RELIABILITY ANALYSIS OF THE LHC BEAM DUMPING SYSTEM TAKING INTO ACCOUNT THE OPERATIONAL EXPERIENCE DURING LHC RUN 1

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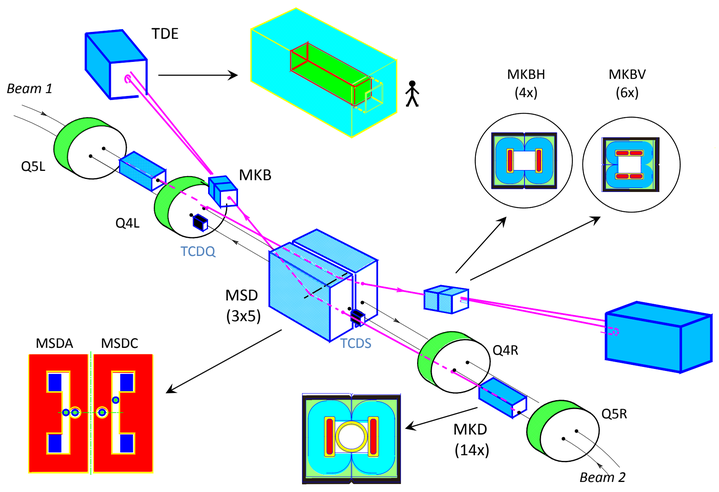
The LHC Beam Dumping System

The LHC Beam Dumping System (LBDS) is responsible for the **safe extraction of the beam** from the LHC collider. It is a **safety critical system**, as it is the final element of the **Machine Protection System**.

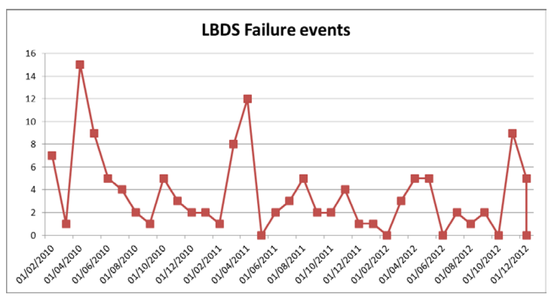
A safety and availability analysis of the LBDS was performed in 2003-2006 and returned:

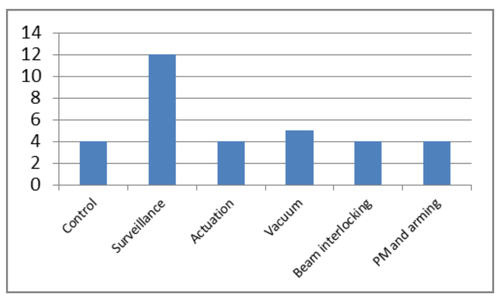
- a **SIL4 figure of safety**
- **8 ±2** expected **false beam dumps per year** due to LBDS internal faults.



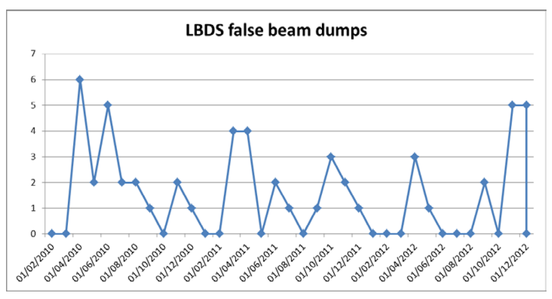
LBDS General Statistics

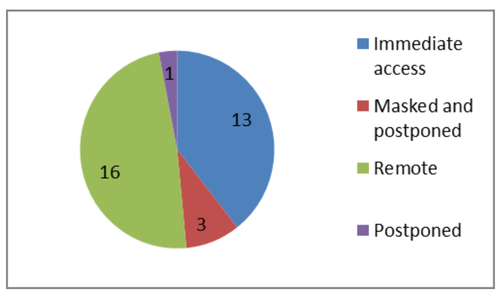
All failure events in the period 2010-2012 have been analysed in detail. There are **139 in total**, of which **58** in 2010, **48** in 2011 and **33** in 2012. The failure analysis allows performing detailed statistics on LBDS operation.





Failures Vs. function in 2012





Type of interventions in 2012

Failure Analysis

The failure analysis consists of three steps:

1. All **recorded failure events** are **classified**, appointed to the **failure modes** of the reliability model, and **censored** through various criteria.
2. The **Time To Failure** (TTF) of every component is then calculated and **compared to the predictions** made by the reliability models.
3. Additional **statistical hypothesis tests** (H. test) were performed to further check whether **observations agreed with predictions**.

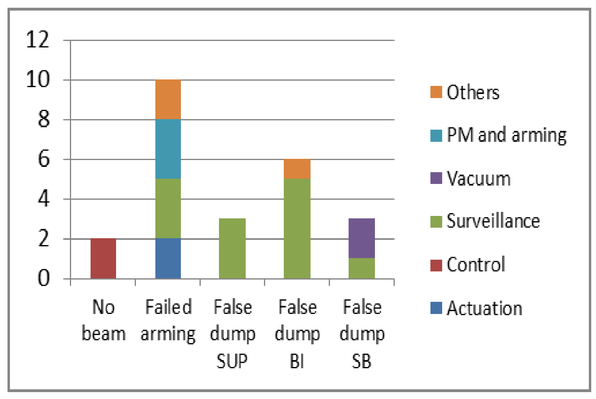
The **reliability prediction models are adjusted** depending on the agreement of the two figures.

Failure Statistics for the LBDS Actuation

#	*Failure mode*	*Model*	*Population*	*TTF (years)*			
				Raw	Corrected	Rel. pred.	H. test
1	MKD HV power supply breakdown	PSP1	30	3*30/7 = 12.8	β model	150	
2	MKD PTU HV PS	HV	60	3*60/10 = 9	1-count 26	16	TRUE
3	MKD Compensation PS breakdown	PSOS1	30	3*30/6 = 15	1-count 18	113	FALSE
4	PTC tracking error	PTC, PTC3	80	3*80/2 = 120	1-count 240	103	TRUE
5	MKD Power switch degradation	SP2	60	3*60/3 = 60	P_D model	633	n.a.
6	MKD PTC card failure	PTC1-3	80	3*80/1 = 240	-	1140	n.a.
7	MKB Power switch degradation	SW2	20	3*20/6 = 10	P_D model	633	n.a.
8	MKB HV power supply breakdown	PSH	20	3*20/1 = 60	-	152	TRUE
9	MKB HV power supply degradation	Not in the model	20	3*20/3 = 20	1-count 60	114	TRUE

LBDS Availability

The LBDS is designed with **fail-safe mechanisms** that prevent the development of failures and **stop the operation by triggering an internal beam dump request** when errors in the system are detected.



The partition of internal beam dump for the different operational phases of the LHC.

Considering only **internal beam dumps** that occurred during phases **with beam** we obtain:

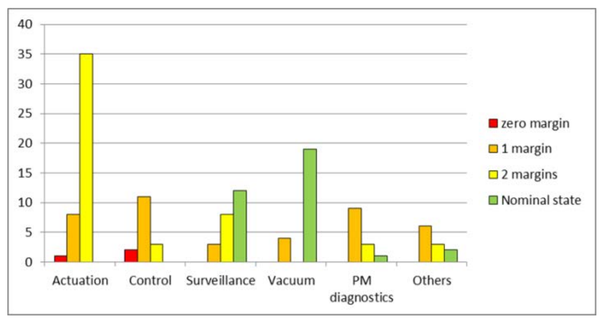
- 2010: **14** internal beam dumps;
- 2011: **10** internal beam dumps;
- 2012: **5** internal beam dump

LBDS Safety

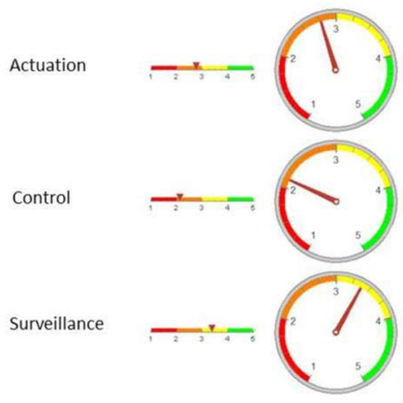
No safety critical failure scenario was recorded during LHC Run1. None was expected from the initial analysis of the LBDS as it was estimated to be SIL4.

The system should never operate under a **single point of failure** conditions.

The **residual safety margins** of the LBDS at the time of dump is inferred by the **safety gauge**.



Safety margins versus LBDS functions.



The LBDS safety gauge.

Summary

A large amount of data concerning failure events in the LHC Beam Dumping System was collected during LHC operation from the years 2010-2012.

139 failure events were recorded and apportioned to **29 failure modes**, of which **7 new failure modes.**

In terms of **safety**, the LBDS meets **SIL3**, which is a **more conservative value** w.r.t the prediction, essentially due to **contribution of new failure modes**.

Overall, the **29** internal beam dumps are **in good agreement with the 2006 predictions (24 ± 6)**, in particular for years 2011 and 2012.

All statistics, including **availability and safety**, show a **positive trend**, which attests **an improvement in operation with LHC.**

The **safety gauge** has been introduced to give experts the **residual safety margins** after every beam dump.