Interlocking LHC screens

- 6 screens in beam dump lines for extracted beam
  - 2 x BTVSE, 2 x BTVD, 2 x BTVDD in LSS6
  - Single beam passage guaranteed
- 13 screens for injection (matching/steering)
  - 4 x BTVS in LSS2
  - 4 x BTVS in LSS8
  - 1 x BTVS in LSS7
  - 2 x BTVM in LSS3
  - 2 x BTVM in LSS4

Input

P+ density limits (EB)

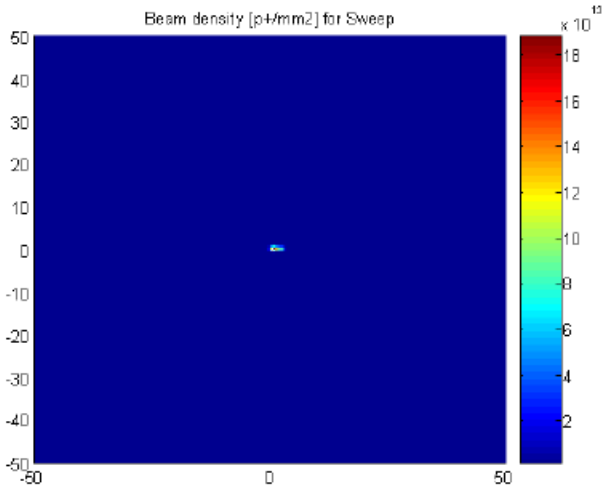
- for the Ti foils you can use a max density of:
  - 1E12 p/cm^2 for a circulating beam (should never happen but...)
  - 1E16 p/cm^2 single shot (just from temperature limits)

- for Al_2O_3
  - No use with circulating beam
  - 1E15 p/cm^2 single shot (from rough thermal-stress estimate)

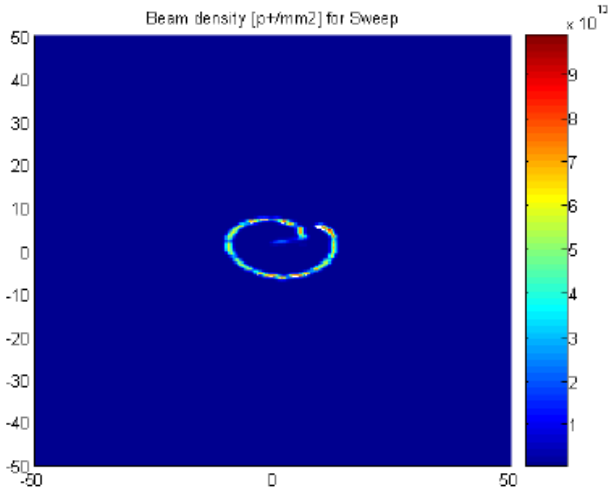
Figures with ‘no safety margin’!

Beam dump screens

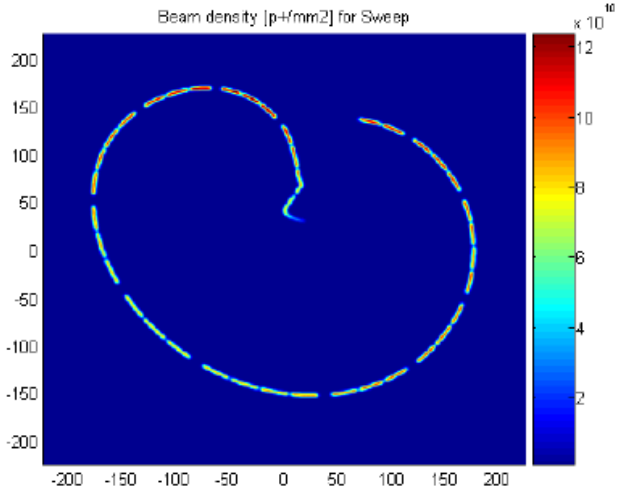
P+ density profiles on screens (BG)



BTVSE 7 TeV



BTVD 7 TeV



BTVDD 7 TeV

p+ densities on TD line screens

bunches	Nominal sweep density p+/mm2		Limit p+/mm2 (factor 2 safety)		450 GeV Max I p+ /bunch		7 TeV Max I p+ /bunch	
2808	450	7000	Ti	Al2O3	Ti	Al2O3	Ti	Al2O3
BTVSE	4.2E+13	2.9E+14	5.0E+13	5.0E+12	2.0E+11	2.0E+10	2.9E+10	**2.9E+09**
BTVD	3.1E+12	1.5E+13	5.0E+13	5.0E+12	2.8E+12	2.8E+11	5.5E+11	5.5E+10
BTVDD	4.2E+10	1.9E+11	5.0E+13	5.0E+12			4.6E+13	4.6E+12

bunches	Single bunch density p+/mm2		Limit p+/mm2 (factor 2 safety)		Ti Max I p+		Al2O3 Max I p+/bunch	
1	450	7000	Ti	Al2O3	450	7000	450	7000
BTVSE	1.9E+10	2.9E+11	5.0E+13	5.0E+12	4.6E+14	4.6E+13	2.9E+13	2.9E+12
BTVD	1.3E+10	2.0E+11	5.0E+13	5.0E+12	6.5E+14	6.5E+13	4.2E+13	4.2E+12
BTVDD	8.2E+08	1.3E+10	5.0E+13	5.0E+12			6.6E+14	6.6E+13

bunches	No MKBH sweep density p+/mm2		Limit p+/mm2		Ti Max I p+		Al2O3 Max I p+/bunch	
2808	450	7000	Ti	Al2O3	450	7000	450	7000
BTVSE	4.2E+13	2.9E+14	5.0E+13	5.0E+12	2.0E+11	2.0E+10	2.9E+10	**2.9E+09**
BTVD	9.9E+12	4.9E+13	5.0E+13	5.0E+12	8.6E+11	8.6E+10	1.7E+11	1.7E+10
BTVDD	3.6E+11	1.5E+12	5.0E+13	5.0E+12			5.5E+12	5.5E+11

bunches	No MKBV sweep density p+/mm2		Limit p+/mm2		Ti Max I p+		Al2O3 Max I p+/bunch	
2808	450	7000	Ti	Al2O3	450	7000	450	7000
BTVSE	4.2E+13	2.9E+14	5.0E+13	5.0E+12	2.0E+11	2.0E+10	2.9E+10	**2.9E+09**
BTVD	1.5E+13	7.6E+13	5.0E+13	5.0E+12	5.6E+11	5.6E+10	1.1E+11	1.1E+10
BTVDD	4.6E+11	2.0E+12	5.0E+13	5.0E+12			4.2E+12	4.2E+11

bunches	No MKB sweep density p+/mm2		Limit p+/mm2		Ti Max I p+		Al2O3 Max I p+/bunch	
2808	450	7000	Ti	Al2O3	450	7000	450	7000
BTVSE	4.2E+13	2.9E+14	5.0E+13	5.0E+12	2.0E+11	2.0E+10	2.9E+10	**2.9E+09**
BTVD	3.7E+13	2.0E+14	5.0E+13	5.0E+12	2.3E+11	2.3E+10	4.2E+10	**4.2E+09**
BTVDD	2.8E+12	1.4E+13	5.0E+13	5.0E+12			6.1E+11	6.1E+10

Safe total intensities

Maximum total swept intensity (beam in 2808 bunches)

	Ti Max I p+ swept		Al2O3 Max I p+ swept	
	450	7000	450	7000
BTVSE	5.7E+14	5.7E+13	8.1E+13	8.1E+12
BTVD	7.7E+15	7.7E+14	1.5E+15	1.5E+14
BTVDD			1.3E+17	1.3E+16

Maximum total unswept intensity (beam in 1 or a few bunches)

	Ti Max I p+ unswept		Al2O3 Max I p+ unswept	
	450	7000	450	7000
BTVSE	4.6E+14	4.6E+13	2.9E+13	2.9E+12
BTVD	6.5E+14	6.5E+13	4.2E+13	4.2E+12
BTVDD			6.6E+14	6.6E+13

Conclusions

- BTVDD (Al_2O_3)
  - Fixed, so no interlocking
    - Safe for nominal sweep up to ultimate intensity at 7 TeV
    - Damaged for total dilution failure beyond 6e10p+/bunch at 7 TeV
- BTVD
  - Ti screen
    - Safe for nominal sweep up to ultimate intensity at 7 TeV
    - Damaged for MKBV or total dilution failures, beyond 4.2e10 p+/bunch at 7 TeV
  - Al_2O_3 screen
    - Safe for nominal sweep for ultimate intensity at 450 GeV
    - Damaged for nominal sweep above 5.5e10 p+/bunch at 7 TeV
    - Damaged for MKBH/MKBV/total dilution failures
- BTVSE
  - Ti screen
    - Safe for nominal sweep at 450 GeV
    - Damaged above 2.9e10 p+/bunch at 7TeV
  - Al_2O_3 screen
    - Damaged above 2e10 p+/bunch at 450 GeV
    - Damaged above 2.9e9 p+/bunch at 7 TeV

- All screens OK with 3e12 p+ at 7 TeV (17 ultimate bunches)

Interlocking proposal

- For all screens no movement should possible with beam in LHC
  - HW interlocking at the front-end to prevent moving using the beam presence flag
  - Signal to BIC to dump beam if screen starts moving (before movement happens!)

- Sequencer to make explicit checks prior to injection that screen positions are coherent with the proposed fill intensity and maximum energy

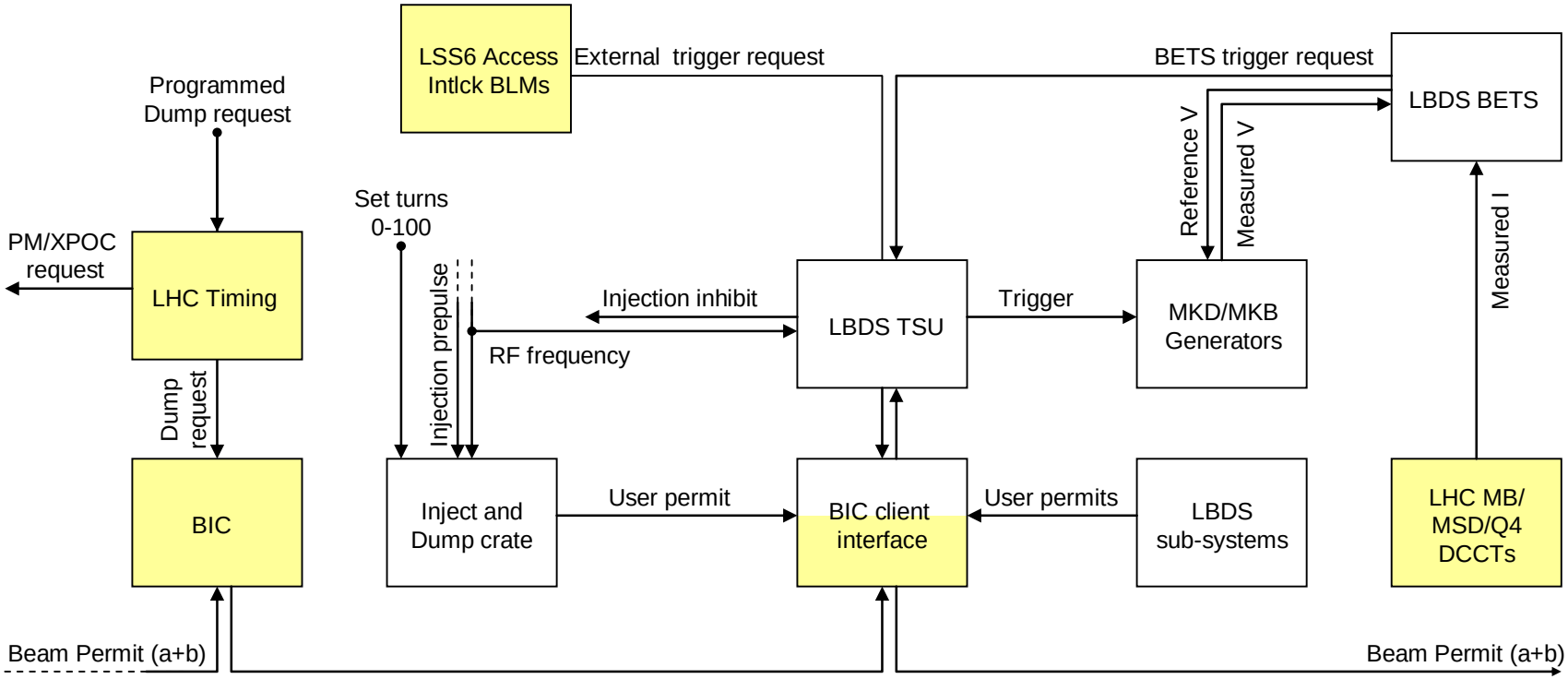
- SW interlocks -> beam dump if conditions violated during fill

- Conditions for sequencer/SW interlocking checks:
  - BTVSE
    - Ti Screen: cannot use above total intensity of 5e13 p+ at 7 TeV.
    - Al_2O_3 screen: cannot use above total of 3e13 p+ at 450 GeV / 3e12 p+ at 7 TeV.
  - BTVD
    - TI screen: no SW interlocking – can be used at all times
    - Al_2O_3 screen: cannot use above total intensity of 1e14 p+ at 7 TeV.

Injection screens

Inject and dump mode

- For injection setting-up with screens, and studies requiring less than 100 ms of circulating beam, e.g. aperture measurements in injection/extraction channel.
- Will use a dedicated hardware system to trigger the beam dump via the BIS
- Necessary to dump after less than one full turn, to ensure that injection setting up with screens can be performed with a single beam impact.
- To protect the screens, maximum number of turns has to be strictly limited.
- This mode has to be limited to Safe Beam from SPS
- Also use a timing event at a few ms after the requested number of turns to provide redundancy for increased screen protection


LSS6 Access
Intlck BLMs
External trigger request
BETS trigger request
LBDS BETS
Programmed
Dump request
Reference V
Measured V
Measured I
Set turns
0-100
PM/XPOC
request
LHC Timing
Injection prepulse
Injection inhibit
LBDS TSU
Trigger
MKD/MKB
Generators
RF frequency
Dump
request
BIC
Inject and
Dump crate
User permit
BIC client
interface
User permits
LBDS
sub-systems
LHC MB/
MSD/Q4
DCCTs
Beam Permit (a+b)
Beam Permit (a+b)

Protection of BTV screens at injection

- Screens can only be in beam in “Inject and Dump I” mode to ensure protection of screens – AND when turns requested is below safe limit (depends on screen type and intensity)

- Safe numbers of turns….
  - Al_2O_3 screens withstand 10^{13} p+/mm^2, and Ti screens 10^{14} p+/mm^2. For nominal optics, p+ density at screen for injected nominal batch of 3.3×10^{13} p+ is $\leq 1.1\times10^{13}$ P+/mm2.
  - Assuming that the safe beam limit is 10^{12} p+ at 450 GeV, safe number of turns for Ti screens is ~ 300, and for Al_2O_3 screens ~30.
  - Taking $\times 3$ margin, max. turns with safe beam should be **100** for Ti and **10** for Al_2O_3 screens.
  - What about 1000 turns with pilot beam? Product of **[turns × intensity]** must not exceed 10^{13} for Al_2O_3, and 10^{14} for Ti screen (so pilot is safe for both screen types).

Interlocking proposal

- Screen interlocking
  - HW interlock from screens to inhibit user permit for unsafe beam, if screen in beam.
  - Sequencer to ensure that: mode = Inject and dump, turns loaded into I&D crate, beam intensity = safe in SPS, beam intensity in SPS below limit (use SPS intensity interlock for this? It works…).
  - SW interlock with turns requested, SPS intensity and screen type to allow or inhibit injection.
- Additional protection measures
  - Limit the maximum number of turns to 1000 in Inject & Dump HW
  - In this mode always include a timing event a few ms after the I&D dump should occur
  - As a real HW interlock with no software dependence, use (existing?) BLMs at each screen, with interlock threshold at an appropriate integration time, to dump beam if losses detected exceed dangerous level.

FS draft ready for checks…

CERN
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Switzerland

the **Large Hadron Collider** project

LHC Project Document No.
LHC-
CERN Div./Group r Supplier/Contractor Document No.
AB/BT
EDMS Document No.
-

Date: 2005-04-04

Functional Specification

INTERLOCKING OF LHC BEAM SCREENS

Abstract

Beam screens will be used in the LHC for commissioning, injection studies and for monitoring the operation of the beam dump. The screens have limits on the circulating and single shot intensity which can be accommodated, given by thermal constraints. The interlocking of the screens must ensure that these limits are respected, while allowing the maximum flexibility for their diagnostic use. For the injection and matching screens their use will require a particular machine mode, 'inject and dump', where the beam is dumped shortly following injection, after a programmed number of turns. This document recalls the function of the different screens, defines the requirements for the interlocking and specifies the functionality required for the different related machine subsystems, including hardware and software interlocking and the LHC sequencer.

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3.2.2 MATCHING SCREENS BTVSM

The minimum beta functions are similar in amplitude to those at the BTVSI monitors. Therefore at 450 GeV the product of the turns with the intensity must be at maximum:

- 1.5×10^{14} p+.turns for the Ti screens;
- 1.5×10^{13} p+.turns for the Al_2O_3 screens.

The BTVSM screens are only to be used for 450 GeV energy.

3.2.3 LBDS SCREENS

For the dump screens, which are used at different energies and with different beam sweeps, the maximum proton density is found by numerically superposing the distributions given by the local β functions using the calculated positions of the swept bunches and finding the maximum density [3]. The calculated proton densities at 450 GeV and 7 TeV are shown below in Table 1 for a single nominal bunch of 1.15×10^{11} p+. Table 2 shows the case of a sweep with a 2808 bunches with nominal intensity. Tables 3-5 show the p+ densities at the screens for the cases of MKBH, MKBV and total dilution failures.

Table 1. p+ densities at the TD line screens for a single nominal bunch.

bunches	Single bunch density p+/mm2	
1	450 GeV	7000 GeV
BTVSE	1.9E+10	2.9E+11
BTVD	1.3E+10	2.0E+11
BTVDD	8.2E+08	1.3E+10

Table 2. p+ densities at the TD line screens for nominal 2808 bunch sweep.

bunches	Nominal sweep density p+/mm2	
2808	450 GeV	7000 GeV
BTVSE	4.2E+13	2.9E+14
BTVD	3.1E+12	1.5E+13
BTVDD	4.2E+10	1.9E+11

Table 3. p+ densities at the TD line screens for 2808 bunch sweep with no MKBH dilution.

bunches	No MKBH sweep density p+/mm2	
2808	450	7000
BTVSE	4.2E+13	2.9E+14
BTVD	9.9E+12	4.9E+13
BTVDD	3.6E+11	1.5E+12

Table 4. p+ densities at the TD line screens for 2808 bunch sweep with no MKBV dilution.

bunches	No MKBV sweep density p+/mm2	
2808	450	7000
BTVSE	4.2E+13	2.9E+14
BTVD	1.5E+13	7.6E+13
BTVDD	4.6E+11	2.0E+12

Table 5. p+ densities at the TD line screens for 2808 bunch sweep with no dilution.

bunches	No MKB sweep density p+/mm2	
2808	450	7000
BTVSE	4.2E+13	2.9E+14
BTVD	3.7E+13	2.0E+14
BTVDD	2.8E+12	1.4E+13