Dump system protections

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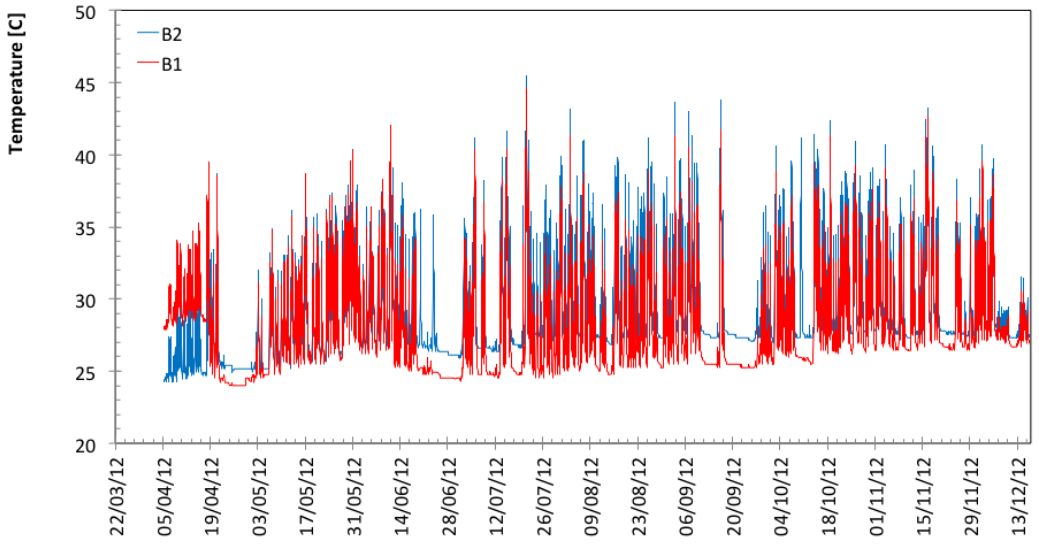
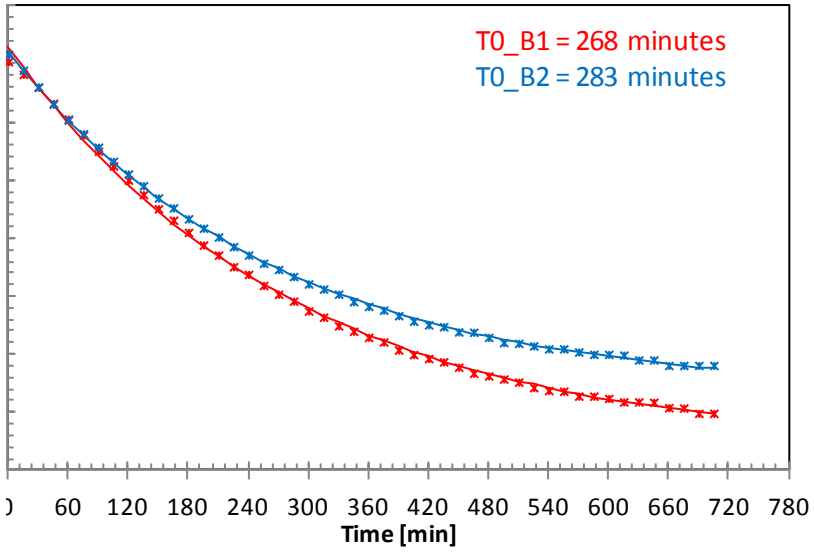
Contents

- TDE thermal response
- Connected systems: changes for LS1 and implications
  - New TCDQ
  - TCSGP-IR6
  - TCDQ connected to BETS (?)
- Improving availability?
  - Interlock BPMs
  - Relaxing tolerances for MKD kick and orbit
- Improving safety?
  - Abort gap monitoring
  - Better validation of dump protection
  - Operational procedures
- Summary

TDE thermal response

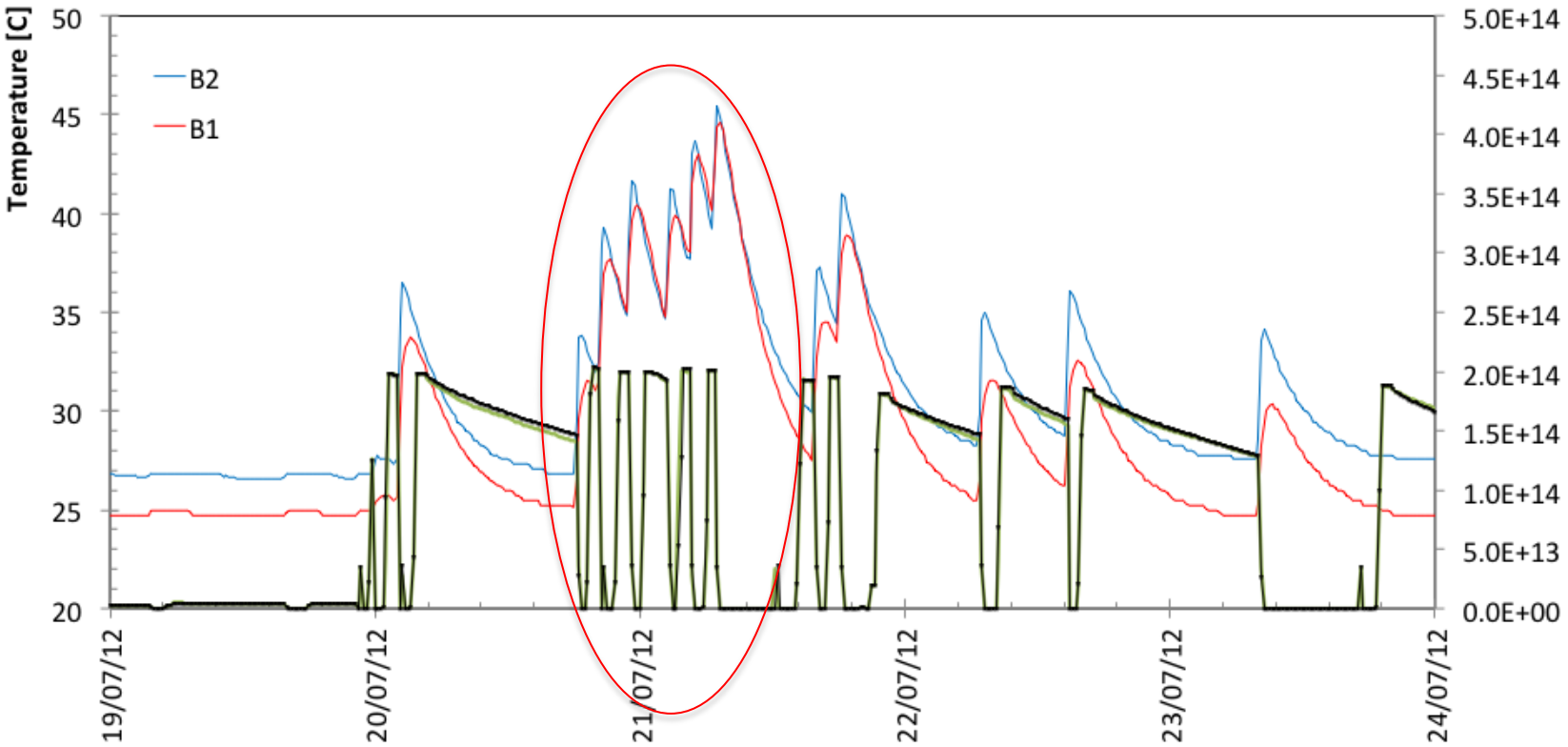
- Beam energy dumped on TDE
  - Maximum ~140 MJ
- TDE thermal response inferred from ΔP data
  - 10 K peak average temperature rise for single dump
  - Reasonably consistent with expected average temperature rise of block + steel jacket (would expect about 22 K if all absorbed and instantaneously spread)





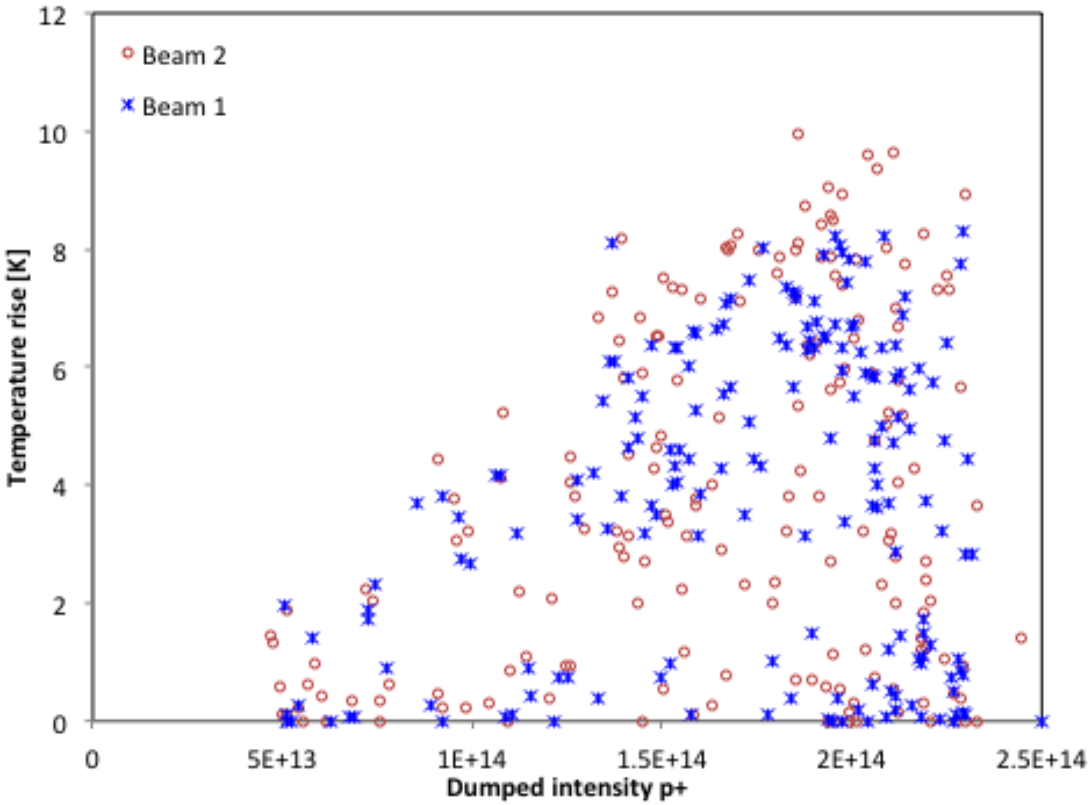
TDE thermal response

- Repeated dumping pushes peak to ~20 K rise
  - Example during 4-5 fills lost with losses on TCTH.4R5.B2
  - 6 high energy, full intensity dumps in 12 hours (good turnaround….)!



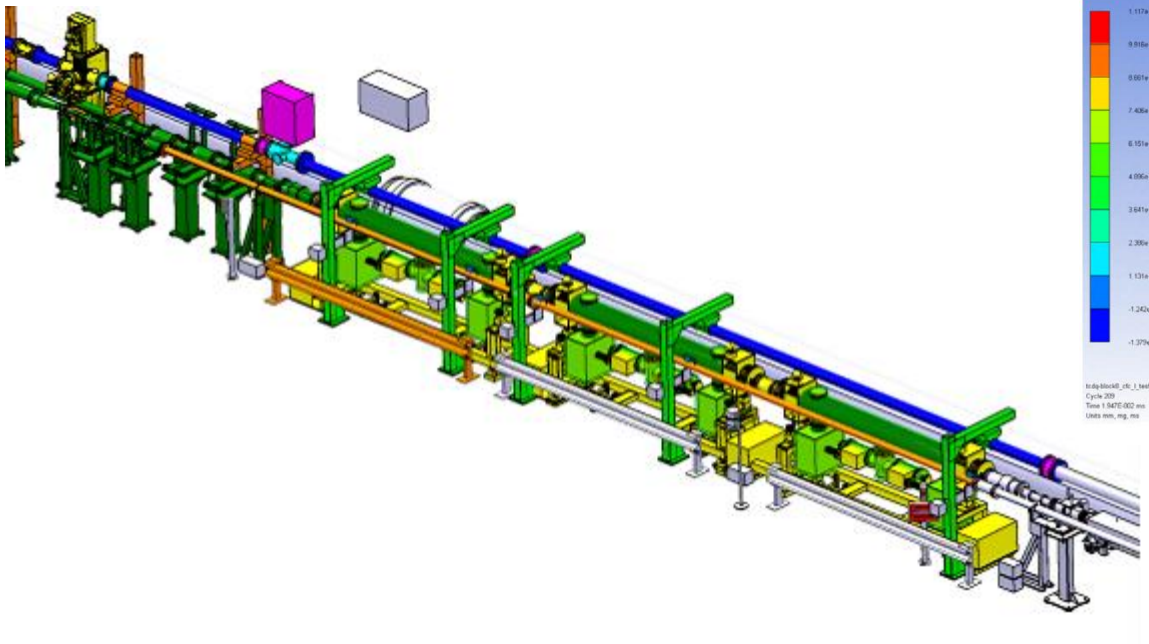
Extrapolation to 6.5 TeV, 25 ns?

- Maximum delta T is ~5 K per e14 p+
- 6.5 TeV, will get ~8 K per e14 p+
  - About 27 K for full nominal intensity 25 ns beam
  - Maybe 55 K for repeated dumps…or ΔP of 233 mbar (to 1.5 bar)
  - Need to be careful with N_2 pressure / venting (nominally kept to 1.3 bar!)



Changes in LS1 – TCDQ upgrade

- Existing 6 m long graphite TCDQ (2 tanks) being replaced by 9 m long CfC diluter (3 separate tanks, external movement)
- Upgraded version robust to 2.5×10^{11} p+/b @ 25 ns (HL-LHC max)
- LVDTs to be replaced with potentiometers
- Motorisation modified to increase stroke and angle (to ±1.1 mrad)



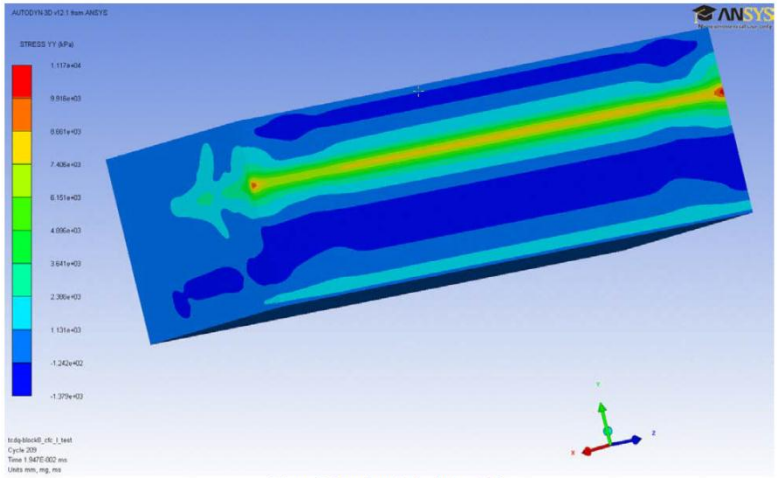
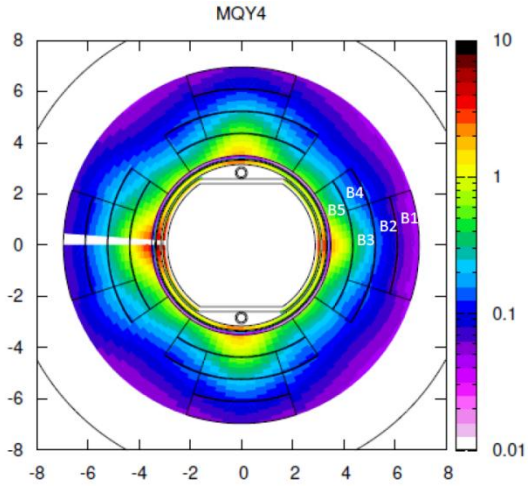
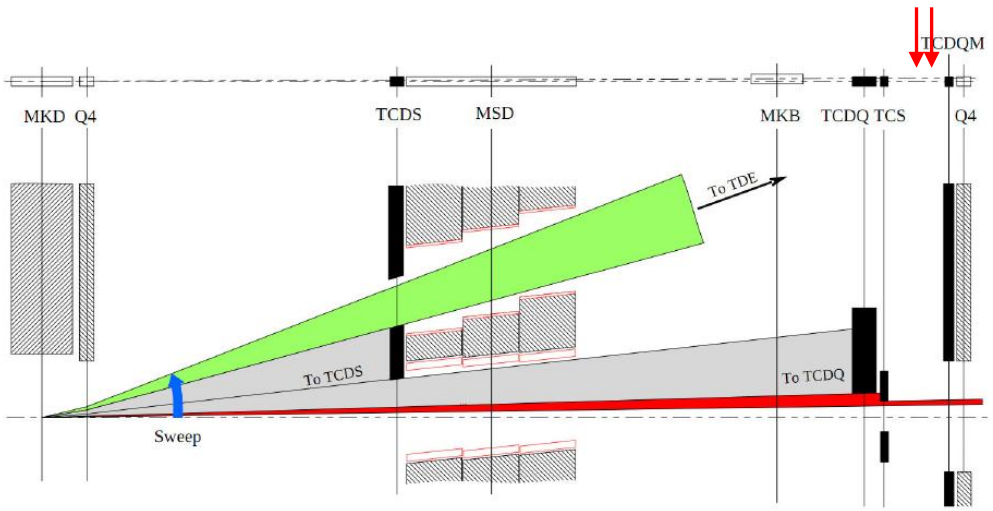


Figure 7: Tensile principal stress YY

(No) changes in LS1 – IR6 TCLAs

- Space left between Q4/TCDQM and TCSG/TCDQ for H + V TCLA
- Reducing cleaning losses on Q4, and reducing peak load in Q4 after asynchronous dump
- Energy deposition in Q4 simulated with new TCDQ and HL-LHC beam parameters: maximum 20 J/cm^3 in coil. (Q5: 40 J/cm^3)
- Conclusion : "*not needed for the operation after LS1 from the magnet protection point of view*" -> no installation in LS1



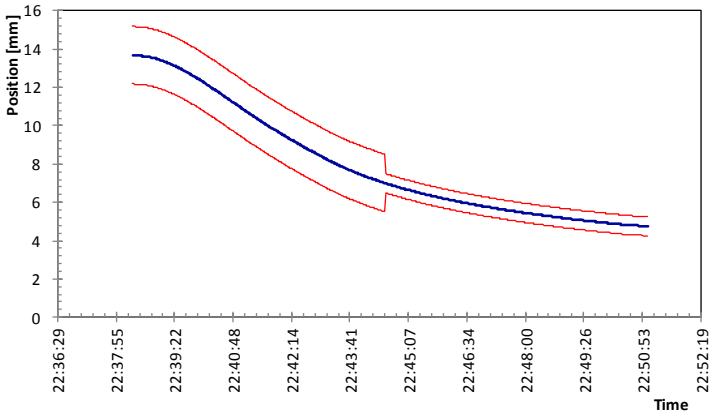


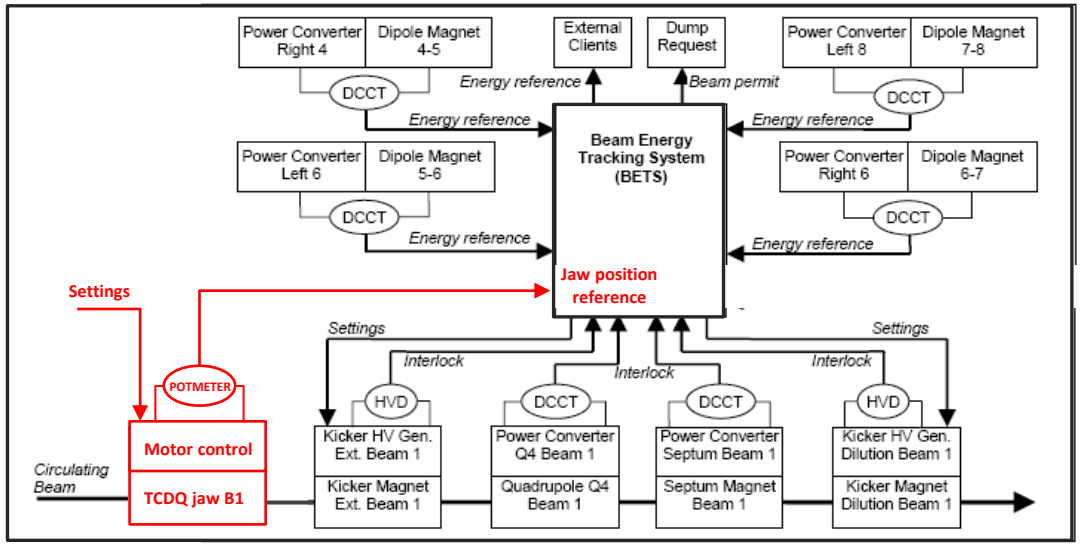
Changes in LS1 – TCSGP/IR6

- TCSGP to be installed for IR6L/R;
- Jaw BPMs will allow more accurate setting-up of TCSG without touching the beam (presently 1.5 sigma TCSG->TCT);
- Orbit instability main contribution, not setting-up accuracy;
- Difficult to immediately 'use' tolerance gained (~1.1 sigma?) in β^* reach as TCSGP and TCDQ would need to dynamically follow orbit
- Present SW interlocking can move to TCSGP to improve accuracy;
  - Investigate if HW implementation possible to avoid CMW etc. issues
- Main gain setting up time/accuracy, and interlock accuracy.
  - No immediate plans to have dynamic changes of collimators to follow orbit
  - Will take some time to learn with the new system

Changes in LS1 – TCDQ in BETS

- TCDQ jaw positioning to be added to BETS system for dump (HW interlock);
- Will generate a synchronous dump if the position reading goes out of tolerance (function of energy);
- New electronics needed in order to be able to mask this input to the BETS when Setup Beam Flag == TRUE (otherwise not possible to set up TCDQ with low intensity);
  - Could overcome if connect BETS to BIS, not directly to TSU (suggested for TDI)?
- Implementation details (electronics, fibres, ...) to be worked out after the MPP WS





Improving availability - BPMS

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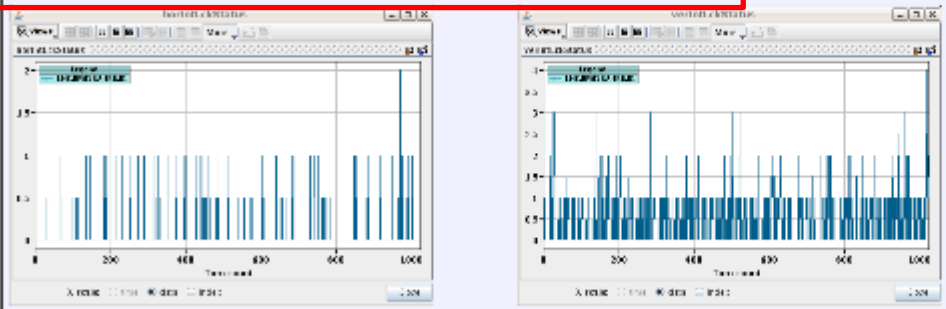
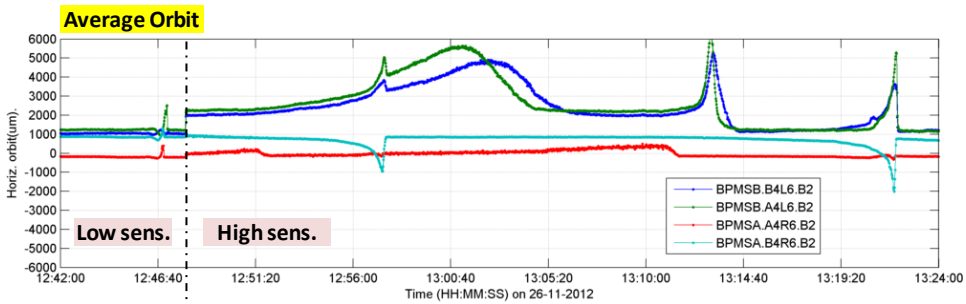
Interlok BPMs for last dump: Similar to the previous fills, BPMSB.A4R6.B1 dumped the beams.

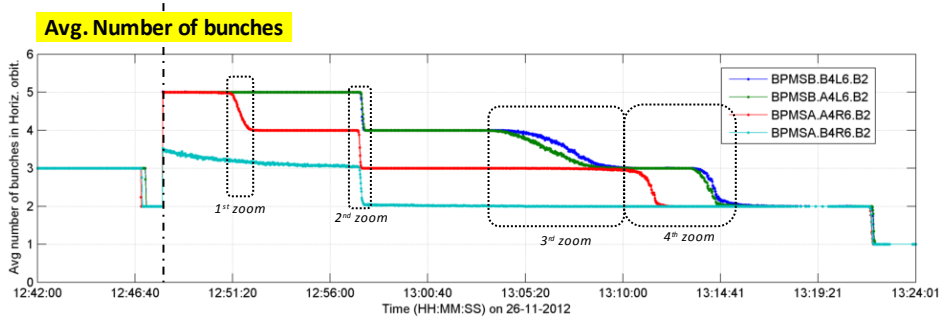
Going to relax the threshold for this BPM



BPMSB.A4R6.B1.Hor.Dump15h00.png BPMSB.4R6.B1.Ver.Dump15h00.png

Improving availability means improving safety, in this case...





Improving availability - BPMS

- Interlock BPMs in IR6 frequent source of dump triggers – for good reasons
  - Many “correct” dumps when beam unstable
  - Reading also suffers when bunch intensity drops below threshold
  - Simple logic for dumping beam (N wrong counts in window of M turns where N includes also bunches with bad readings)
  - Several interventions made to adapt attenuators to increase dynamic range (measurement needed afterwards to scrape beam and check)
  - Relaxed on a few occasions the single channel limits (with ions)
- Changes foreseen for LS1
  - Improved Post-Mortem diagnostics, to be able to trace origin of dump (bad bunch reading, position out tolerance, ...) $\rightarrow$ into XPOC
  - Improvements on system to increase dynamic range?
- Calibration made every fill only taken into account when FEC rebooted - change?

Improving availability – BPMS tolerances?

- ±4 mm maximum orbit excursion acceptable at LBDS (TCDS and MSD losses)
  - Should ensure (transverse) loss free dump
  - Checked during initial LBDS commissioning at injection, and indeed OK
  - Beam extracted ~cleanly with 14/15 MKD available – tested in 2010 commissioning. But NOT combined with 4 mm orbit offset (independent failures)
- BPMS thresholds now set to about ±3.0 mm around measured orbit
  - ±1 mm for fast dynamic orbit changes (plus initial uncertainly on BPMS HW)
  - Do we still need ± 1 mm? PM data of positions on BPMS at dump would help decide
- Options:
  - Tighten thresholds to improve HW protection against instabilities. But not needed for dump aperture and will adversely affect availability.
  - Open thresholds to give more margin for bad bunches – assuming 2 um emittance we might gain ±2 mm. But need to then 'interlock' beam emittance (or rely on losses at TCPs?). Also TCDS protection of MSD also depends on maximum local orbit excursion. Plus BPMS response non-linear.
  - Improve beam centering in BPMS or update more frequently threshold centre wrt measured orbit – but both would bring marginal gains
- Best solution is to address issue of BPMS dynamic range.

Improving availability/safety – MKD tolerances

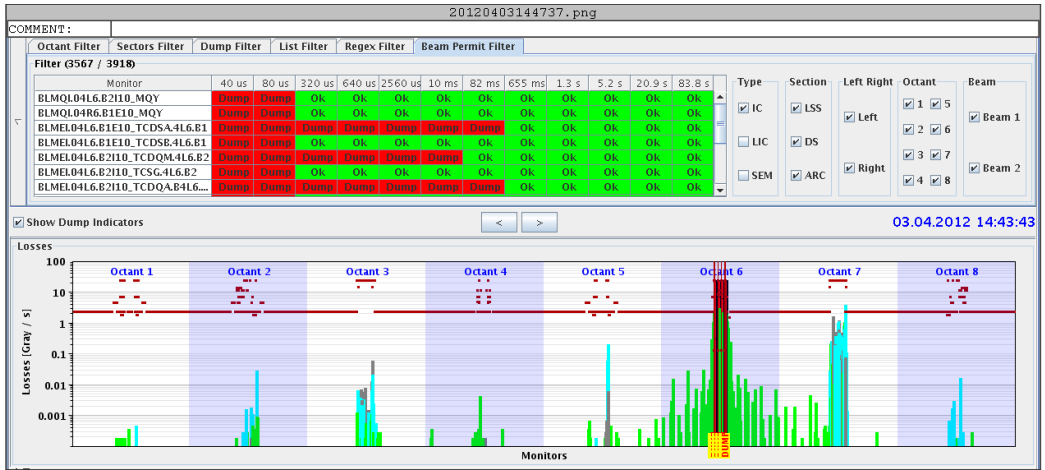
- Dump channel aperture was designed for ±4 mm orbit, 3.75 um emittance at 450 GeV, 0.27 mrad MKD total kick, and 14 or 15 MKD firing
  - Validated under these conditions, including missing MKD case
  - Much effort made in stabilising temperatures of MKD switches (Peltier system) to reach specified current stability (±0.5 – 1.0 %)
  - Very close control of actuators and sensors (power supplies, voltage dividers, ...), but operational issues (full 24h recalibration or FE adjustments of calibration factors)
- Experience from Run 1 shows smaller emittance and more stable orbit than foreseen in design. Also no missing MKD (yet)...
- Margin for MKD/B current error could potentially be increased safely (e.g. by small reduction in BPMS thresholds)
- Could conceivably use this margin to stop cooling the switches, and to stop fudging FE calibration factors when components are changed
  - Would need wider IPOC and XPOC tolerances
  - Less sensitive to gradual degradations of switches/connections
  - ABT equipment experts prefer to keep constant operating switch temperature
- Not recommended to stop cooling, despite need to keep complex system running
- Question of calibration factors needs to be discussed in more detail – compromise between minimising risky manual updates, and having nice tight thresholds for operational tolerances to spot degradation

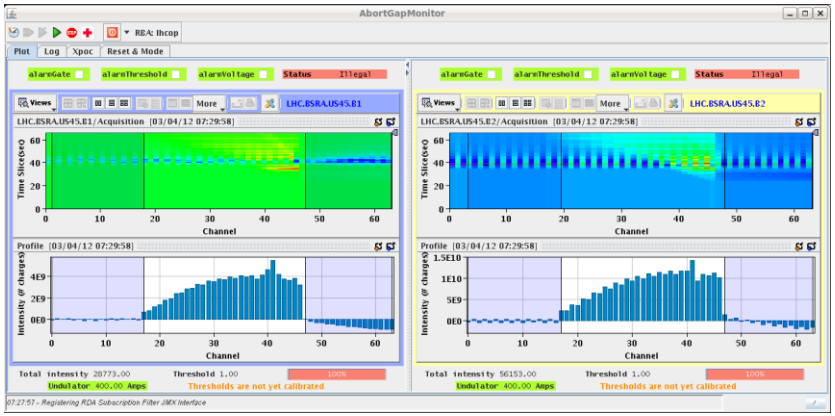
Improving safety – abort gap monitoring/cleaning

- Presently using AGM (BSRA signal) with “wetware” connection (Announcer + EiC) to BIS to launch AGC or dump beam
- Concept is working well (clean dumps, problems are spotted)
- Issues include:
  - Reliability of this approach (SIL 0?) – e.g. must not mask/turn down announcer
  - Backup system in case of BSRA issues (addressed in 2012 after BSRT failure with compensatory measures including periodic AGC)
  - Dependence on BSRT steering
- Possible improvements include
  - Improvements to AGM with automatic calibration, to improve availability to a level where SW connection to AGC and/or BIS could be foreseen (for dump only?)
  - Development of backup abort gap population measurement, from diamond BLMs in collimation region or/and from experiments?
- Still needs definition of optimum overall approach plus BSRA HW upgrades
- To follow in a coordinated way – specifications to discuss and generate
- For cleaning, impact on luminosity to solve – would allow AGC ‘always on’
- Need also to quantify how important AGM/AGC is for safety – eg TCT settings

Improving safety – dump protection validation

- Presently we make asynchronous dump loss maps analysed ‘by hand’
  - During commissioning, after configuration/collimator changes, periodically with collimation loss maps
  - Should standardise when/which asynch maps are needed, before run starts!
- Always some beam in abort gap and measurable losses on TCDS/TCDQ
  - Note that this only gives loss map in collision, without 1.2 mm offset at TCDQ
  - Should consider updating XPOC module to check TCDQ/TCT loss ratios
  - Trending analysis?
- More sophisticated tools using Diamond detectors (needs improvement)?
- XPOC modules to review (TCDQ/TCSGP/losses/abort gap population/...)





Improving safety – operational procedures

- Operational procedures were very complete for LHC commissioning phase (we had lots of time to prepare), but less well defined for regular running
  - Clearly impossible to foresee all combinations of problems / faults / configurations
- Most important aspects are that: a) potentially dangerous situations are recognised and communicated and b) that time is taken to discuss before allowing operation to proceed
  - This requires open communication and availability of experts
  - It also requires Machine Coordination / Management to take warnings seriously – it is not easy to say “we need to stop the machine while we think”, but it’s much better than exposing the machine to potential damage
- Strongly support need to continue rMPP as an ‘online’ reactive body, able to provide a consensus on possible issues – reinforcement important
- Need a better definition of what to do in terms of requalification for different types of equipment intervention (power supply or switch exchange, ...)

Summary and conclusions

- Still waiting for 1st Asynchronous dump with full machine at high energy
  - Continue to maintain and even improve associated protection
- Changes to some systems connected to LBDS for LS1 designed to increase robustness / safety / availability
  - TCDQ absorber, TCDQ in BETS, new TCSGP, improved AGM, improved BPMS, XPOC module for dump protection validation
  - Work needed now on agreeing specifications and requirements
- Need also to carefully consider associated changes in commissioning and validation procedures
  - Forum for this? Commissioning team, MPP, LIBD?
- Relaxing tolerances for MKD current by removing temperature control or to ease recalibration needs could be possible, but may then mask onset of other issues – needs full discussion
- rMPP / experts role still crucial for post-LS1

Topics for follow-up

- When/if TCLAs will be needed in P6?
- Maximum TCDQ-TCSGP6 retraction, and MP issues of orbit ‘tracking’ ?
- Connecting BETS to BIS, rather than TSU?
- BPMS dynamic range, procedures for threshold changes and calibration improvement?
- Relax MKD tolerances to gain simplicity in revalidation (but lose some trending ‘trigger’)?
- BSRA availability, and automatic triggering of cleaning and/or dump?
- Alternative abort gap monitoring?
- Abort gap cleaning transparency?
- XPOC modules to review (asynch dump checks, abort gap population, TCDQ/TCSG retraction/setting, ...)?
- Procedures for revalidation after component exchange to review?