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REPORT FROM THE JOINT MACHINE-EXPERIMENT MEETING ON THE EXPERIMENTS PROTECTION FROM BEAM FAILURES

Abstract

This document summarises the main points discussed during the meeting “Joint Machine-Experiment Meeting on the experiments protection from beam failures” held at CERN on 2007-06-12. The discussion has triggered a number of open actions listed at the end of the report. The open actions need to be followed up by the appropriate people as proposed in the document.

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1. INTRODUCTION

D. Macina introduced the newly defined role of Beam Interlock Supervisor (BISU), i.e. the contact person within each experiment providing the interface to the machine on the experiment protection from beam failures. This person is aware of the beam failures scenarios which may affect the experiment, of the general machine protection system and is responsible for the implementation, commissioning and operation of the dedicated experiment protection system, interlocks included. The currently appointed BISUs are listed below:

- Antonello Di Mauro (ALICE)
- Siegfried Wenig (ATLAS)
- Alick Macpherson (CMS)
- Richard Jacobsson (LHCb)
- Anne-Laure Perrot (LHCf)
- Mario Deile (TOTEM)

Unlike HERA, TEVATRON, RHIC etc.., the LHC cannot be operated without collimators (except at injection with low intensity). In fact, the protons lost along the ring must be intercepted with very high efficiency before they can quench a superconducting magnet. This is done via the collimation system which defines the aperture limitation in the LHC. Collimators are located mainly in the cleaning insertions (IR3, IR7). A few additional collimators are located in the dump insertion (IR6) and in the experimental insertions. This has an important impact on the Machine Protection since, for most of the multi-turn failures, the beam will hit the collimator first. This means that, for most of the multi-turn failures, the experiments are protected by the collimators mainly located in the LHC beam cleaning insertions. However, a few scenarios (both multi-turn and single-turn) potentially dangerous for the experiments have been identified and discussed.

2. SAFE BEAM

SAFE BEAM is defined as a beam which cannot damage the machine even if lost entirely at a single location. It depends on the beam energy and on the beam intensity. Currently, SAFE BEAM is defined as following:

- 10^{12} protons at 450 GeV and nominal emittance (it is below the melting point of Cu)
- 10^{10} protons at 7 TeV and nominal emittance (scaled from 450 GeV, still under discussion)

Consequently, the SAFE BEAM flag is set to TRUE whenever the beam intensity is less or equal the values above according to the beam energy.
When the SAFE BEAM is injected or circulating in the machine, the following settings/operations are allowed:

- Injection into an empty machine.
- The "maskable interlocks" may be masked if needed.
- None of the movable collimators is required to be at its nominal "protect" position (i.e. they could be at any position from opened to closed). Actually, the safe beam is used to set the collimators at the nominal position for the machine protection.

The SAFE BEAM has the following consequences for the experiments:
- The experimental insertions are not necessarily protected by the collimation system. Therefore, in case of failure, the beam may hit exposed detector parts in the experimental areas or hit machine elements that generate excessive showering into the experimental areas. However, this probability is considered very unlikely apart from the movable detectors (VELO and Roman Pots).
- The experiments are sensitive to incorrect magnet settings at injection (see Section 3). This failure is only possible when injecting into an empty machine. **Even though nominal operation foresees the injection of a pilot bunch ($5\text{x}10^9$ proton at 450 GeV) if the machine is empty,** it is technically possible to inject a maximum intensity corresponding to the SAFE BEAM (i.e. no interlock forbids the injection into an empty machine of a beam intensity between the pilot bunch and SAFE BEAM). See Chapter 6 for the discussion.

3. FAILURES AT INJECTION AND EXTRACTION

These single turn failures are particularly dangerous. These types of losses cannot be detected in time by any active protection system and, therefore, the LHC relies on dedicated passive protection systems using fixed and movable absorbers, and on the right value/status of the elements involved in the operation. The following failure categories can be defined:

- **Wrong settings at injection**
  This failure is due to the wrong setting of one or more magnets located in the experimental insertion (in particular, the orbit correctors and the D1/D2 separation dipoles). This failure concerns **all** experimental insertions. A dedicated study for ATLAS has shown that, depending on the type of error, the injected beam may hit/scrape the TAS and shower into the experimental

regions, or directly impact the beam pipe. ALICE and LHCb are more exposed due to the fact that no TAS is foreseen in IP2 and IP8 and to the fact that these IPs have the added complication of a dipole magnet (associated to corrector magnets).

- **Error failures at injection (IR2 & IR8)**
  This failure is due to the wrong setting of the transfer line magnets or of the injection septum, a fast trip of the power supplies, failure of the SPS extraction kicker during extraction, etc. Protection from these failures is based on the response to magnet current surveillance and fast current change monitors and on passive protection from absorbers and collimators. In particular, the injection kicker failures in the LHC ring are caught by dedicated moveable absorbers like the TDI and the TCLI. These failures affect directly either IR2 (beam1) or IR8 (beam2). However, the injection failure can in principle affect the whole machine depending on the phase advances and the absorber/collimator settings.
- **Error at extraction (IR6)**
  This failure is related to the loss of synchronisation with the abort gap, an over-populated abort gap, the pre-firing of one of the 15 kicker modules or a failure in the energy tracking system. It is difficult to quantify the frequency of the pre-fire failure but it looks like once per year is possible. The downstream magnets and the adjacent Insertion Regions (IR5 and IR7) should be protected by dedicated passive absorbers (movable TCDQ and TCS, fixed TCDS and TCDQM). However, in case of problems during extraction coupled with TCDQ settings and/or obit/optics errors, some beam loss may occur at the tertiary collimators (TCT) or triplets in IR5. The loss is difficult to quantify but a detailed analysis is ongoing (existing studies were done without taking into account the TCT/TCDQ since introduced at a later stage). The abort gap (re)population is monitored via a dedicated instrument which could be connected to the interlock system (under discussion). This failure directly affects only IR5/CMS. However, there is the possibility that the mis-kicked beam passes through IR5 and IR3 and hits IR2 and/or IR1. In fact, the momentum cleaning collimators have a rather large aperture compared to the ones in the betatron cleaning insertion (aperture ~ 15 sigma in IR3 compared to ~ 6 sigma in IR7) and, therefore, the protection due to IR3 is less effective compared to IR7. This probability is expected to be low and it should be checked by simulation looking at the mis-kicked beam phase advance.

4. FAILURES WITH CIRCULATING BEAM

This concerns magnet failures including operational mistakes. It is usually slow and detected first in the aperture restrictions of the machine. The potential danger for the experiments (in particular the near-beam detectors like Roman Pots and VELO) is due to uncontrolled closed bumps since they could affect only the experimental areas. However, they build up slowly (BLM should trigger a beam dump early enough), they are extremely difficult to create at 7 TeV (less difficult at 450 GeV) and only critical if combined with a fast failure of one of the insertion elements. Therefore, the probability of this failure is considered very low. It should be noted that the cases presented at the workshop refers only to direct beam impacts (i.e. no showers or scattered particles from impacts somewhere else).

5. EXPERIMENTS

All experiments have the possibility to trigger a beam dump or inhibit injection. The experiments interlocking strategy is defined in the document EDMS 653932. Each experiment, with the exception of LHCf, has a dedicated and independent radiation hard protection system located close to the beam pipe. In general, the protection system consists of monitors based on synthetics diamond sensors which form the experiment's input to the BIS. LHCf will use, as protection system, the scintillator counters which are part of the detector itself. The experiment's protection system is supposed to be always active even if the experiment is not taking data with the exception of LHCf (see slides). CMS raised the issue of not allowing beam circulating in the machine if the experiment protection system is off.

6. OPEN ISSUES AND LIST OF ACTION

- **Pilot bunch injection into an empty machine and Safe Beam**

  The non-interlocked procedure "pilot injection into an empty machine" is a concern for all experiments. In fact, if the procedure is skipped and, at the same time, one or more magnets in the experimental insertion are wrongly set, beam of non negligible intensity (maximum intensity = SAFE BEAM) may hit directly the experimental areas. The SAFE BEAM intensity for 450 GeV is felt to be at the limit of what detectors may stand even though no dedicated calculation/test have been performed. Therefore, the experiments have asked to lower this limit to the minimum required intensity for commissioning and operation. According to the machine people present at the meeting, a good balance between efficient operation and risk reduction may be an intensity limit about equal to a nominal bunch (~ 1.1-1.5x10^{11} p). In the discussion that followed the meeting, all experiments (ATLAS in particular) have stated that the risk derived from skipping the procedure is too high and therefore not acceptable. The machine has already found and implemented a solution able to solve this specific problem: an interlock is added at the SPS level which forbids the extraction of beam from the SPS into the empty LHC if the beam intensity is higher than I(*safe injection*). If I(*safe injection*) is defined to be the pilot bunch, then the procedure "pilot injection into an empty machine" becomes compulsory with no possibility to overcome it. This solution has the advantage that there is no need to lower the value of SAFE BEAM to very small intensities (probably too small for an efficient machine operation) to solve the specific problem of the "wrong settings at injection" accident scenario. However, it should be noted that, in this case, everything written in Chapter 2 about SAFE BEAM remains valid apart, of course, from the possible injection into an empty machine. The value for I(*safe injection*), and possibly SAFE BEAM, will be discussed in the Machine Protection WG and approved by the LTC. Finally, the machine invites each experiment to explain which are the most sensitive elements in their detectors and possibly define the maximum beam intensity which would not cause a permanent damage to the detector.

  - *Action: Machine Protection Working Group (MPWG) and BISU*

- **Post Mortem Data**

  It has been decided that the experiments should provide the post mortem data whenever a trigger is issued, i.e. even if it is not the experiment's equipment issuing the dump. The details and the technical implementation need to be discussed. It was suggested to use GMT for triggering PM read out.

  - *Action: AB/CO+ AB/OP + LEADE*

- **Safe Beam Flag to the experiments**

  Technically all experiments can receive it via the GMT receiver. However, only LHCb has officially requested it. Is it of interest also for the other experiments?

  - *Action: BISU*

- **Injection inhibit (injection interlock for the experiments)**

  The injection inhibit for the experiments will be part of the already existing Software Interlock System. Details (protocol) to be decided. In addition, there are new ideas how to implement, in the near future, a hardware injection interlock dedicated to the experiments (fiber-CIBU).

  - *Action: MPWG + AB/CO + LEADE*

- **Power for the protection system**

  The machine has recommended the experiments to put their protection system under Un-interruptible Power Supply (UPS) to survive a power cut for a few minutes. In fact, in general, this will give time to the experiment to send their post mortem data in case a beam dump is triggered. All experiments have put their protection system under UPS (the autonomy varies with the experiment). In particular, CMS has decided to power its protection system with the machine UPS-power. This assures CMS that the protection system will always be powered if the machine is powered and makes it independent of the CMS detector status. This option looks attractive. The other experiments are encouraged to look into this possibility.

  - *Action: MPWG + LEADE + BISU*

- **How to detect direct beam loss in the experimental area at injection if the detector is off?**

  This should be possible with the experiment protection system since it is supposed to be always active. However, depending on the amount of shower created by the failure, the protection system may not always detect the loss in an efficient way. Experiments are invited to investigate if additional detectors could be kept active at safe settings during injection.

- *Action: BISU*

- **TCTs for 2008**

  The design of the Vertical TCT in IR2 and IR8 has been completed in May 2007. These collimators are mechanically different compared to the other TCTs since they are positioned where the two beams run into a single beam pipe. Actually, their production dates are compatible with the run in 2008. It should be noted that, if late and not installed, the LHCb's request to reach small β* (β* < 6 m) during the LHC startup may not be satisfied.

  Action: MPWG + Collimation WG

- **Bump scenarios and wrong settings at injection**

  The risk due to these failure scenarios can be considerably lowered using a software interlock current surveillance of the most dangerous magnets in the experimental insertions (like D1,D2 and correctors) both at injection and collision.
  - *Action: SIS + MPWG*

- **Abort gap monitor**

  The status of the abort gap monitor and its possible connection to BIC should be checked.
  - *Action: MPWG + AB/BI*

- **Simulations**

  A number of simulations may still be needed for the optimization of the experiment protection system. In particular:
  - Asynchronous beam dump and the consequences for both CMS and Roman Pots in data taking position. The simulation will be done by *B. Goddard and T. Kramer (AB/BT)* and provided to the experiments as soon as the results are available.
  - The consequences for LHCb and ALICE according to the failure scenarios at injection should be looked at. This work involves *AB/BT, TS/LEA and the LHCb/ALICE BISUs*.
  - Wrong settings at injection. Data are available for IR1; IR5 is expected to be very similar. A few differences are expected in IR2 and IR8. *Simulations will be followed by TS/LEA*.
  - Additional failure scenarios during circulating beam (beam steering) should be envisaged. In addition, it would be useful to gather categories of failures scenarios and the associated losses (location and magnitude). This would help in defining operational scenarios for the experiments sub-detectors. This work will probably involve AB/ABP and AB/CO/MI (to be discussed).

  - Simulations on accident scenarios involving Roman Pots. The simulations should include mechanical stresses on the pot. This work will probably involve *TS/LEA and TS/MME.*

- **Procedures**

  A few procedures should be discussed and agreed upon:

  - "CMS Philosophy" i.e. no beam allowed in the LHC (CMS BEAM PERMIT = FALSE) if the CMS protection system is OFF. On the other hand, according to the same philosophy, beam is always allowed if the CMS protection system is ON independently of the status of the CMS detector. Should this approach be adopted by all experiments and accepted by the LHC? The answer may depend on the reliability of the experiment's protection system and on the availability of a backup solution (input is required here from the BISUs).
  - CMS requested to agree that no experiment is allowed to prevent beam from circulating in the case of local failure (detector, service cavern, or otherwise) that is independent of safe machine operation.
  - How many unjustified dumps can be tolerated per experiments? Is the aim for 1/year/exp acceptable?
  - Procedure after emergency beam dump. Will the experiments inhibit injection until the problem is understood? Important to understand the experiment's re-arm timescale and the interaction between the experiments and the LHC in regard to PM analysis. Action: LEADE (AB/OP, MPWG, BISUs)

  Once the above questions have been answered, the procedures should be discussed and agreed in the appropriate bodies (yet to be defined).

- **Additional items not discussed in detail during the meeting**
  - We should get more information and check consistency of the radiation damage threshold for similar detectors in different experiments. *(Action: BISU)*
  - We should better define the injection inhibit requirements. *(Action: BISU)*
  - We should clarify the commissioning procedures for the protection systems that are to be installed by the experiments. *(Action: BISU, Commissioning of the Machine Protection System Sub-Working-Group)*

7. CONCLUSIONS

The progress on the above list of actions and open issues will be monitored and coordinated within LEMIC and associated working groups. Final decisions will be taken at the LTC. It is proposed to organize a follow-up meeting towards the end of 2007 to review the status of the action list.