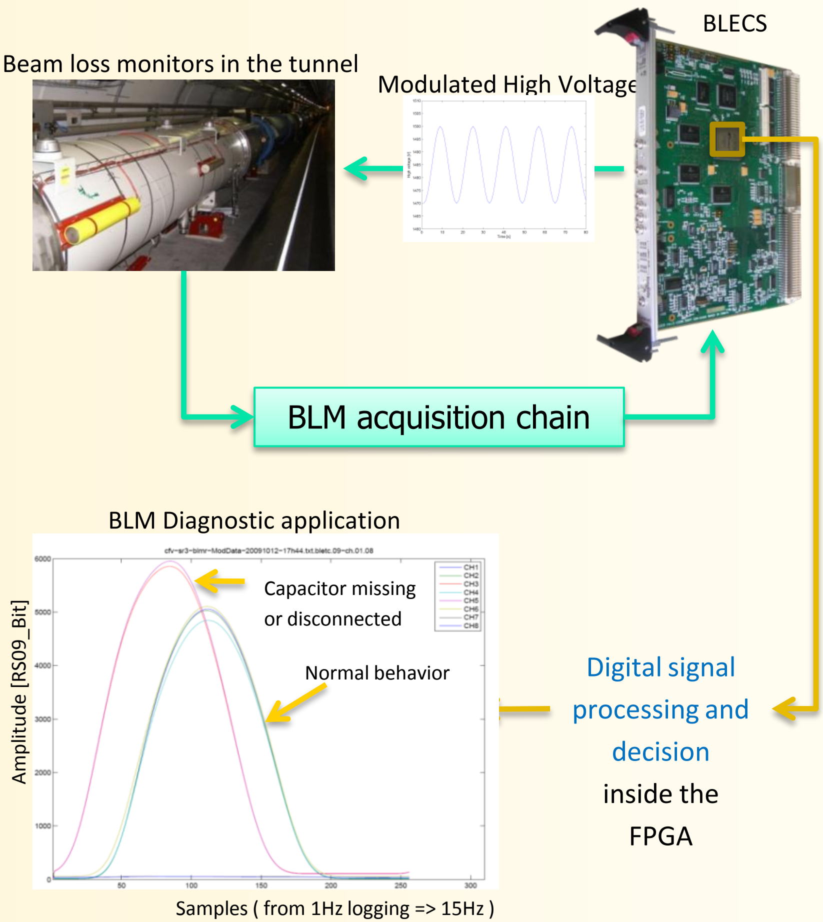
System latency (2009 – 02/2010)

Analysed several Beam Dumps in detail.

Difference in time between the bunch at injection kicker magnet and the break of the beam permit loop (by the BLMS) recorded at the BIC was always between **100** and **130 μs**.

- Time of flight:
  - MKI => monitor = **10 μs**
  - monitor => acq. electronics (0.5 km cable) = **3 μs**
  - Acq. => processing electronics (1 km fibre) = **3 μs**
- Detection of change in frequency in the daisy-chain = **5 μs**
- Integration in the acquisition electronics = 40 μs.
- Decision at the BLETC (for fast losses) is taken every 40 μs.
- Processing of data to decide < 1 μs.

System Tests == Sanity Checks



- Decision of pass or fail in surface electronics FPGA (combiner)
- Every 24 h required, (beam permit inhibit if time limit exceeded
- Tests
  - Comparison between data base and backend electronics (MCS)
  - Internal beam permit line test (VME crate)
  - Connectivity check (modulation of chamber HV voltage supply amplitude an phase limit checks
  - Duration of test: about 7 minutes

Post Mortem Data (some examples)

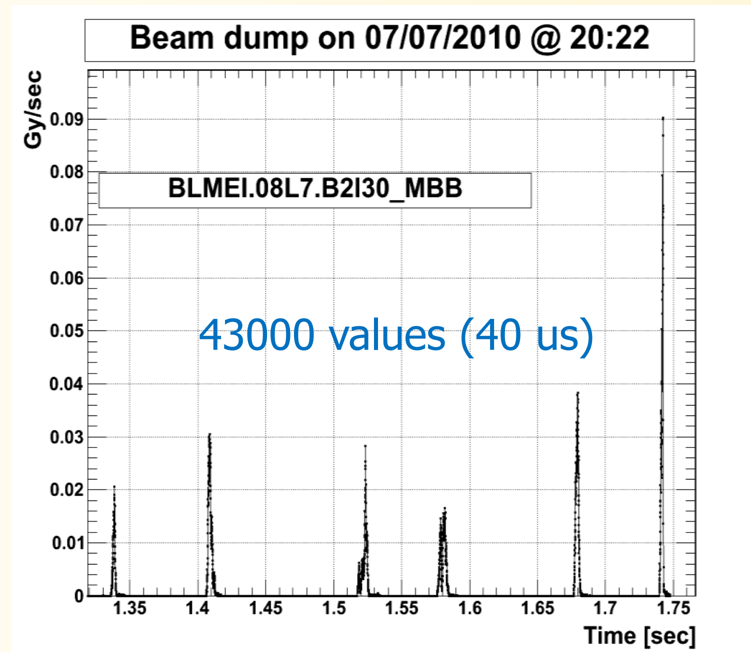
Loss in a bending magnet

PM application: BLM data of 0.082 sec
online available

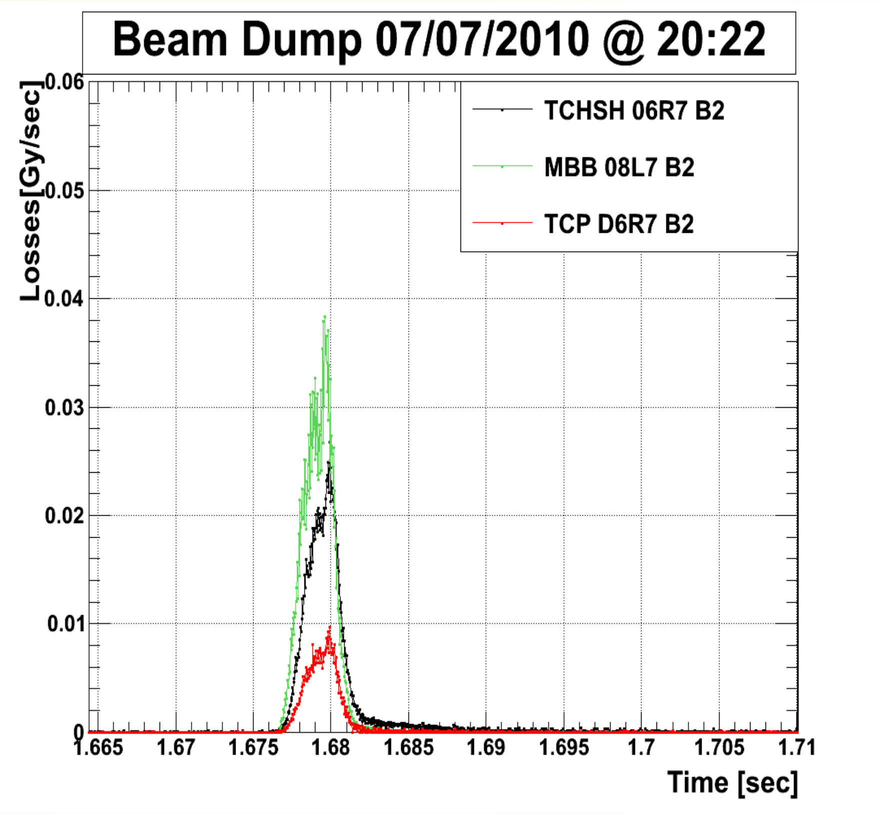
Longer PM buffer: BLM data of 1.72 sec
offline available

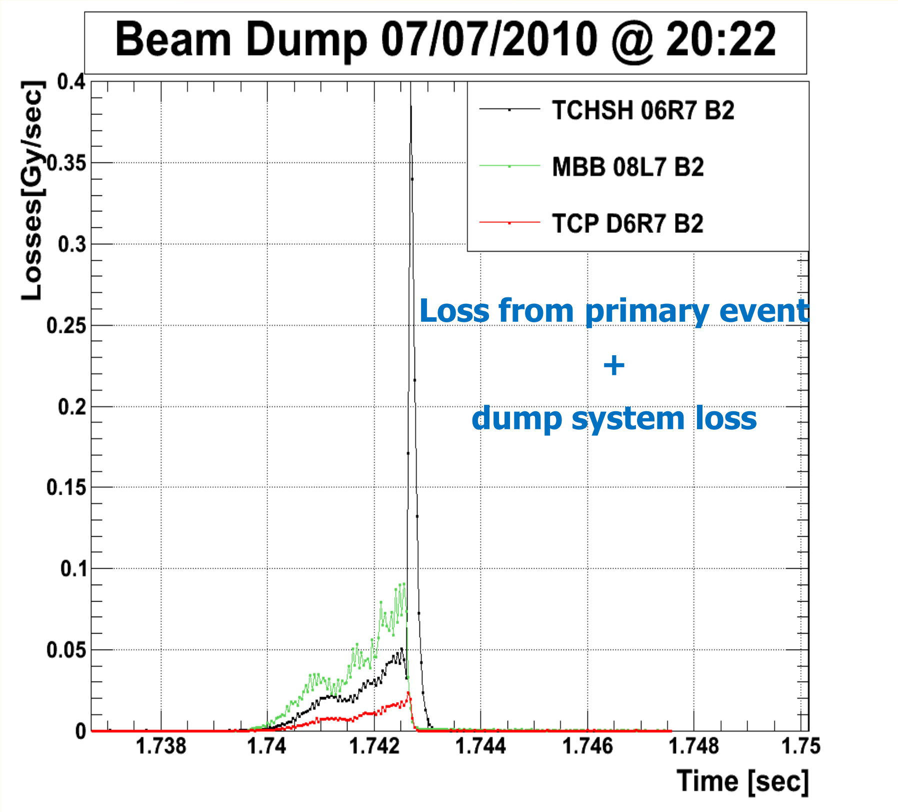
Monitors →

Time →

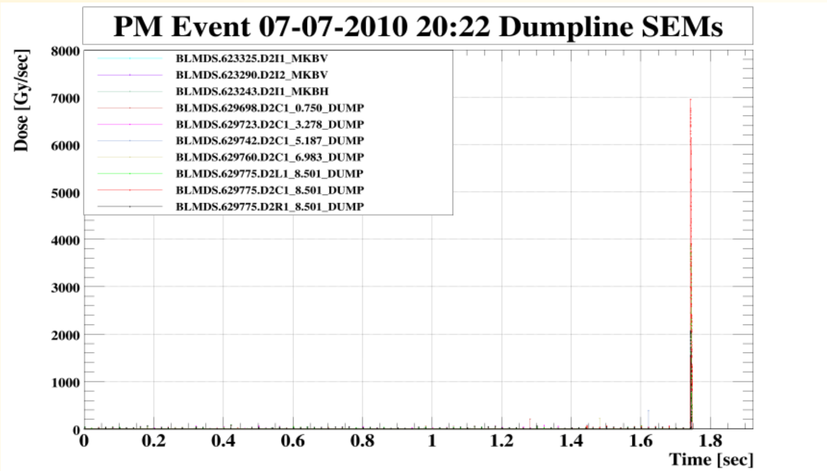


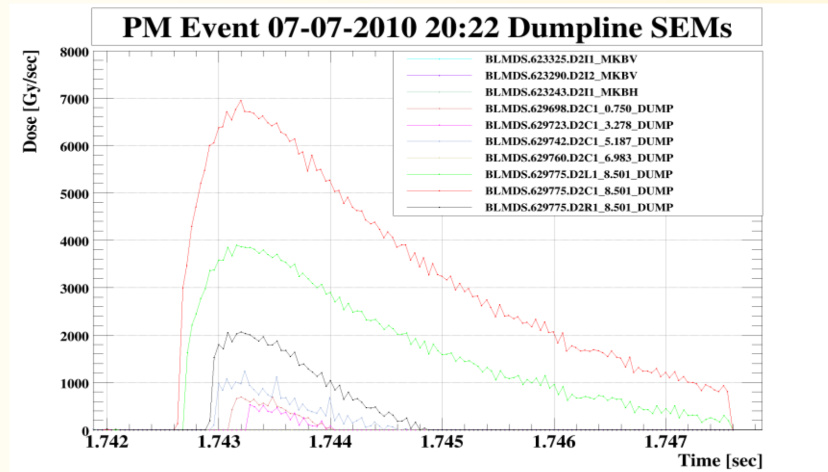
Post Mortem Data (some examples), Zoom

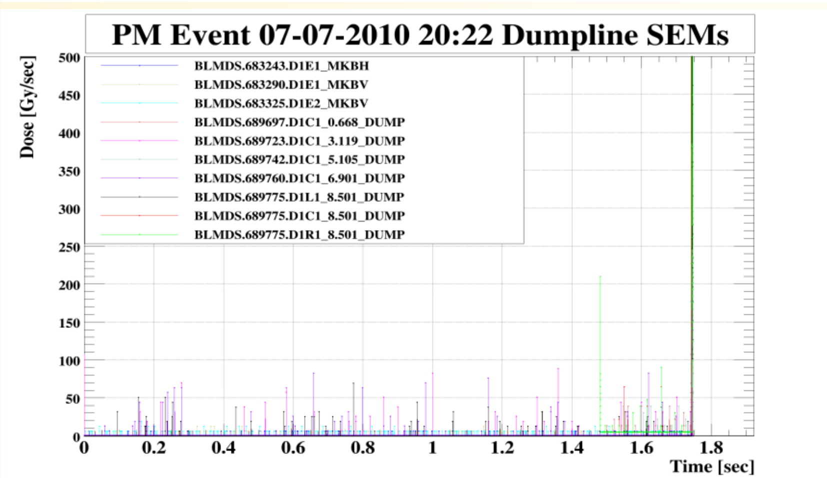


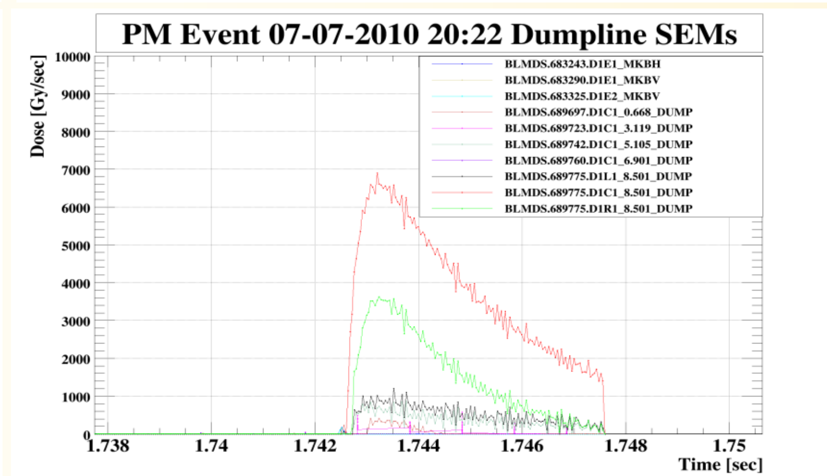


Post Mortem Losses in Dump Line and Dump, Secondary Emmission Monitors



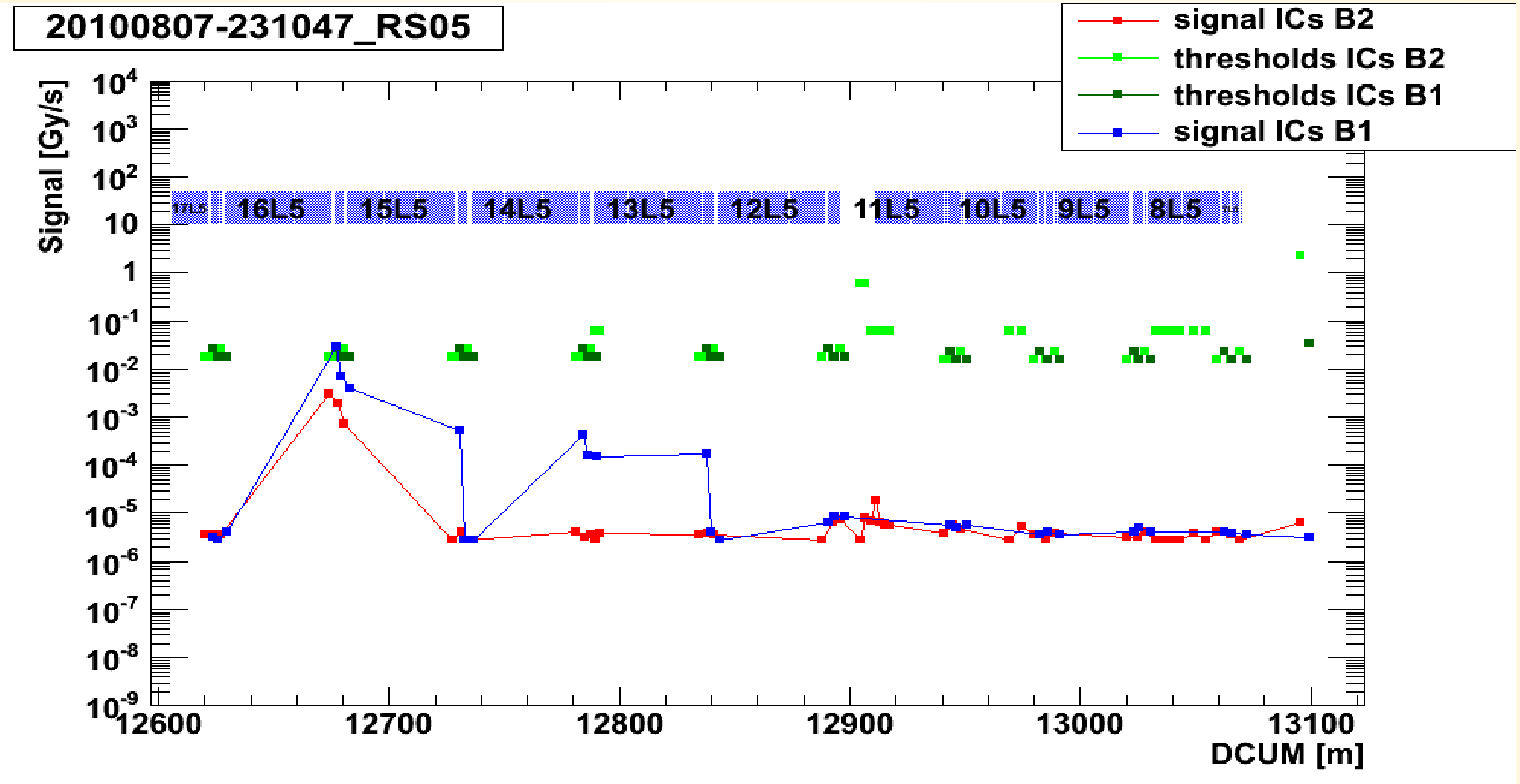






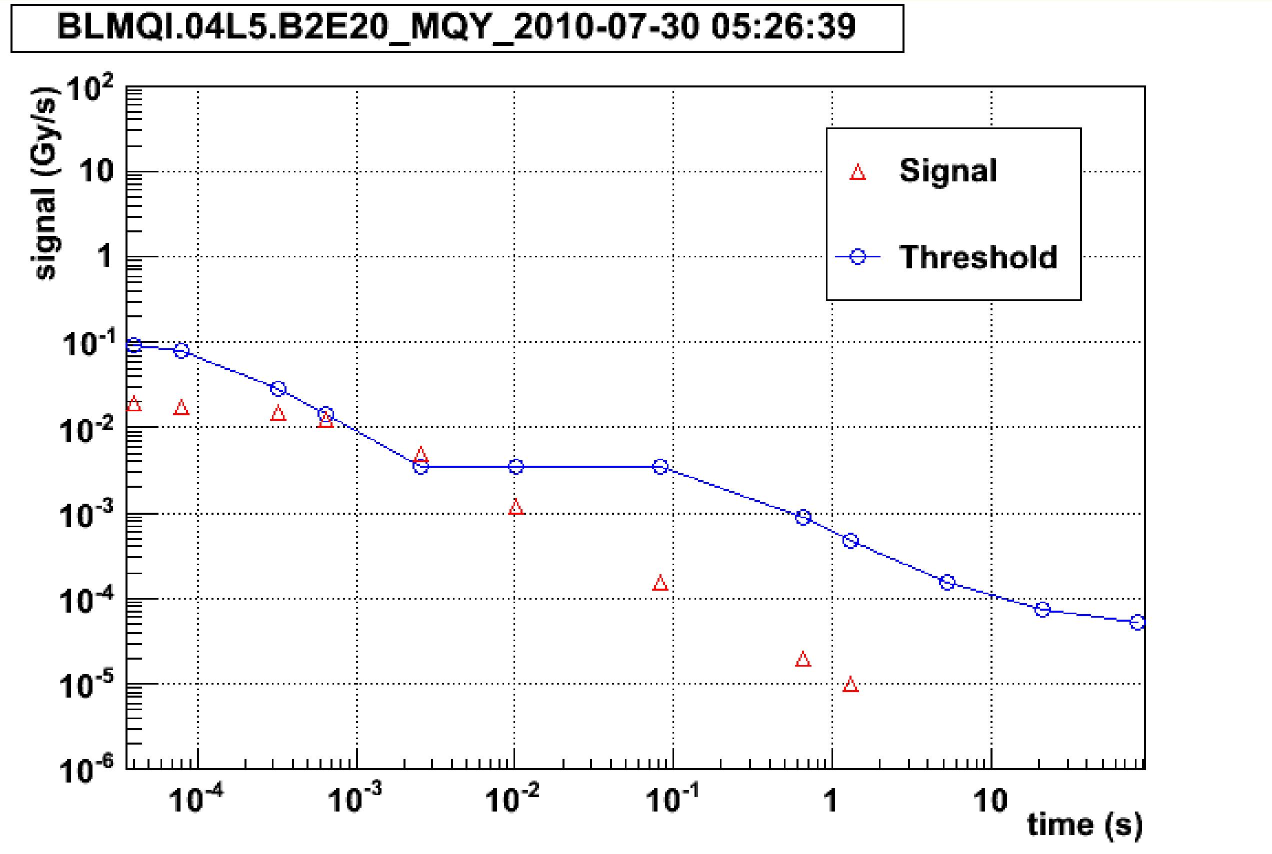
Logging Data Base Data (fast event)

- Beam 1 loss (from left to right)
- Loss monitor of B1 at MQ 15 over threshold
- Beam 2 monitors measure about 5 times lower loss
- Shown average value over 2.5 ms (maximum in 1.3 s)



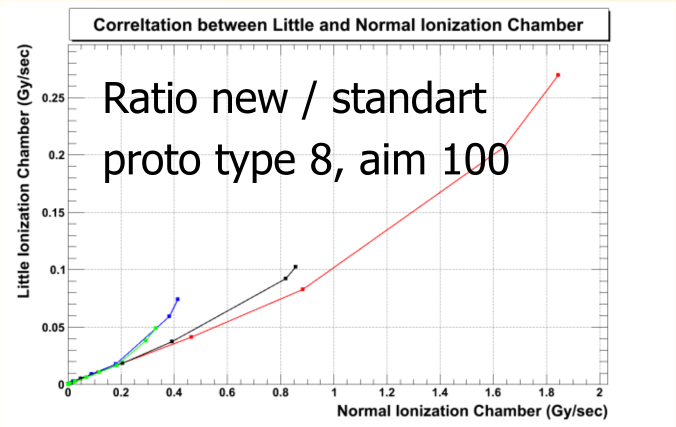
Threshold and Loss Data versus Averaging Duration

- Online Display and Logging data base Storage
- Data reduction in surface electronics
  - Averages from 40 us to 660 ms == every 1.3 second max value in last 1.3 s
  - Average 1.3 s directly stored
  - Average 83 s every minute
  - Logging 40 GByte / day
- Reconstruction of duration of events possible by max value shapes (identification of kink)

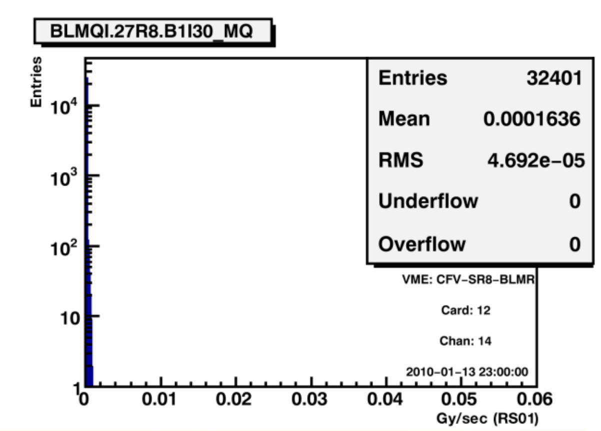


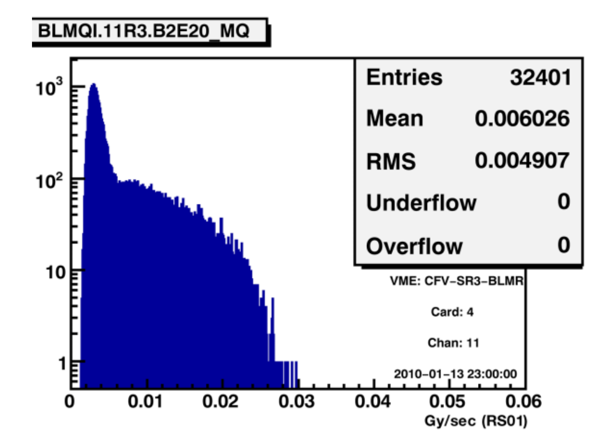
BLM System Upgrades

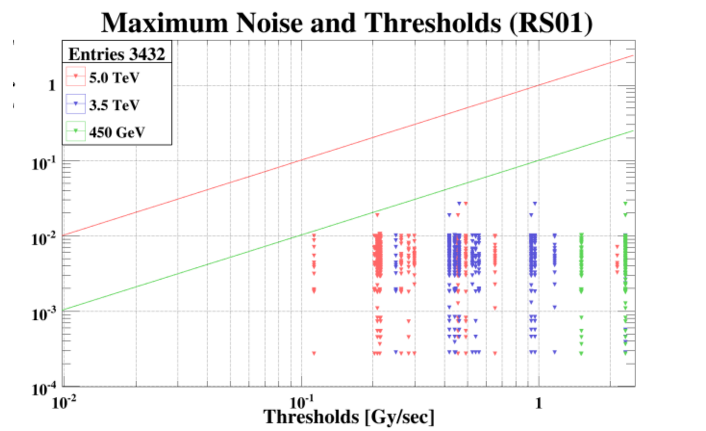
- Online program predicting loss characteristics and likely loss origin, PhD
- Long cable issue in IP3
- Development of an Detector with intermediate measurement range
- New cables for noise channels (7 TeV operation)



Data set: 8.1.2010-15.1.2010





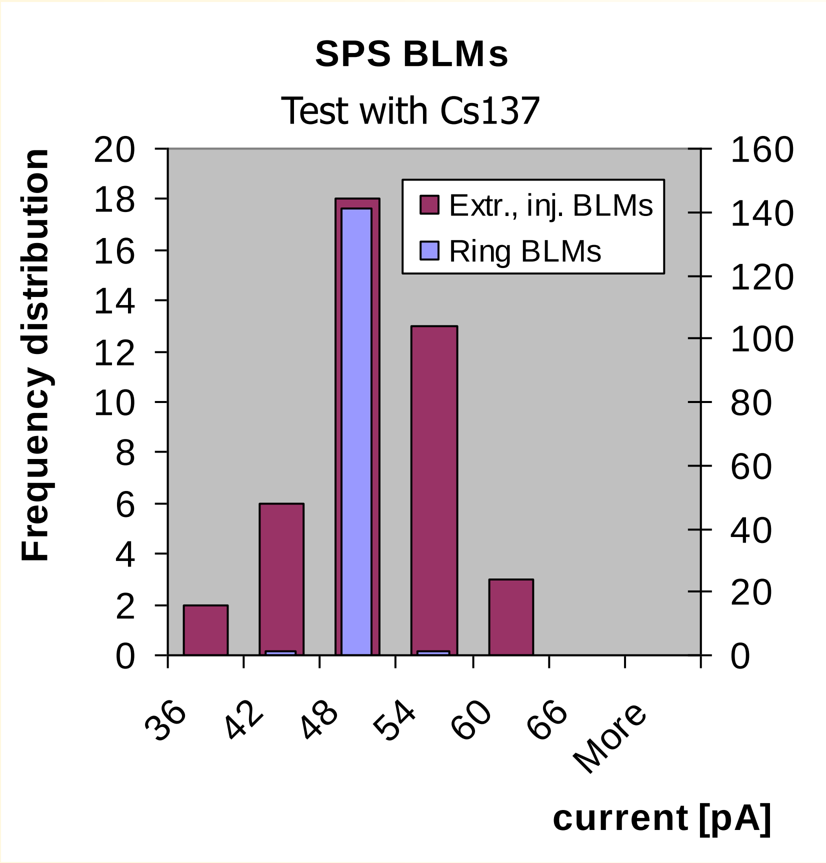


Summary

- No evidence has been found that a single beam loss event has been missed
  - The initial threshold settings have to be sufficiently conservative in order not to damage the LHC magnets. During the initial runs of the LHC, they must then be iteratively adjusted. (Audit report 2008)
- The hardware failures never caused a degradation of the reliability of the system
- False dumps
  - The number of hardware failures are as expected (reliability and safety study, PhD. G. Guaglio)
  - No noise events

Spare Slides

Gain Variation of SPS Chambers



Total received dose:

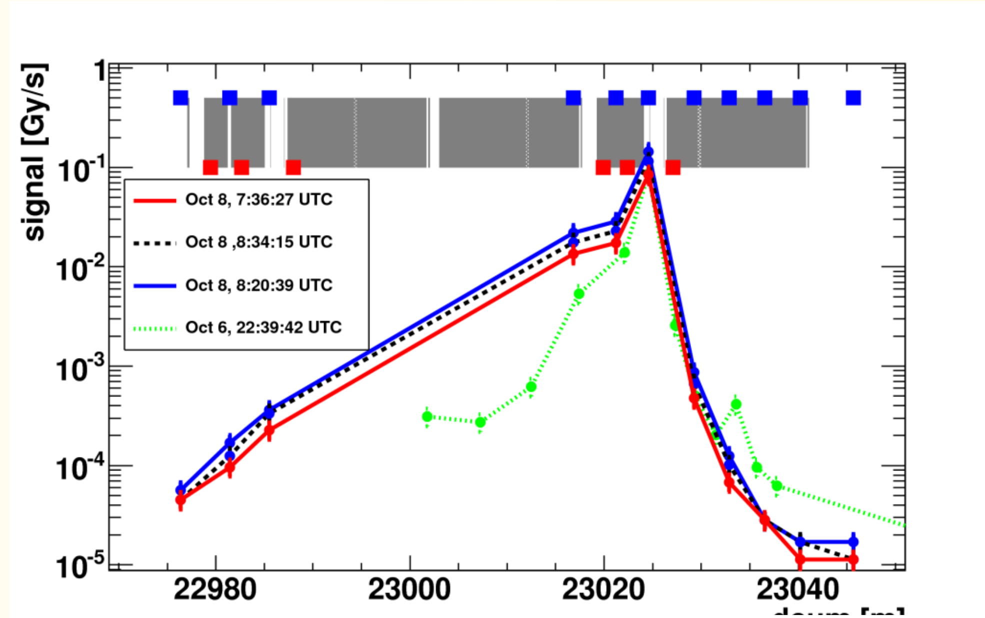
ring 0.1 to 1 kGy/year

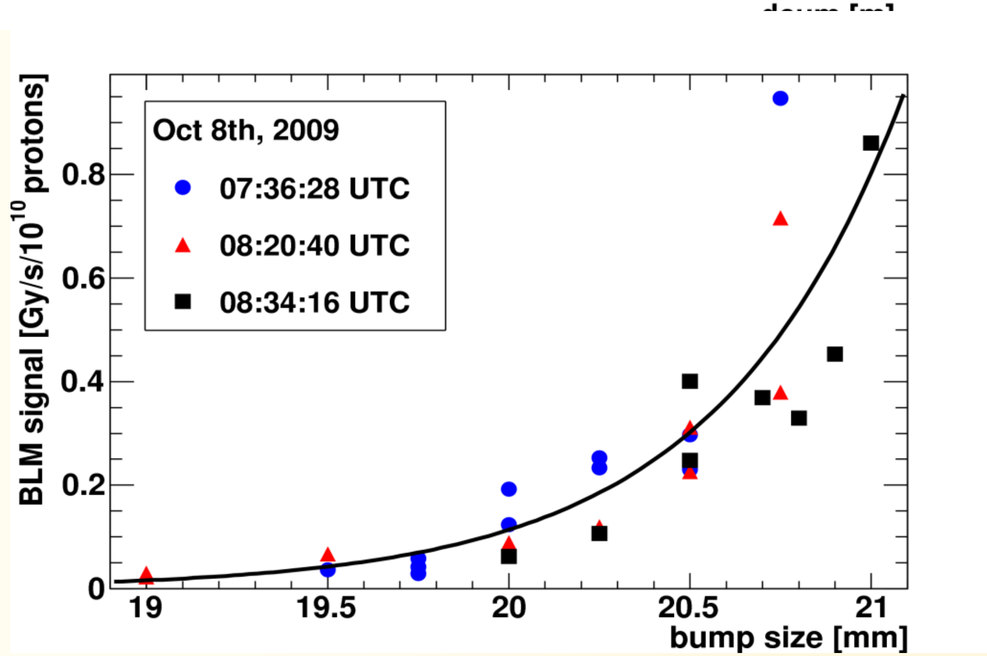
extr 0.1 to 10 MGy/year

- 30 years of operation
- Measurements done with installed electronic
- Relative accuracy
  - $\Delta\sigma/\sigma$ < 0.01 (for ring BLMs)
  - $\Delta\sigma/\sigma$ < 0.05 (for Extr., inj. BLMs)
- Gain variation only observed in high radiation areas
- Consequences for LHC:
  - No gain variation expected in the straight section and ARC of LHC
  - Variation of gain in collimation possible for ionisation chambers

Thresholds Test with 3 corrector orbit bump measurements

- 3 corrector bump already used during threshold tests
- Top: BLM signal at trigger level vs dcum
- Bottom: BLM signal vs bump size
- Beam position reproducibility is estimated to 150 μm peak to peak, max BLM signal variation 50 %





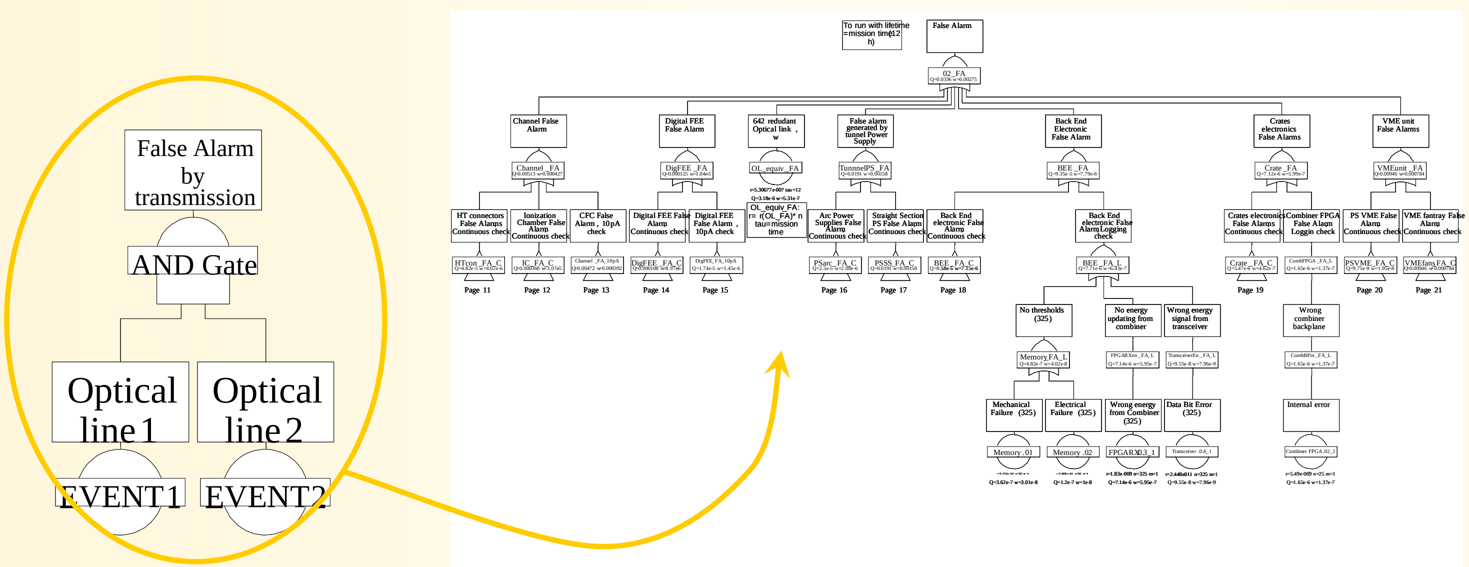
Fault Tree Analysis

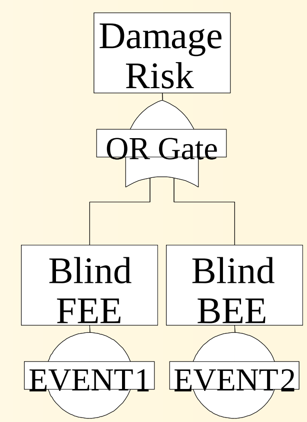
- Almost 160 Failure Modes have been defined for the BLMS using the FMD-97 standard.

Three Ends Effects:

1. Damage Risk: probability not to be ready in case of dangerous loss.
2. False Alarm: probability to generate a false alarm.
3. Warning: probability to generate a maintenance request following a failure of a redundant component.

- **The probability to have an Failure Mode A, Pr{A}, is calculated per each Failure Modes of the FMECA, given the hazard rate, the repair rate and the inspection period .**





Fault Trees Results

- The probabilities to fail (unavailability) for the BLMS have been calculated.
- Per each End Effects, the major contributors to such probabilities have been pointed out too.

	Consequences per year	Weakest components	Notes
Damage Risk	$5 \cdot 10^{-4}$ (100 dangerous losses)	Detector (88%) Analogue electronics (11%)	Detector likely overestimated (60% CL of no failure after 1.5 10^6 h).
False Alarm	13 ± 4	Tunnel power supplies (57%) VME fans (28%)	Tunnel power supplies likely underestimated (see sensitivity example).
Warning	35 ± 6	Optical line (98%) VME PS (1%)	LASER hazard rate likely overestimated by MIL.