Machine Protection System Availability (& Performance) 2010-12

B. Todd, A. Apollonio, S. Gunther, D. Wollmann, M. Zerlauth

MPS Availability (& Performance)

1. operational view point = impact-on-physics
   physics fills above 450 GeV… — 2010 - 2012
2. equipment view point = reliability
   all beam aborts
   all failures or events in 2012 — 2012
3. conclusions
   future work, and outlook — LS1 +

12-14% of physics fills aborted due to internal failure of MPS (≈constant 2010-12)

56/82 = QPS 18/82= BLM 4/82 = LBDS ~~4/82 = SIS~~ PM field needed

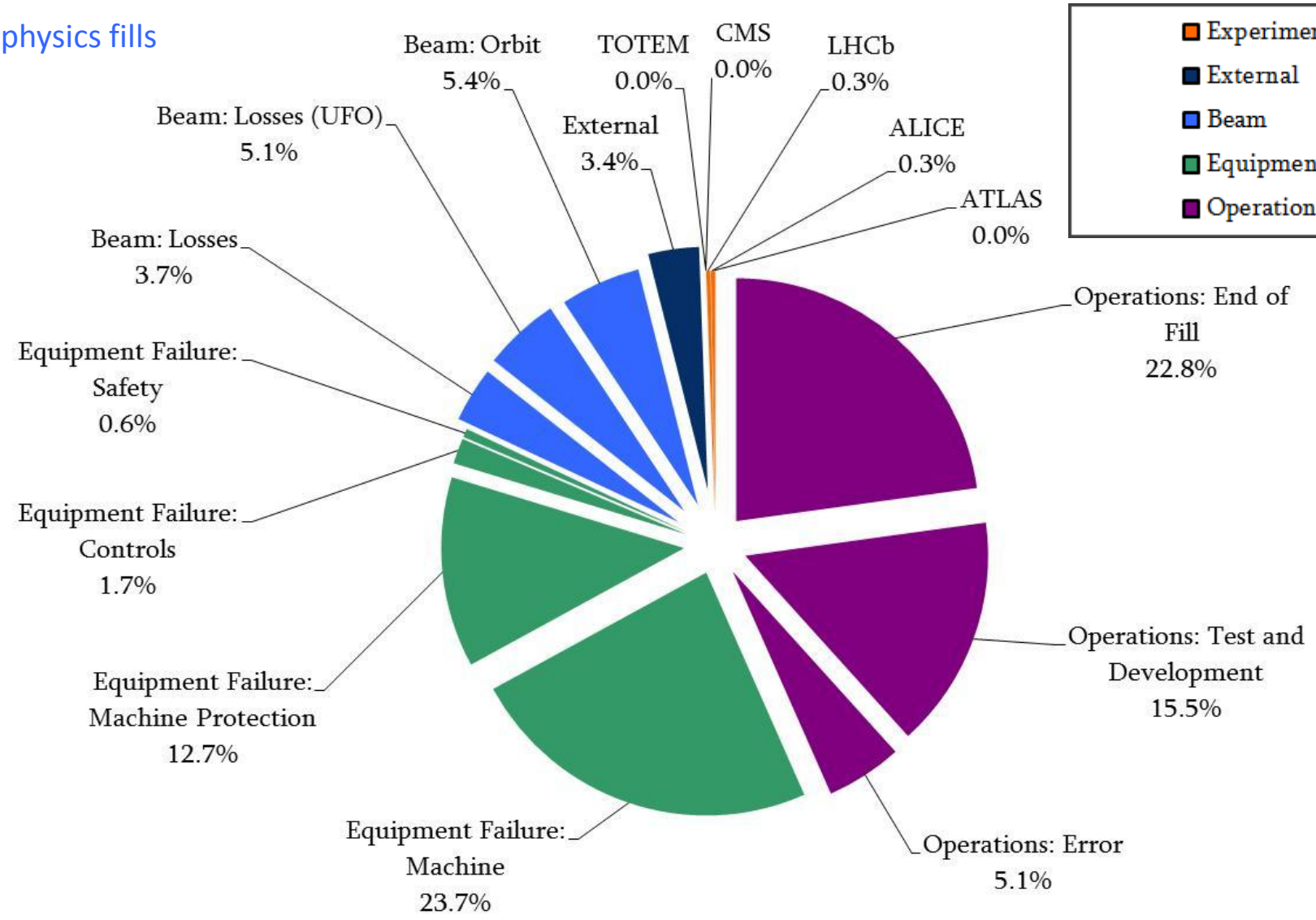
7 systems, >250 faults, ≈36 failure modes, >400h total repair time
cannot rigorously correlate impact on physics using current information — fault tracker

dormant failures in parts of the MPS are not excluded — identify and test

Hazard Chains help identify if there are holes in protection — identify

Operations View: 2010

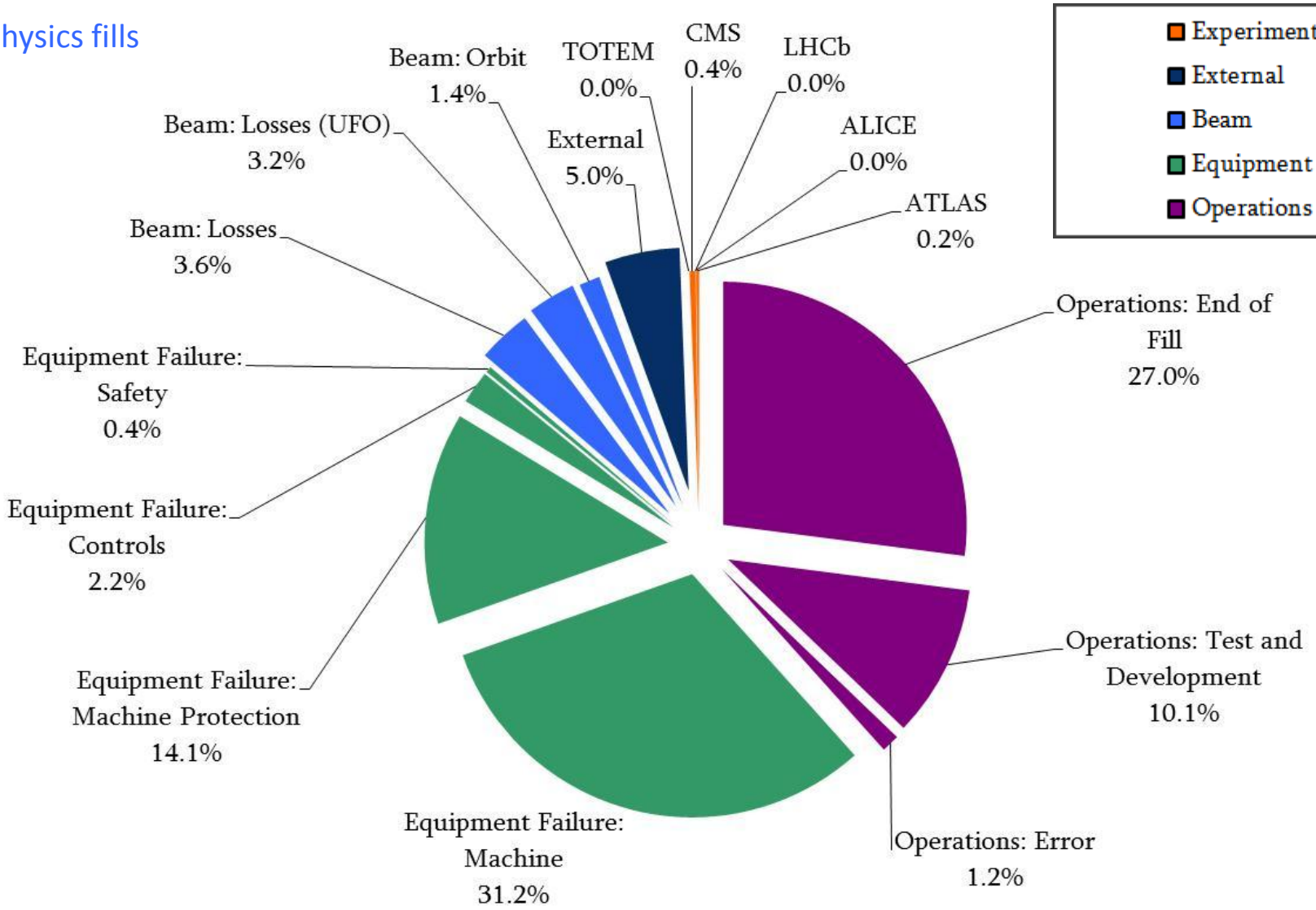
355 physics fills



[1]

Operations View: 2011

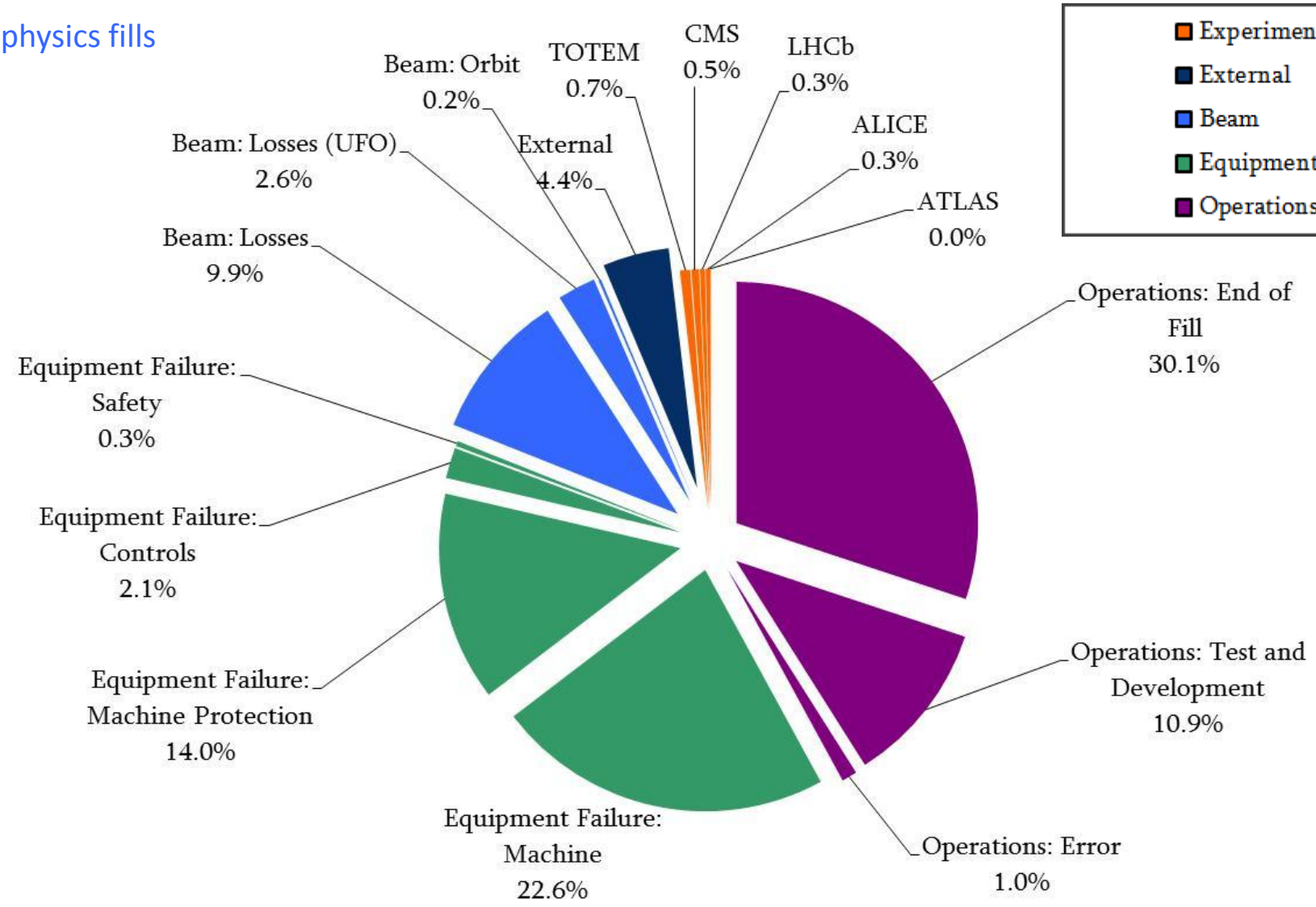
503 physics fills



[2]

Operations View: 2012

585 physics fills



[3]

2010 – 2012

	2010	2011	2012	Totals
Qualifying Fills [#]	355	503	585	1443
MPS Equipment Failure [#]	43 [12.7%]	71 [14.1%]	82 [14.0%]	196 [13.6%]

[3]

2010 – 2012

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Quench Protection				
Beam Loss Monitors				
Beam Dumping System				
Software Interlock System				
Powering Interlocks				
Beam Interlock System				

[3]

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Quench Protection	24	48	56	128
Beam Loss Monitors	4	4	18	26
Beam Dumping System	9	11	4	24
Software Interlock System	4	2	4	10
Powering Interlocks	-	5	-	5
Beam Interlock System	2	1	-	3

[3]

2010 – 2012

Operational Availability = "Impact-on-Physics"

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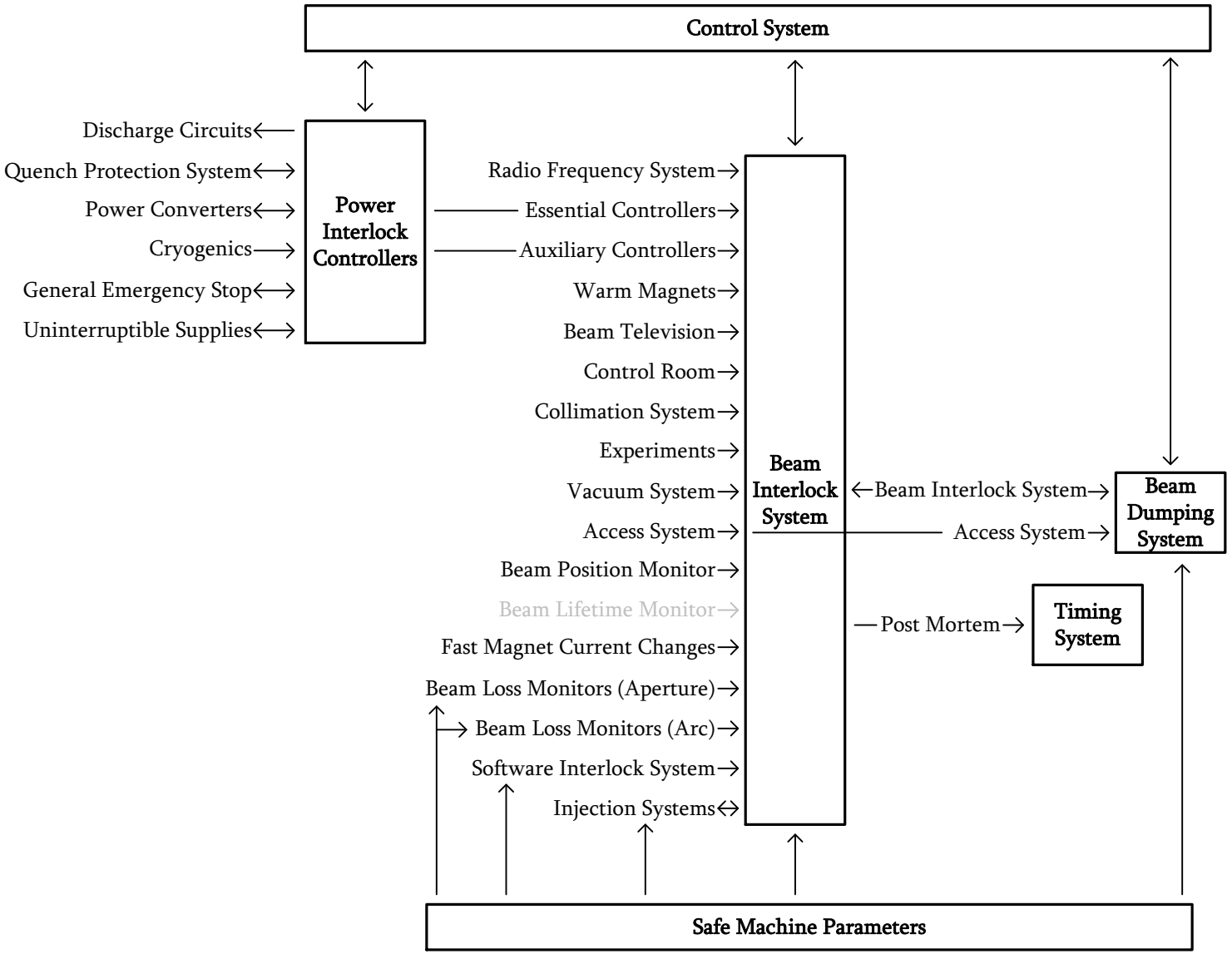
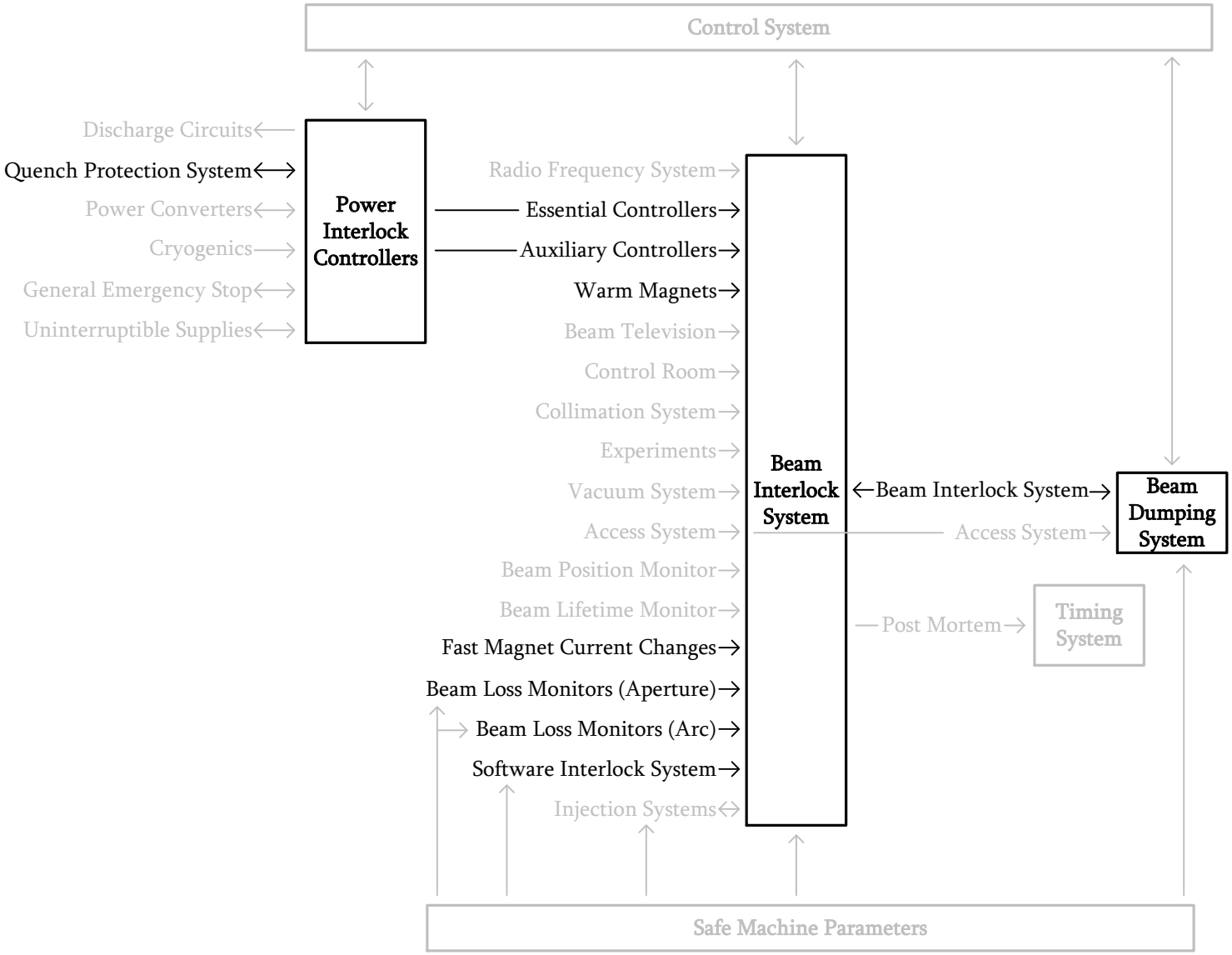
[3]

Equipment View: Scope



Equipment View: Scope



Equipment View: Scope

Investigate all failures related to each system, not only those having impact-on-physics

- Failure Modes
- Frequency
- Repair Times

Fast Magnet Current Change (FMCM)

Powering Interlocks (PIC)

Warm Magnet Interlocks (WIC)

Beam Interlock System (BIS)

Beam Loss Monitors (BLM)

Beam Dumping System (LBDS)

Quench Protection System (QPS)

+

Software Interlock System (SIS)

4 x physics fill abort root cause (of 565)

In 2012 SIS did not fail, events are due to real interlocking conditions

mining the documented SIS events for typical causes…

SIS Dump Cause	Creates Interlock?	Ratio
CMW Failure	Yes	20%
Orbit Feedback Crash	Yes	20%
Power Converter Fault	Yes	15%
Beam Position Measurements	Yes	10%
Beam Loss Monitor HV	Yes	10%
Others…	Yes	25%

Difficult to extrapolate but agrees with the general perception

- PM database field needed for SIS interlock root cause

External
Random Hardware
Radiation Hardware
Exploitation

L. Ponce, J. Wenninger [12]

0 x physics fill abort root cause (of 565)

Failure Mode	#	Total [hours]	Average [hours]
Earth Cable Intermittent	1 (4)	5.8	5.8
Combined	**1**	**5.8**	**5.8**

External
Random Hardware
Radiation Hardware
Exploitation

S. Gunther, I. Romera [5]

0 x physics fill abort root cause (of 565)

Failure Mode	#	Total [hours]	Average [hours]
PVSS - Ethernet Switch Failure	1	1	1
Combined	**1**	**1**	**1**

External
Random Hardware
Radiation Hardware
Exploitation

S. Gunther, I. Romera [6]

0 x physics fill abort root cause (of 565)

Failure Mode	#	Total [hours]	Average [hours]
Power Converter Trigger	2	11	5.5
Combined	**2**	**11**	**5.5**

External
Random Hardware
Radiation Hardware
Exploitation

P. Dahlen, S. Gunther, I. Romera [7]

0 x physics fill abort root cause (of 565)

Failure Mode	#	Total [hours]	Average [hours]
User Side Powering	3	6	2
User Side Infrastructure	2	40	20
User Interface Powering	2	4	2
Monitoring Function Corruption	1	1	1
Power PC Failure	1	1	1
Reference Database Version	1	1	1
Combined	**10**	**53**	**5.3**

Most significant connection User to BIS → expert assistance for complete diagnosis
Two cases above input was disabled until failure understood.

Almost all failures do not stop operation…

External
Random Hardware
Radiation Hardware
Exploitation

C. Martin [8]

4 x physics fill abort root cause (of 565)

→ 9 in total identified by LBDS team

QPS Failure Mode	#	Total [hours]	Average [hours]
Slow Surveillance Hardware Failure	10	4	0.4
Vacuum Fault	5	3	0.6
Power Electronics Failure	4	8	2.0
Post-Mortem / Arming Problem	4	0.5	0.1
Beam Interlock System Fault	4	3.5	0.9
Control Hardware Failure	4	1	0.3
Energy Tracking Hardware Failure	2	7	3.5
Combined	**33**	**27**	**0.8**

External
Random Hardware
Radiation Hardware
Exploitation

R. Filippini [9]

18 x physics fill abort root cause (of 565)

Failure Mode	#	Average [hours]	Average [hours]
Optical Link – Surface	15	45	3
CMW	14	14	1
SEM Connectivity Fault	10	20	2
Optical Link – Tunnel	6	30	5
LIC Connectivity Fault	5	10	2
High Voltage Drop	4	12	3
IC Connectivity Warning	3	9	3
VME Power Supply Failure	1	3	3
Programmable Logic Corruption	1	1	1
Combined	**59**	**146**	**2.5**

CMW faults = ½ MCS check, ½ front end communication
IC Connectivity Warning doesn't cause interlock

- most time = finding expert and diagnosing problem, accessing …

External
Random Hardware
Radiation Hardware
Exploitation

C. Zamantzas [10]

56 x physics fill abort root cause (of 565)

QPS Failure Mode	#	Total [hours]	Average [hours]
Radiation Induced Malfunction	39	35	0.9
Internal Communications Lost	25	15.5	0.6
Spurious Signal	23	23	1.0
Power Converter Trigger	13	13	1.0
WorldFIP Fault	12	17	1.4
DFB / Current Lead Fault	9	18	2.0
Mains Perturbation	8	9	1.1
600A Energy Extraction Fault	7	13	1.9
13kA Energy Extraction Fault	6	11	1.8
Electro-Magnetic Interference	2	3	1.5
CMW	1	0.5	0.5
13kA Power Supply Fault	1	2.5	2.5
Others	9	6	0.7
Combined	**155**	**166.5**	**1.1**

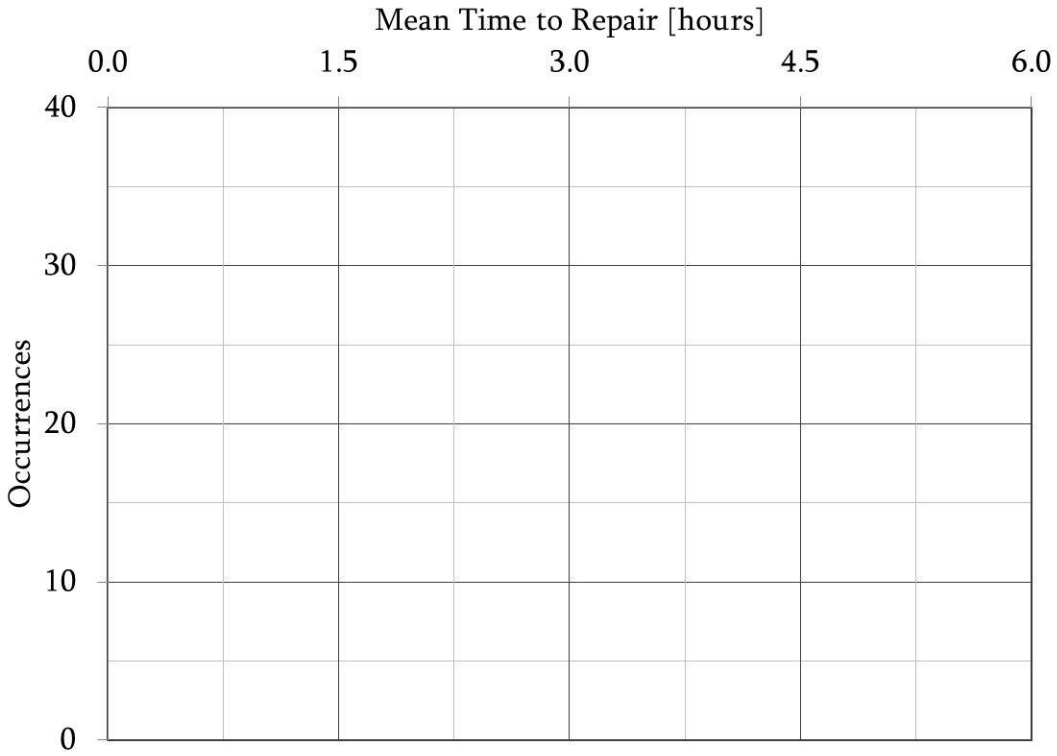
subject to changes in LS1… difficult to infer performance post LS1
consolidation with a running machine is challenging

External
Random Hardware
Radiation Hardware
Exploitation

K. Dahlerup-Petersen, R. Denz, S. Gunther, I. Romera [11]

Conclusions

7 systems, >250 faults, ≈36 failure modes, >400h repair time



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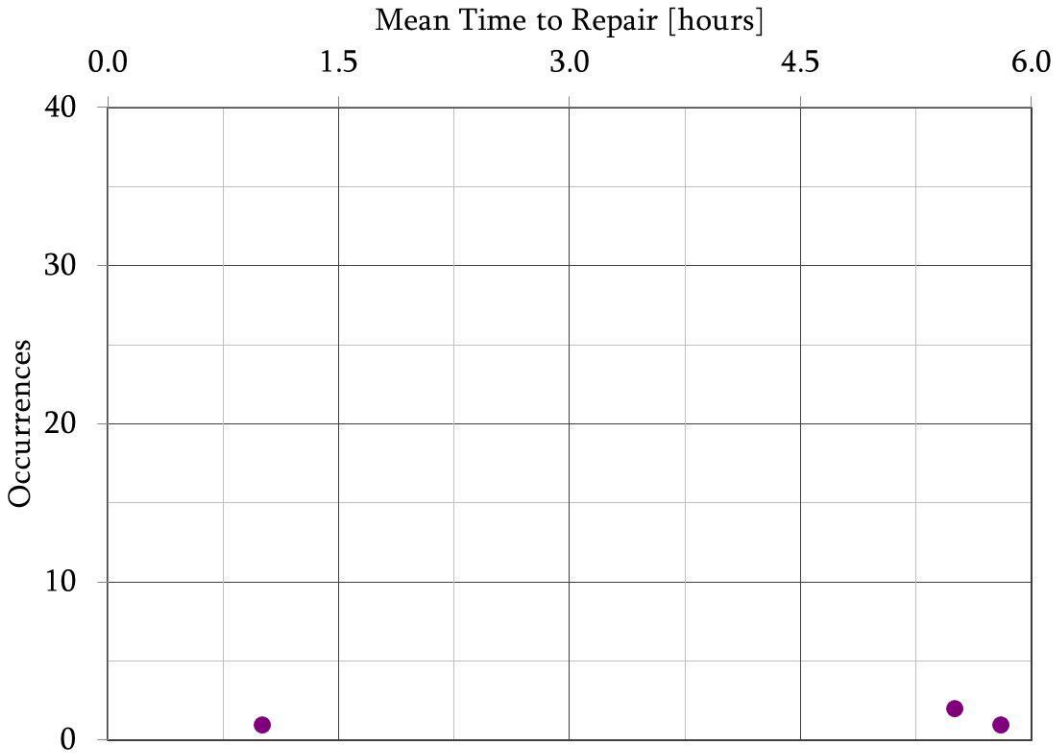

FMCM, WIC, PIC

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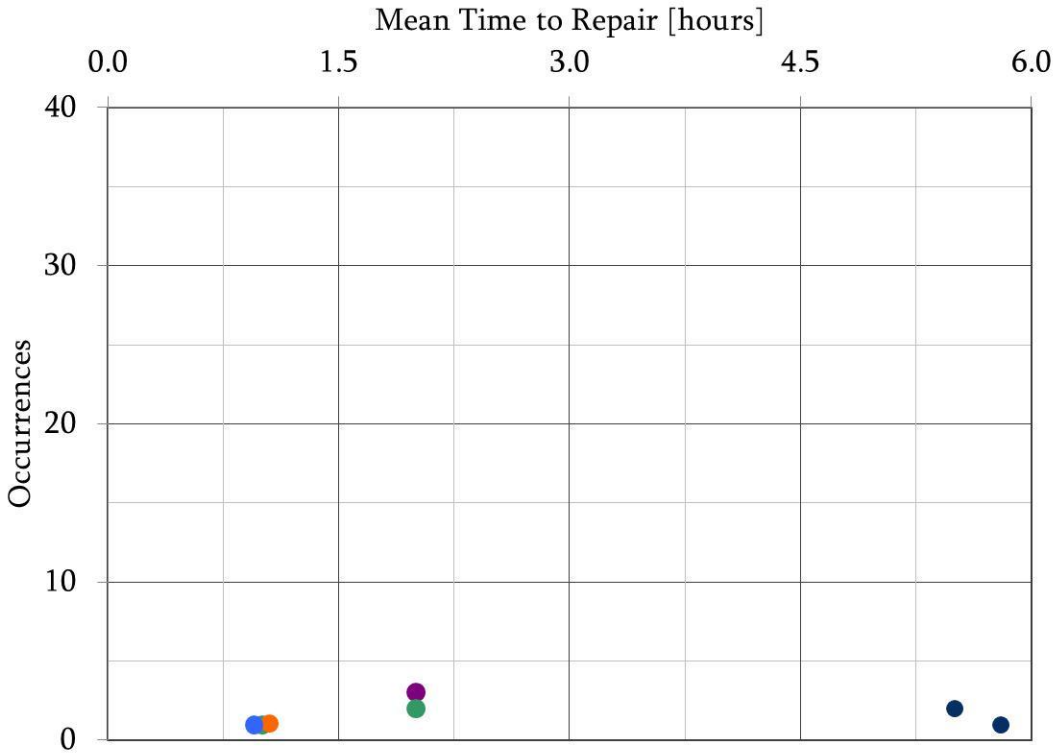

FMCM, WIC, PIC, BIS

2 x 20h events not plotted here…

Conclusions

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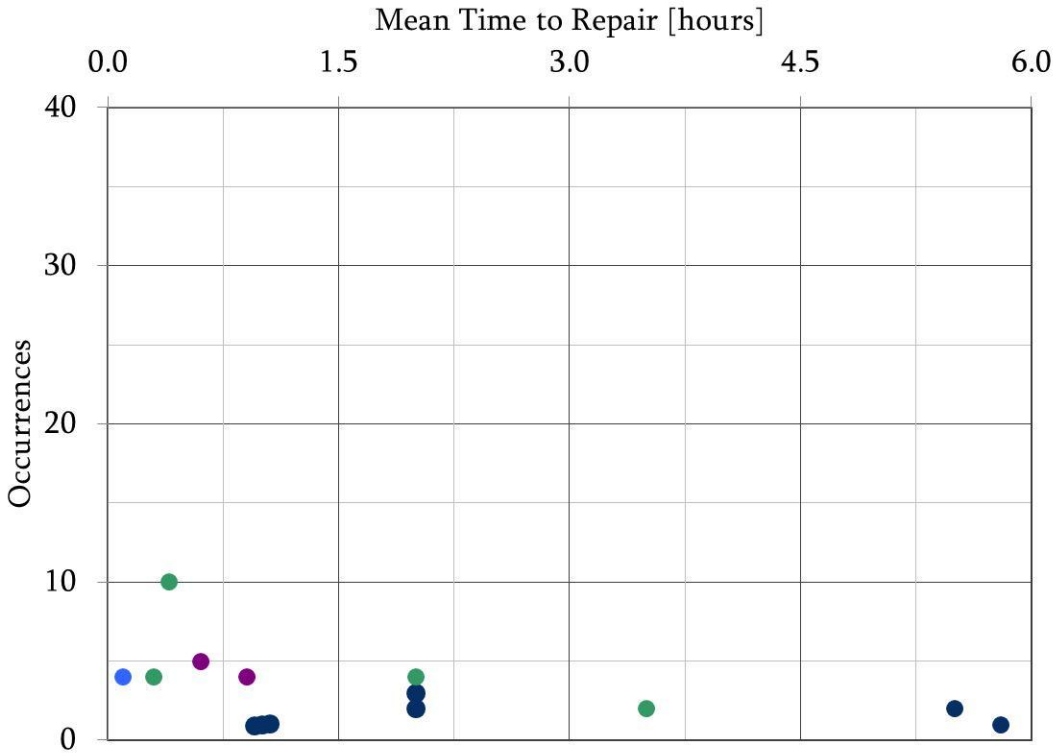

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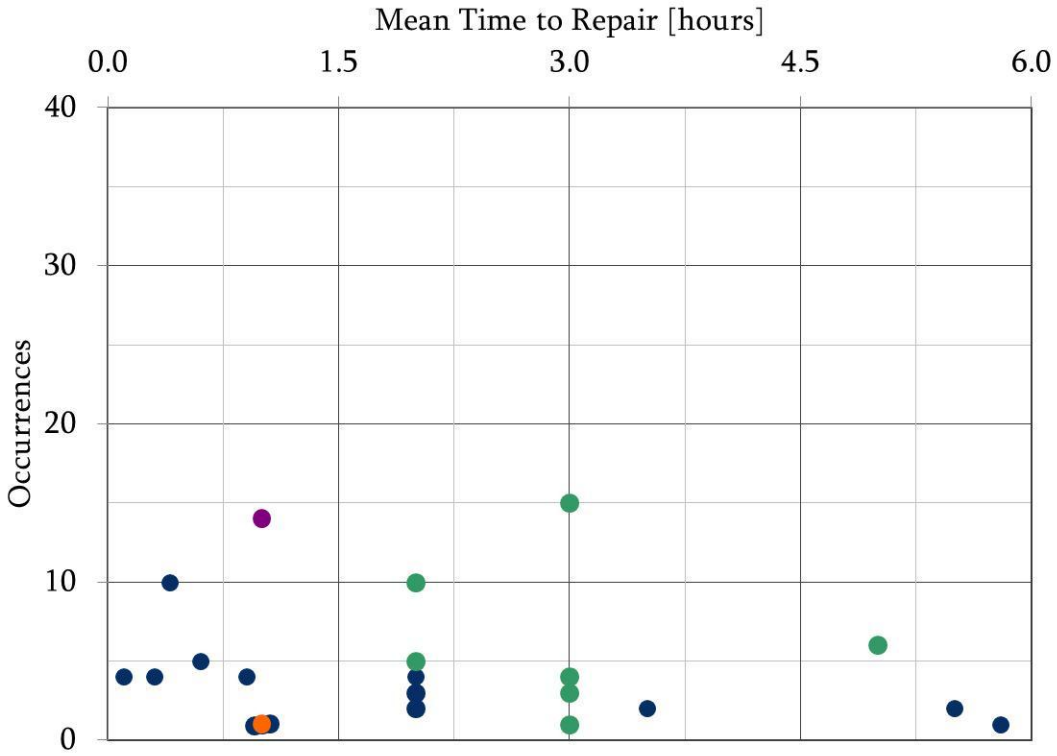

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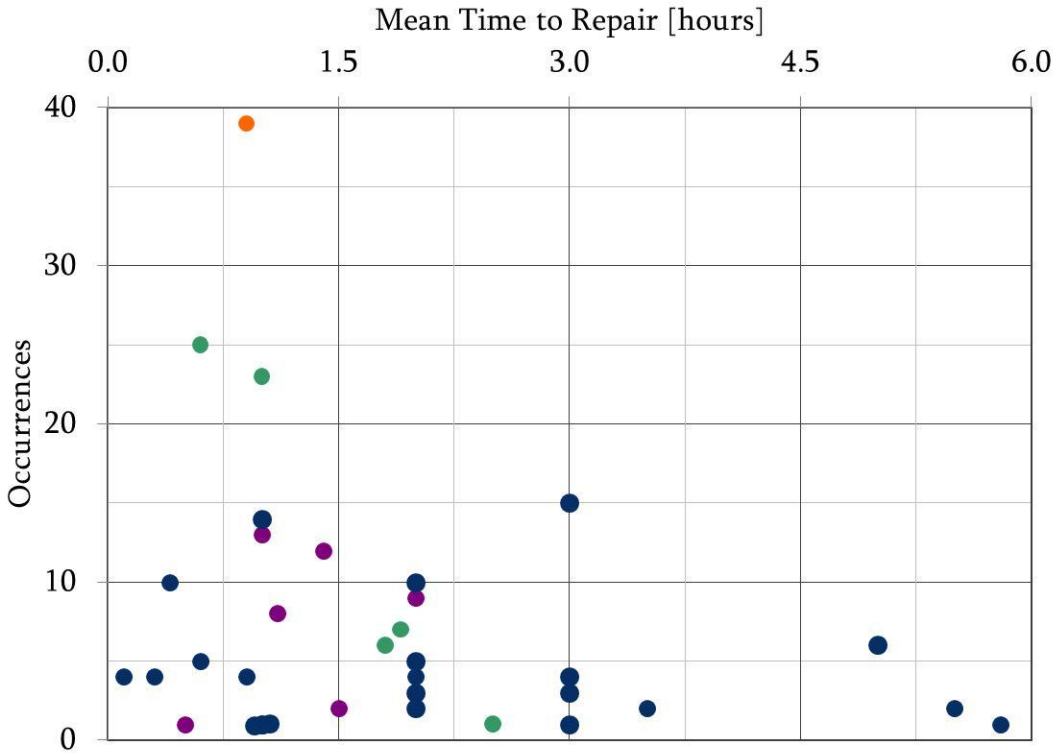
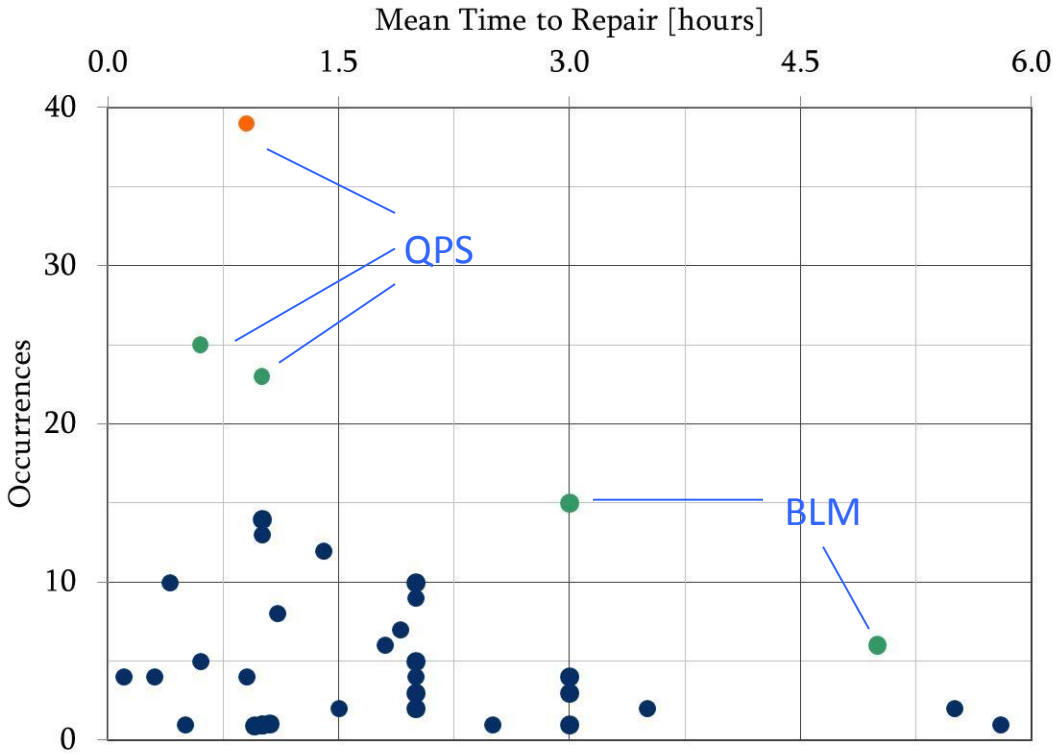


FMCM, WIC, PIC, BIS, LBDS, BLM, QPS….

Conclusions

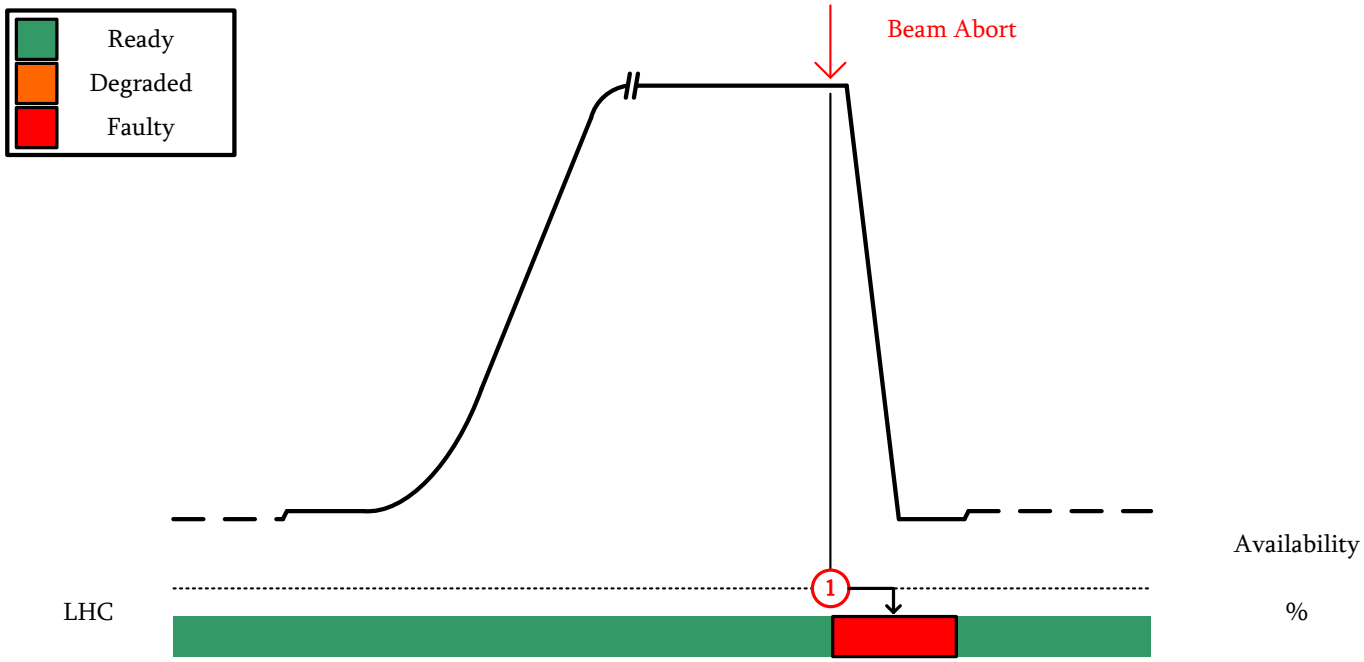
7 systems, >250 faults, ≈36 failure modes, >360h repair time



- In all failure cases it takes expert help to diagnose the problem.
- Impact on physics is not clear from this… Need to fold in operation
- Access time and call-out-time not consistently registered between systems

An LHC Fault Tracker

Visualisation of Events of 15th – 16th August 2012



[13]

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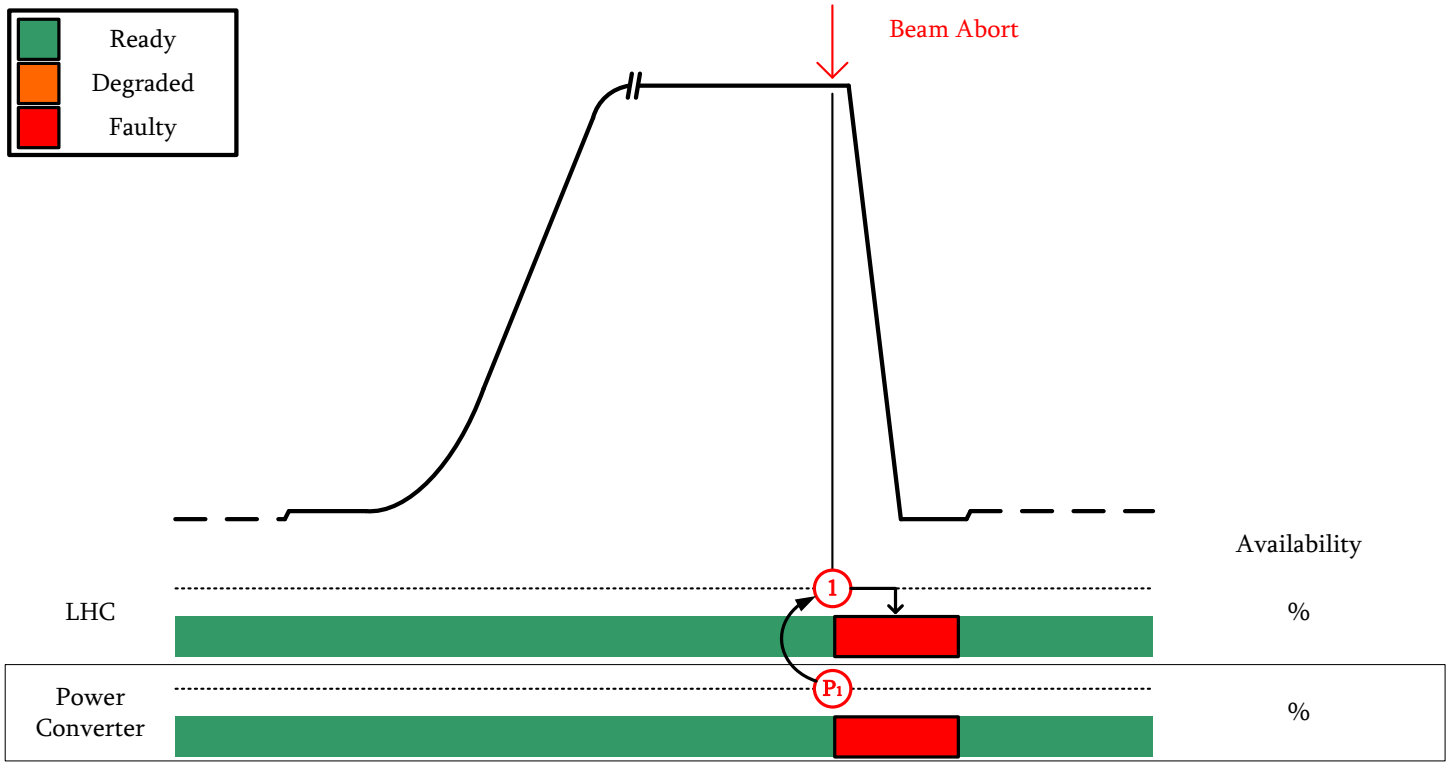

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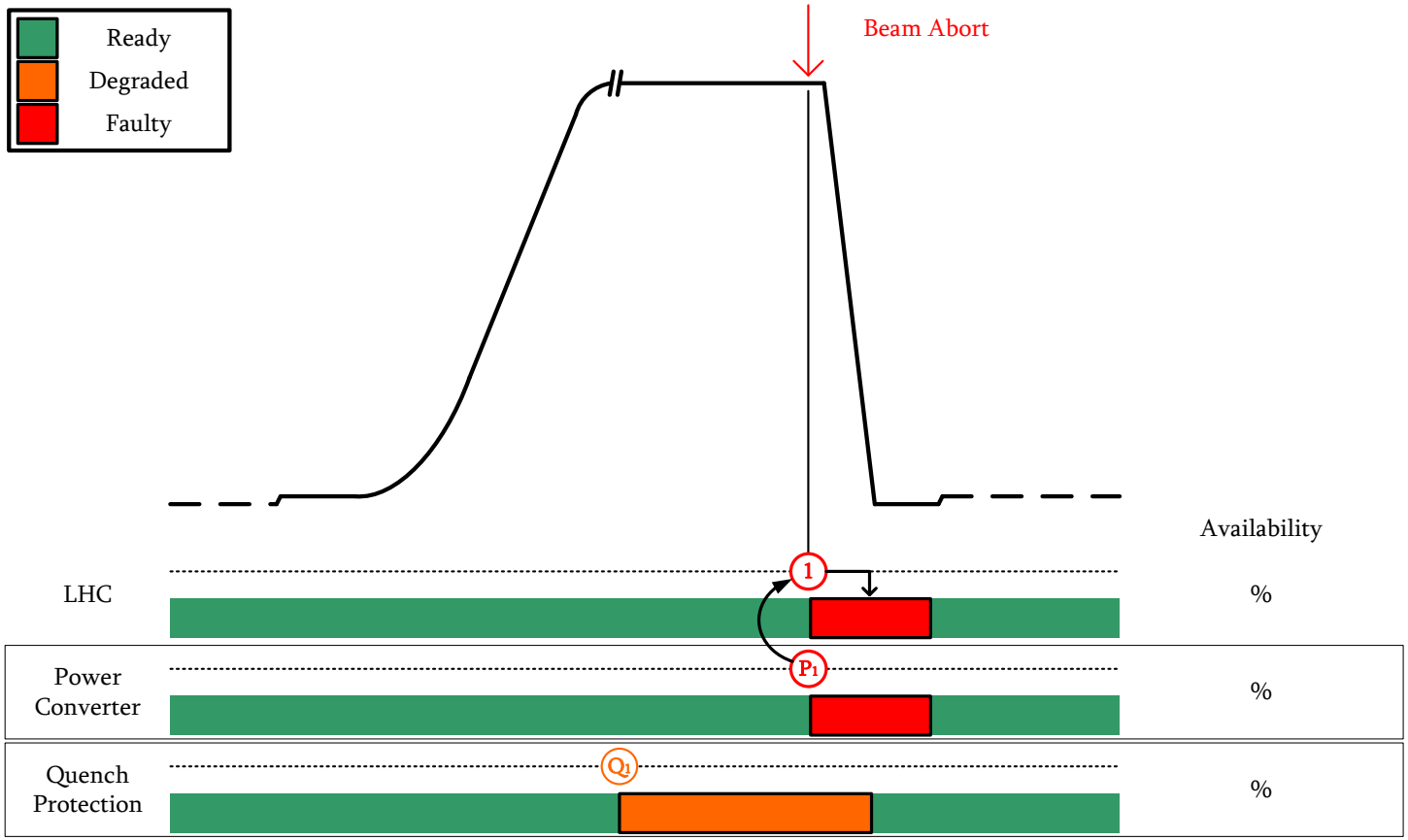

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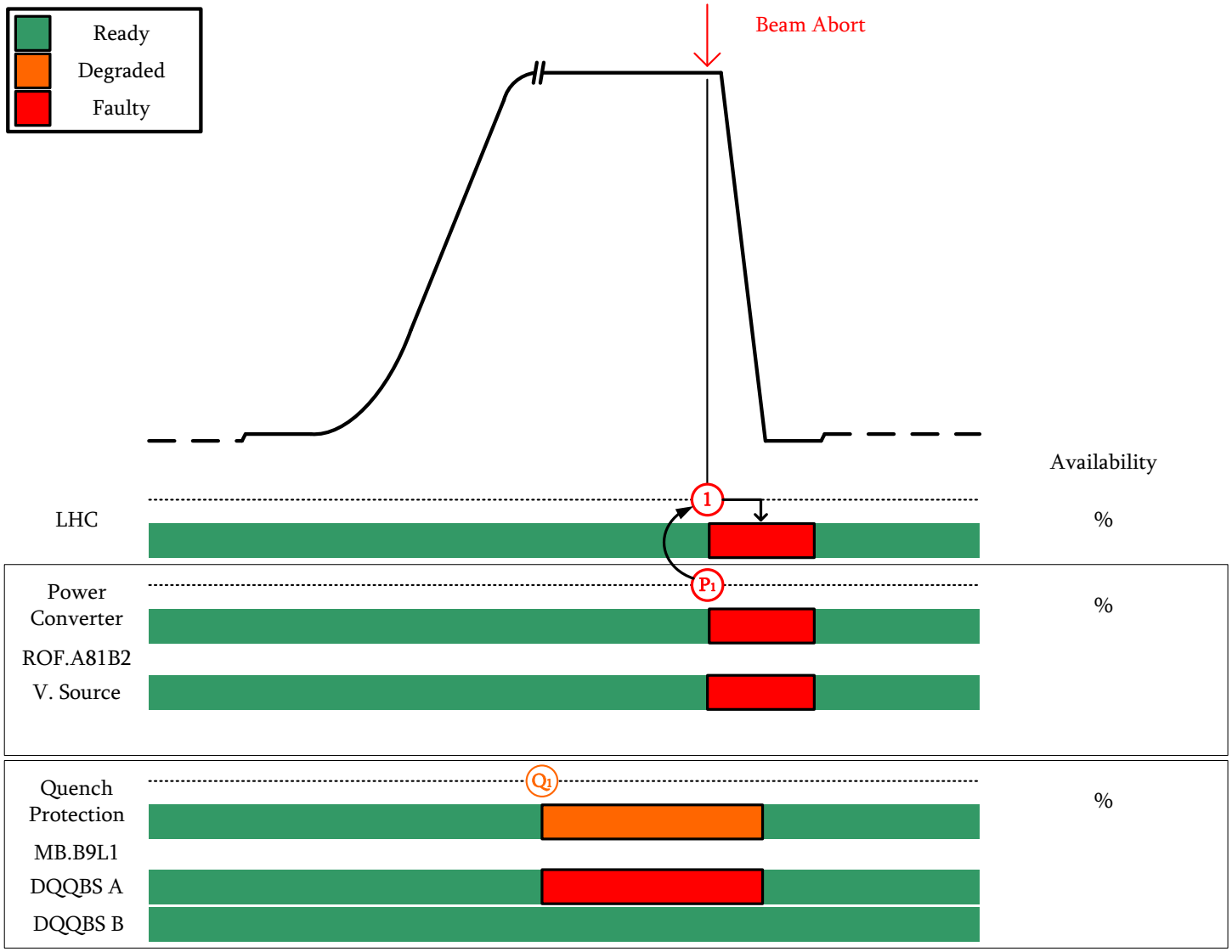

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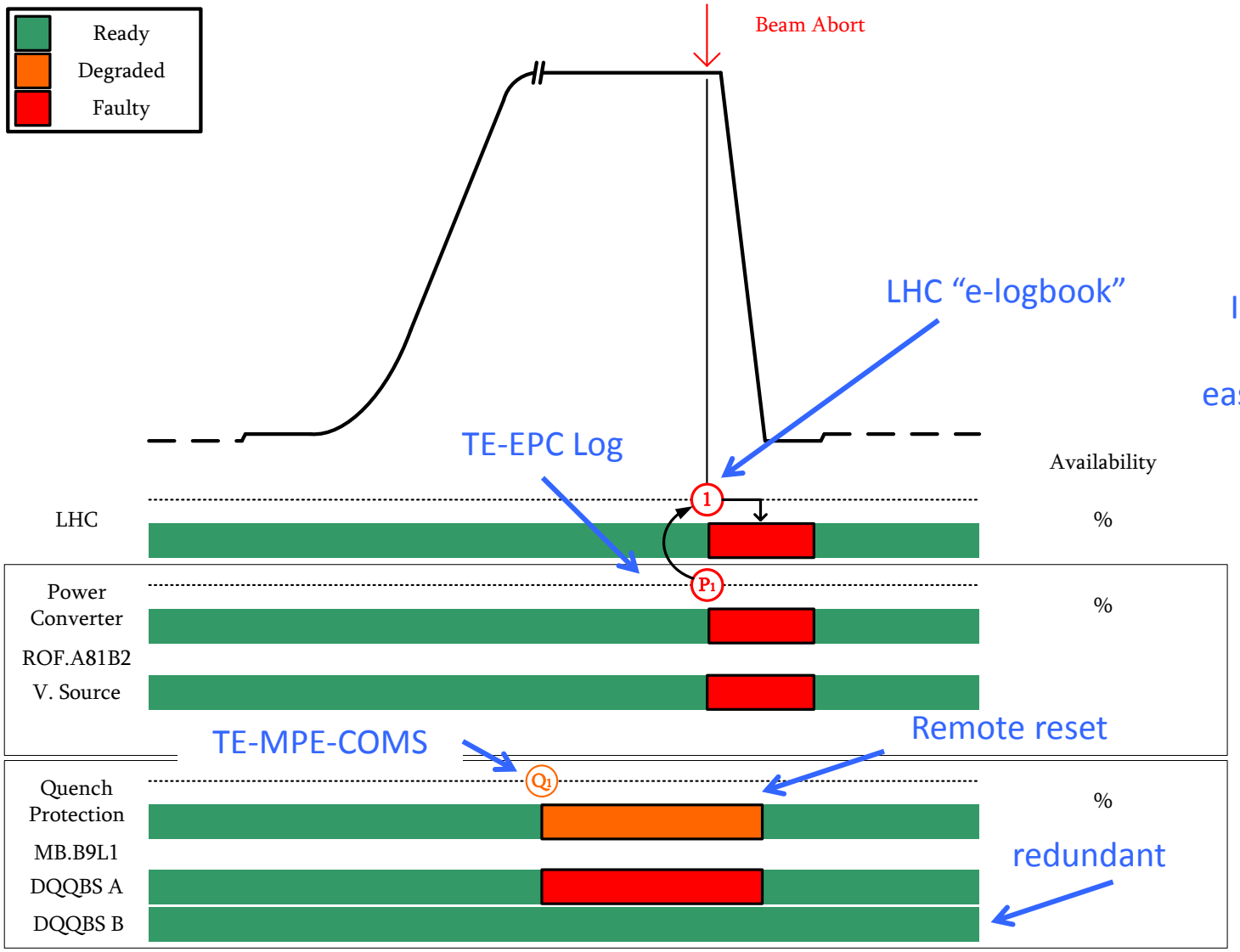


Impact on machine easier to infer

↓

OP view

+

TE-EPC view

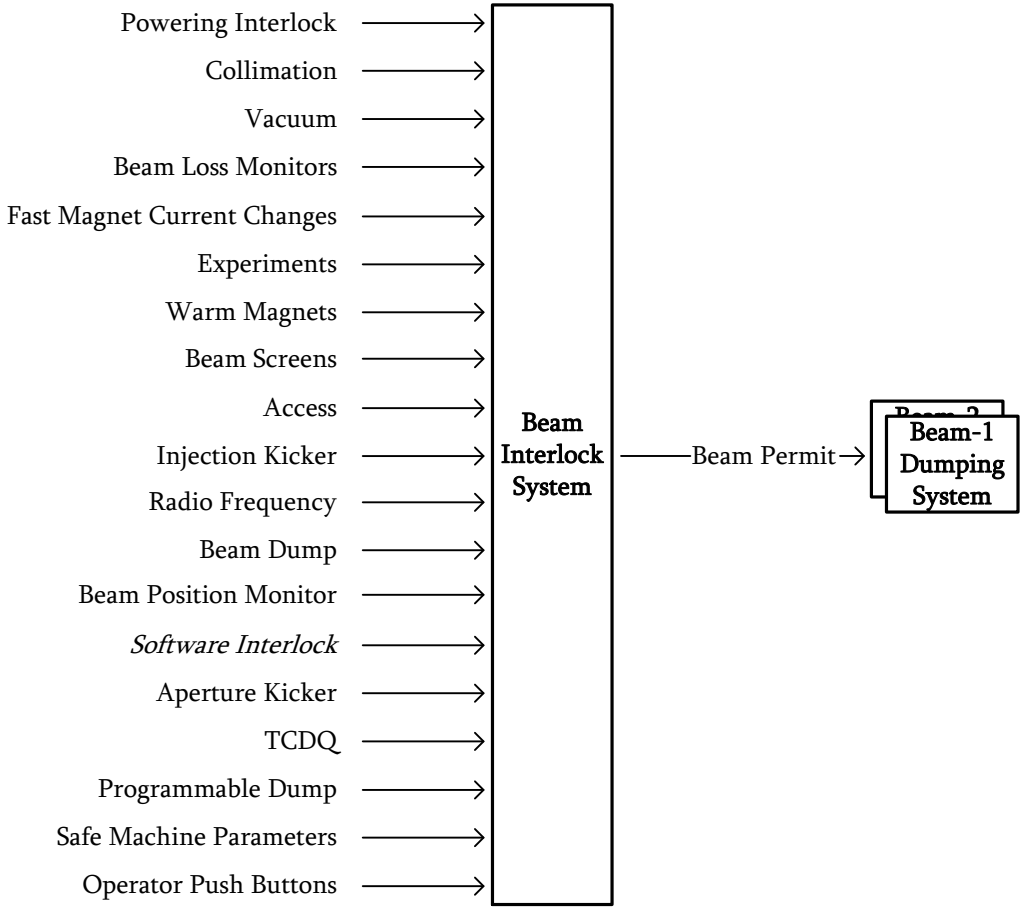
+

TE-MPE view

[13]

Hidden Faults

A worked example of potential dormant failure…



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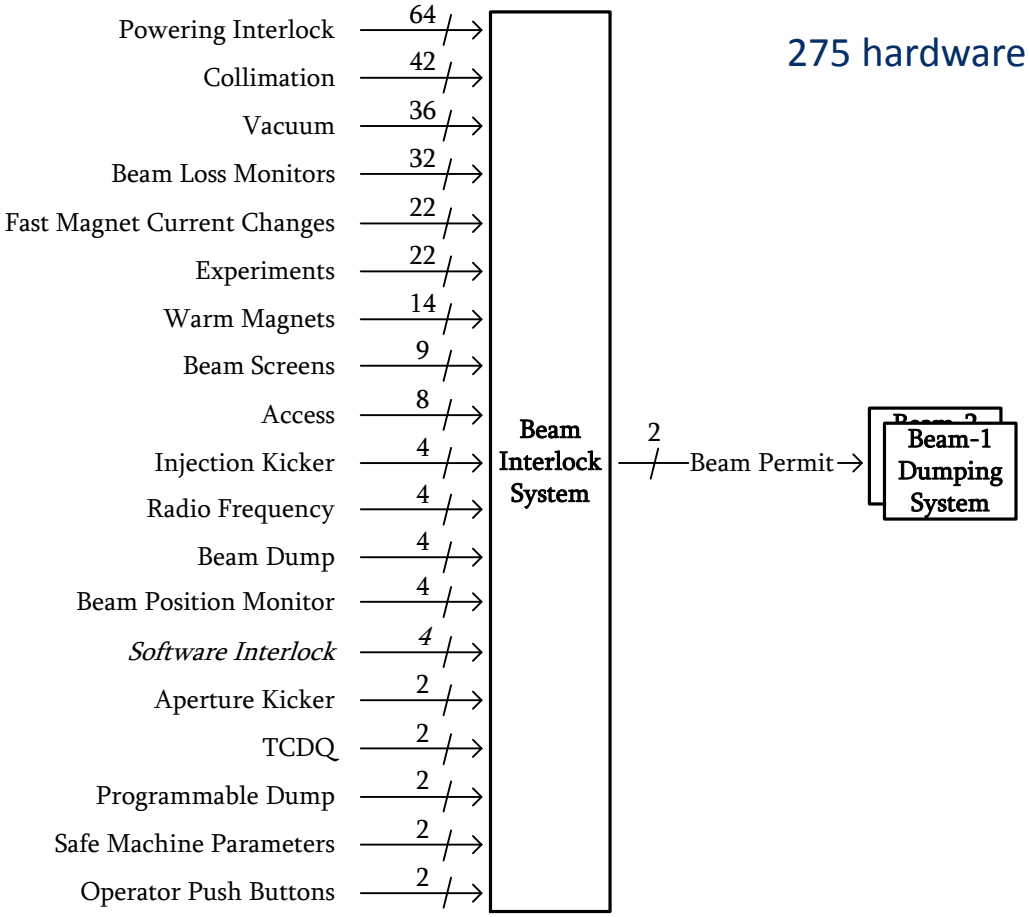

275 hardware inputs, 4 software inputs

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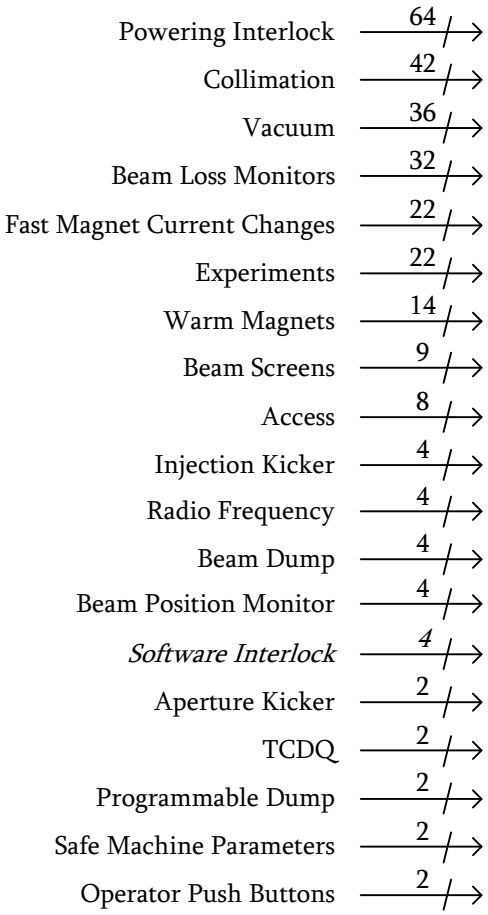


275 hardware inputs, 4 software inputs

136 (48%) never triggered

53 (19%) triggered once

564 (>50%) beam aborts from 12 inputs

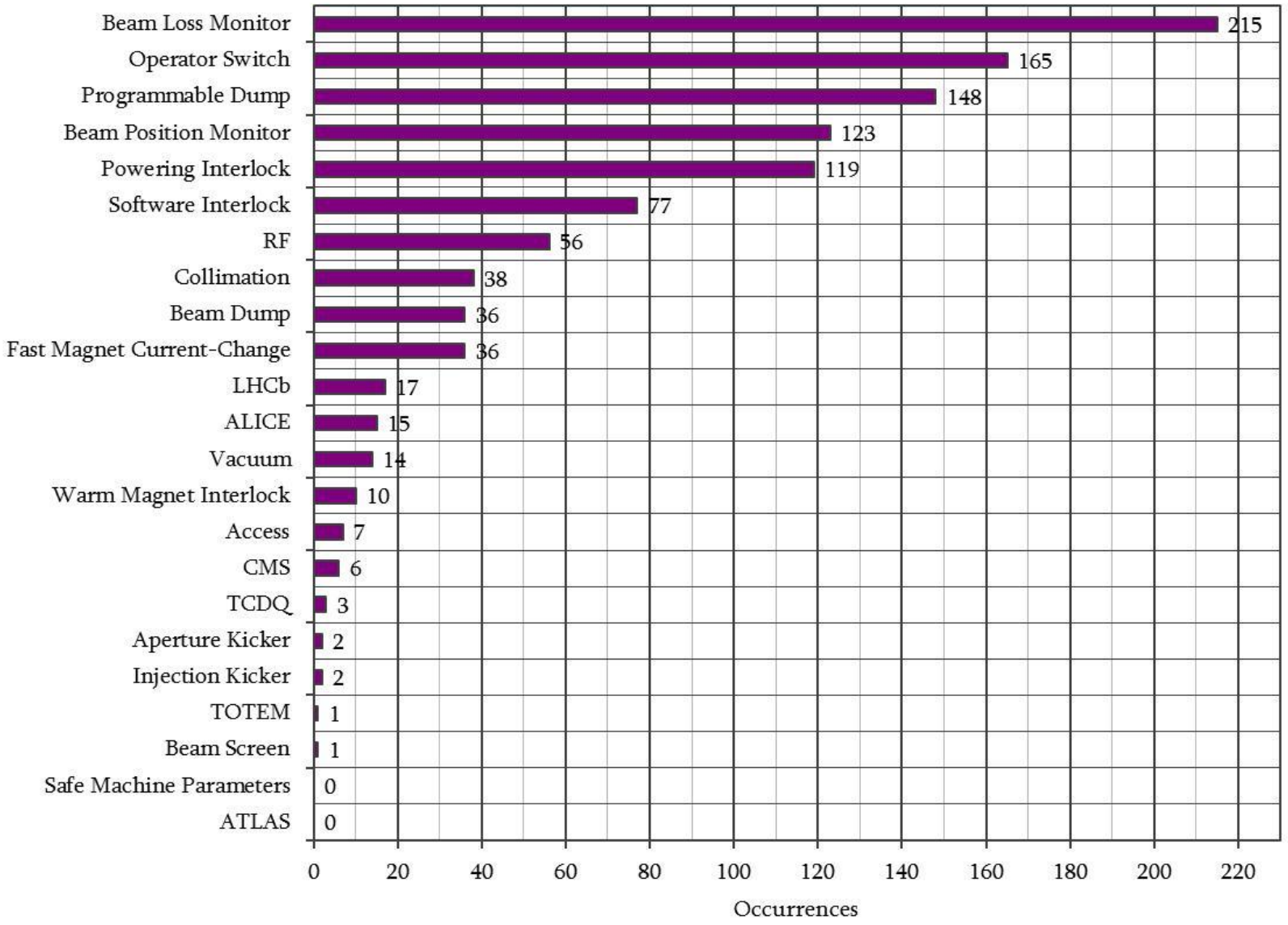
7 systems:

165 x Operator Buttons
148 x Programmable Dump
93 x BPM (IR6)
49 x SIS
45 x BLM (SR7)
43 x RF
21 x PIC (US15)

testing & maintenance plan needed - periodically ensure function.

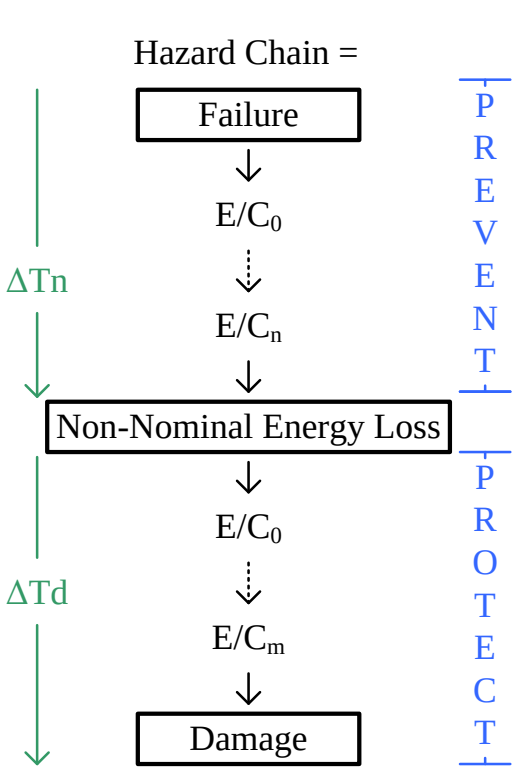
Beam Interlock System First Trigger

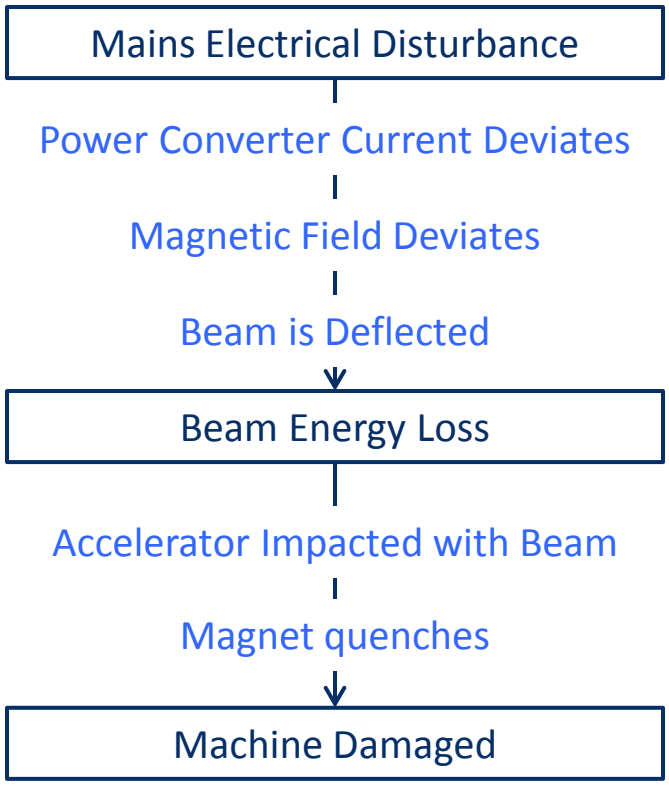
In 2012: 1090 beam abort events in the PM database



[4]

Defense in Depth





FMCM

Power Interlock

Beam Position

BLM

QPS

Based on risk: break chain many times, break chain as early as possible

BLMs were first trigger in 215 cases

What are hazard chains leading to non-nominal energy loss in these cases?
Can prevention be added?

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3. conclusions
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2010 - 2012

2012

LS1 +

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cannot rigorously correlate impact on physics using current information

→ fault tracker

dormant failures in parts of the MPS are not excluded → identify and test

Hazard Chains help identify if there are holes in protection → identify

Fin!
Thank you

References

[1] – PM database Extracted from 23rd March – 6th December 2010

[2] – PM database Extracted from 17th February – 13th December 2011

[3] – PM database Extracted from 1st March – 6th December 2012

- Fills above 450.1 GeV
- Ignore "no input change"

[4] – PM database Extracted from 1st March – 6th December 2012

- All fills

[5] – S. Gunther, I. Romera – Extracted from TE-MPE-COMS "FMCM" Issue Tracker

[6] – S. Gunther, I. Romera – Extracted from TE-MPE-COMS "PIC" Issue Tracker

[7] – P. Dahlen, S. Gunther, I. Romera – Extracted from TE-MPE-COMS "WIC" ignore SPS / TL events

[8] – C. Martin – Extracted from personal logs and TE-MPE-COMS "BIS"

[9] – R. Filippini – Compiled from TE-ABT logbook, LHC-OP logbook and experts

[10] – C. Zamantzas – Extracted from personal logs and BI-BMLS Issue Tracker

[11] – K. Dahlerup-Petersen, R. Denz, S. Gunther, I. Romera & TE-MPE-COMS "QPS" Issue Tracker

[12] – L. Ponce, J. Wenninger, PM database, filter by SIS, extract labelled events and generalise

[13] – raw data from Z. Charifoulline, compiled by A. Apollonio, B. Todd, based on work by the LHC Availability Working Group…