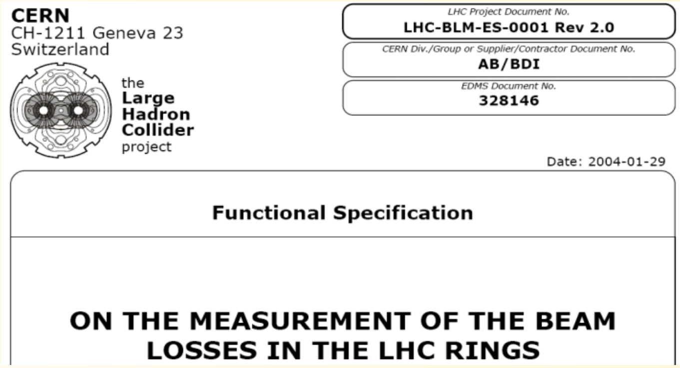
Beam Loss Monitor System Overview & Reliability

Content

Beam Loss Monitor Specification


CERN
CH-1211 Geneva 23
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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

Loss Levels and Required Accuracy

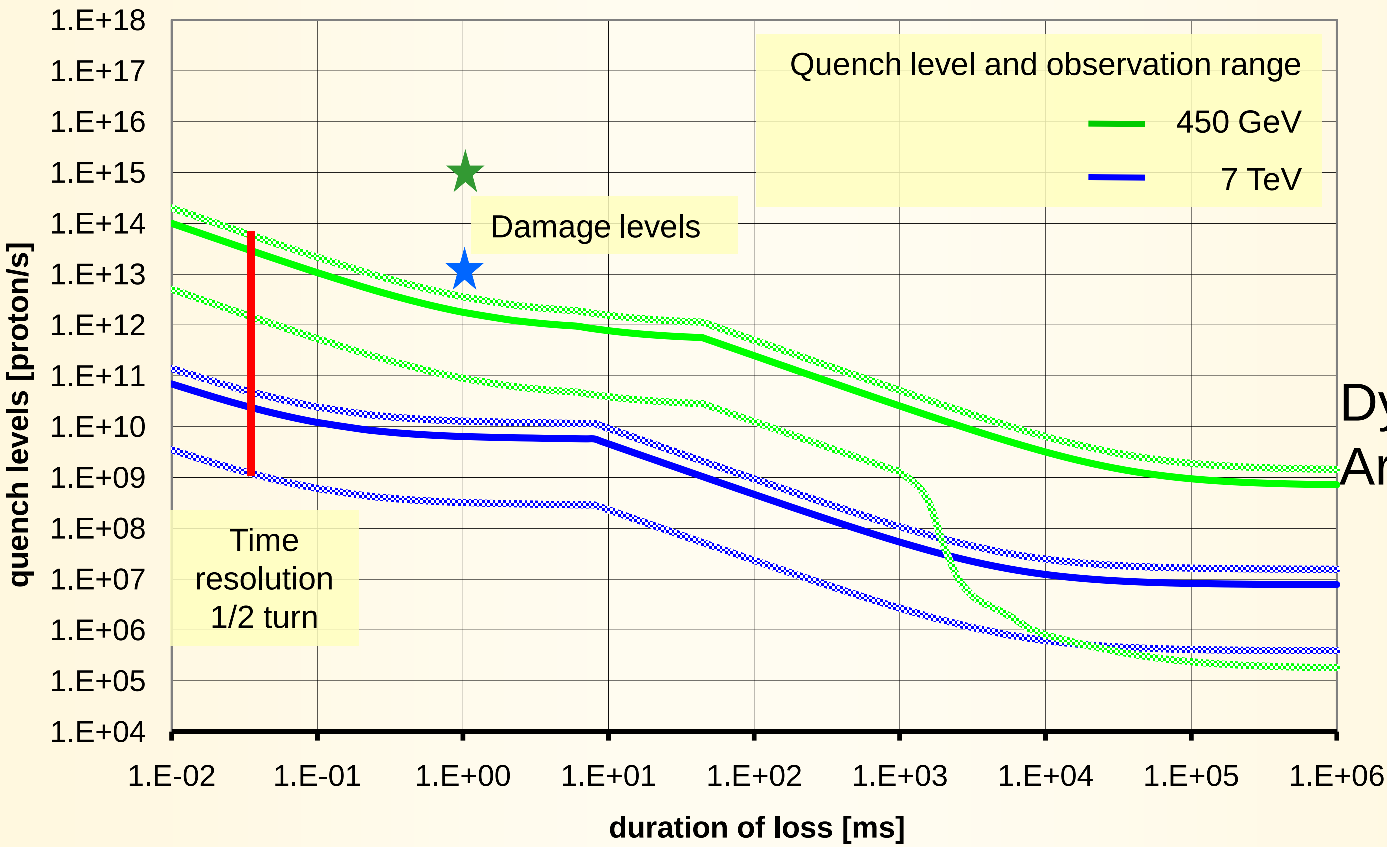
Relative loss levels		
	450 GeV	7 TeV
Damage to components	320/5	1000/25
Quench level	1	1
Beam dump threshold for quench prevention	0.3	0.3/0.4
Warning	0.1	0.1/0.25

Absolute precision (calibration)	< factor 2 initial < factor 5)
Relative precision for quench prevention	< 25%

Functional specification:
https://edms.cern.ch/file/328146/2.0/LHC-BLM-ES-0001-20-00.pdf

Quench and Damage Levels

- Detection of shower particles outside the cryostat or near the collimators to determine the coil temperature increase due to particle losses



Dynamic Arc: 10^8

BLM Aims

1. Monitor the 27 km of accelerator to detect dangerous losses.
2. Trigger beam extraction requests to avoid damages of the superconductive magnets and of other equipments.

The BLMS must be :

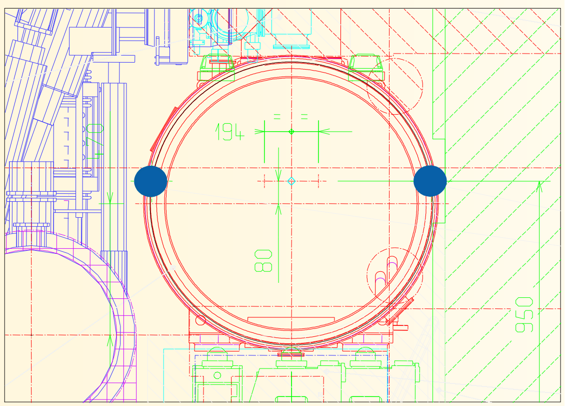
- 1. SAFE: in case of dangerous loss, it has to inhibit the beam permit. If it fails, there will be ~30 days of downtime.

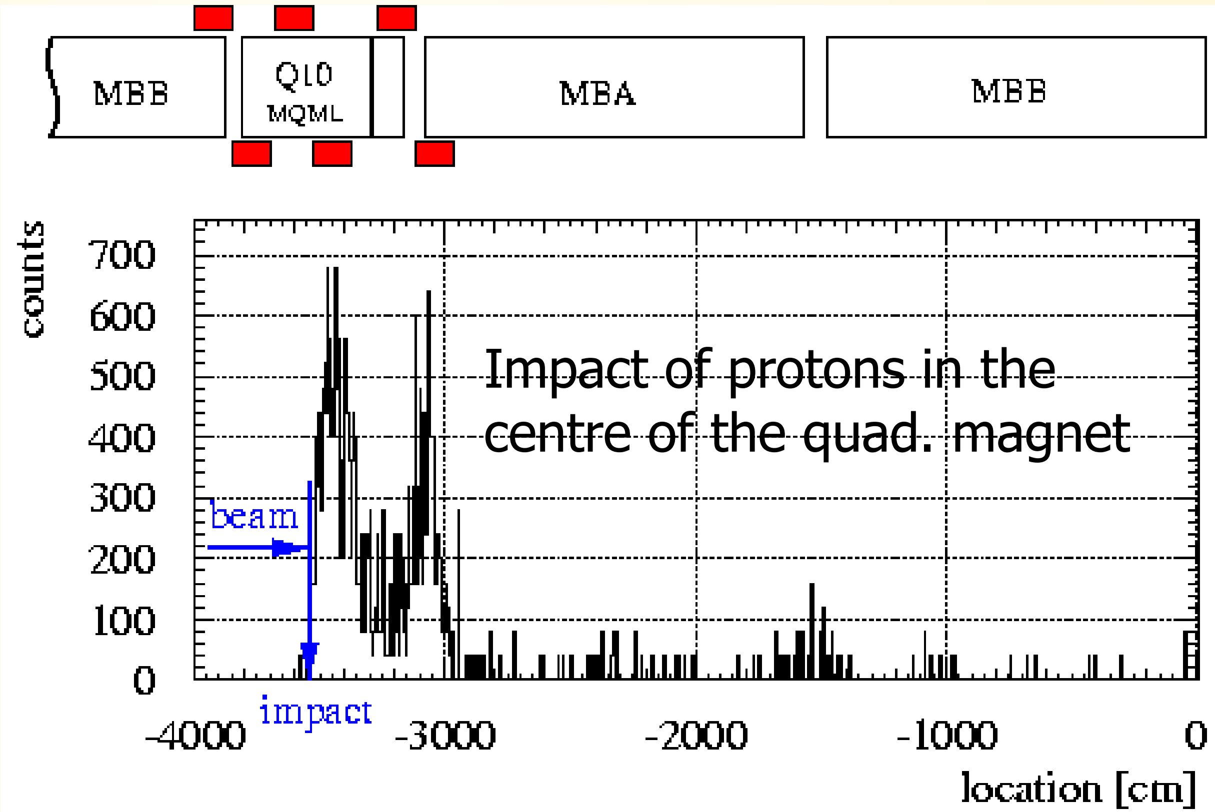
- 2. FUNCTIONAL: in case of NO dangerous loss, it has NOT to inhibit the beam. If it fails, it generates a false alarm and 3 h will be lost to recover the previous situation. Such an event will decrease the LHC efficiency.

Location of Detectors

1. Distinguish between beams
2. Observe losses due to magnet misalignments
3. Observe losses due to orbit changes and emittance growth

Every dangerous loss could be seen just by one detector.





BLM Signal Chain

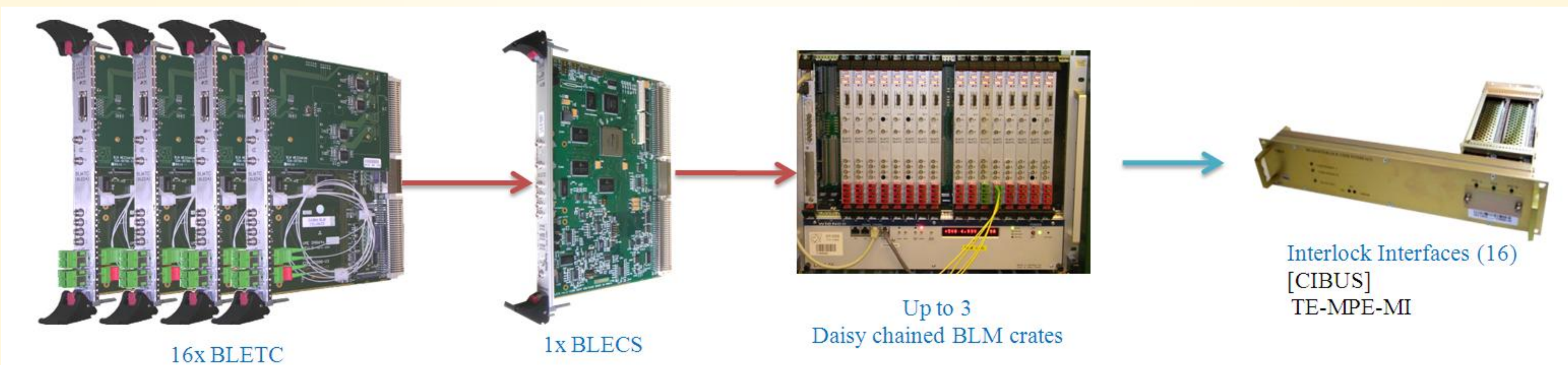
Tunnel

Beam Loss Monitors (4000)

Acquisition Cards (700)

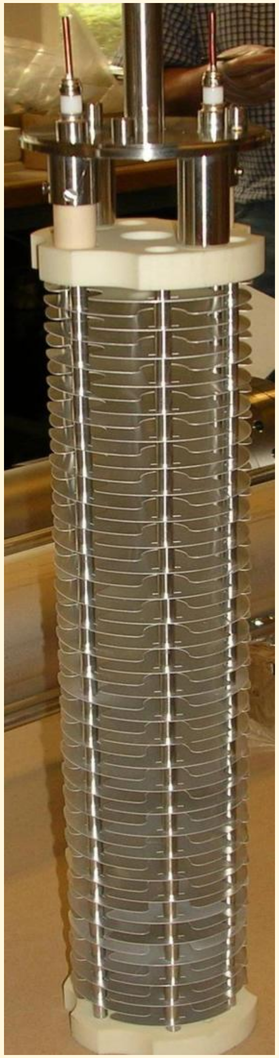
Optical fibres

Surface



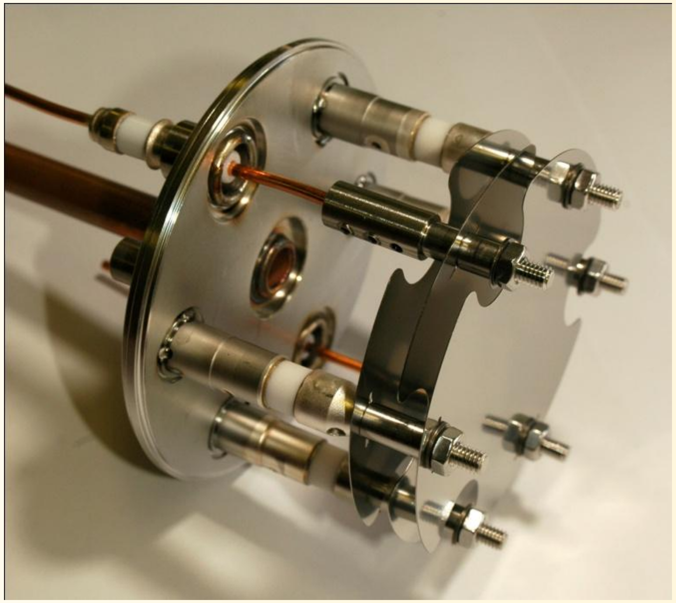
around the LHC ring

Ionisation Chamber and Secondary Emission Monitor



- Stainless steal cylinder
- Parallel electrodes distance 0.5 cm
- Diameter 8.9 cm
- Voltage 1.5 kV
- Low pass filter at the HV input

Signal Ratio: IC/SEM = 60000



IC:

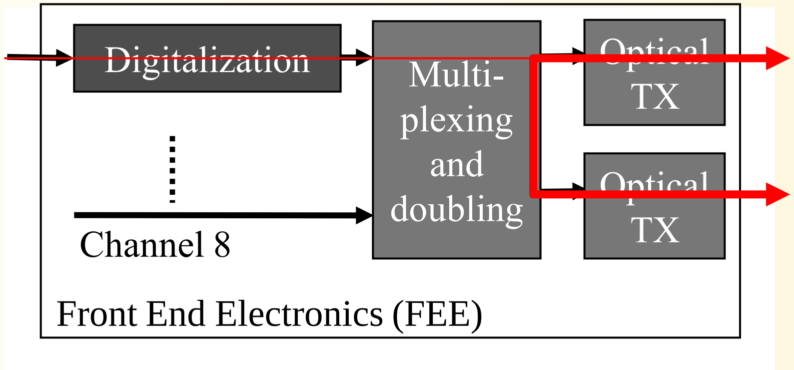
- Al electrodes
- Length 60 cm
- Ion collection time 85 us
- N_2 gas filling at 1.1 bar
- Sensitive volume 1.5 l

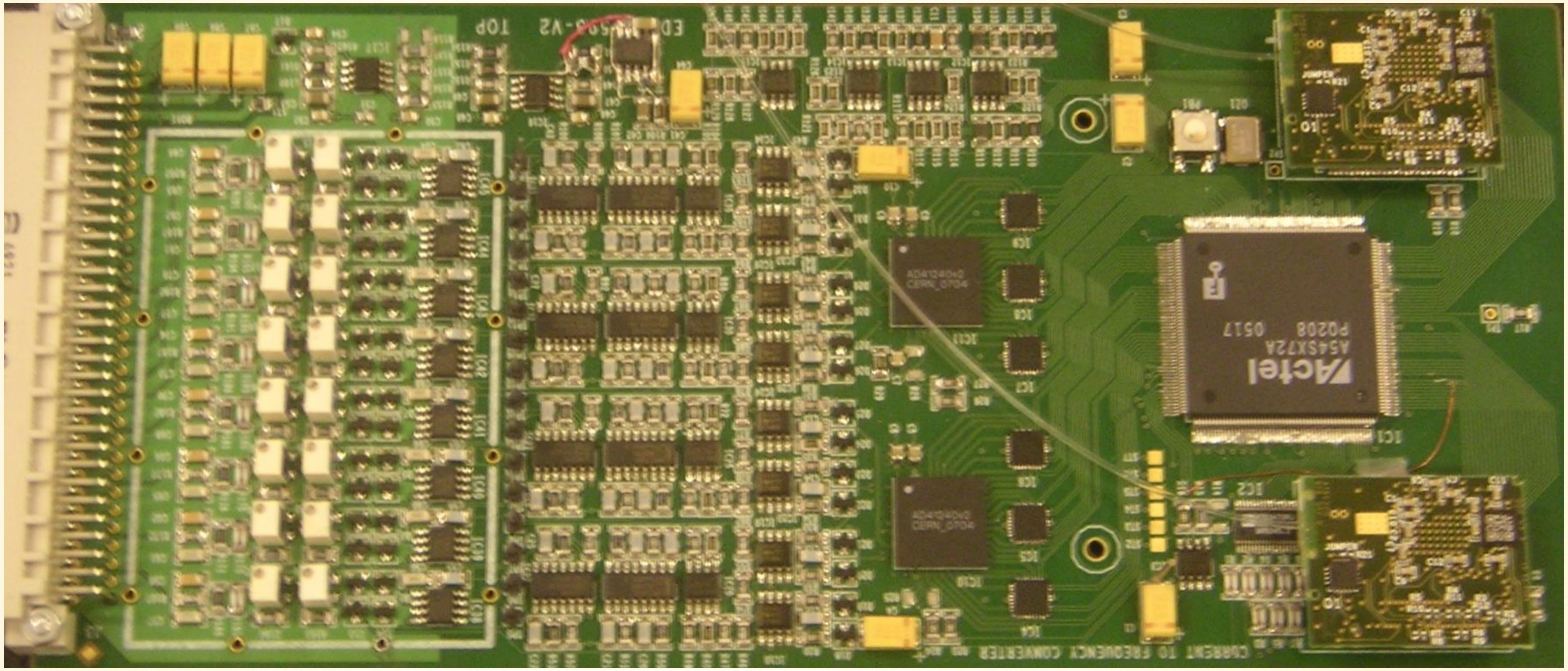
SEM:

- Ti electrodes
- Components UHV compatible
- Steel vacuum fired
- Detector contains 170 cm2 of NEG St707 to keep the vacuum < 10-4 mbar during 20 years

Front End Electronics (CFC)

- **Transformation of the current signal in a digital data.**
- **Multiplexing of 8 channels with redundant optical transmission.**
- **Electronics in an harsh environment (radiations).**

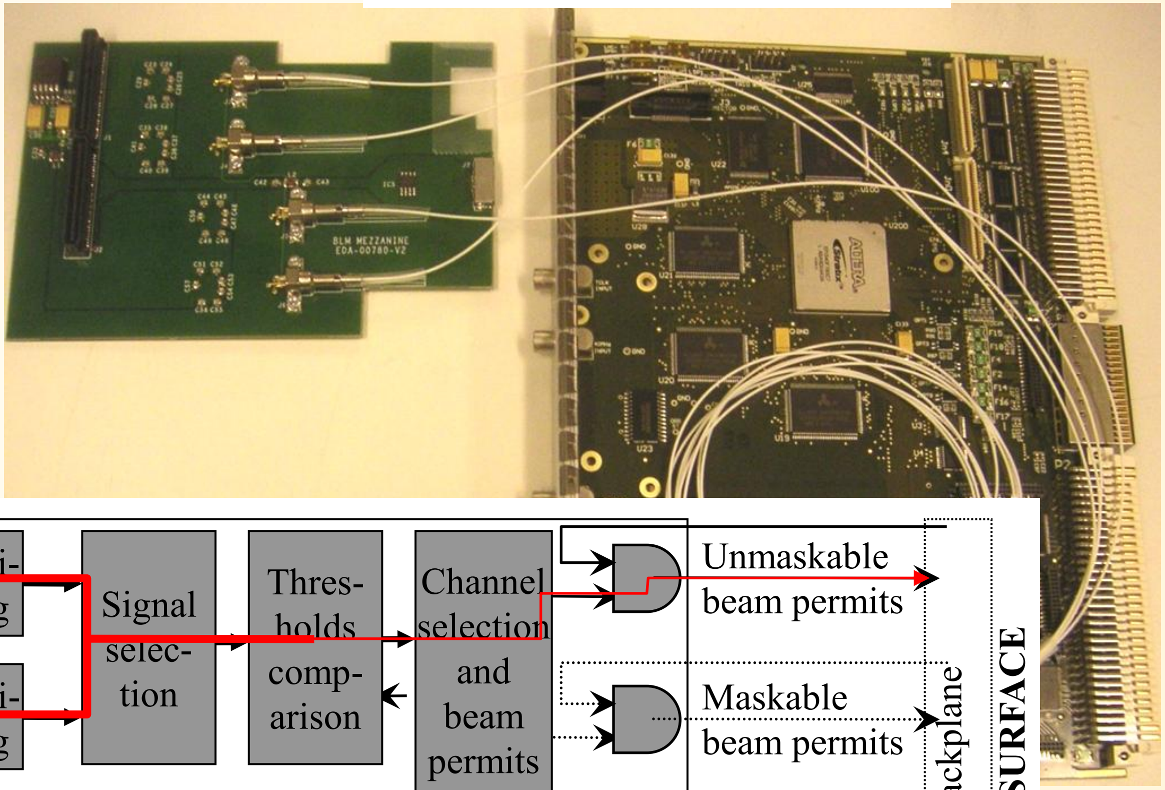


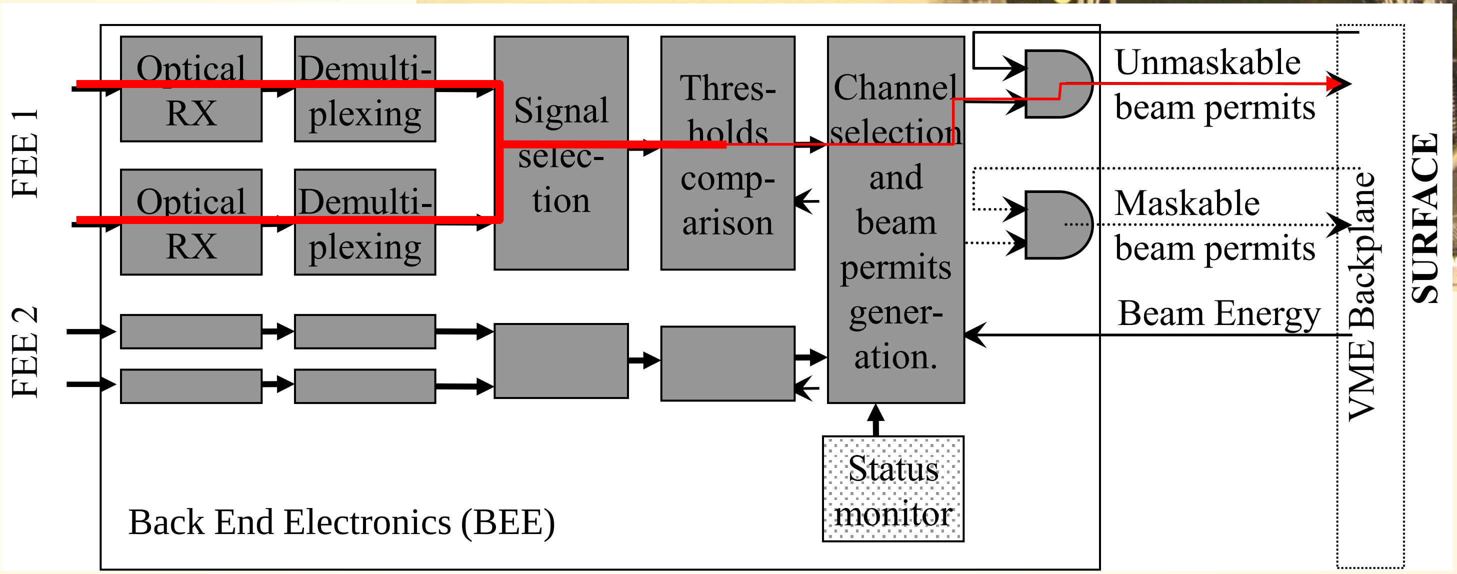


Back End Electronics (Threshold Comparator)

Christos Zamantzas

- Optical receivers in a mezzanine board.
- Data treatment in a Digital Acquisition Board. Energy input for the selection of the threshold levels.
- Beam permits connected to the backplane.

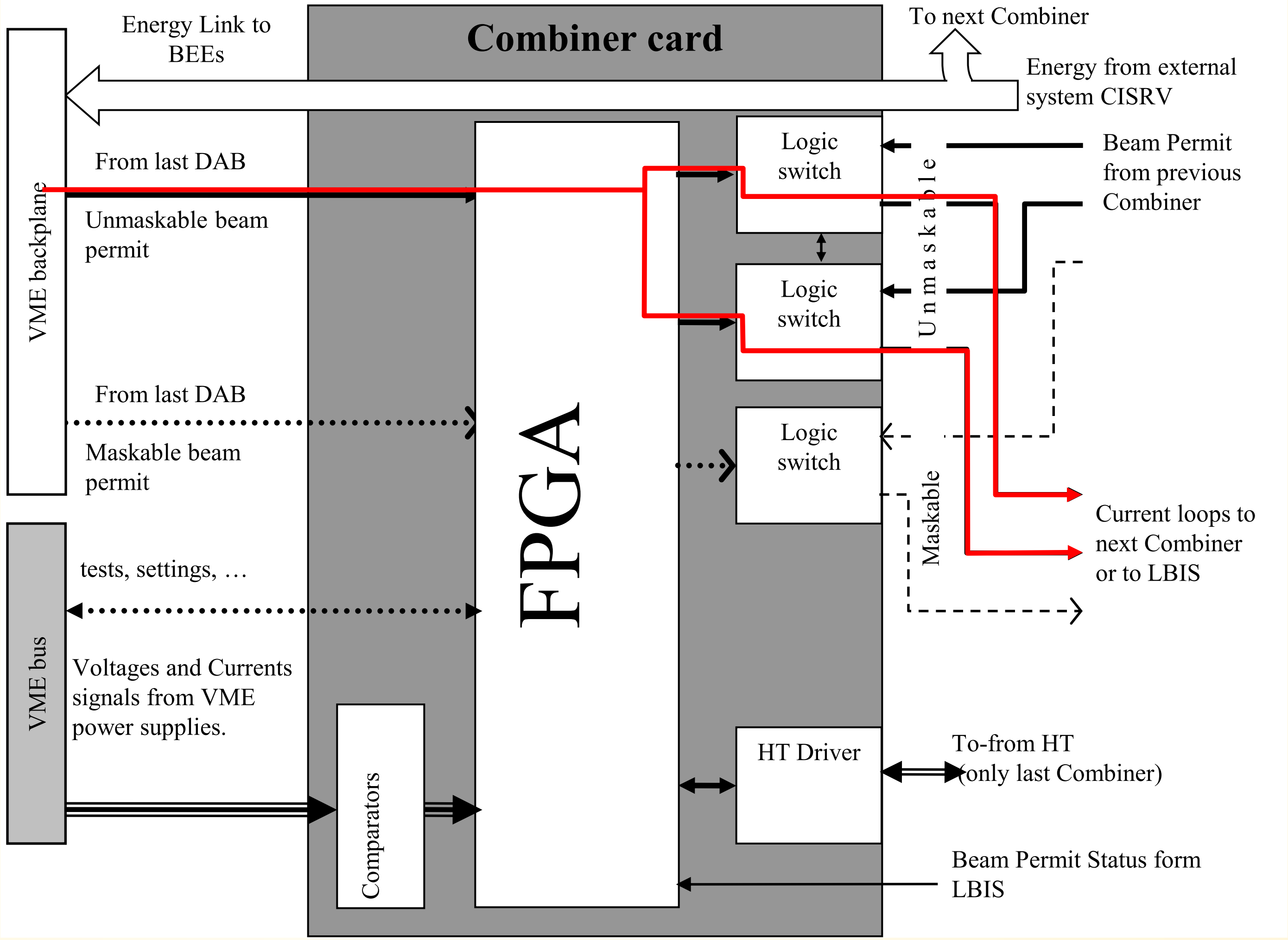




Combine & Survey (Combiner)

Jonathan Emery

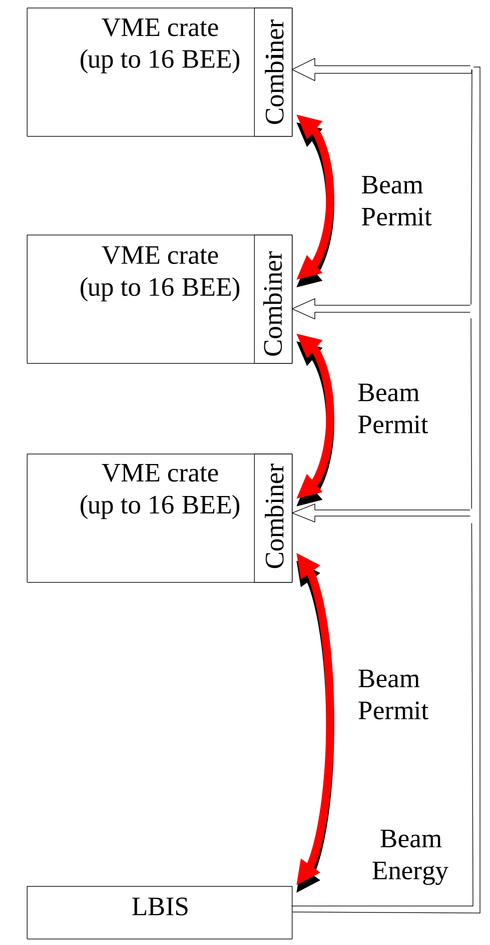
- Reception of the beam permits and forwarding them to the LHC Beam Interlock System.
- Reception and distribution of the energy signal to the BEE cards.
- Surveillance: several testing process for the BLMS.



VME Crate and Rack

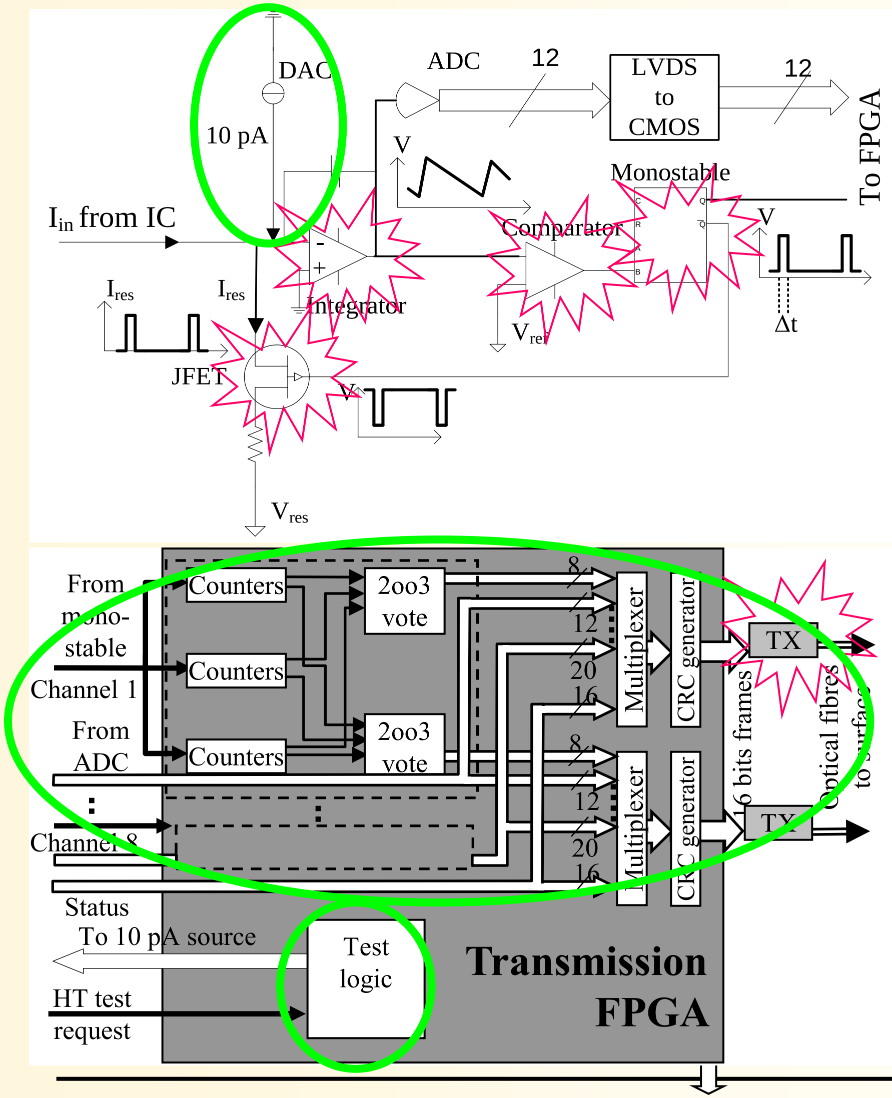
Jonathan Emery

- Up to 16 BEE cards and a Combiner card are located in a VME crate.
- The beam permit lines of the BEE cards in a crate are daisy chained up to the Combiner card.



- 25 VME Crates in 8 racks per LHC octant. In each rack there will be a LHC Beam Interlock System user interface.
- The beam permit lines of the Combiner cards in a rack are daisy chained up to the LBIS user interface.
- The energy signal is provided in parallel to each combiner card.

FEE Dependability



Ewald Effinger

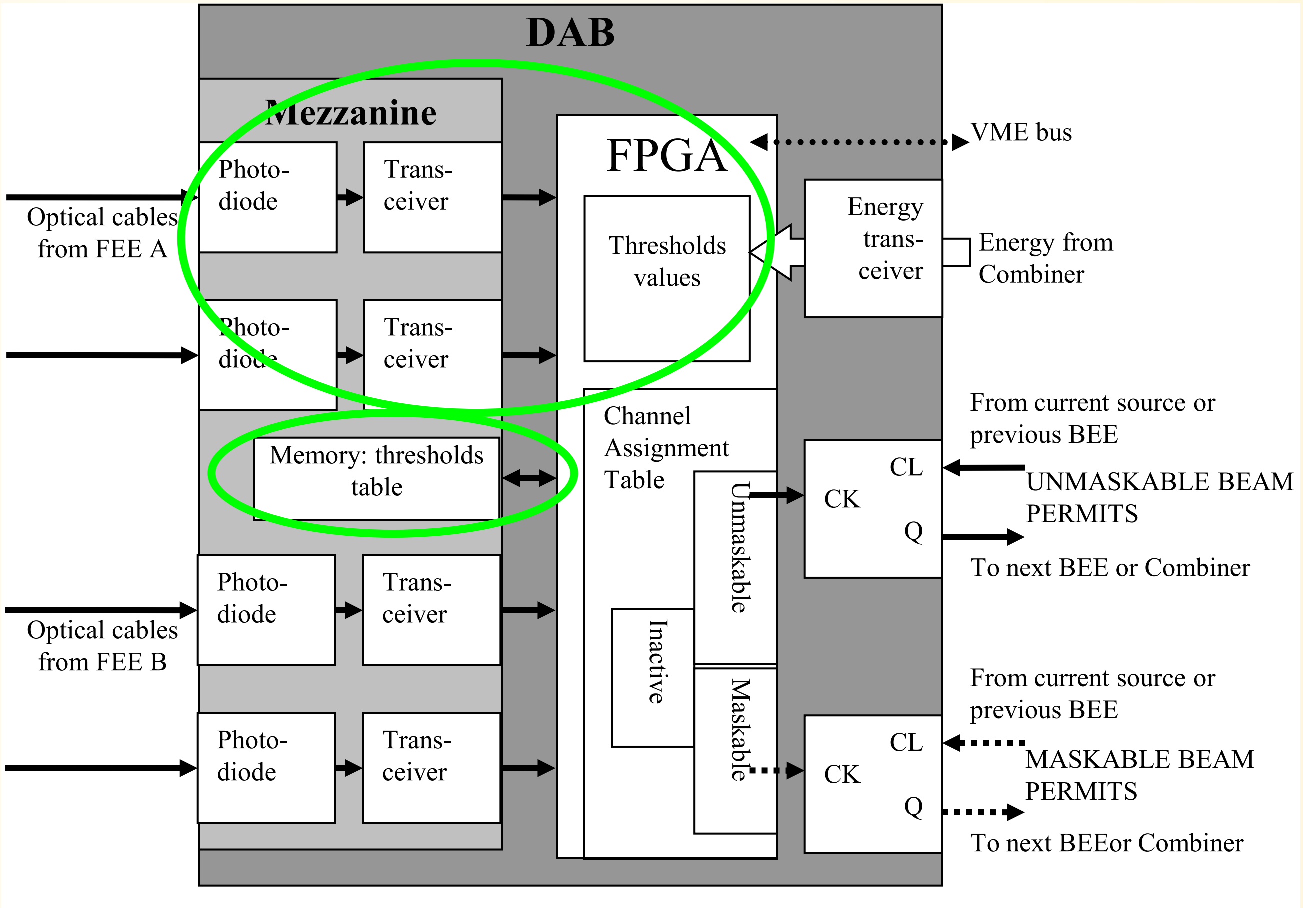
- Irradiation tests on the analogue components to investigate hazard rate variation.
- Definition of the 10pA test to check the analogue channel.

- Irradiation tests of the optical transmitter LASERs.
- Doubling of the optical lines and two-out-of-three (2oo3) redundancy in the FPGA.
- Definition of the HT test to check all the channel functionalities.

BEE Dependability

Christos Zamantzas

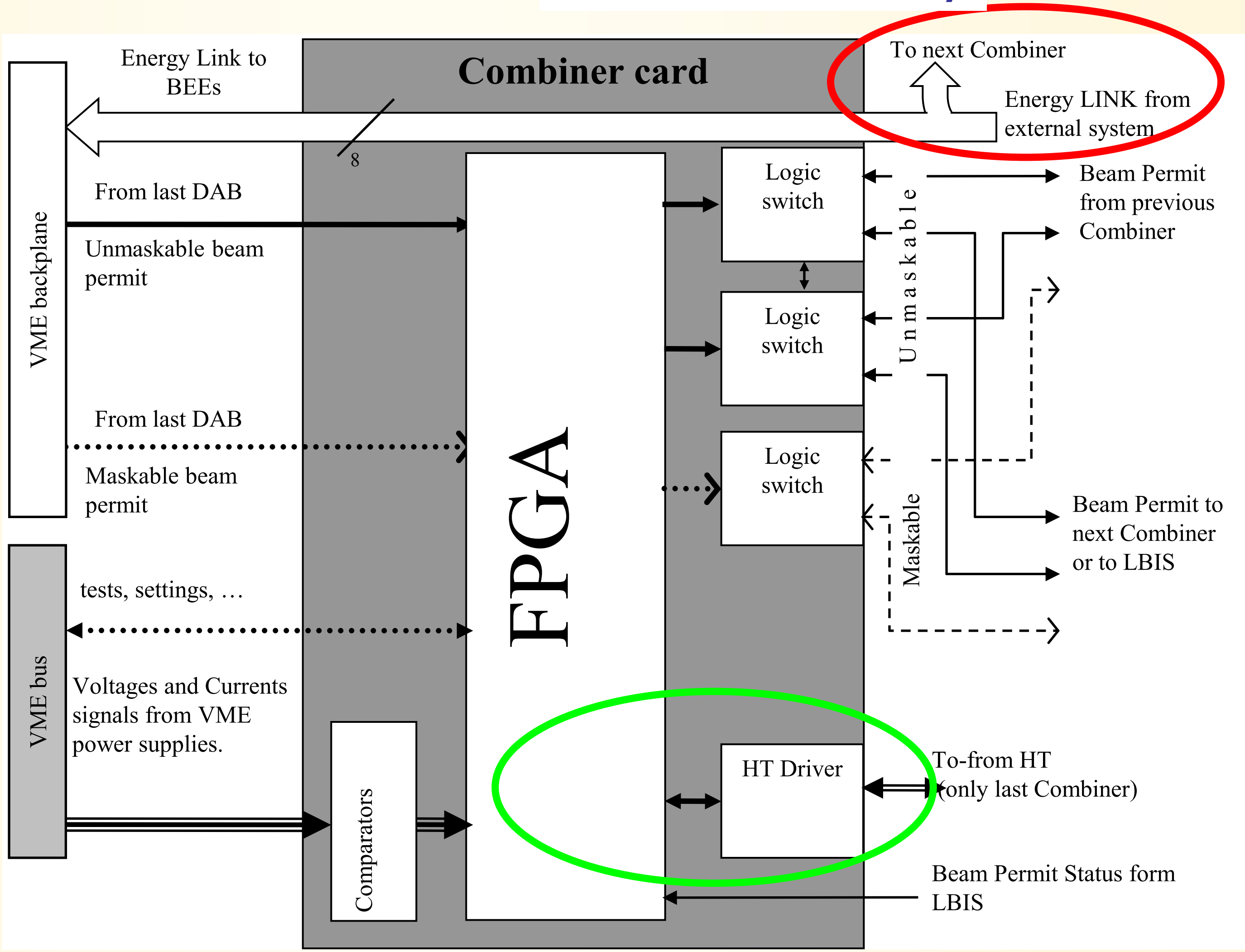
- Definition of the tests to check the integrity of the data.
- Definition of the thresholds windows to minimize the evaluation error (see next slide).



Combiner Dependability

Jonathan Emery

- Definition of the tests to check whole signal chain.
- Definition of the criticalities of the energy signal.



Functional Tests Overview

PhD thesis G. Guaglio

Functional tests before installation

Barcode check

Current source test

Radioactive source test

HV modulation test

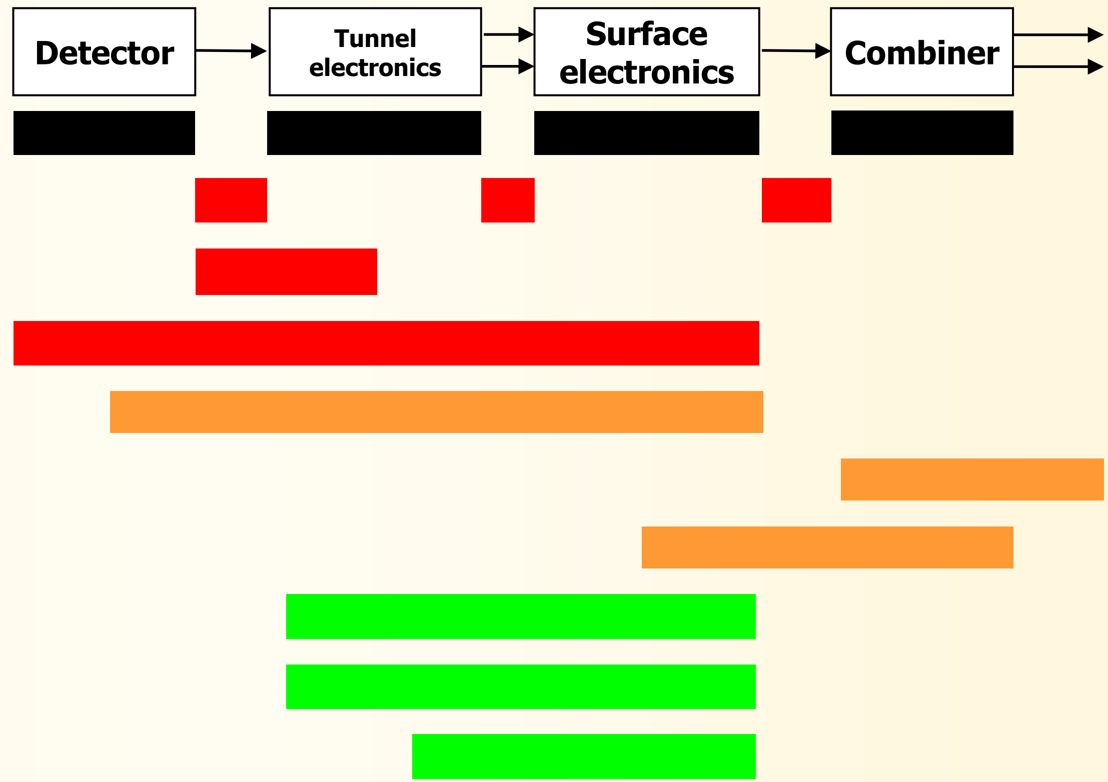
Beam inhibit lines tests

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

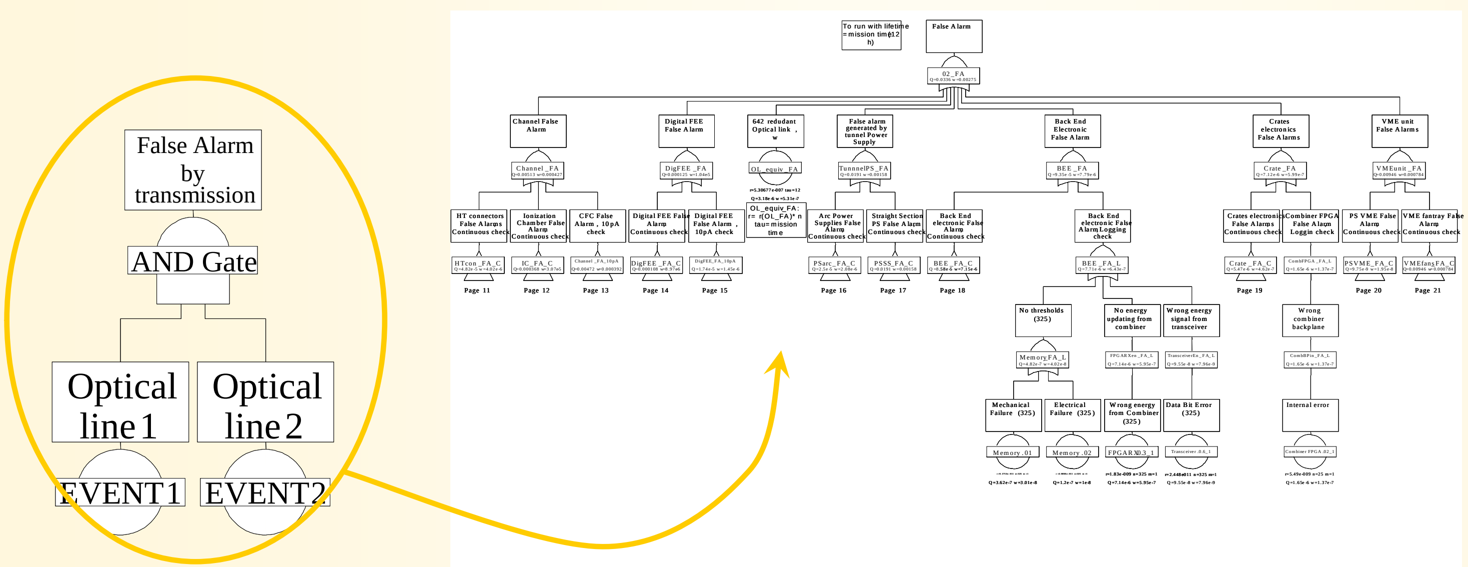
Fault Tree Analysis

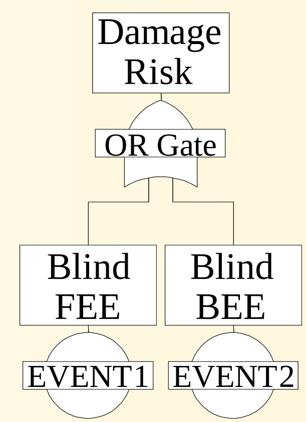
- Almost 160 Failure Modes have been defined for the BLMS using the FMD-97 standard.

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 .**



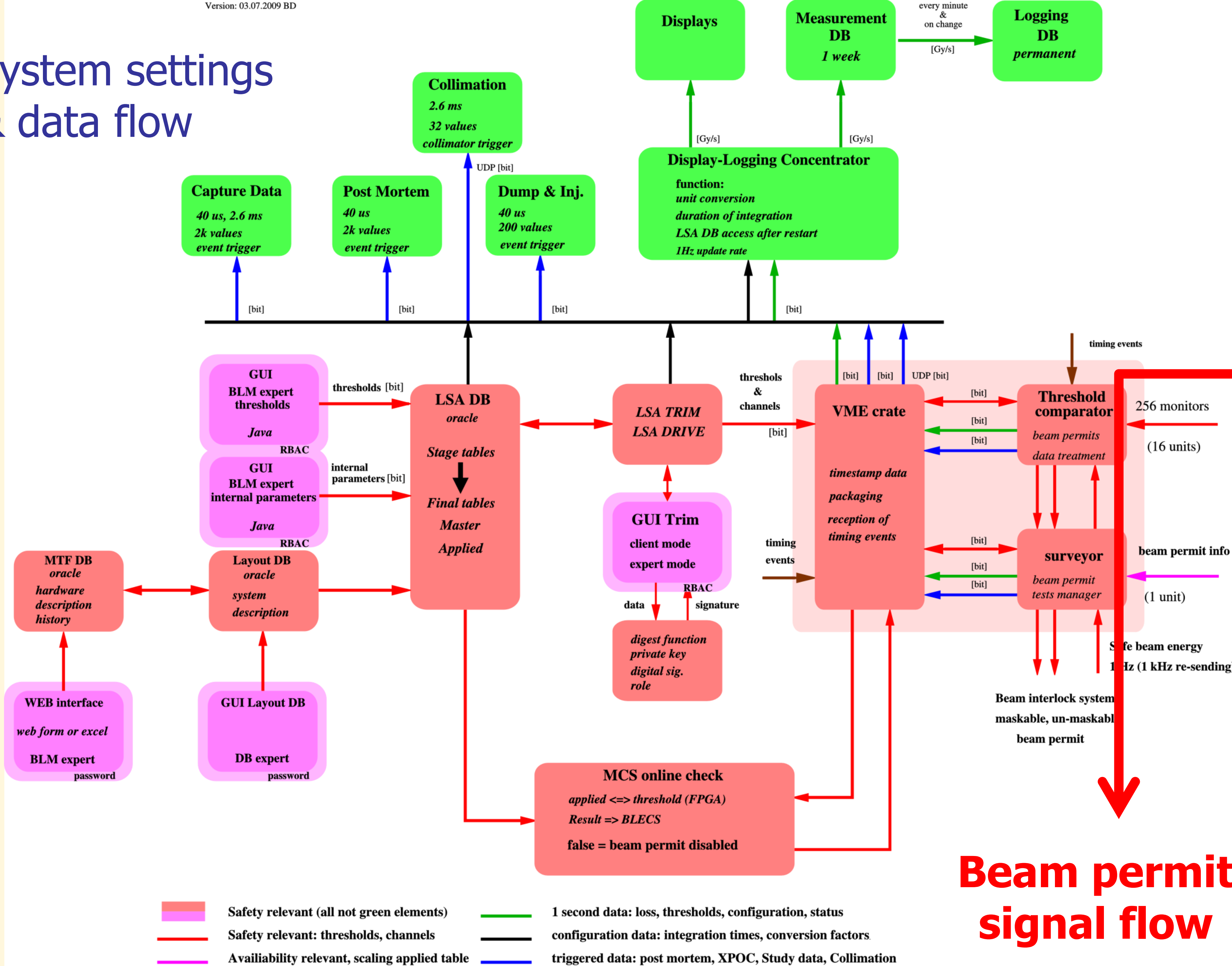


Fault Trees Results

- The <u>probabilities to fail (unavailability)</u> for the BLMS have been calculated.
- Per each End Effects, the <u>major contributors</u> 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.

System settings & data flow



Beam permit signal flow

Reliability and Time Resolution

Type	*Area of use*	*Criticality*	*Time resolution*
Ion chamber + SEM	Collimation sections	yes	1 turn
Ion chamber + SEM	Critical aperture limits or critical positions	yes	1 turn (89 us)
Ion chamber	All along the rings (ARC, ...)	no	2.5 ms (7.4.4)

Definition (specs):

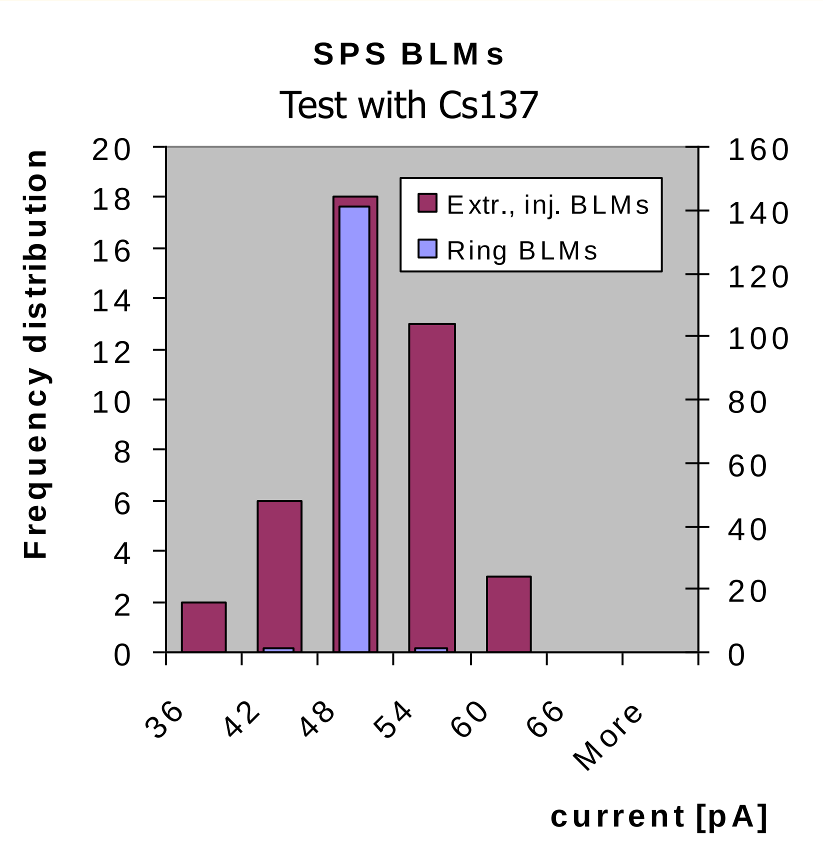
By criticality, we mean that the system must be 100% operational to allow beam injection and that the beam is dumped if it fails.

- In case of a non working monitor this monitor has to be repaired before the next injection

Ionisation chamber currents (1 litre)

		Collimation	All others
450 GeV, quench levels (min)	100 s	3.3 mA	12.5 nA
7 TeV, quench levels (min)	100 s	100 uA	2 nA
Required 25 % rel. accuracy, error small against 25% => 5 %			100 pA
450 GeV, dynamic range min.	10		10 pA
	100	33 nA	2.5 pA
7 TeV, dynamic range min.	10 s		160 pA
	100s	1.1 nA	80 pA

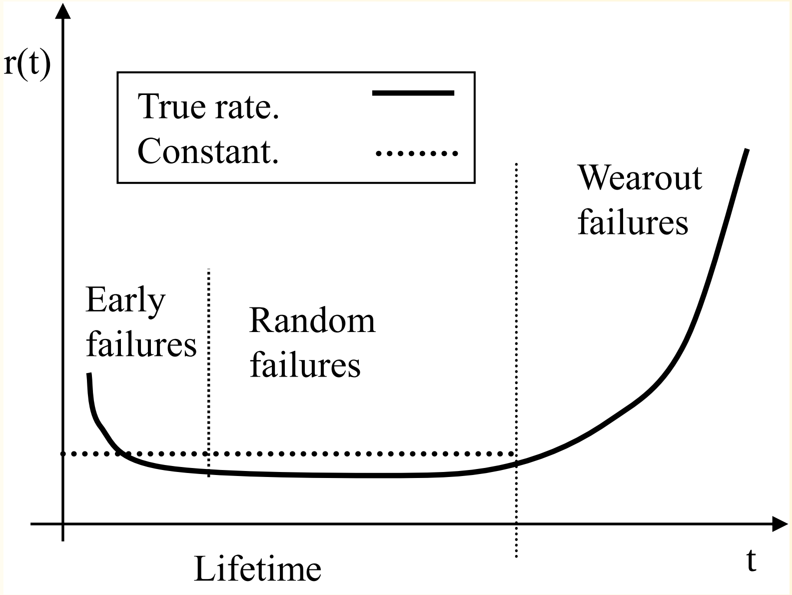
Gain Variation of SPS Chambers



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
  - < 0.01 (for ring BLMs)
  - < 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

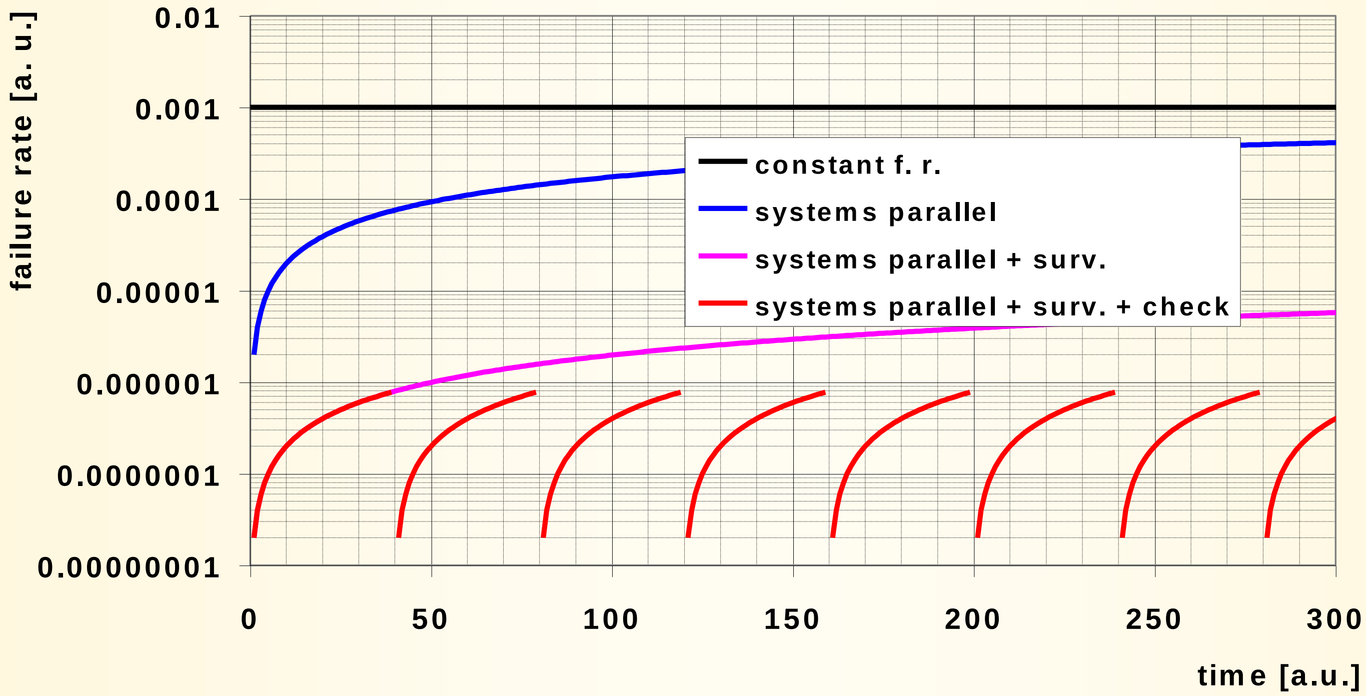
BLMS Predictions



- Rates collected mainly from the suppliers, then from historical data, and finally from the MIL-HDBK 217F.

Predictions Uncertainties

Failure Rate and Checks



Systems parallel + survey + functional check:

1. in case of system failure dump beam (failsafe)
2. verification of functionality: simulate measurement and comparison with expected result => as good as new

BEE Thresholds Levels

- An error less than 25% in the approximation of the threshold lines is reached with 11 times windows and 32 energy steps.