Proposal for Beam Induced Quench Tests at the end of 2013 run

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for Quench Test Strategy WG
(including experts from BE/CO, MPP, BE/BI, RF, ABT/BTP, Collimation)

LHC Machine Committee, 2012/10/24

Fast beam losses in the order of 1 ms due to UFOs:

- Scaling from past experience it is expected that the losses from UFOs could become one limitation to the performance

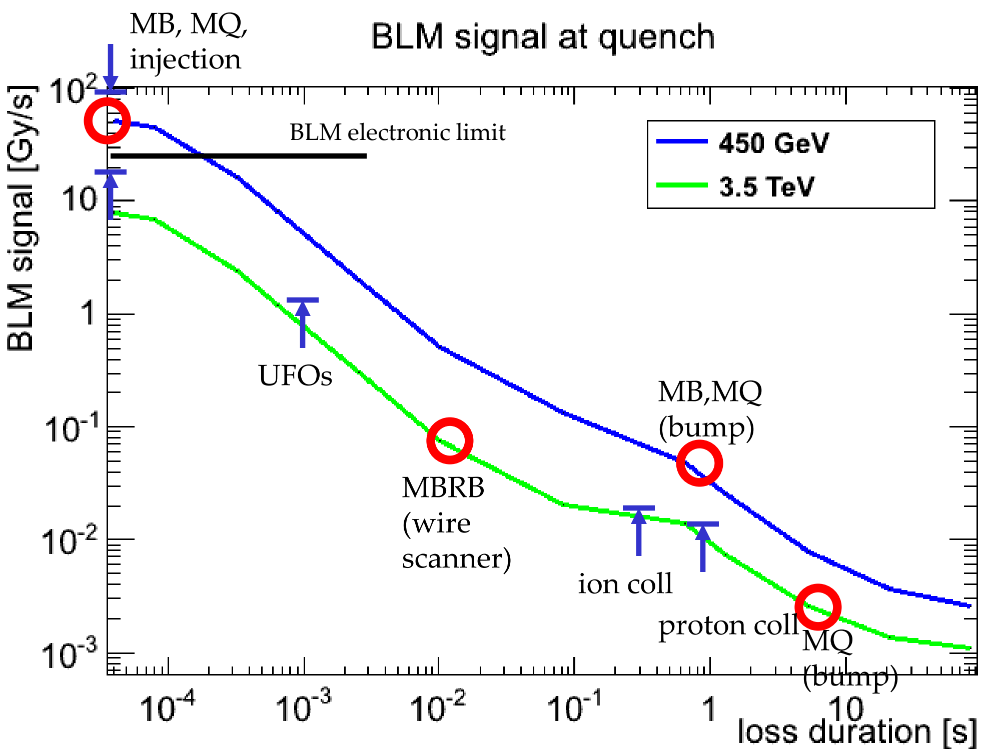
Slow losses in ~ seconds, in particular during squeeze and adjust:

- The cleaning system prevents too high beam losses in the arc, however, the limitations have not been fully explored

Improved understanding of the quench threshold is required:

- As input to the definition of the beam parameters (e.g. 50 ns versus 25 ns with respect to UFOs)
- As input for the operation after LS1: collide before squeeze? Private bunches? …
- As input to decisions about equipment upgrades (also the ones which will take place during LS2…)

Situation reported in Chamonix 2012



⭕ Beam induced quenches

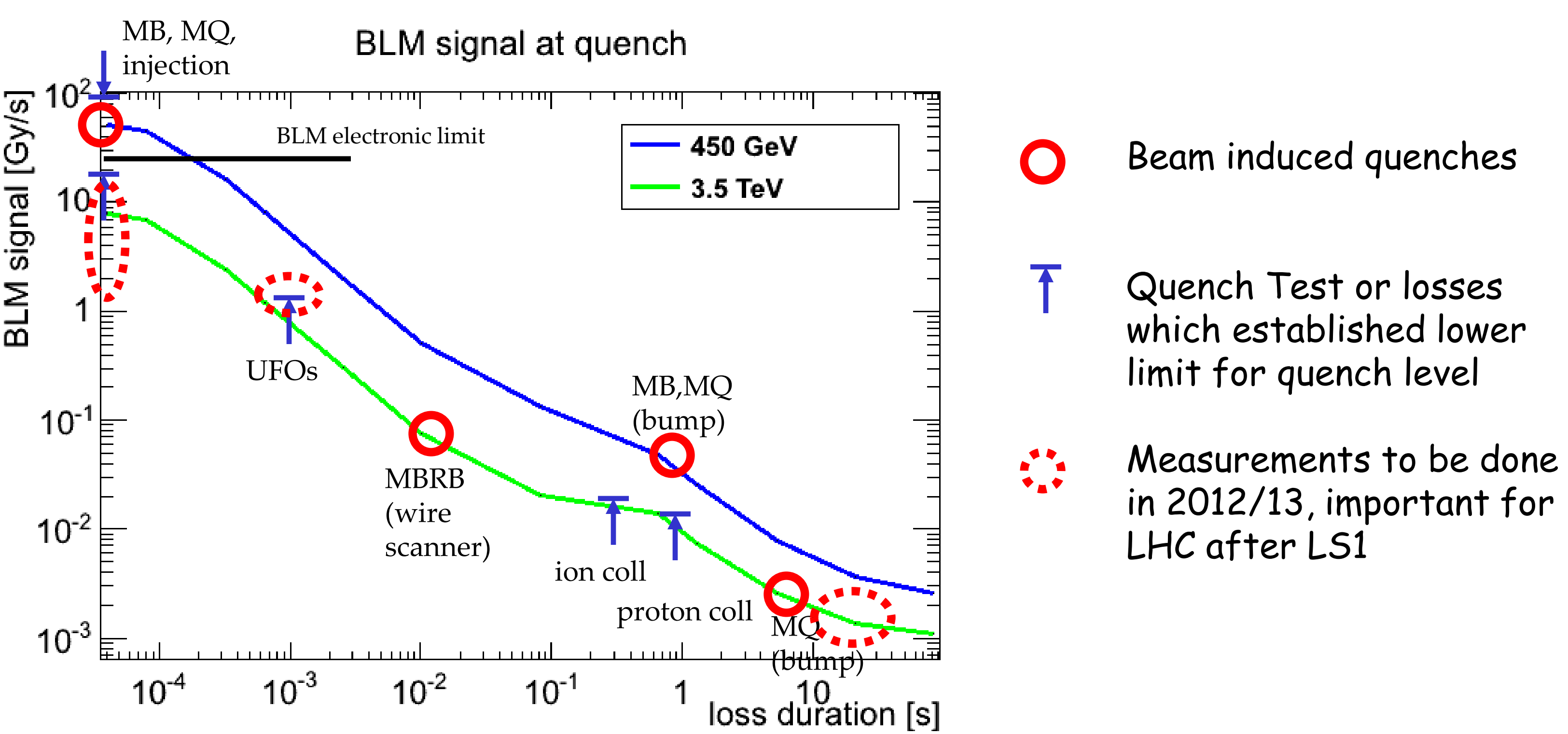
⤒ Quench Test or losses which established lower limit for quench level

Quench limits depend on beam energy and duration of the loss. Plot shows generic shape of quench limit in BLMs (Gy/s). It is obtained assuming proportinality between BLM signal and quench limits in coils (mJ/cm^3 or mW/cm^3).

KEY PROPOSALS AT CHAMONIX12:

- **Perform quench tests.** **(…2013)**
- **When possible use 3.5 TeV to reduce risks.** **(dropped)**
- **Establish a panel where tests priorities will be evaluated.** **(4 meetings)**

Chamonix 2012: first proposals



Quench Test Strategy WG first priority:

1. Steady state quench limit with collimators (with protons)
2. UFO – timescale quench limit with ADT

Time calculations

Proposed approach:

- preparation (PREP): 1h

  (BLM threshold changes, ADT software modifications, etc, etc)

  (can be optimized to be done in a shadow of rampdown)

- injection+ramp+test (TEST): 2 h
- recovery from quench (QR): 2.5 h (cooldown of energy extraction switches)
- precycle (PC): 1 h

Steady-state on collimators with protons (I)

Motivation:

Test the machine limitations in operational conditions (maybe without quench)

Possible consequences /gain:

- prepare BLM thresholds in order to work closer to quench limit,
- estimate luminosity reach, because lumi losses in dispersion suppressor have similar pattern to loss maps

Studies started in 2011:

(EDMS 1151015, CERN-ATS-Note-2011-042 MD, paper at HB2012)

- about 1s losses generated, only 64% of assumed quench limit reached
- improve: longer (10s) and more intense (>100% of QL) loss

Steady-state on collimators with protons (II)

IMPORTANT

How to do:

- similar to loss maps but with higher beam intensity (100 nominal bunches)
- new: use of ADT allows better control amplitude and duration of losses
- collimators in operational positions – safety
- modify BLM thresholds in order not to dump before quench
- new: maybe use squeezed beams to see if there are unexpected loss locations
- new: probably reduce cleaning by use of *relaxed* collimation settings

Remarks:

- 1 hour of ADT calibration at injection requested! (D. Valuch)
- expected quench in dispersion suppressor of IR7 (MB and/or MQ)
- cryogenic measurement with ~5 kJ resolution (K. Brodzinski, L. Tavian)
- time needed: PREP+3*TEST+2*QR+3*PC = 15 h

1 ms with ADT (I)

Motivation:

Test the quench limits in the UFO timescale

- UFOs will hit us again at higher energies, probably leading to magnet quenches
- we can be prepared in advance if we know quench limit at millisecond timescale

Possible consequences /gain:

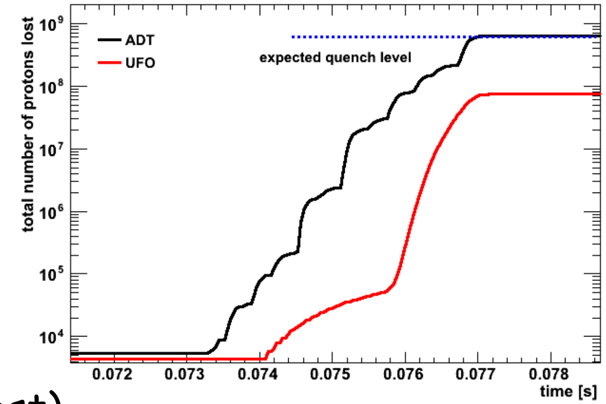
- prepare BLM thresholds in order to work closer to quench limit
- could have some input into optimization of BLM redistribution (spare slide)
- ultimately optimize operation by minimizing downtime due to quench and to dump

1 ms with ADT (II)

How to do:

- method to generate fast losses with ADT developed (MD2 & MD3)
- generate orbital bump and blow the beam with maximum ADT amplitude
- install additional BLMs (Xmas)
- install fast QPS measurement system (Xmas)

MD 2012.10.13



Remarks:

- quench arc MQ or MB (preferably in arc 56, the safest)
- disadvantage: source term different from UFO (spread of loss), but it is possible to conclude on UFO type losses with simulations

time needed: PREP+2*TEST+2*QR+2*PC=12 h

1 ms with ADT (III)

Potential beam-screen damage:

- discussion raised by MPP
- after some iterations: damage to beam screen not expected
- (spare slides for some calculations/arguments)

Other recommended tests (I)

Steady state on collimators with ion beam

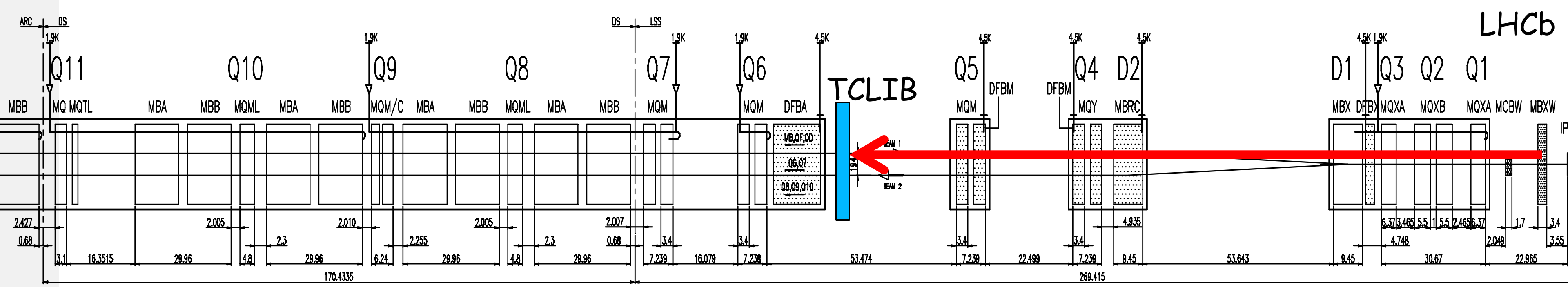
- Different loss locations than in case of protons
- Tests in 2011 – confusing (short losses, signals above QL)
- Very important to see intensity reach for future Pb-Pb and p-Pb runs in view of ion lumi upgrade (relevant also for Ar-Ar limit)
- Preparation of BLM thresholds is difficult and crucial for the test
- time needed: PREP(!)+2*TEST+2*QR(?)+2*PC = 12 h

Other recommended tests (II)

Q6 quench test

- Shooting a fat pilot on TCLIB while increasing current in Q6L8 (4.5K)
- Quench limit dependence on magnet current (">4 TeV" ultra-fast losses)
- Relevant to magnet quenches during asynchronous beam dump
- If agreement with FLUKA might lead to conclusion about Q6 damage at injection
- Done before no quench, no conclusions…
- Reinstallation of QPS equipment needed
- Check on BLMs with filters needed
- time needed: 2h (short!) + QR+PC(?) = 5 h

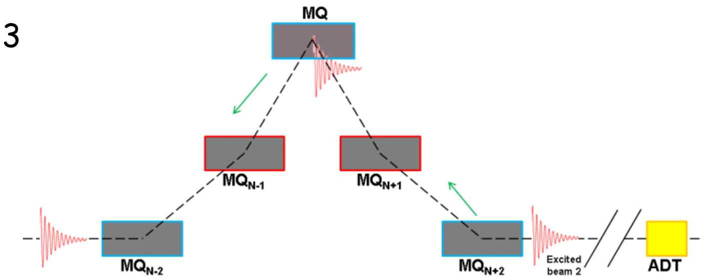
BTW Fluka simulations needed before the test to asses if energy deposition in the coil can be close to QL.



Other recommended tests (III)

Steady state with orbital bump

- Orbital bump with circulating beam
- Successfully done in 2010, loss of about 5.6 s,
- Steady-state quench limit ~ 150-250 mW/cm^3
- New: use ADT, 10s (or longer) flat loss
  (as for collimation test),
- New: horizontal loss
- Complementary to collimation test, easier FLUKA/G4 simulations
- This test gives number in mW/cm^3 , difficult to get it from
  Collimation test, and this number is input to simulations during LS1!
- Needed 4 TeV, ~3 bunches with 3e10 protons each
- The same magnet as for ADT fast test (MQ/MB arc sector 56)
- Time needed: PREP+2*TEST+2*QR+2*PC = 12 h



Remark

Steady state losses take place in cleaning insertions (dispersion suppressor)

and in triplet magnets.

Currently we do not plan any quench tests in triplets.

Even if we probably could go beyond design lumi after LS1 so they might be limiting.

We believe quench limit is very similar to other 1.9 K magnets (similar cables).

Loss difference (protons vs interaction debris) can be assessed by FLUKA.

Summary of time required

test	Time needed	Accumulated time
Steady-state on collimators with protons	15 h	15 h
1 ms with ADT	12 h	27 h
Steady-state on collimators with ions	12 h	39 h
Q6 test	5 h	44 h
Steady-state with orbital bump	12 h	56 h

This is the first estimation, subject of future changes and optimizations.

About priorities

Personal point of view:

Priority is to get all these tests done.

How to do it?

1. Need enough time (~2 x 24 h)
2. Compromises between teams
3. Dynamic schedule
4. Luck

How the first round could look like:

Coll steady-state prot: PREP+2TEST +1QR+2PC= **9h**

→

1ms ADT: 1 TEST+ 1 QR + 1 PC = **6h (tot 15h)**

→

Coll steady-state ion: 1TEST+1QR+ 1PC= **6h (tot 22h)**

→

Steady-state bump: 1TEST+1QR+ 1PC= **6h (tot 28h)**

→

Q6: 2h+1QR+1PC= **5h (tot 33h)**

Conclusions

1. Five tests are proposed
2. Main addressed issues:

   performance reach after LS1 due to steady-state and UFO losses

   outlook towards after-LS1: decisions on upgrades (R&Ds)
3. All five test should take about 48 hours (estimate uncertain).
4. All tests at 4 TeV except Q6 test at “>4 TeV”.
5. Considered magnets are: MB, MQ (1.9 K) and MQML (4.5 K).
6. It would make sense to have 2 quench test periods, to minimize the risk of not performing the last-day tests and to give people some rest.
7. All these tests are well prepared (repetition, pre-test MDs).

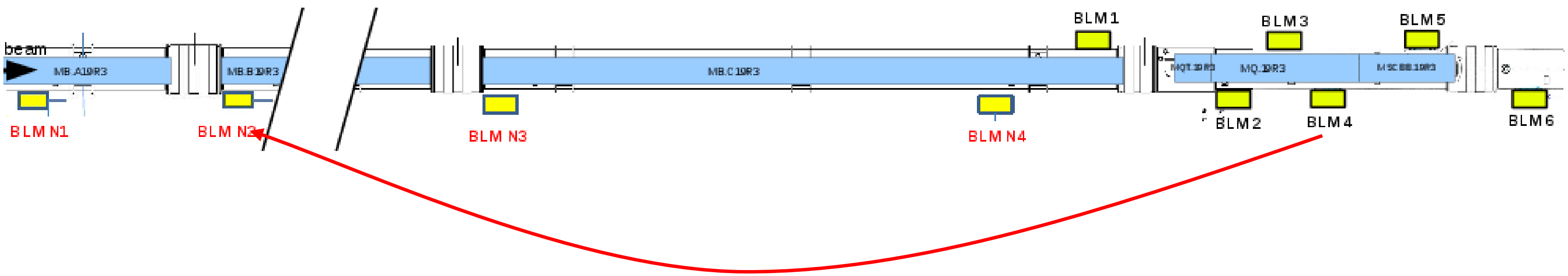
Request for 48 h period for quench tests. If some time is lost due to machine unavailability, the priorities have been established.

Thank you for your attention

Spare slides

Discussed at MPP on October 12th

- outcome of UFO measurements in cell 19R3: ~uniform distribution (T. Baer)
- in order to measure UFO losses over most of the arc length (and prevent UFO-generated quenches):



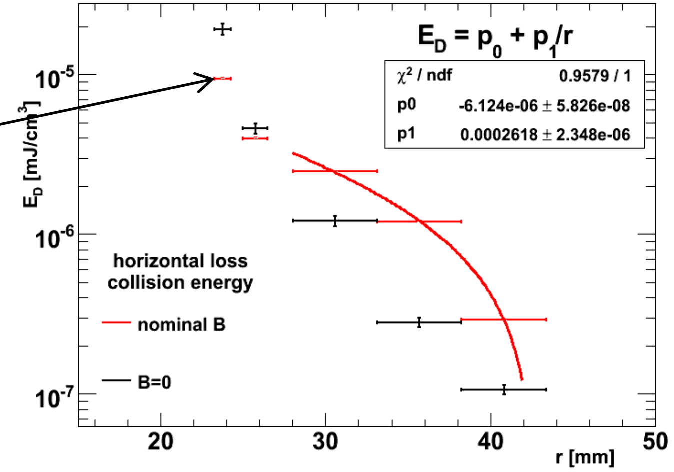
- FLUKA simulation of various UFO locations in the arcs show factor 50 gain in BLM sensitivity (A. Lechner)
- initial idea accepted by MPP, optimization work needed

1 ms with ADT (III)

Potential beam-screen damage:

- discussion raised by MPP
- context: we had $5{\cdot}10^9$ at injection on aperture
- Geant4 simulation (at 7 TeV)
- beam screen gets 10x more than coil maximum
- expected quench $\sim 10^8$ protons

  (total loss will be higher, we'll leave BLMs at max threshold to dump)



- so energy deposited about 1 J (conservative)
- loss distributed over 1 mm (beam size) x 1 m (loss length) x 1 mm (thickness)
- from heat capacity local temperature raise to about 20-30 K over 1 ms
- no damage to beam screen expected (very small thermal deformations below 80K)

Heating of beam screen by beam losses

Copper parameters

$\rho_{Cu} = 8.96 \cdot \frac{gm}{cm^3}$ $\quad c_{Cu\_spec} = 385 \cdot \frac{J}{kg \cdot K}$

Asssume beam screen is hit:

Length: $L_{bs} := 1m$

Depth: $D_{bs} := 1mm$

Width: $W_{bs} := 1mm$

Volume: $V_{bs} := L_{bs} \cdot D_{bs} \cdot W_{bs}$

Number of protons: $N_{pbs} := 10^9$

Energy per proton: $E_{pbs} := 4TeV$

Total energy: $E_{bs} := N_{pbs} \cdot E_{pbs}$

Total energy: $E_{bs} = 640.81\,J$

Total volume: $V_{bs} = 1.00\,cm^3$

Specific heat: $c_{Cu\_spec} = 3.8456 \times 10^2 \cdot \frac{J}{kg \cdot K}$

Temperature increase: $T_{increase} := \frac{E_{bs}}{c_{Cu\_spec} \cdot V_{bs} \cdot \rho_{Cu}}$

$T_{increase} = 185.98\,K$