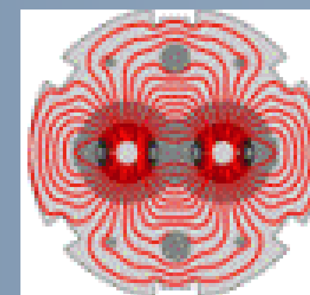
How to safely reach higher energies and intensities?

Settings and commissioning of MPS for 5 TeV operation



Preconditions for operating at 5 TeV in 2010

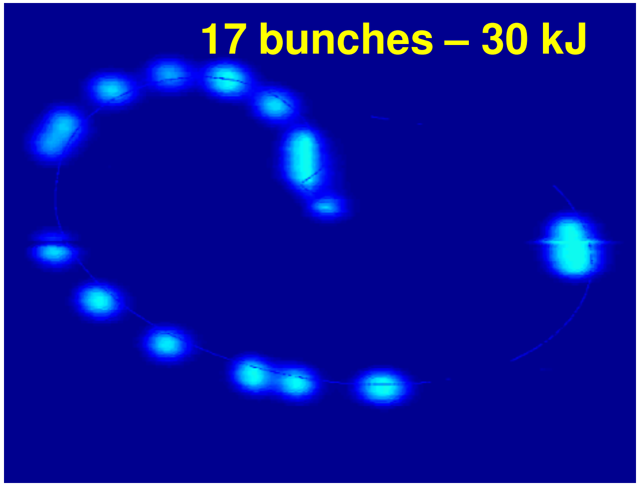
Session 1 - 25th January 2010

J. Wenninger BE/OP

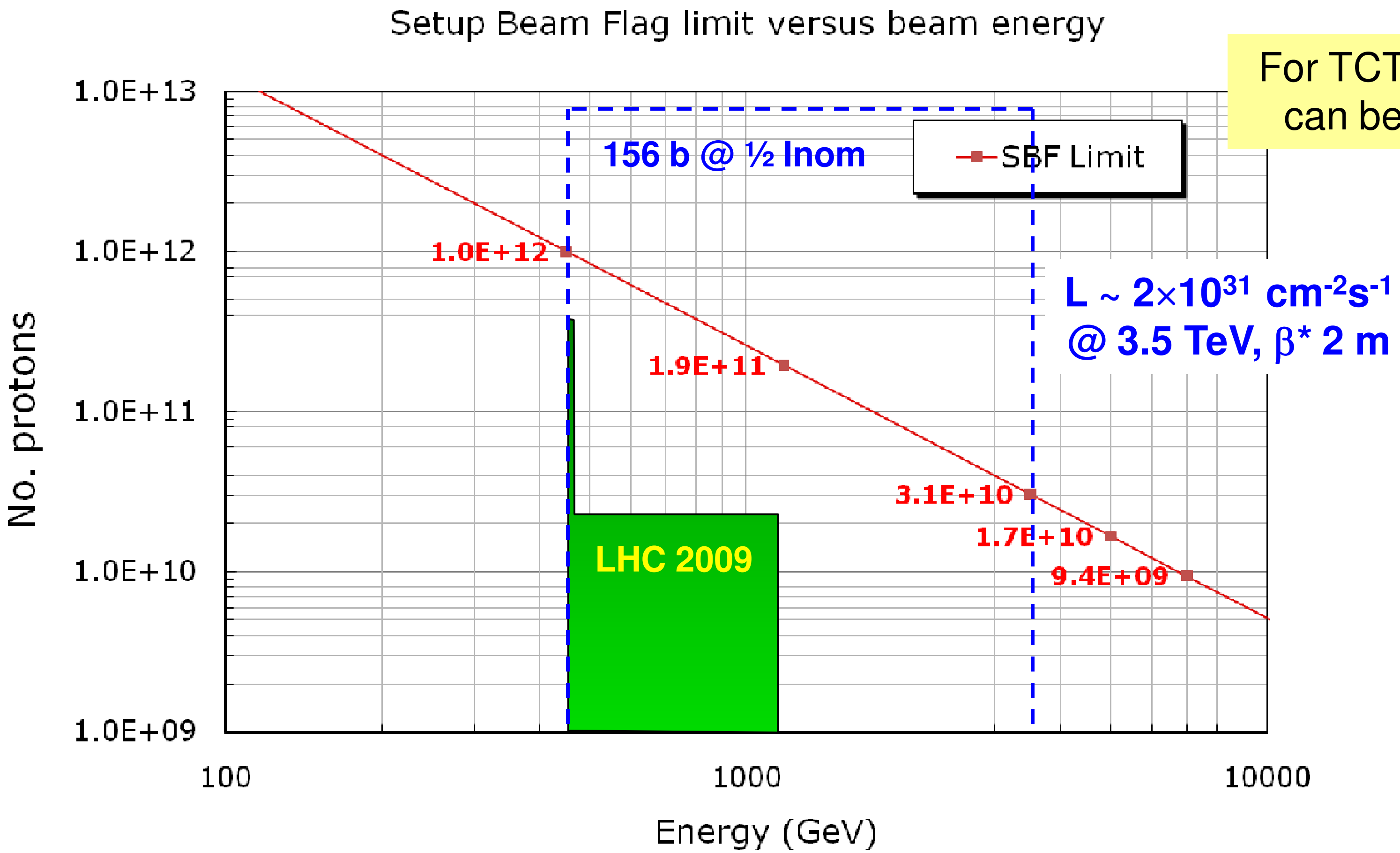
MPS in 2009

- The large majority of interlocks were tested and ACTIVATED !
  - and we could still operate the LHC !
  - and we did not quench with circulating beam – thank you collimation !
  - the '*with so many interlocks it will never work*' scenario did not occur !
- But the beams were modest – compared to design:
  - the maximum stored energy was ~30 kJ – a factor 10'000 to go…
  - no beam made it above the SBF limit.

The 2010 plans imply World record stored energies ~10xTEVATRON to be reached on the time scale of a few months !



MP footprint



For TCTs the limit can be lower !!

A pilot bunch (5E9 p) is the only beam that can be used for commissioning (and for most MD) activities at ≥ 3.5 TeV !

Status of LHC MPS – end 2009

- **MPS tests without beam.**
  - Almost completed (some test were not required for low intensities).
  - Only a few need to be repeated (equipment changes or upgrades).
- **MPS tests with beam.**
  - ~2/3 of individual system beam tests completed.
  - Global setup and tests were performed for injection energy.
    - Setting up of collimators and absorbers (some only partially).
    - To be repeated at all energies and β^* values.
  - A major item missing in 2009 was abort gap cleaning.
    - Tested, but operational (one undulator missing !) and not interlocked.
    - Critical at high(er) intensity and small β^* (aperture limited by triplet).

The more tricky issues from 2009

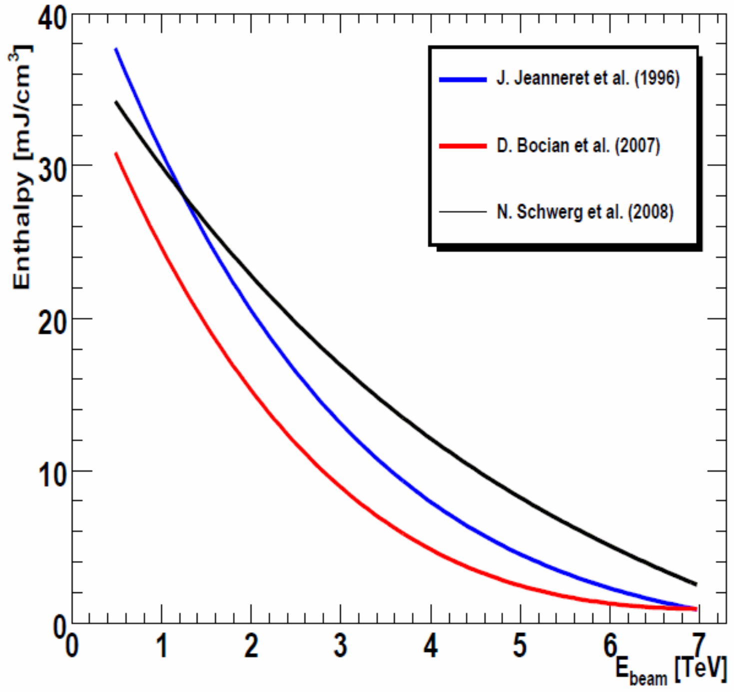
- **Safe Machine Parameters (SMP).**
  - Reliability issues on ‘Safe Energy’ before startup with beam.
  - ‘Setup Beam Flag’ and ‘Beam Presence Flag’ issues related to BCT.
  - ➢ Solutions are (will be) in place to address safety issues – to be evaluated.
  - ➢ SMP system specification and design to be reviewed in 2010.
- **BLM signal ‘cross-talk’ and saturation (see previous talk).**
  - **Remarkable performance of the (very complex) BLM system.**
  - BLMs at injection dumps saturated for short time scales.
  - Losses on transfer line collimators induce large signals on ring BLMs.
    - Scrapping in SPS mandatory – reliability issue (ISR scrappers !).
  - Over-injection not possible on ring2 due to similar effect from injection dump losses.
  - ➢ Solutions should be available for the startup…

3.5 TeV, 5 TeV …

For MPS *operation at 3.5, 5 or 7 TeV is essentially equivalent*.

(splices not considered here…)

- Emittance, minimum β* and collimator settings are different.
  - Collimators and absorbers must be setup again at every energy.
- Quench level decreases with energy.
  - Collimator setup more critical at 5 TeV.



Moving towards unsafe beams

To operate with unsafe beam:

- All MPS system test steps must be completed (with/without beam).
- Global protection tests must be completed.
- Collimators and absorbers must be in place.
  - Injection protection only required when unsafe beams are injected directly.
- Beam diagnostics must be working.
- Post-mortem diagnostics must be adequate.
  - In place, more online analysis to be developed.
- Operational cycle must be established.

Trust your systems

The systems that are part of the MPS monitor equipment and beam parameters and aim to safely extract the stored energy in case of failure.

- Safety levels are either unknown or estimated from reliability analysis.
  - ‘Dry’ operation to verify reliability estimates (LBDS and BIS reliability runs).
- Critical point: common cause and correlated failures leaving the machine unprotected in some situations!
  - Protection redundancy based on a diversity of systems reduces likelihood of correlated failures – but we do not always have redundancy.
  - Careful performance monitoring during operation may reveal issues before they are the cause of incidents.

Confidence in the safety is mostly obtained by running the system and monitoring it carefully >> this takes time !

A good and stable setup

For unsafe beams, we need a careful machine setup, a well established operational cycle, good diagnostics and a reliable control system.

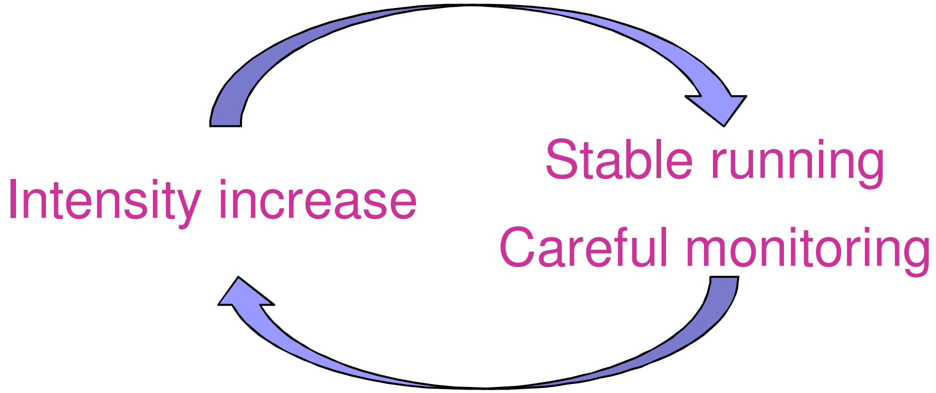
- Machine must be under control.
  - Optics, orbit, aperture.
- Protection by collimators and absorbers at all times.
- Appropriate interlock settings (BLMs, PCs…).
- No (if possible!!) operational mistakes.
  - Good sequences, state machines, clear UIs…
  - Avoid dangerous failure coincidences (OP error + other failure).

And there is the beam

The beam is a complex variable in the MP game.

- ❑ Must control and know shape and position.
- ❑ Tail populations and distributions are an issue.
  - The tails of a high intensity LHC beam constitute an unsafe beam.
  - Available reaction time to certain failures depends strongly on tail properties. And tails can vary a lot (beam-beam…).

We must build up experience step by step:



Startup 2010

The ‘safe’ part: ⇔ **proposal from Evian Workshop (19-20.01)**

- Initial operation with setup (‘safe’) beams (I < SBF limit).
  - Up to 4 pilot bunches/beam are ~ at SBF limit (3E10) – limited risk.
- Step 1: establish STABLE BEAMS @ 3.5 TeV, β^* = 11 m.
- Step 2: establish STABLE BEAMS @ 3.5 TeV, β^* = 2-3 m.
  - Commissioning of β^* squeeze in parallel to physics with β^* =11 m.
  - No intensity increase wrt Step 1.
- No more ‘Quiet beams’ periods.

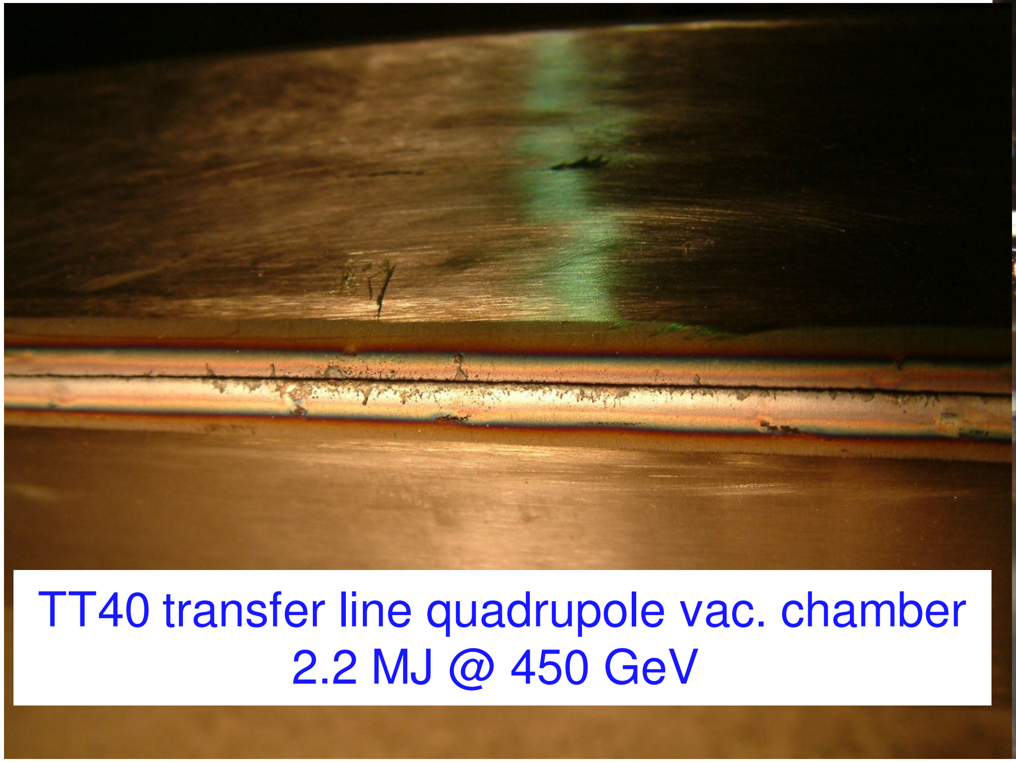
Increasing intensity

- Monitor MPS performance and operation stability.
  - Losses (all machine phases), Post-mortem diagnostics,
- Green light for intensity increase by MPx:
  - MPP for machine protection performance.
  - MP3 for magnet performance (quenches…).
- Moderate intensity steps.
  - f ≤ 2-4 max, f decreasing function of intensity).
- Maximize luminosity/stored energy.
  - Increase bunch intensity first, then increase number of bunches.
- Plan a long(er) stable running period at ~0.5-1 MJ stored energy – that 's when we start drilling holes in the SPS!

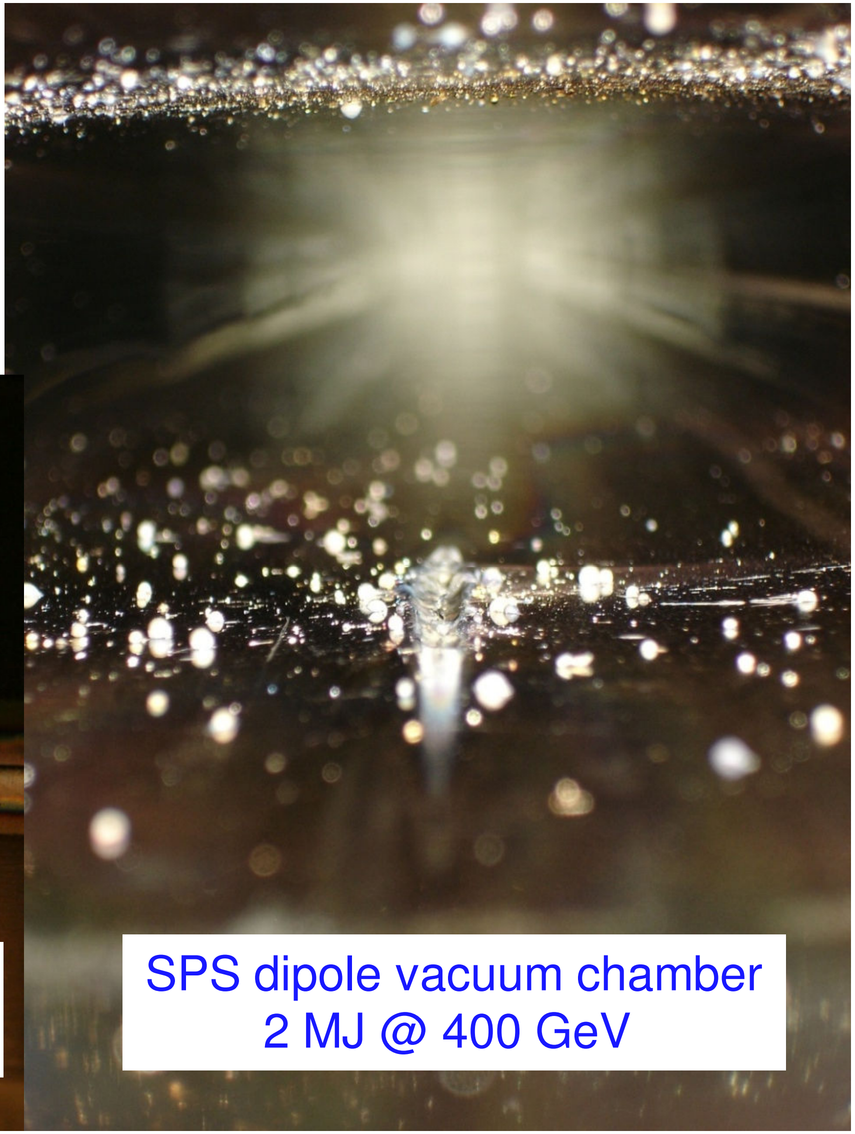
(Recent) SPS incidents

Uncontrolled beam loss in the SPS at 400-450 GeV leads to severe damage for stored energies **≥ 1 MJ.**

(**SBF limit = 70 kJ**)



TT40 transfer line quadrupole vac. chamber
2.2 MJ @ 450 GeV



SPS dipole vacuum chamber
2 MJ @ 400 GeV

Lessons from SPS incidents

- Simulate failure scenarios, design the MPS to cope with the fastest failures.
  - SPS ring is not fully protected against fastest failures.
  - Detailed analysis at the LHC
- Stop when you have doubts, make sure you have good diagnostics.
  - TT40 MD was continued despite some warning sign.
  - Insufficient diagnostics to evaluate situation.
- Both incidents: direct impact on vacuum chamber.
  - Even imperfect dilution by collimators reduces strongly the local energy deposition and prevents damage.

    >> Respecting collimator/absorber hierarchy is essential !

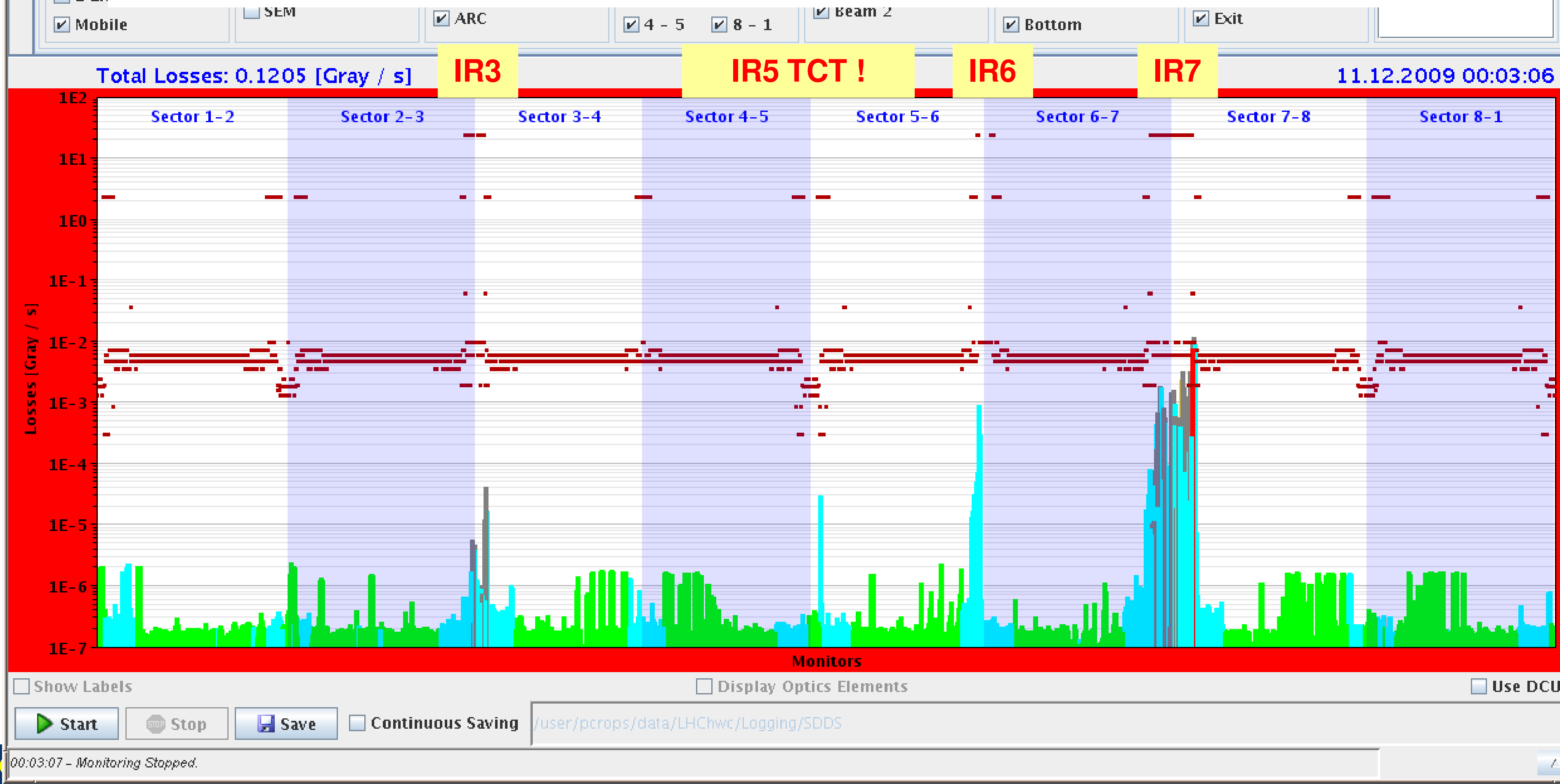
A MJ-class beam in the LHC presents a much lower risk of damage than at the SPS if the collimators are properly setup !

Global protection checks with beam

Test that collimators intercept the (almost) all the beam.

- Beam moved across tune resonance to induce large losses.
- Mask BLMs for full loss of beam (low intensity).

>> very successful : >99% of the beam intercepted by collimators



MPS envelope

- MPS setup and global MP tests must be repeated when:
  - β^* is changed.
  - Crossing angles are switched on.
  - Energy is changed.
- To gain efficiency, minimize the number of MP setups.
  - Choose 1-2 β^* values - stick to them (if possible).
- At any given time there is a well defined operation envelope.
  - Total intensity
  - Injected intensity
  - Minimum β^*
  - Crossing scheme

To be respected

Machine Development (MD) periods

- During standard physics operation sequences and settings can be 'nailed down' for MP.
  - So far only orbit correctors are surveyed.
- MD phases interleaved with standard OP are a potential threat.
  - Interlock masking.
  - Settings changes could break the collimator-absorber hierarchy.
  - One MD participant responsible to restore machine conditions.
  - Separation of settings for MD and for regular operation.
- *The scope of End-of-fill MDs will be severely limited* because beams will be unsafe.
  - no squeeze, crossing angle, etc MDs that have not been tested before at low intensity.

(Interlock) masking

- **BIS inputs**: *maskable channels are conditioned by the SBF.*
  - SBF reliability depends on BCTs – more experience needed.
  - For regular fills we will force the SBF to FALSE (start ramp).
  - Beyond a certain intensity we could consider forcing permanently SBF to FALSE. Unforced by expert for MDs.
- **Software Interlock System**: masking conditioned by RBAC.
  - Limited to EICs and SIS experts.
- **BLMs**: approved procedure.
  - Strict rules for disabling a loss monitor.
- **PIC/PC**: masking of circuits by expert possible.
  - Repairing a circuit may be more efficient that rechecking ramp & squeeze!
  - Faulty orbit correctors could be an (efficiency) issue – MCBX…

Improvements & upgrades

- **Setting interlocks.**
  - Protection against settings errors at injection is implicitly performed by the concept of beam presence for high intensity injection.
  - Circuits settings are only checked for RBs and orbit corrector (Software Interlock) – we may have to consider extending considerably, and performing interlocking PC currents at the level of the PC FECs.
- **Injection protection.**
  - No protection by absorbers in horizontal plane.
- **Abort gap population**.
  - Reliability and safety of synchrotron light monitor based protection.
- **Squeeze factor (= min. β^*)**
  - Additional 'Safe Parameter' to be distributed to collimators and absorbers.
- …

Conclusions

In 2010 we will operate (highly) unsafe beam: we may reach sufficient stored energy to shutdown the LHC for some months in case of incident.

- MPS commissioning to be finished, some part to be repeated (global tests).
  - Collimators and absorbers are critical.
- Careful commissioning planning will avoid repetition of MP testing.
- Operational cycle must be established to switch to unsafe beam.
- Intensity increase must be gradual.
  - Careful analysis of losses and post-mortem data to validate safety.
- Machine (MPP) and Magnet (MP3) Protection must work close(r) together.
  - In particular if we start to quench!
- Great care must be used during MD periods not to jeopardize safety of regular operation.