Initial Experience with the Machine Protection System for LHC

Rüdiger Schmidt

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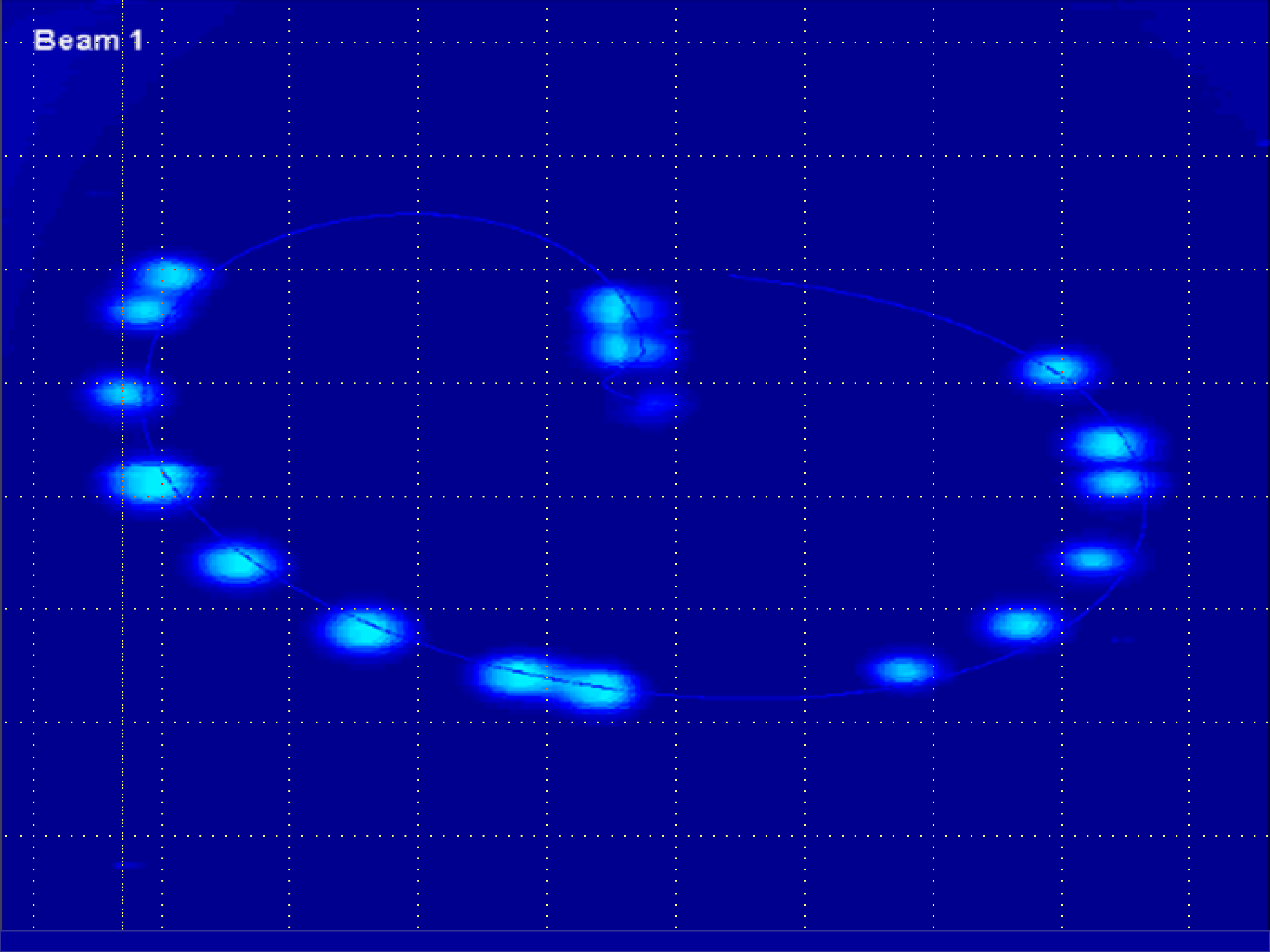
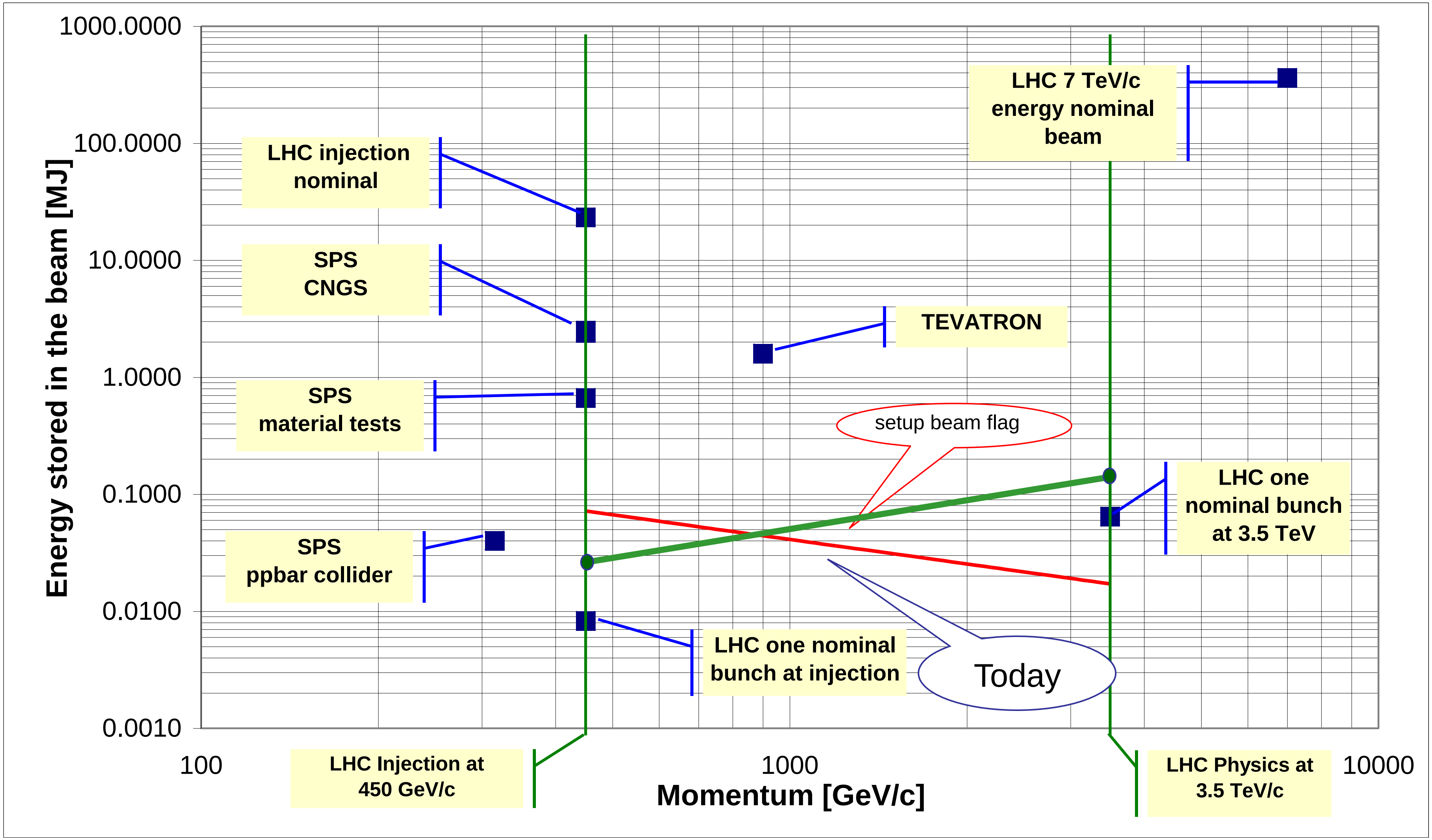
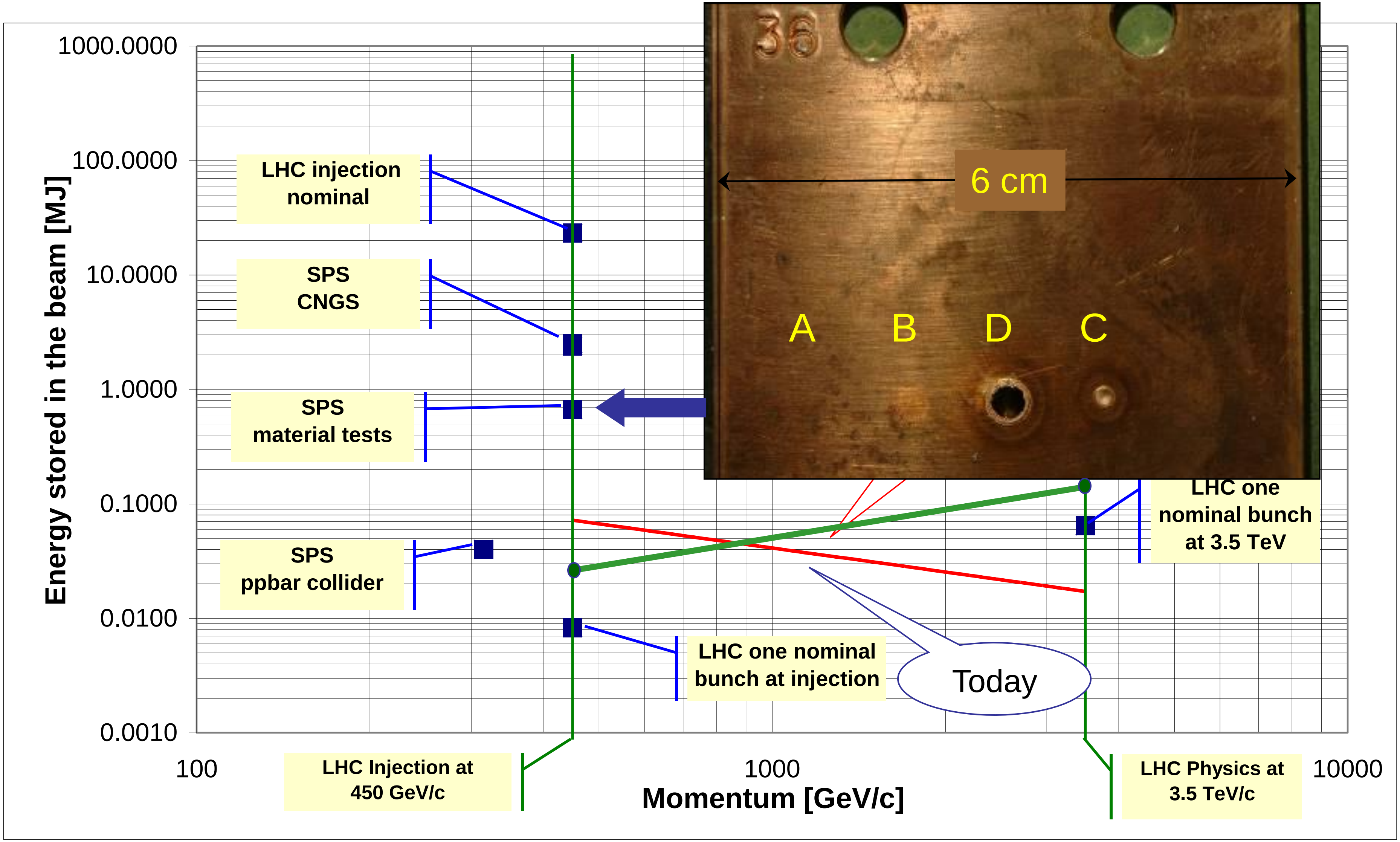
- LHC cycle and machine protection
- Strategy for machine protection
- Commissioning
- Operational experience
- Conclusions


Beam 1

Energy stored in one LHC beam



Energy stored in one LHC beam

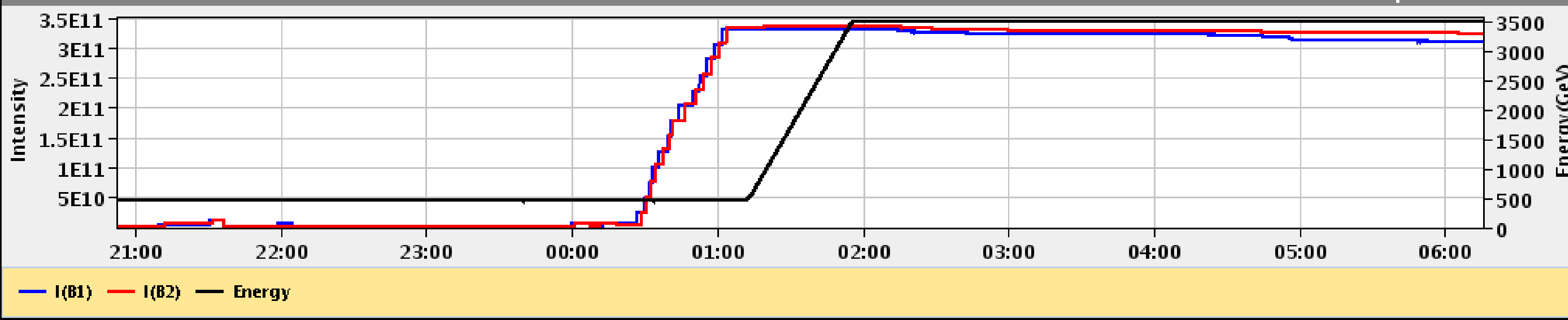


25-May-2010 06:15:26 Fill #: 1122 Energy: 3500 GeV I(B1): 3.09e+11 I(B2): 3.23e+11

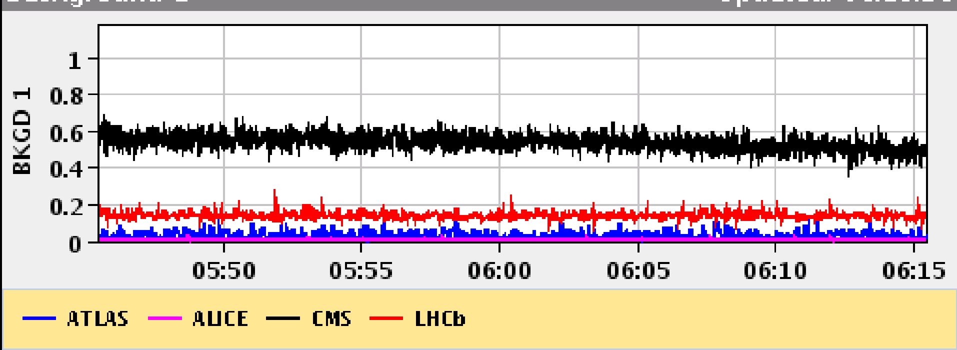
	ATLAS	ALICE	CMS	LHCb
Experiment Status	PHYSICS	PHYSICS	PHYSICS	PHYSICS
Instantaneous Lumi (ub.s)^-1	0.122	0.131	0.154	0.136
BRAN Count Rate (Hz)	1.660e+03	1.014e+03	2.747e+03	3.386e+03
BKGD 1	0.030	0.005	0.476	0.131
BKGD 2	0.000	255.270	61.464	1.236
BKGD 3	0.000	0.002	0.003	0.045

LHCf	PHYSICS	Count(Hz): 47.800	LHCb VELO Position	IN	Gap: 0.0 mm	TOTEM: STANDBY

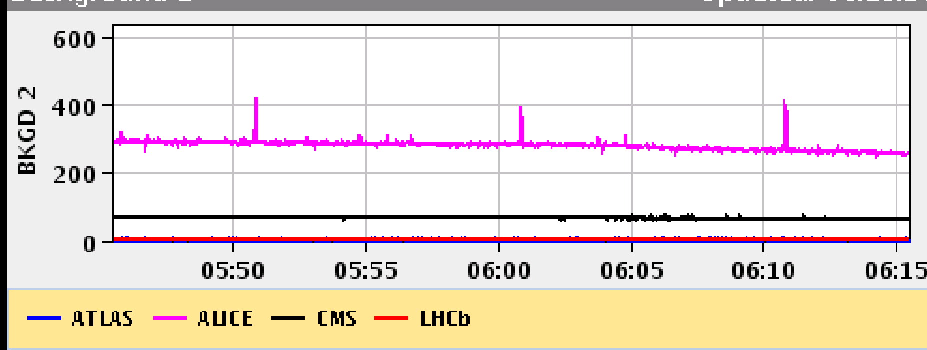
Performance over the last 12 Hrs — Updated: 06:15:26



Background 1 — Updated: 06:15:26



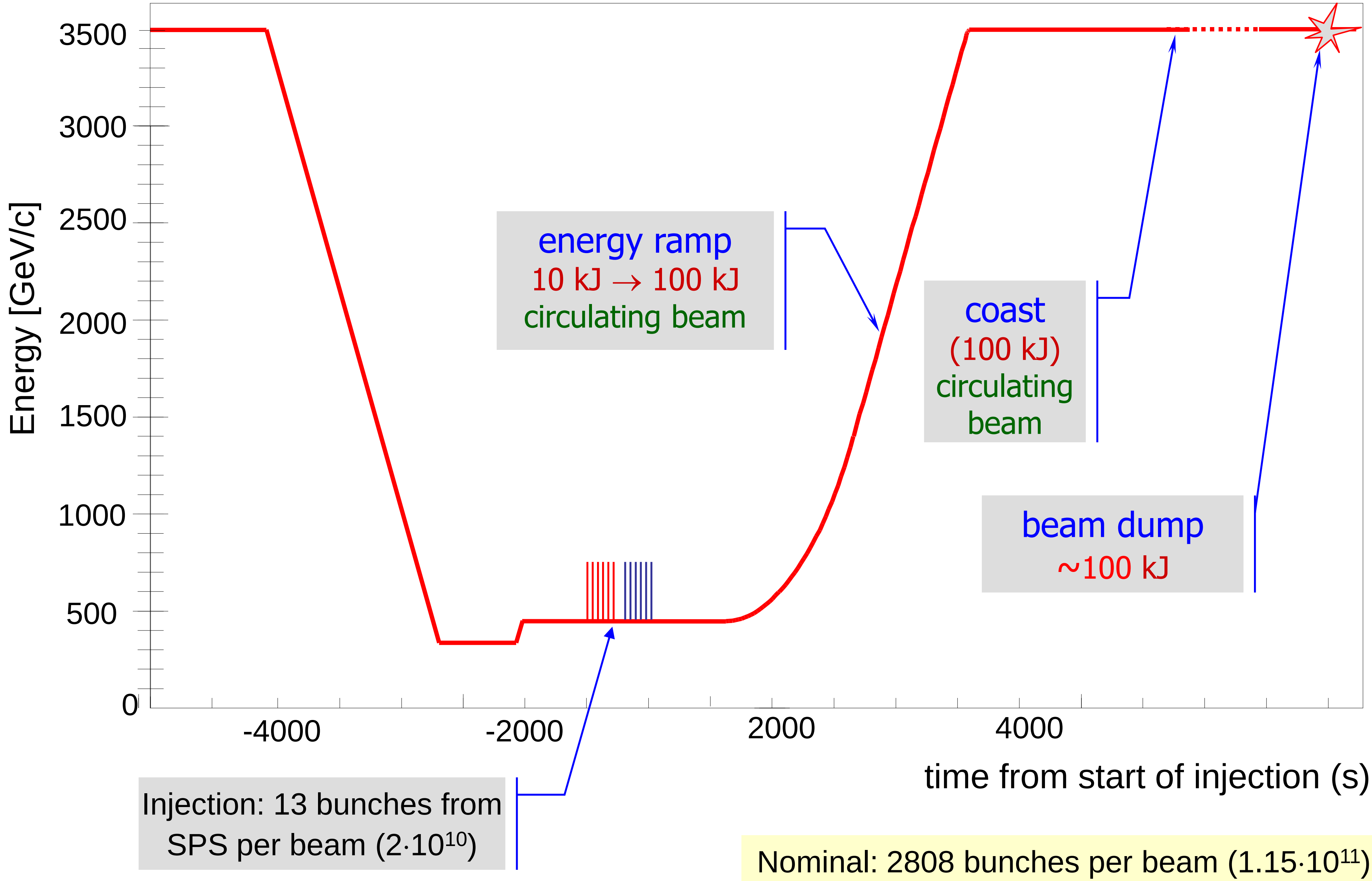
Background 2 — Updated: 06:15:26



v1.

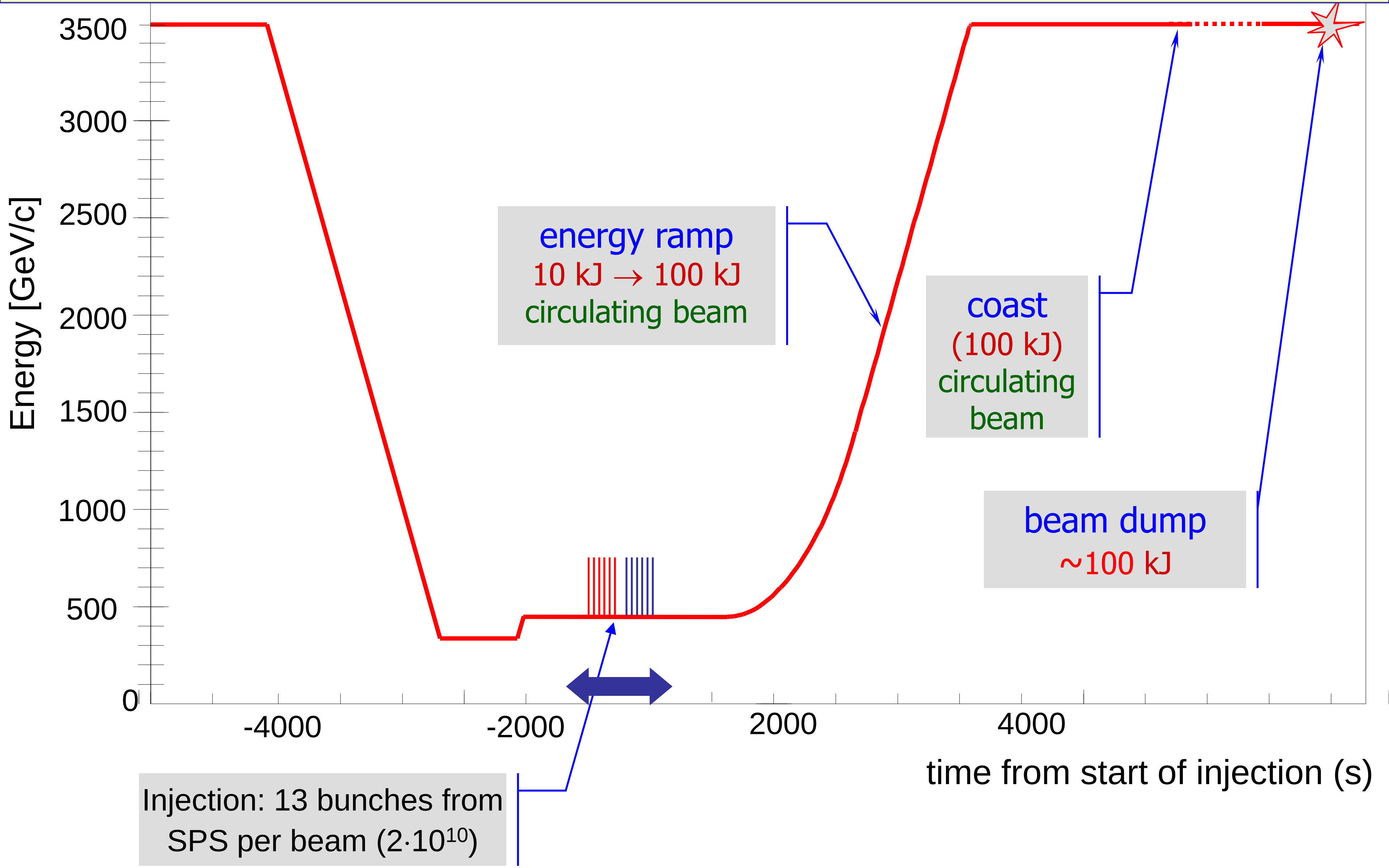
IPAC May 2010 Kyoto

LHC operational cycle and machine protectioin



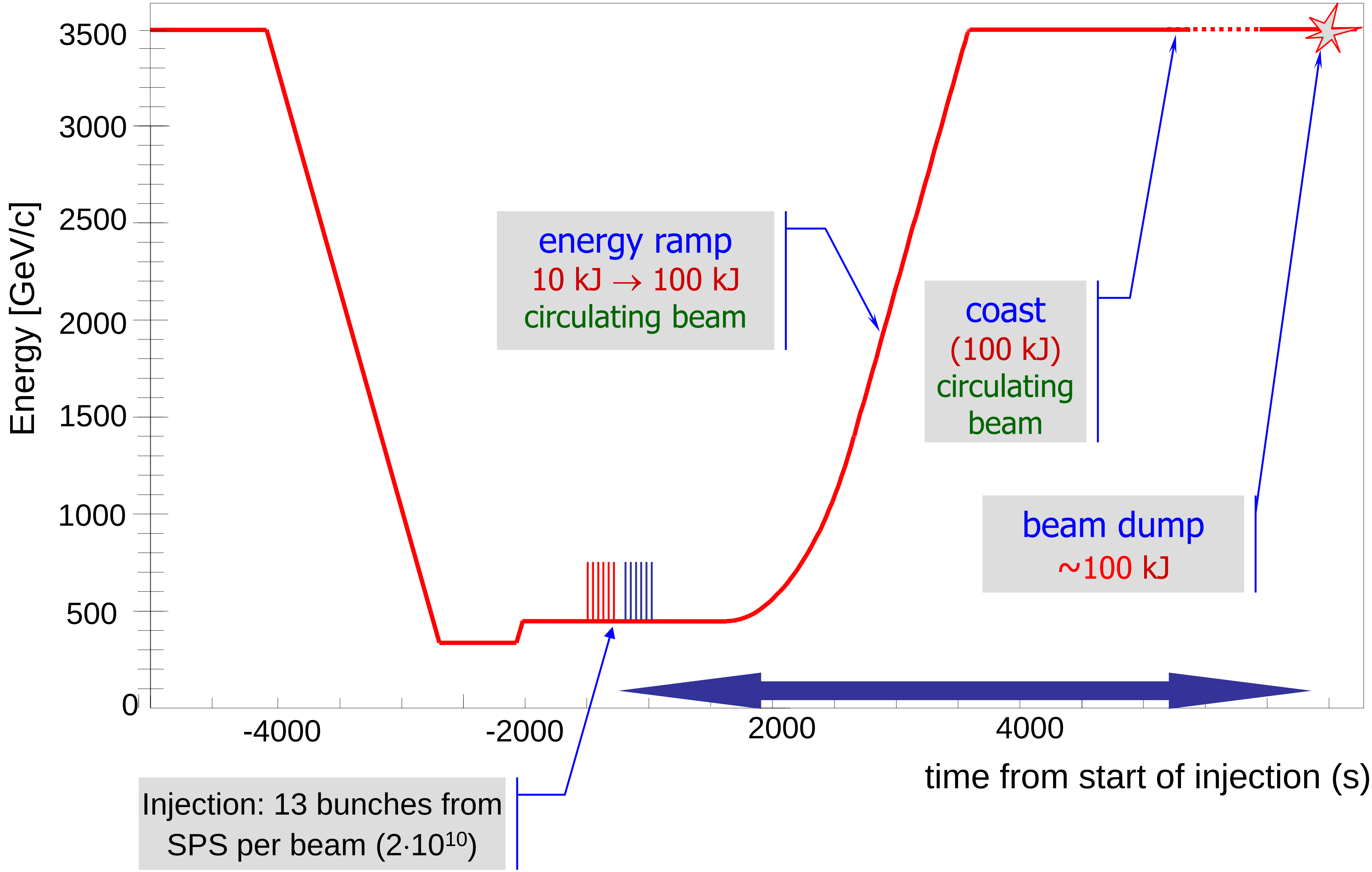
Nominal: 2808 bunches per beam ($1.15 \cdot 10^{11}$)

Injection: Without quenching magnets or causing damage
No kick by injection kicker of circulating beam (correct synchronisation)
Injection protection absorber in place in case of kicker failure

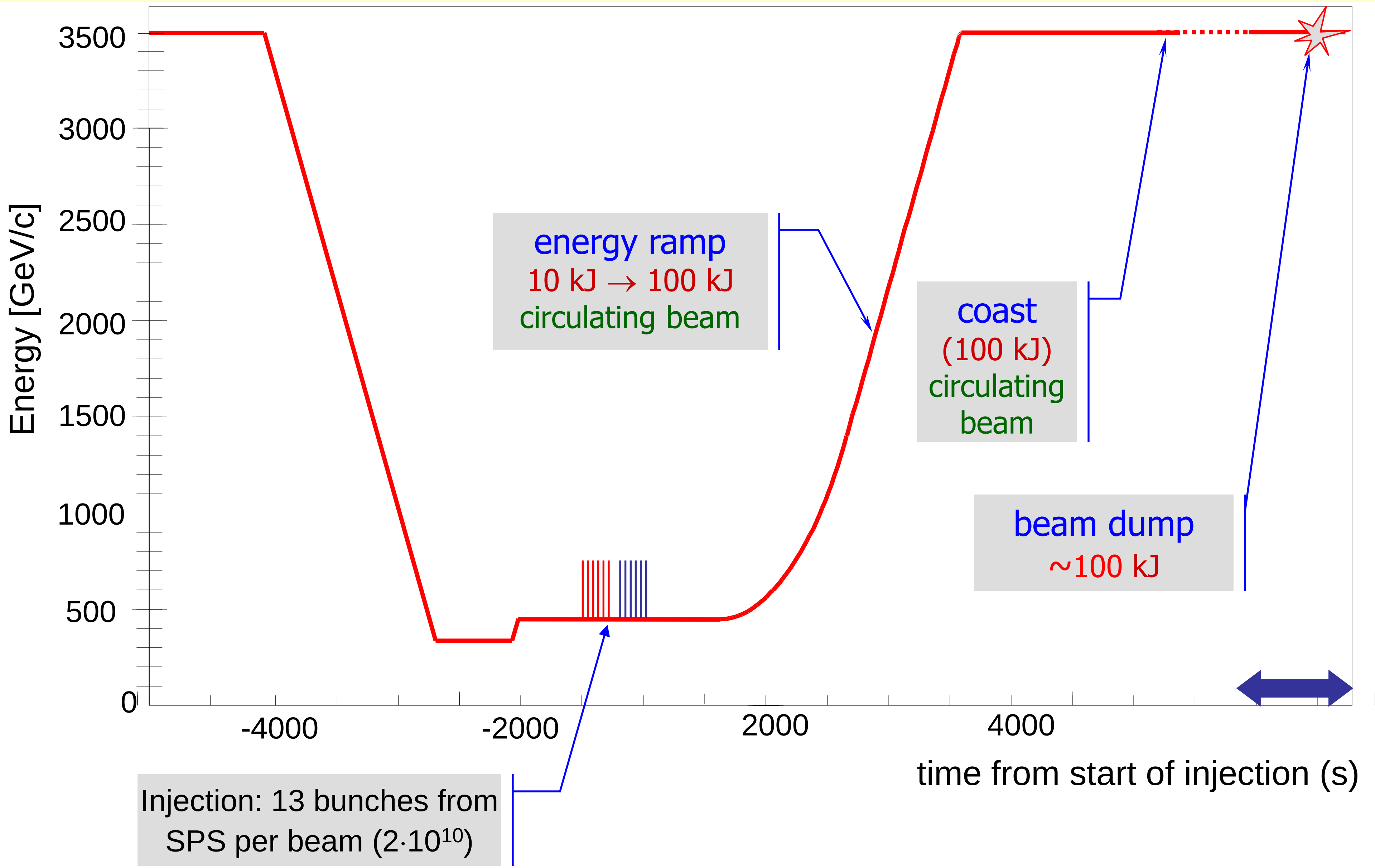


Circulating beam: In case of failure, detect failure and extract beam into dump block for some failures within a few turns

No accidental firing of a kicker magnet



Extraction: Beams must ALWAYS be extracted into beam dump block
Kicker rise must be synchronised with the 3 μs long beam abort gap
Abort gap must be clean of particles



Strategy for machine protection

Early detection of equipment failures triggering beam dump request.

- Powering Interlocks: failures in powering system (quench, PC trip,..)
- Fast Magnet Current change Monitor

MOPEB045

Monitoring of beams to detect abnormal beam conditions and triggering dump request, down to a single machine turn.

- Beam Loss Monitors and Beam Position Monitors

WEPEB069

Reliable transmission of dump requests to beam dumping system and stop injection + extraction from SPS

- Beam Interlock Systems

WEPEB073

Reliable operation of beam dumping system, safely extracting beams onto the external dump blocks.

- Beam Dumping System

TUPEB063

Definition of LHC aperture by collimators, to limit beam losses to (warm) collimator regions.

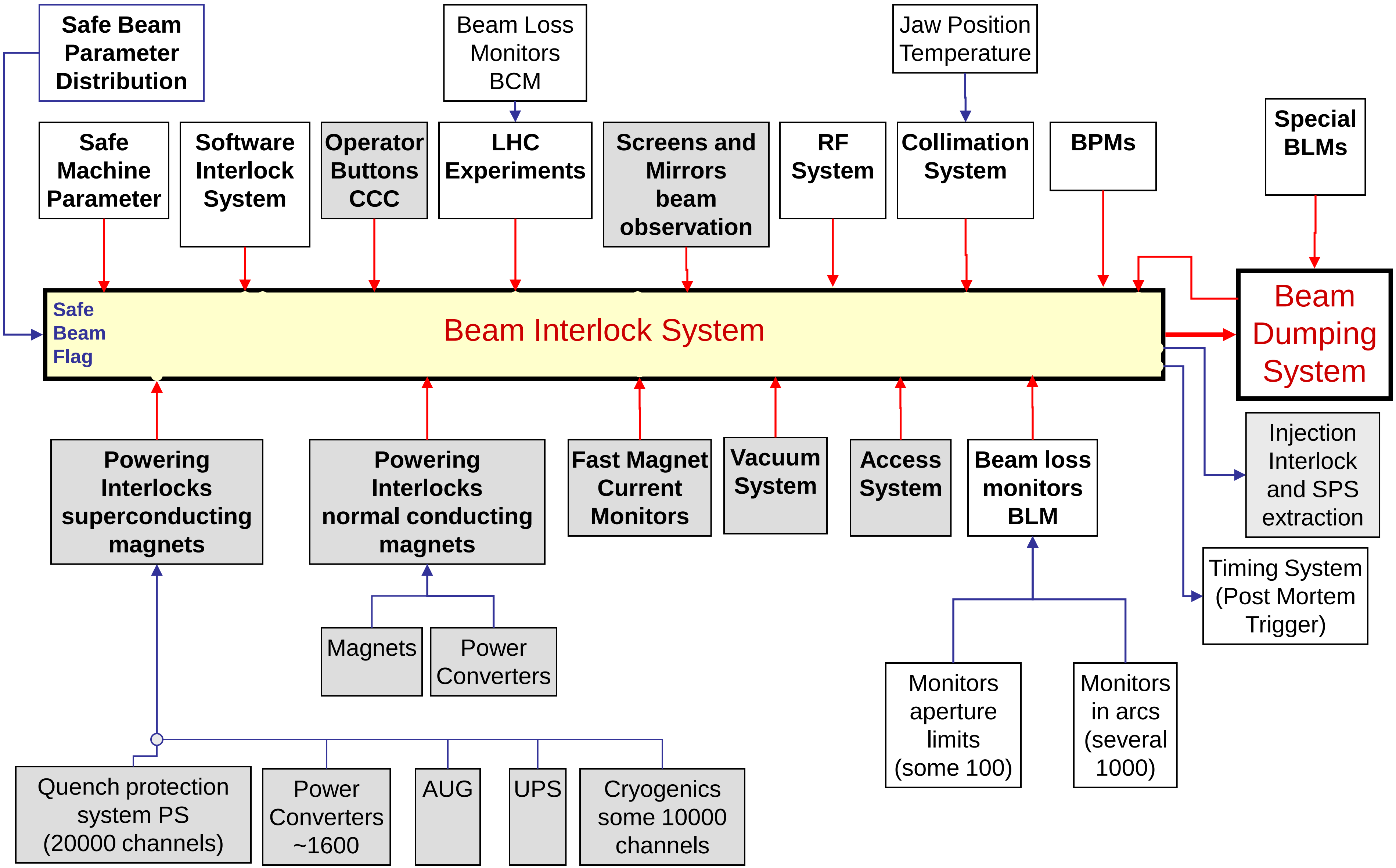
- Beam Cleaning System

TUOAMH01

Passive protection by absorbers and collimators for specific failure cases.

- Beam Absorbers

Architecture of the Beam and Powering Interlocks

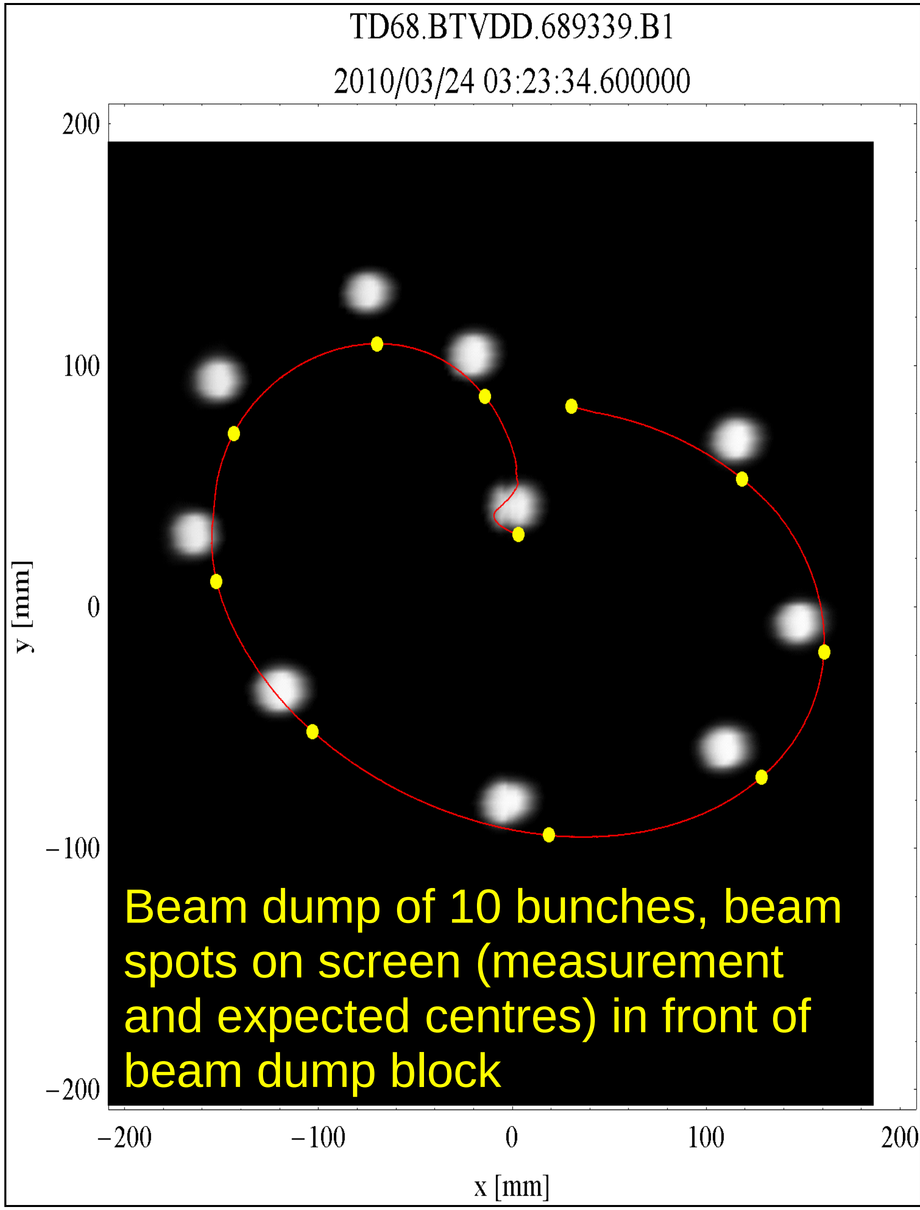


Steps in commissioning of machine protection

- **Before starting beam operation**, **check interlocks** from all system (as far as possible)
- **Start** with **low intensity beam** (no risk of damage)
- **Commissioning the beam dump system** at different energies
- **Commissioning the beam cleaning system** (80 collimators) at different energies, and for different optics
- Specific tests with beam (**Machine Protection tests**)
- **Analyse operation** (for all beam dumps and for beam losses not leading to a beam dump)
- Early commissioning: **masking of interlocks**
  - setup beam flag: when energy density is below critical value
- Exceed the stored energy of the setup beam flag ("safe beam") – **masking automatically removed**
- **Get confidence** in machine protection to go to higher intensity

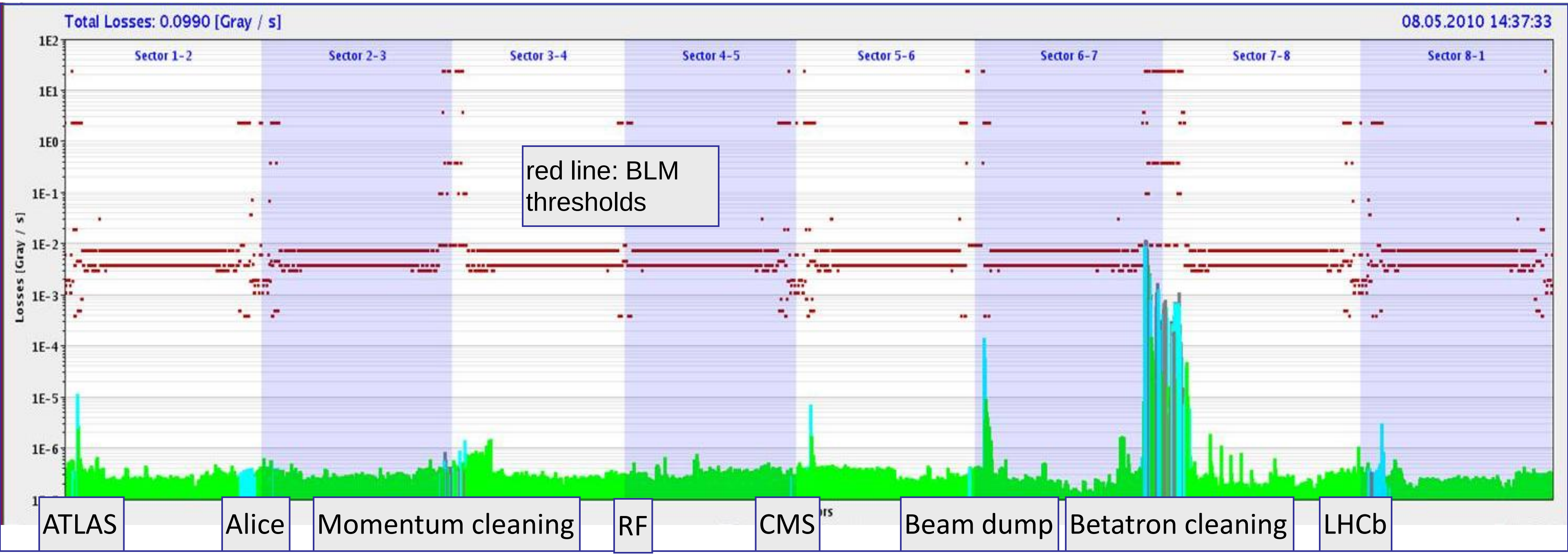
Commissioning of the beam dump system

- Beam dumps done at different energy, to demonstrate that bunches are correctly extracted via a 700 m long line into the dump block
- To reduce the energy density on the dump block, beam is “painted” by fast deflection of two families of kicker dilution magnets
- A 3 μs abort gap for the switch-on of the extraction kicker field allows loss free extraction under normal operating conditions.
- Some asynchronous beam dumps are expected. Collimators are installed to capture beam that is deflected with a small angle. Tests with de-bunched beam: particles in abort gap are correctly intercepted



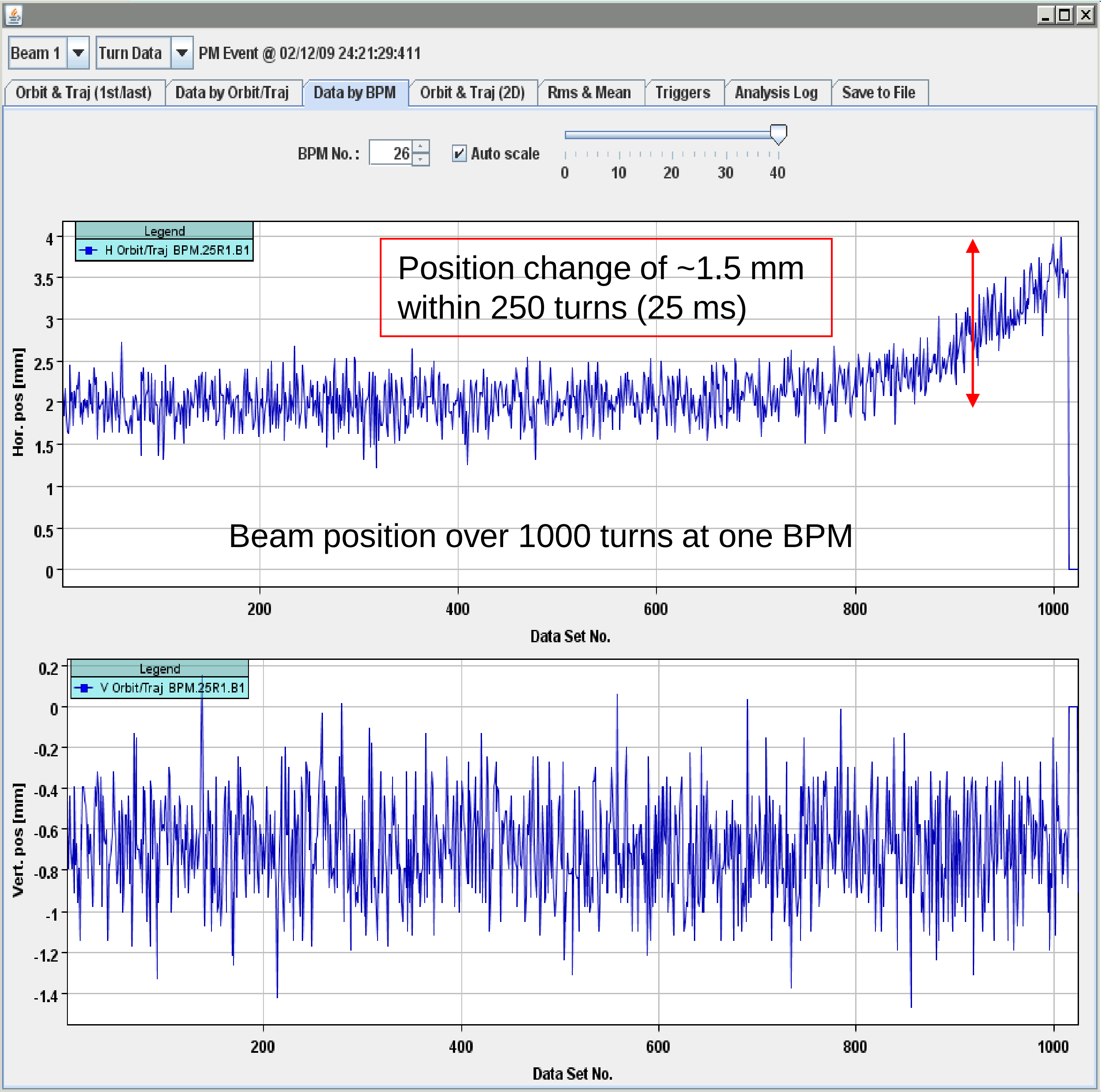
Beam dump of 10 bunches, beam spots on screen (measurement and expected centres) in front of beam dump block

Collimator setup



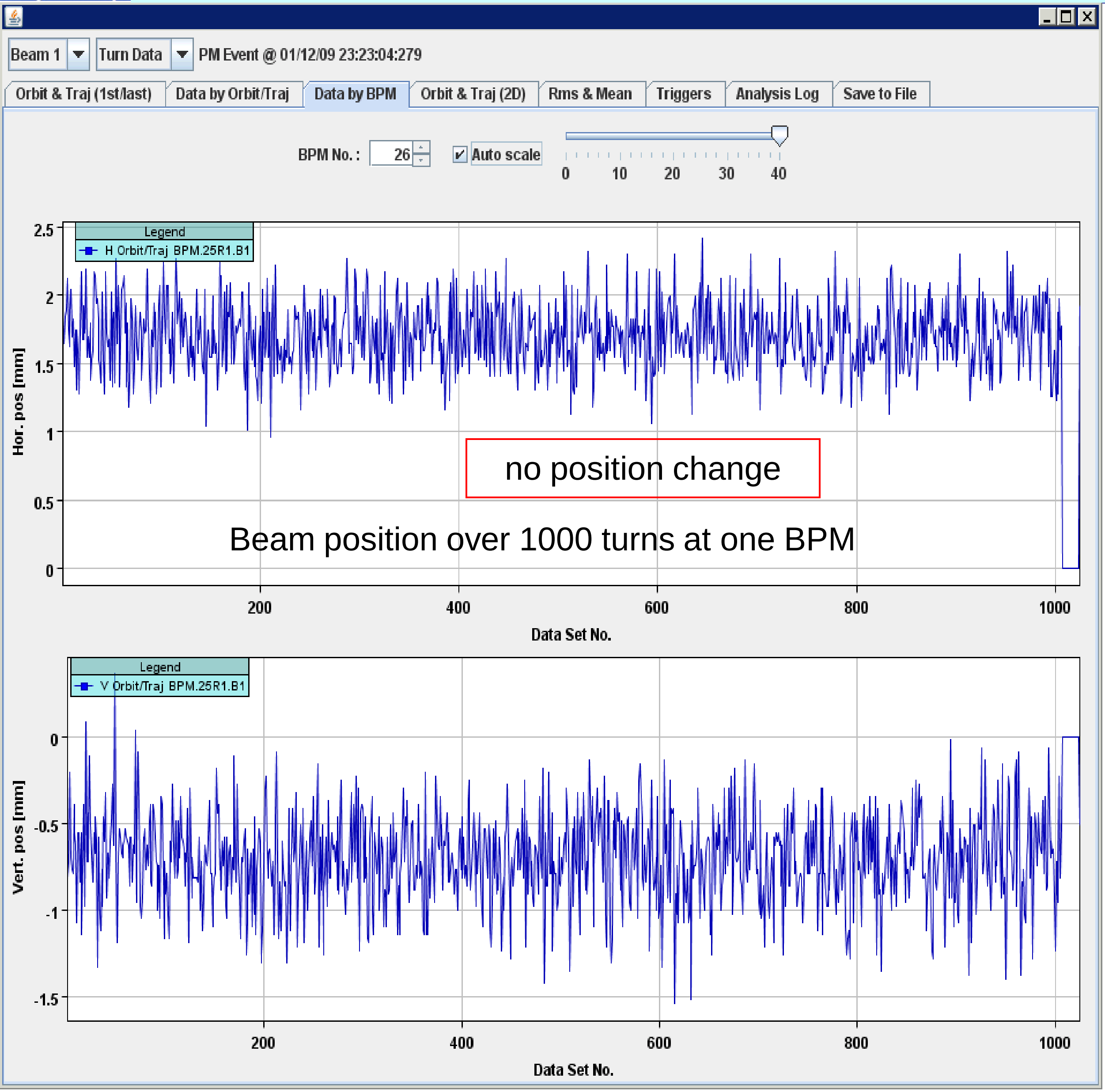
- Cleaning efficiency depends jaw centring on beam, accuracy of gap size and jaw parallelism with respect to beam. The collimators are aligned during the different operational phases (injection, top energy, etc.)
- Excellent performance, no beam induced quench. The efficiency is measured by driving the beam on a resonance.

Early detection of powering failures (FMCM OFF)



- With low intensity beam, the monitor was disabled and a trip of the power converter triggered
- A trip of normal conducting magnets close to the experiments is most critical (fastest beam loss)
- The beam position changed, and beam loss monitors close to collimators recorded the loss and triggered a beam dump
- Redundant protection is required, by measuring voltage drops in the circuit within less than one ms

Early detection of powering failures (FMCM ON)

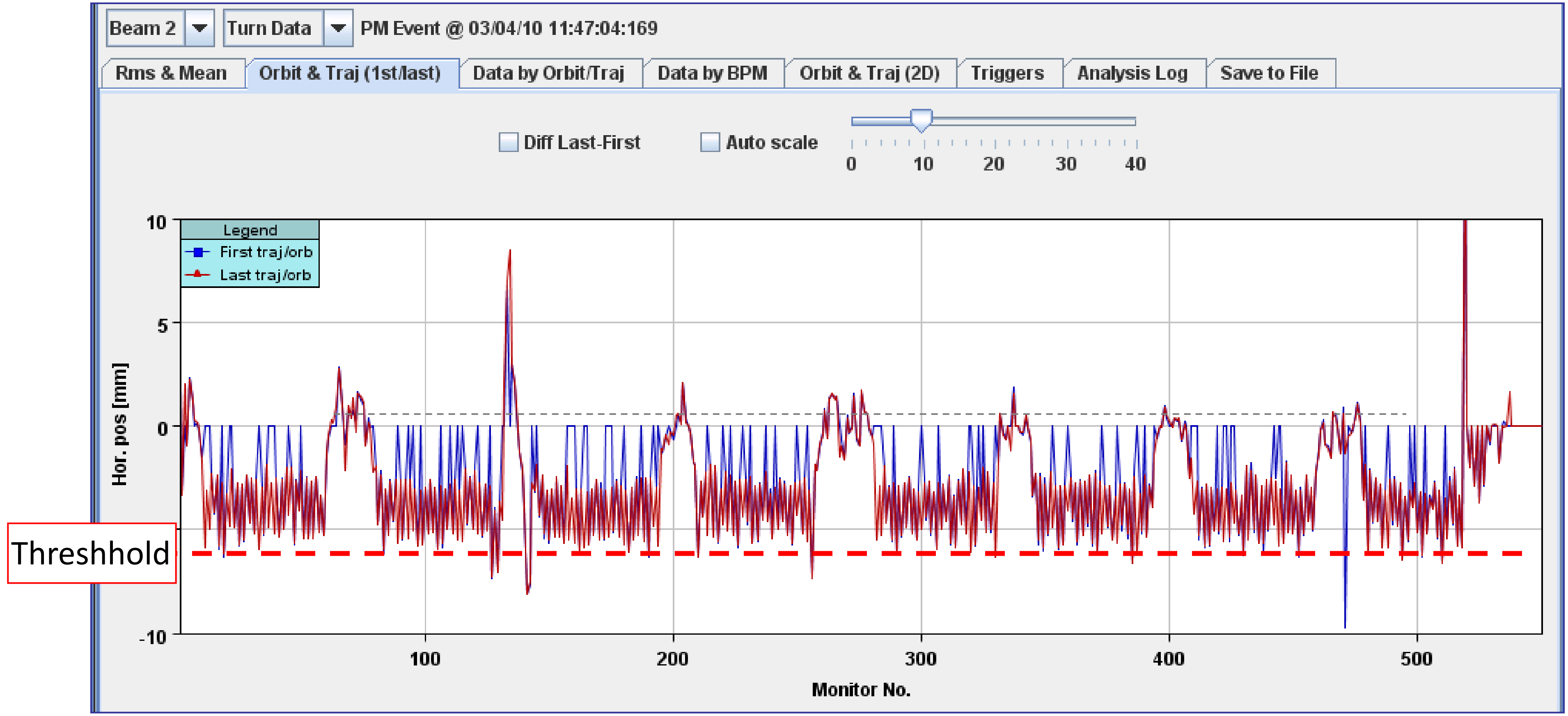


- The **F**ast **M**agnet **C**urrent change **M**onitor (FMCM) to detect fast powering failures was enabled
- The test was repeated
- The beam was dumped, before any effect on the beam position was visible
- No beam losses were detected
- The redundant protection works. This is an example that we try to use for all possible failures
- Very sensitive in case of problems with the electrical network (a number of beam dumps)

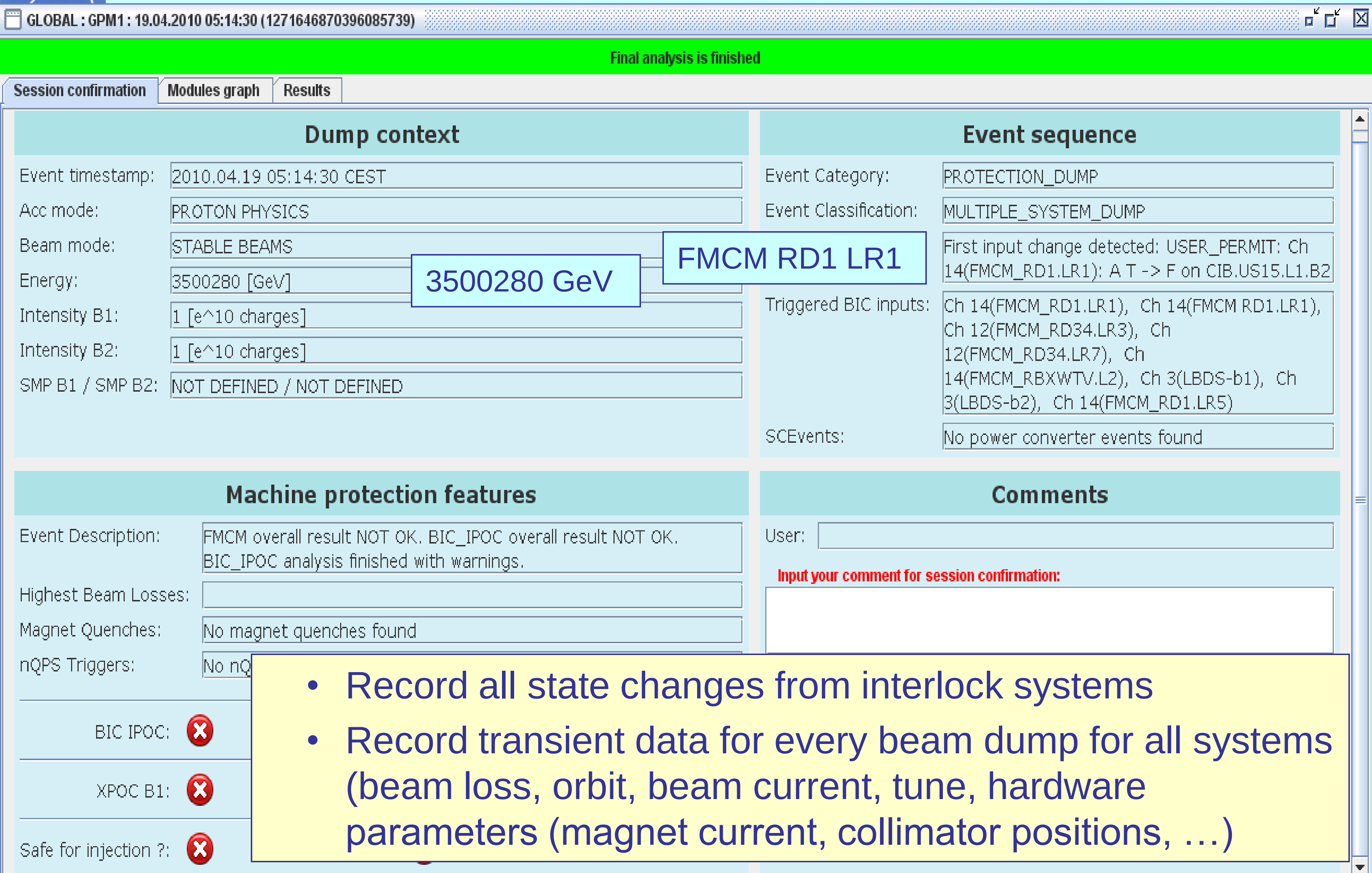
Software Interlock System

Provides additional protection for complex but less critical conditions (e.g. surveillance of magnet currents and closed orbit)

- Example: triggered on large orbit excursion (> 12 BPMs over 6 mm for beam 2 in the horizontal plane (too large RF frequency change)



"Post Mortem" after beam dump



- Record all state changes from interlock systems
- Record transient data for every beam dump for all systems (beam loss, orbit, beam current, tune, hardware parameters (magnet current, collimator positions, …)

Early experience

- Many beam dumps at injection, in general for commissioning purpose
- “False” beam dumps: if a protection system dumps the beam because of an internal failure (e.g. noise spikes, problems in connectors, …)
- About **75 beam dumps** after the start of the energy ramp
- **All beam dumps are understood** (thanks to the interlock systems and post mortem recording)
- **Not a single quench** with circulating beam
  - Stored energy of **100 kJ** with respect to **10 mJ** for quenching a magnet
  - Cleaning system did an excellent job
  - Detection of failures worked very well
- **Very few beam induced magnet quenches** (“quenchinos”), only during injection at 450 GeV
  - the threshold of a quench detector was exceeded, the quench heaters fired and quenched the magnet (without firing the magnet would have recovered)
  - one event: main quadrupole current in one sector 350A instead of 760A
  - other events: during special aperture studies

Conclusions

- For many Machine Protection sub-systems: **Commissioning finished** before **LHC beam operation** during hardware commissioning (all interlocks related to the magnet powering system)
- **Commissioning** of LHC with **low intensity beams**, slowly increasing the intensity, bringing up all machine protection systems
- The beam intensity where interlocks can be masked has been exceeded. LHC operates **with all interlock enabled**
- LHC **can operate** with the **full machine protection** system
- Operational experience and machine protection experiments demonstrated that the **machine protection system works as expected**, no surprises until today
- These are **early days**, a **huge step** in **beam intensity** is still required
- Next month(s): 1 MJoule, end of this year: >10 MJoule

Acknowledgements

LHC Machine Protection reflects the complexity of the LHC accelerator.

Many colleagues contributed to LHC Machine Protection. We like to thank them and are very grateful for their contributions.