Update on Beam Failure Scenarios

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Thanks to:
T.Baer, R.Schmidt, J.Wenninger, D.Wollmann, M.Zerlauth, other MPP members and authors of publications I used

Introduction

- Standard failure scenarios at time of design of LHC Machine Protection System
  - Did they actually occur?
  - Did the protection work as we expected?
  - Do we need to change our protection for these failure scenarios?
- Some other failure modes we were afraid of
- Did failures occur which were not foreseen
  - Were we correctly protected against them or do we need to make changes to the MPS?
- Things which went differently
- Conclusions

Failure scenarios

- Failure from 2008, splice quench, was not included in the failure scenarios
  - People were aware of this failure mode but classified it as extremely unlikely
  - As a results no ‘Splice QPS system’
- Non-beam related failure mode
  - Not treated here
- However, it ***<u>shows the importance of getting the failure scenarios right</u>***

Slide from presentation ≈ 2004

R.Schmidt and J.Uythoven, June 2008, LHC Point 6.
Discussion on how the Beam Dump System reliability could be improved

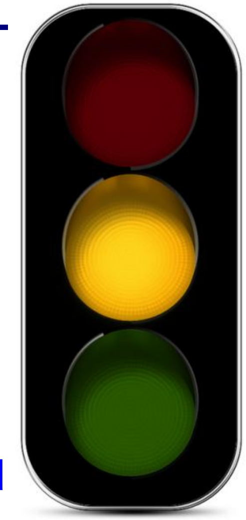
This failure scenario did not happen

The different failure scenarios

- The Big Three (*New J.Physics 8 (2008), R.Schmidt et al*.)
  - Single turn failure – Injection kicker flashover
  - Single turn failure – asynchronous beam dump
  - Multi-turn failure – normal conducting D1 magnets
- Some other failure modes we were afraid of
  - Other fast kickers/systems: MKQ / MKA / AC-dipole / Transverse Feedback
  - Beam hitting the cold aperture
  - The beam dumping system does not dump
  - Power cuts
  - Magnet quenches
  - Instabilities
- Some failures we were not afraid of but which happened

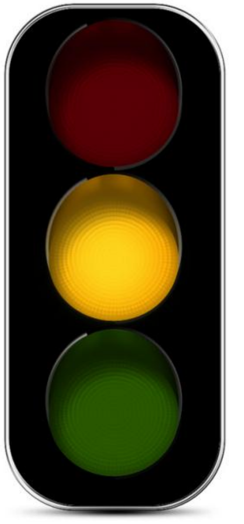
Classification

Single turn failure – Injection kicker flashover



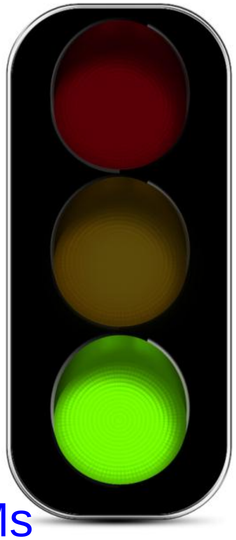
- Description
  - Injection kicker flash-over, affecting injected OR stored beam
  - Beam to be absorbed by the injection absorber TDI
  - Can expect quench
- Did this failure mode actually occur?
  - Yes, several times
  - In case of grazing incidence (sweep) downstream magnets quenched
    - As quench at injection energy, not a big issue for sc magnets
    - However, ALICE detector affected and short in some sc circuits related in time…
- Did the protection work as expected
  - Yes, beam absorbed by the TDI
- Do we need to change our protection for these failure scenario's
  - Not really, but it showed the importance of the correct positioning of the TDI
  - Additional difficulties because of heating / deformation of the TDI
    - Jaws move, position readings change
    - TDI got 'stuck' on some occasions
  - Actions
    - TDI out at injection, check temperature during operation
    - LS1: replace all present TDI with similar version – general service and rigid beam screen
    - LS2: complete overhaul, upgrade for LIU and HL-LHC

Single turn failure – asynchronous beam dump



- Description
  - One beam dump extraction kicker, MKD, firing asynchronously relative to the other 14 MKD kickers. Beam gets swept over the aperture and absorber elements
- Did this failure mode actually occur?
  - NOT in the way it was foreseen
    - No switch break-down
    - Trigger Fan Out problem – different recognised failure mode (see talk N.Magnin)
- Did the protection work as expected
  - Yes, TCDQ was in the right place
- Do we need to change our protection for these failure scenario's
  - Yes, TSU will be modified including powering
  - Showed dependency on TSU: add a redundant triggering of the BIS to the re-triggering (see talk N.Magnin)

Multi-turn failure – normal conducting D1 magnets



- Most critical of all powering failures
- D1 has large beta and beam can touch the collimators a few turns after the magnet power converter has tripped
  - Reaching 10^9 protons (detection) after about 15 turns
  - Reaching 10^12 protons at collimators (damage) could be reached after 25 turns
  - Between 15 – 25 turns the beam should be dumped via the BLMs

V.Kain LHC Project Note 322

- Did this failure mode occur
  - As part of general power perturbation and power converter trips
- Did the protection work as expected
  - Beam dumped by FMCM before significant change in current of the D1 or the orbit were measured.
  - This additional protection always worked, never needed to dump by BLMs
  - Sometimes worked too well: FMCM tripped but not power converter afterwards
- Do we need to change our protection for these failure scenario's
  - We might be dumping too early with the FMCMs and plan to relax
    - Presentation by Ivan Romera

Some other failure modes we were afraid of

- Other fast kickers/systems:
  - MKQ / MKA / AC-dipole / Transverse Feedback
  - Limited their strength and interlock operation of MKA / AC-dipole with safe beam only and extra keys ‘in the back (CCCR)’
    - As ‘Safe Beam Flag’ not SIL3, need special procedures in place to kick ‘stronger’. Put in place for MD with MKA

- Beam hitting the cold aperture
  - Never really happened
  - No beam induced quenches
  - Limits on collimation imposed by cleaning efficiency not an issue

Some other failure modes we were afraid of

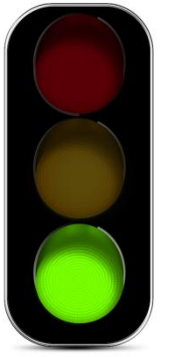
- The beam dumping system does not dump
  - List of ***procedures edms 1166480***, based on three different stages:
    - Force open the BIS loops using a number of client inputs and one of the BICs itself
    - Generate an internal fault of the LBDS
    - Last resort: scrape away the beam on the collimators in IR7, using ADT (parameters not finalised and could be very dangerous)
  - Tested without beam
  - Never needed

- Power Cuts
  - FMCM
  - Do we need to test calculate the SIL level of the FMCM if we like it so much?
    - Hardware AND acquisition chain

- Magnet quenches
  - No quenches at top energy
  - Only quenches due to injection failures.
    - Circulating beam always correctly dump

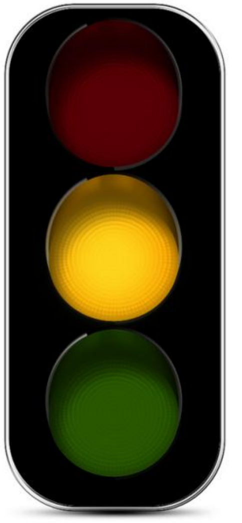
Some other failure modes we were afraid of

- Beam instabilities
  - When beams were unstable beams always safely dumped by
    - BLMs in collimation region
    - BPMS in point 6

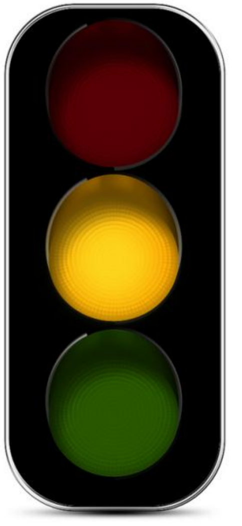


Some failures we were not afraid of but happened

- Injection errors
  - Injecting the wrong beam from the SPS after changing some injection timing settings SPS
  - Issues with the timing system
- Orbit feedback putting bumps in the orbit
  - Kind of protected by Jorg’s SIS / Kajetans software but this is very specialist and information to be spread
- Beam heating
  - TDI getting stuck or deformed
  - BSRT mirror possibly falling through the beam
  - MKI getting close to Curie temperature
- Other stuff falling through the beam
  - UFO’s, Roman Pots UFO’s



Some failures we were not afraid of but happened

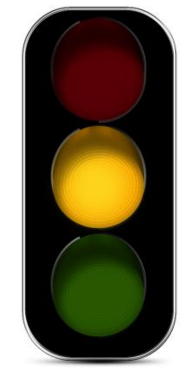


- Filling of the abort gap due to RF ‘failures’
  - These ‘failures’ often only discovered by filling of abort gap
  - Abort gap cleaning not fully automatic
  - Abort gap monitoring not working over several weeks
- Dumping one beam, absence of LR beam-beam kick dumping the other beam
  - MD 13/12/2012, did in fact not dump the other beam but measure 0.6 σ effect when other beam dumped
  - This is a one turn kick and is very fast…
  - Simulations for post LS1 ongoing (TB)
- Radiation leading to many false dumps (QPS)
  - Did they bring us into dangerous situation due to missing redundancy or surveillance?
- During last powering tests discovered some circuits unprotected by the QPS.
  - Reset procedures combined with (known) fault

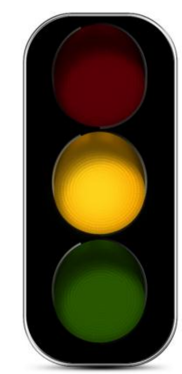
Things which went differently

- Never needed to mask BLMs because they're not working
  - Much better than expected reliability of the 4000 BLMs
  - General safety against all failures which are not too fast. Performed incredibly well

- Connect direct BLM to the beam dump
  - Only did this later during operation (for 2012)
  - However it never needed to trigger (as it should)



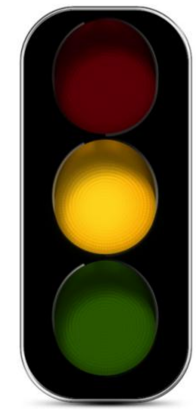
- Not done as such
  - Beam Position Change Monitor
    - Dump the beam if position changes faster than 1 mm/ms
    - No absolute reference
    - Not done. However, present BPMS with absolute measure against reference of *individual* bunches provide the required interlock in case of beam instabilities
  - Beam Current Change Monitor
    - Alternative to measurement of beam losses (at collimators)
    - Direct measurement of any problems; to be **operational** for 2015



- Many BIS channels never triggered. Do they (still) work?

Conclusions

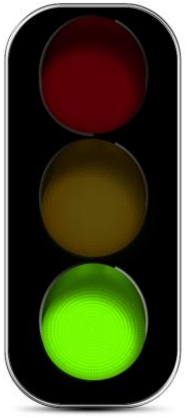
- The LHC Machine Protection System worked properly
  - No major damage after 2008.
- The Big Three failure scenarios
  - They all occurred, with some modifications !
  - However, *equipment weaknesses detected with equipment related to 2 oo 3 of the Big Three failure modes:*
    - TDI
    - LBDS – TSU and powering
  - Changes to FMCM related to the third failure scenario



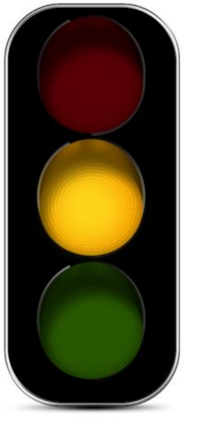
- Unexpected failure scenarios occurred (as expected)
  - Timing system, beam heating, orbit bumps, UFOs, abort gap, QPS
  - We need to further improve our protection against these due to improvement of the equipment involved and surveillance
- Continue to understand each beam dump (post mortem) before continuing operation

In other words

- On first glance, we might think that all is



- However, there was a lot of
  - This requires actions during LS1
  - Most of them treated at other talks in this workshop
  - A lot of work !



- Unexpected failures scenarios have been identified during operation over the last year. This will continue in 2015. If we don’t stay vigilant we might end up