Machine Protection in 2011 and beyond
Session 6 - Summary

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LHC Performance Workshop 2011

Session Overview

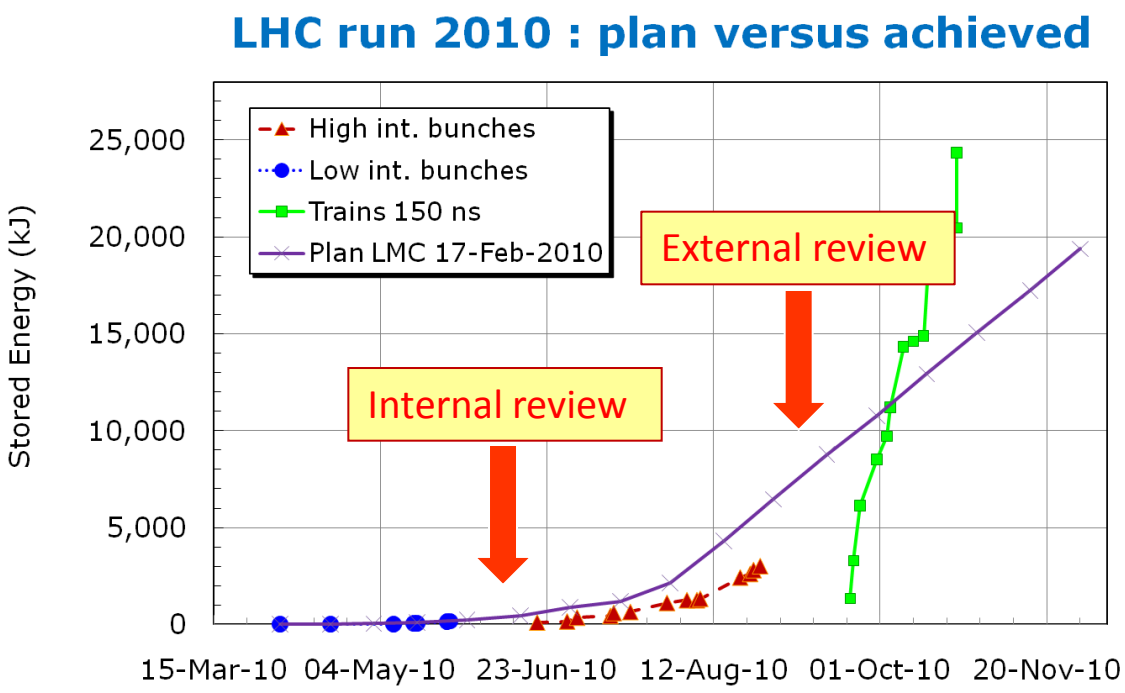
Session Mandate:

The session intended to provide a synthesis of the experience with the commissioning and operation of the LHC machine protection system during the initial 2010 run. The focus was on the stored energy target of 30MJ, but also to identify possible show-stoppers , their necessary mitigations and trying to identify a strategy to start increasing the intensity beyond the 2010/11 target, with a special emphasis on injection protection for very unsafe beam (ie >= 32 bunches).

1. Experience with MPS during 2010 run – **Jorg Wenninger**
2. Can operations put the MPS into an unsafe state? – **Laurette Ponce**
3. Preparing the MPS for the 2011 run – **Jan Uythoven**
4. Is the BLM system ready to go to higher intensities? – **Mariusz Sapinski**
5. What are the issues with injecting unsafe beam into the LHC ? – **Chiara Bracco**
6. Is there a limitation to the stored beam energy for 2011 and beyond? – **Rudiger Schmidt**

Experience with the MPS in 2010

- Increase of intensity/stored energy in 2010 partially driven by understanding of Machine Protection System performance
- The intensity increase plan was reasonable given that we were in a commissioning year
  - Don't forget we had a steep and sometimes rocky learning curve (operation + MPS) in parallel
  - Not a single accidental beam induced quench with circulating beam!
  - Very good stability of orbit and beam cleaning but not yet sufficient for nominal tolerances
  - Issue of controlling fast losses (UFOs) dominated final slope (still 4* steeper than planned)

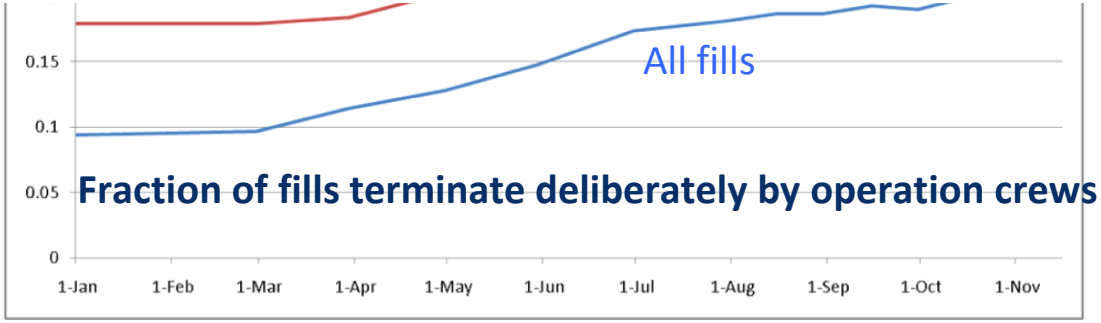


J.Wenninger

Minimizing the human factor

- Tuning of the nominal sequence and training of operations crews additionally exercised the MPS in 2010
  - Large majority of events are annoying, but 'only' impact availability
  - Only very few occasions where redundancy of MPS has been broken, e.g. masking interlocks, etc… Good news: Sometimes unexpected redundancy kicked in
- Considerable efforts ever since to mitigate potentially dangerous events & to increase availability (less manual tasks, sequences to unmask interlocks, state machine, no stop points in squeeze, feedbacks,…)
  - Additional tools like e.g. Abort Gap Meter would be highly beneficial

LHC EIC: "Hardly ever managed to make the same mistake twice, when coming back on shift there was normally already something prohibiting me from doing so again… "



L.Ponce

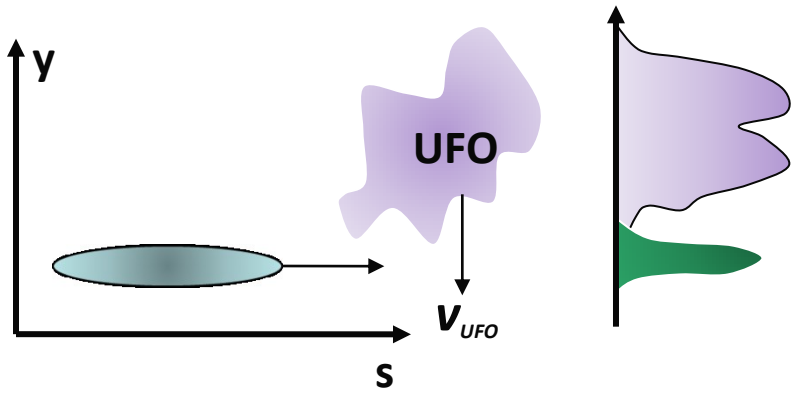
Preparing the MPS for 2011 run

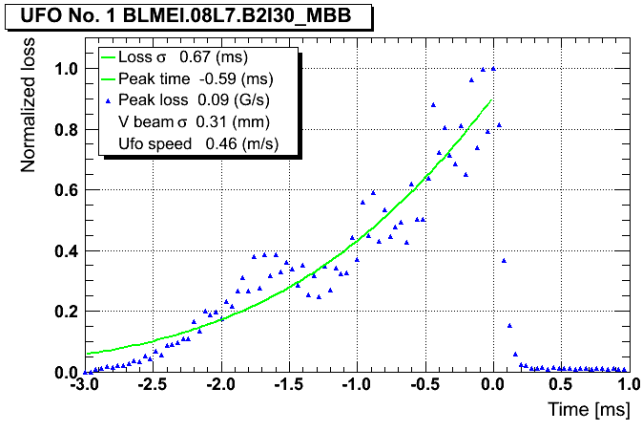
- MPS undergoing an impressive amount of changes in this Technical Stop (> 65 items with sizable impact identified)
- Essential for dependability of MPS systems to track related changes during technical stops & machine operation -> need better / dedicated tools
- Improvements focus on known weaknesses seen during 2010 operation and aim at improving Safety & Availability
- Full re-commissioning required (~ 12 days during cold checkout and beam commissioning)
- **Operational envelope for 2011 as seen by machine protection systems**
  - **Energy:** 4 – 5 TeV due to some noisy BLM cables and 4.5 TeV due to HV break downs of beam dump generator MKD (to be solved during 2011)
  - **Intensity:**
    - Limited to 144 bunches per injection in present configuration
    - Nominal for circulating beam, but small risk of limited TCDQ damage in case of asynchronous dumps -> detailed studies ongoing
  - Effect of small **emittances** on TCDQ needs more studies
  - **Limit $\beta^* \approx 1.5$ m** due to risk of exposing collimators (depending on orbit stability, beta-beat etc.) -> Needed to be balanced with risk of increasing energy

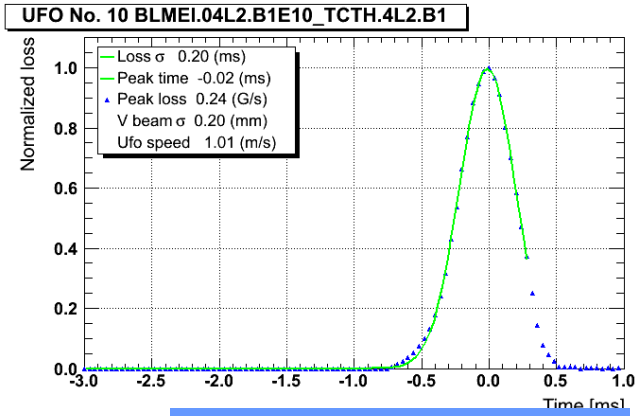
J.Uythoven

Beam Losses in 2010 and the UFO story…

- Excellent performance of the BLM system, catching & precisely measuring as well unforeseen events (fast losses)
- Few events and variations of losses between identical stable fills not fully understood
- UFOs have been THE surprise in 2010. Current hypothesis of (dust) particles interacting with the particle beam(s)





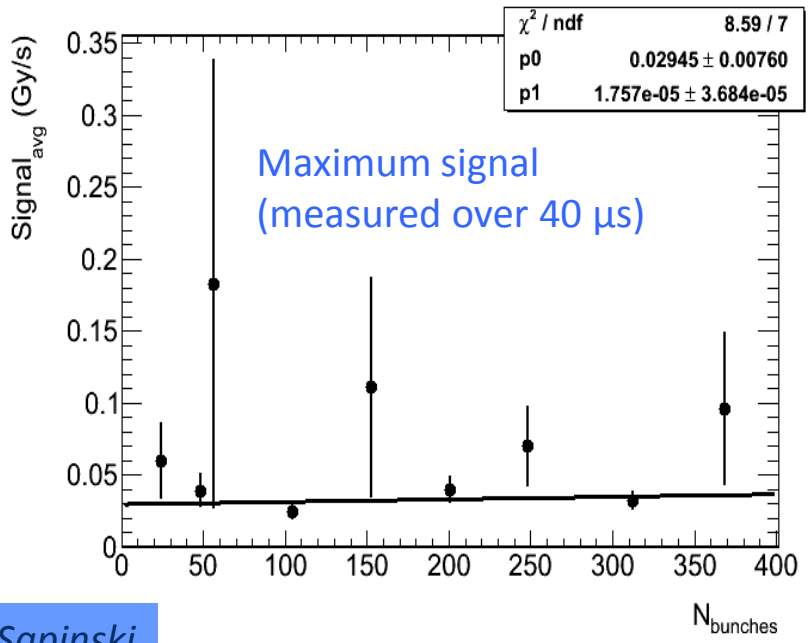


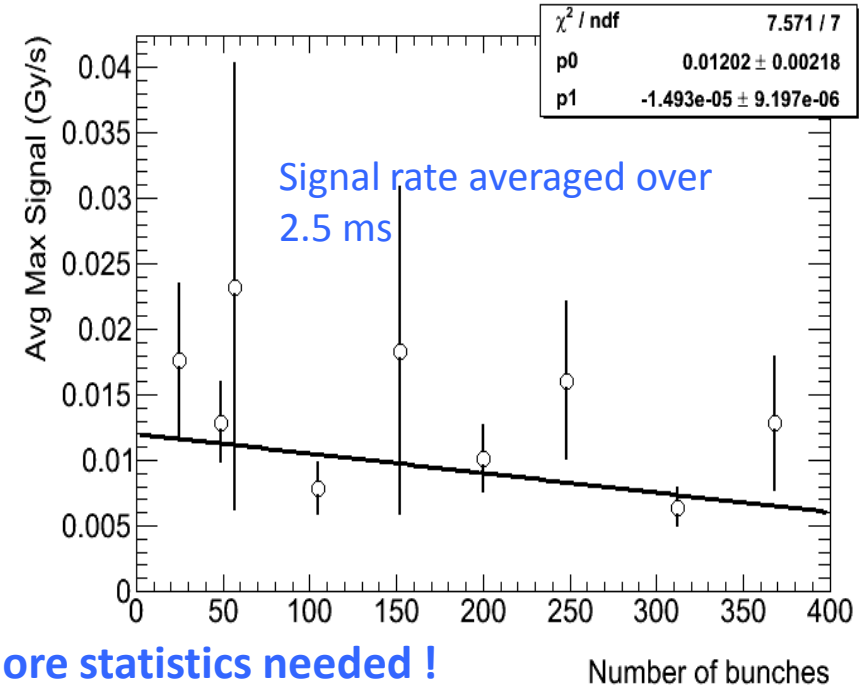
- 3D density profile can be complicated, BLMs allow us to get a glimpse at the overlap of beam and UFO
- 2 types, increasing/decaying losses @ dump time
- Average speed of this precursor 0.31 m/s < v_{Free_Fall} : could indicate that the UFO was larger than the beam, and that it fell across the beam…

Courtesy of J.Wenninger

Beam Losses in 2010 and the UFO story…

- Lot of effort has gone into the analysis of these events and we know much more today:
  - Equally distributed around the ring (34 is not special) ☹
  - More events at higher intensities ☹
  - Only 1 event at 450GeV, scrubbing maybe not possible/inefficient at this E? ☹
  - Signal shortens, i.e. the losses are faster with intensity ☹
  - Speed != free fall, electromagnetic forces involved (1-2 'bouncing' UFOs observed)
  - Signal amplitude does not increase with intensity ☺ ☺



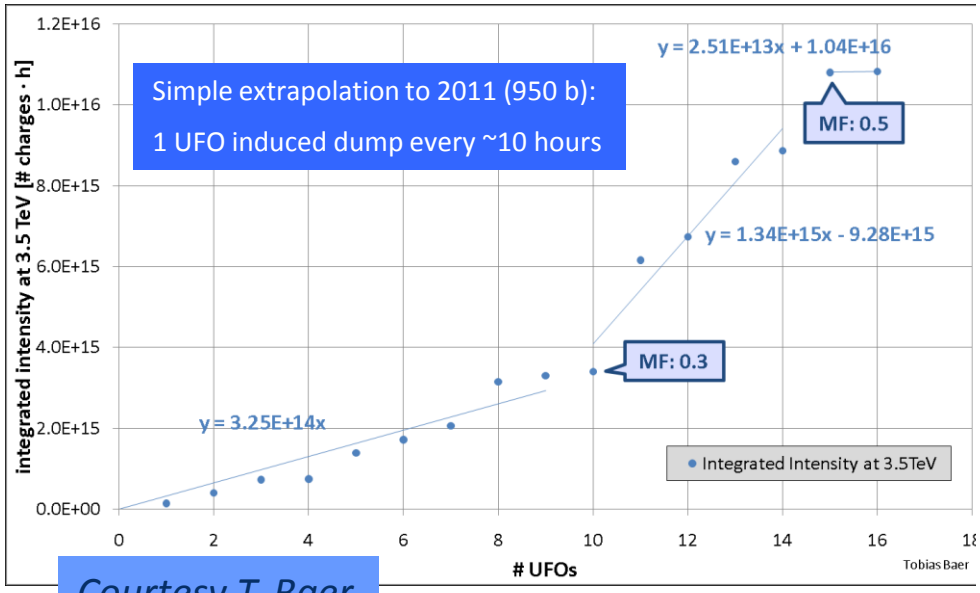


M.Sapinski

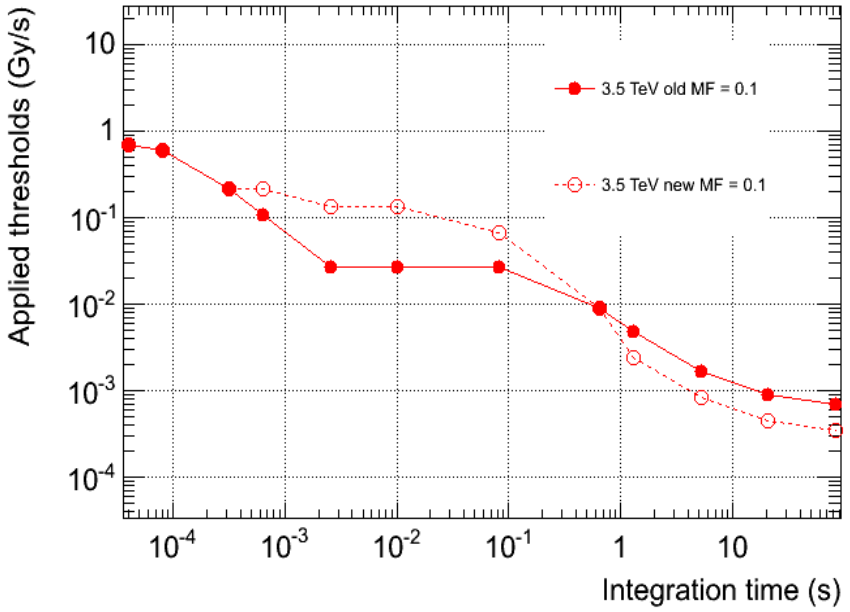
More statistics needed !

UFOs vs BLM thresholds – the solution?

- Revision of thresholds on sc magnets could make the UFO effects acceptable, e.g. after increase of the BLM Monitor Factor by a factor of 3 about 4 times fewer UFO related beam dumps
  - increasing the thresholds for ms-scale losses
  - lowering thresholds for losses longer than 1s (quench test showed thresholds for long losses on MQ magnets to be underestimated by factor 2-3)
- Increasing thresholds more delicate for 4TeV than for 3.5TeV (risk for > quenches), more analysis to understand discrepancies with current simulations + additional quench tests to benchmark



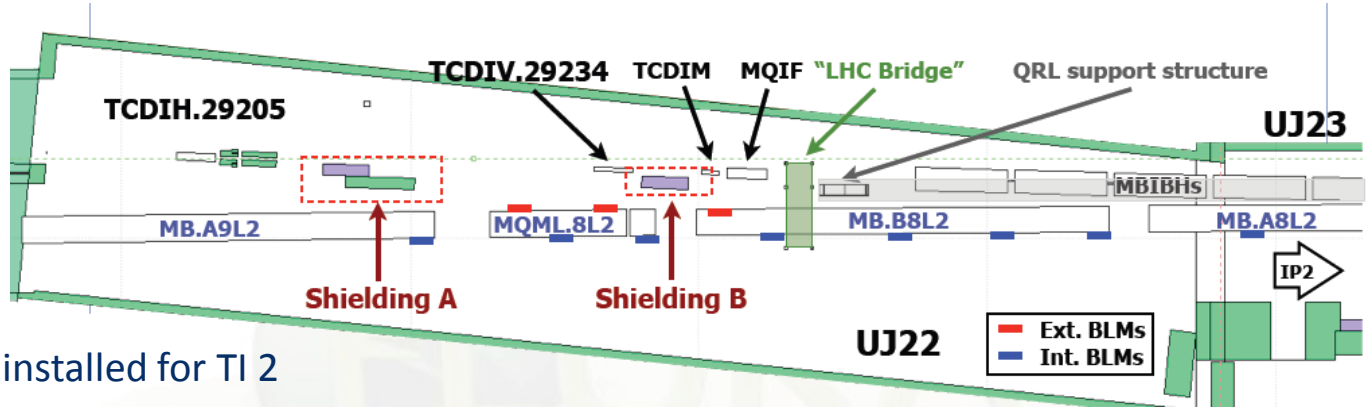
Courtesy T. Baer



How much beam can we safely inject in 2011?

- To inject safely into the LHC depends fundamentally on correctness of
  - **State machine**
  - **Setup of injection protection collimators** (in particular TDI) ➔ safe machine also in case of failures of other systems (for example MKI)
- Injected already unsafe beam in 2010, predicted limit for **2011 is 144 bunches** (due to losses at end of TL triggering BLMs in the LHC ring)
- A number of **possible solutions** to go to higher intensity have been presented
  - No impact on MPS: Shielding, Abort gap and injection cleaning, Improved diagnostic
  - Modifications to MPS (under discussion): BLM sunglasses (masking of LHC BLMs during injection), increased BLM thresholds, larger TCDI apertures
- **Upgraded and safer logic** for operation of **injection protection collimators** has been agreed and implemented but needs to be carefully reviewed/tested

C.Bracco



Shielding installed for TI 2

It can still go (seriously) wrong…

- No serious limit for beam energy and intensity for the next 2 years, but are we safe in the long run?
- Additional mitigations where risk of (beyond repair) damage is possible
  - Occasional magnet quenches to be avoided, but not considered a major risk for LHC
  - Full (nominal) batch injected into LHC = 3 MJ: Damage beyond repair is unlikely, but availability of spares could be an issue
  - Serious failures of beam interlock or beam dumping system can result in serious damage to large parts of the machine
- In the light of 2009-2010 experience, should start quantitative studies of catastrophic failures with simulation programs (see also A.Bertarelli's talk in session 5)
- Assess and implement additional mitigations of serious failure modes of BLM, BIS and LBDS, e.g.
  - BLMs close to TCSG in IR6 to be connected to Beam Dumping System
  - Fast Beam Current Change Monitor
  - Procedure for CCC: What to do if an operators requests a beam dump, and it does not work?
  - TCDQ / TCS positioning to be improved (e.g. energy tracking)
  - Redundant triggering interface between BIC and LBDS
  - TCDQ consolidation should take into account studies of beam tunnelling simulations (stop full beam with minimum consequences)

R.Schmidt

Summary

- Machine Protection and Safety has become a daily concern not only of MPS experts, but also operations and equipment experts!
- A lot of work has gone into additional improvements for the 2011 run and we can expect a safer and more available machine in 2011
- The usual word of caution: Beware of any unusual / degraded operation of the machine (protection systems) as during MDs, interventions, technical stops, ….
  - E.g. air safety statistics show that majority of fatal mistakes are not made during times of peak load, but right afterwards… -> remain vigilant!

Thanks a lot for your attention and to all speakers and the MPS/OP teams for help in preparing this session!

"Harris, when I said 'any questions' I was using only a figure of speech."