# Machine considerations and constraints for the Safe Injection Flag and Safe Beam Flag

**Jörg Wenninger**
**AB-OP-SPS**

- **Introduction to 'injection flags'**
- **Machine considerations on injection intensities**
- **Summary**

# LHC Machine Protection – Jurassic area (2001)

Rudiger and Jorg are having lunch in a Migros Restaurant…

They are trying to figure out how to protect the LHC at injection without having to survey 1600 PC currents and much more !


The idea emerges that the beam itself is the best surveillance system …

By the time they have coffee, the basic schema for injection protection was born, with Beam Presence and Safe Beam Flag !

MIGROS

Where the Beam Presence Flag was born!

# Safe Beam Flag

The fundamental role of the Safe Bean Flag (SBF) is to provide a safe means of masking interlocks for special operational phases with low intensity (safe) beam : machine commissioning and machine experiments.

- Selected MPS client signals can be maskable, but only when the SBF is TRUE (safe beam). When the SBF is FALSE masks are ignored automatically without 'human' intervention.
- SBF is TRUE when :
  - LHC beam at 450 GeV — $I < 10^{12}$ protons
  - LHC beam at 7 TeV — $I \sim 10^{10}$ protons
  - SPS beam (any energy) — $I < 1.3\times10^{12}$ protons - value used for 2007 SPS operation.
- Comments for SPS :
  - The limit of $1.3\times10^{12}$ p is due to the difficulty of accelerating CNGS beams of $< 10^{12}$ p without 'complex' manipulations (RF).
  - For commissioning of the SPS-LHC + CNGS transfer lines the masking has proven to be an invaluable tool, avoiding frequent interlock threshold changes. Without SBF, 100's of thresholds (!!!) would been changed back and forth during the commissioning !!
  - Without SBF the author of this presentation would not have been able to sleep during the CNGS operation period where the intensity is > LHC beam intensities !

# Beam Presence Flag

The role of the Beam Presence Flag (BPF) is to provide a safe means of injecting into an empty LHC ring.

- The basic idea is that if some beam is present in a ring, the conditions for injection of high intensity are sufficient to avoid immediate loss of the beam over one turn: for example if a magnet setting is totally off. Even if the lifetime is very poor (seconds or less !), the beam will stay for some turns and the BLMs have time to detect losses and trigger the dump if necessary.
- The BPF is **TRUE** when measurable beam is present in the ring, ~ $10^9$ p (or charges).
- The BPF is send at 1 kHz via direct link to the SPS extraction interlock system where the decision to extract from the SPS/inject into the LHC is taken.

# SPS Extraction/LHC Injection Logic

The initial extraction logic, enforced at the interlock system level (NOT by operational procedures), which is acceptable from the machine point of view is :

- If the beam in the SPS is safe (SBF = TRUE), extraction can happen independently of the state of the BPF:

  **SBF_SPS = TRUE** → Extraction/injection is **ALWAYS** allowed.

- If the beam is the SPS is not safe (SBF = FALSE), extraction can only happen when BPF = TRUE, i.e. there must be some beam circulating in the LHC ring:

  **SBF_SPS = FALSE** → Extraction/injection only if **BPF = TRUE**.

It is important to note that this does not mean that each LHC injection sequence starts with $10^{12}$ p, but only that it is not forbidden by the MPS to do so !

# NEW SPS Extraction/LHC Injection Logic

A new extraction logic has been proposed following the June Workshop on Experiments Protection. The new logic decouples the limits for safe masking in the SPS from the safe beam for LHC injection:

- Before : **what is safe for masking in the SPS is safe for injection into the LHC.**
- New : we introduce yet another Safe Flag in the SPS, the Safe LHC Injection Flag with an intensity limit that is decoupled from the SPS_SBF. The new logic becomes:

  **SLIF_SPS = TRUE** → Extraction/injection is ALWAYS allowed.

  **SLIF_SPS = FALSE** → Extraction/injection only if **BPF = TRUE**.

- To be defined :

  SLIF_SPS = TRUE if **I < ????? & I < SBF Threshold.**

- Subtle detail:

  By decoupling SBF and SLIF, it is possible to mask interlocks in the SPS-LHC transfer line when injecting with SLIF_SPS = FALSE (when I sits between the SLIF and SBF limit).

# The PILOT bunch

- The pilot bunch intensity of $5 \times 10^9$ protons was defined (long ago) such that a pilot bunch can be lost entirely in a magnet without quenching. The safety margin was around a factor 2…

- The limit has not changed fundamentally since then, but it still deserves experimental conformation.

- The pilot bunch has the role of the 'probe' beam for an empty machine, since even if lost entirely it should not quench.

- The standard LHC injection scenarios begin with injection of a pilot <u>at the start of a new fill</u>, to avoid quenching right away if the machine is not fully reproducible (or if we cannot anticipate all changes).

  But : once a pilot has circulated 'happily' there is a priori no reason why one cannot dump it and then re-inject a SAFE beam (for example a nominal bunch of $10^{11}$ p) in the empty machine, once some experience has been gained on the magnet/machine behavior at injection !

# Injection into an empty machine – case 1 : screens

- The screens used for optics matching and for injection region steering can only be used WHEN THERE IS NO CIRCULATING BEAM in the LHC.
- Any beam that is injected with screens in beam must be dumped after some number of turns – 'INJECTION AND DUMP' mode. There is a dedicated interlock logic for the screens.
- In other words: BPF is **FALSE** when injecting with screens !
- What is the minimum intensity that provides good data quality for screen matching?
  - Experience from the transfer lines shows that the screens provide already reasonable to good data for pilot bunches.
  - For best use of the screens the possibility to inject few $10^{10}$ protons should be maintained.

# Injection into an empty machine – case 2 : transfer line collimation

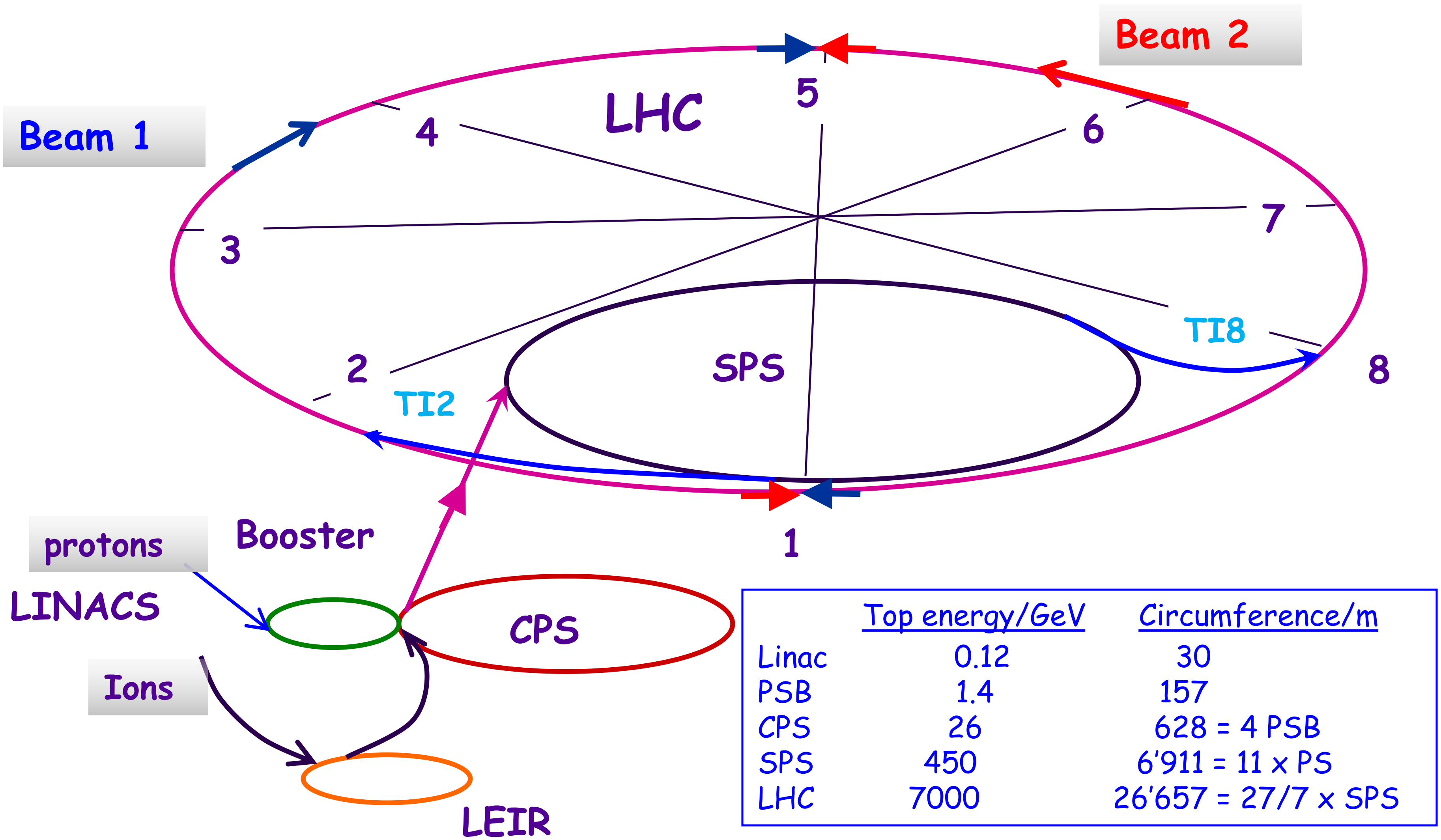
- The collimators in the SPS-LHC transfer lines must be setup with beam. They are essential for injection protection.


- The alignment is performed by a transmission measurement which requires normalization of BLM/BCT LHC signals by SPS BCT data : for pilots this normalization is not precise (from few to 10 %) which makes such measurements excessively lengthy.
- What is the minimum intensity for alignment?
  - Present experience indicates that 3-5x$10^{10}$ p may be sufficient.
  - In principle it could be possible (to be confirmed) to first inject a pilot into the LHC and then perform some 100 measurements by injecting one bunch after the other into the LHC (into different buckets). Then dump beam in the LHC and restart. But this means storing up to $10^{13}$ p in the LHC – issue for the 'early days' ?

# The orbit feedback & BPM issue

- Although the LHC BPMs are designed to operate for bunch intensities of > ~2x$10^9$ charges, significant systematic measurement errors develop at pilot intensities.
- Measurements of the same real orbit, performed with a pilot bunch and a nominal bunch, may differ systematically by some 0.2 mm –ish. Not insignificant wrt collimation tolerances !!!
- Such offsets are a serious problem for the orbit correction (feedback) if during the filling sequence the intensity jumps frequently back and forth between say pilot and nominal.
- For orbit correction, such drastic intensity changes should be minimized, if possible only inject pilot at the beginning and then try to stick to few $10^{10}$ p.

# The injector issue / 1




| | Top energy/GeV | Circumference/m |
|---|---|---|
| Linac | 0.12 | 30 |
| PSB | 1.4 | 157 |
| CPS | 26 | 628 = 4 PSB |
| SPS | 450 | 6'911 = 11 x PS |
| LHC | 7000 | 26'657 = 27/7 x SPS |

# The injector issue / 2

- The LHC beams have a long journey from the gas bottle to the LHC, including lot's of 'manipulations' in the injectors.
- It is important to realize that a pilot bunch and a bunch of few-$10^{10}$ to $10^{11}$ p are subject to different manipulations and settings in the injectors.
- Changing back and forth between a pilot and a more intense bunch requires:
  - A cycle change in the injectors: minimum delay is 1-2 minutes. For the time being > 5 minutes is more realistic…
  - A long and more complex cycle which combines cycles for the pilot and the more intense bunch: less efficient, not always possible.
- This means that machine studies (and possibly also normal filling) can be significantly less efficient if pilot bunches must always be injected first into an empty machine!

# Summary

- Following the June WS on MP for experiments, we have introduced a new Safe Flag in the SPS, **the Safe LHC Injection Flag, that allows us to decouple the safe intensity for injection from the safe intensity for masking (in the SPS).**

- What limit to intensity limit to set for this new flag?
  - From the machine point of view I consider that *the best limit* would be around $1.2 \times 10^{11}$ p, which would allow injection of a single nominal bunch into an empty machine and would give sufficient flexibility for measurements etc..
  - If *'pressed very hard',* I could consider a limit of $3\text{-}5 \times 10^{10}$ p. Note that there may be other situations where this limit is too low !
  - To lower this limit to $10^{10}$ p may be a serious 'handicap' for machine operation and efficiency.

- Nothing prevents us from REVISING the limit after some time of beam operation, but I would still recommend to start with a reasonable value to avoid endless discussions when limit changes are considered.

Those limits reflect the opinion of the author and cannot be assumed to represent the AB management's or MPMG's point of view!