Interlock system for the TI8/TT40 tests : setup & ‘post-mortem’ considerations

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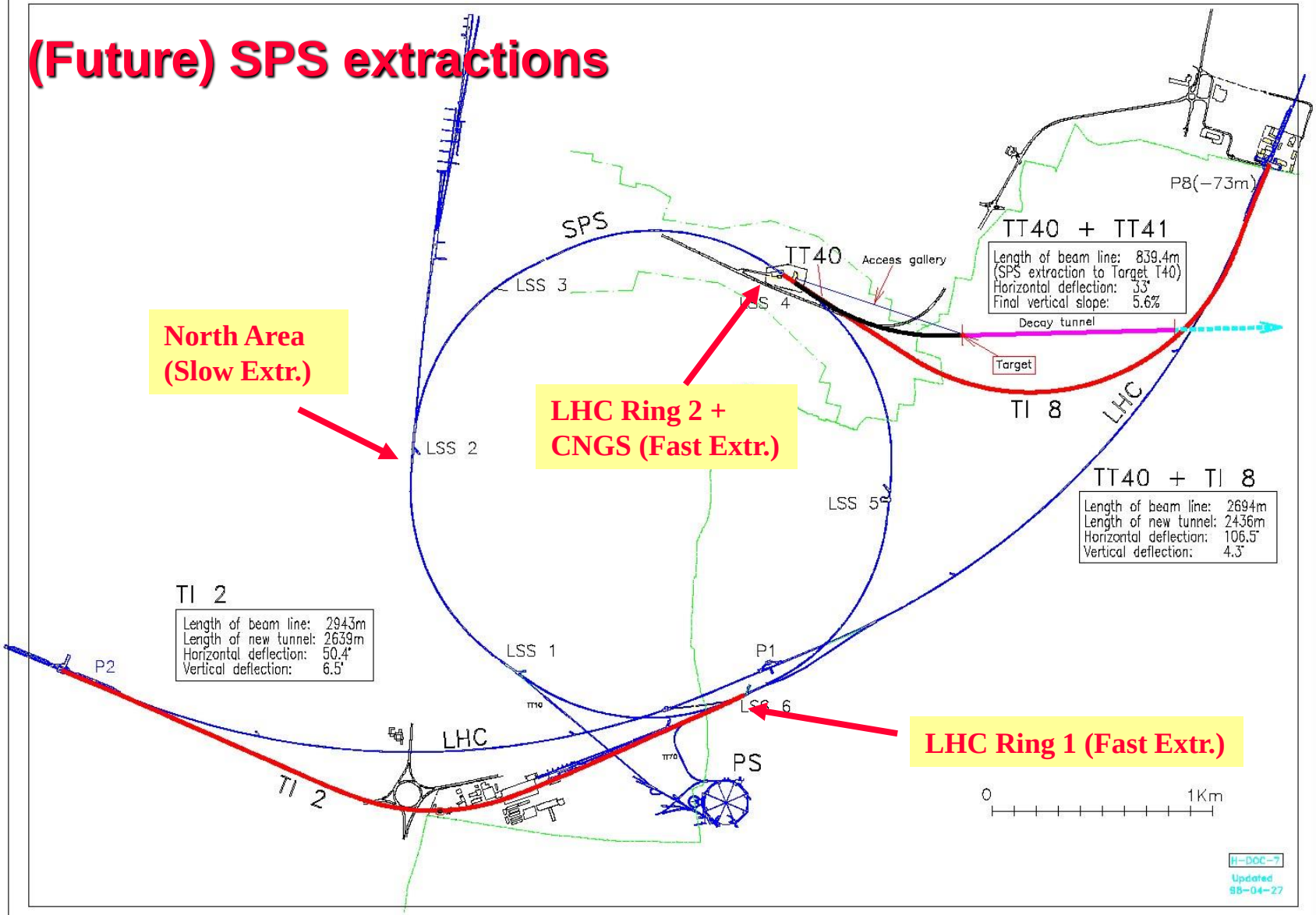
- The interlock system for the TI8/TT40 tests
- The beam incident on 25th October
- User interfaces
- Logging
- Outlook

TI8 / TT40 tests

- Two 48 hours periods for the TI8 transfer line commissiong up to the downstream dump block (TED) :
  - Tests performed over the week-end because IP8 had to be closed (due to muon rates from the TED dump).
  - Total intensity on TED limited to ~ 5 $\times 10^{13}$ protons / 48 hours.
    → no activation of the LHC tunnel area
  - Intensity per extraction limited to 3-4 $\times 10^{10}$ protons.
  - Most of the time we extracted pilot bunches of 5 $\times 10^{9}$ protons.

- A ~ 24 hour high intensity extraction period (TT40 line only) for collimators, material tests and CNGS targets.
  - Max. extracted intensity : 3.2 $\times 10^{13}$ protons (LHC nominal).
  - During the first test : beam incident where a nominal LHC batch impacted on a quadrupole vacuum chamber following a magnet interlock on the extraction septum MSE → presentation by J. Uythoven.
  - The test was successfully repeated 2 weeks later with improved interlocking and better understanding of the ‘septum problems’.

(Future) SPS extractions

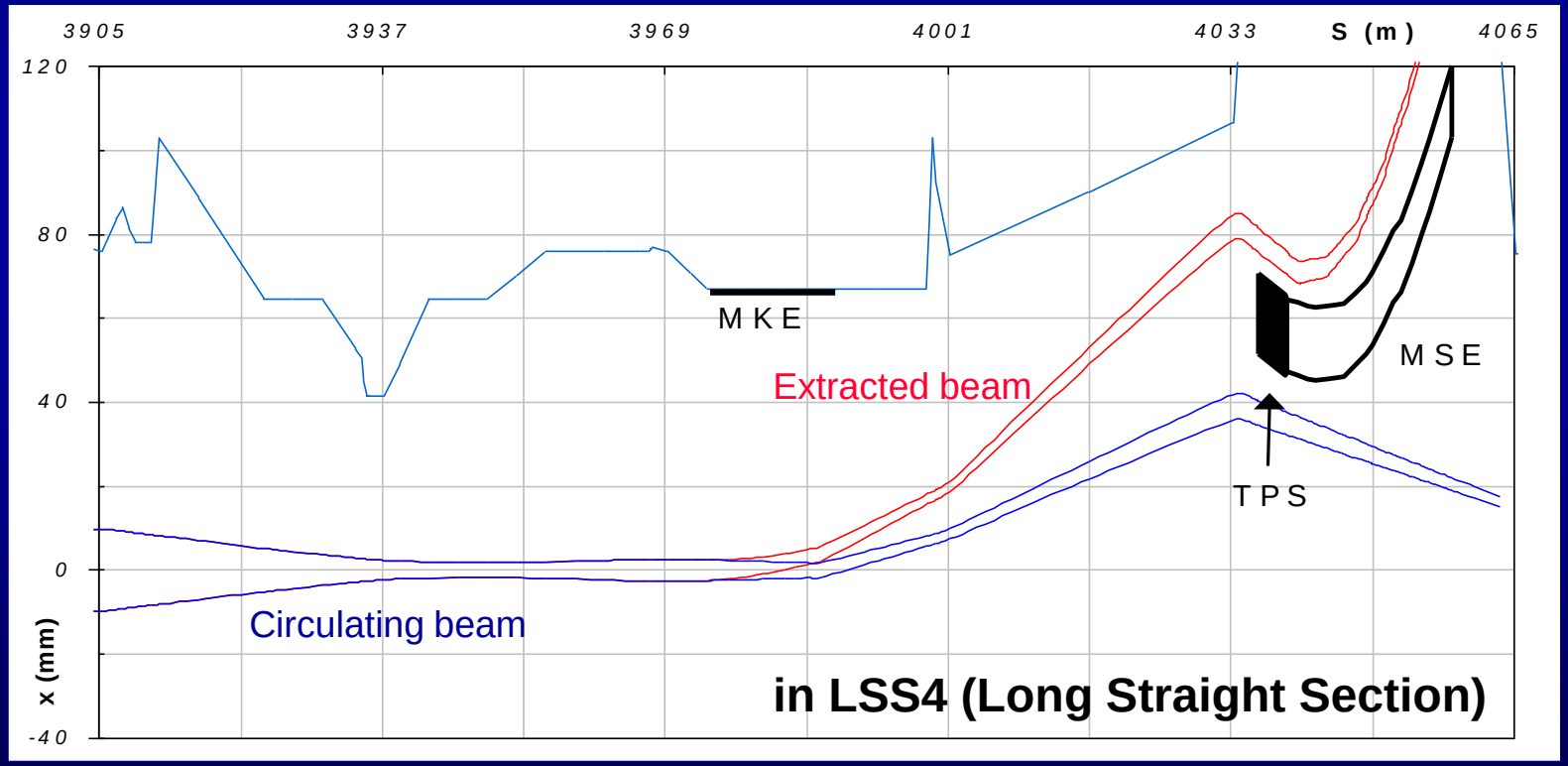


TED dump

- Mobile dump – able to withstand the impact of the nominal LHC injection.
- In this picture – the upstream dump in TT40.

Extraction channel

- Extraction bumpers (= strong & fast orbit correctors, 4 / plane) :
  → 35 mm amplitude horizontal bump @ beam position monitor.
- Extraction kicker MKE (5 magnets, 0.53 mrad).
- Magnetic septum MSE (6 magnets, 22000 A, 12 mrad, $\tau = L/R = 23$ ms).



What was interlocked ?

- Vacuum valves in the entire line.
- Extraction kicker state.
- Beam intensity → see later.
- The current of power converters :
  - Tolerances :
    - 3×10^{-4} on main dipoles and quadrupoles (2 converters).
    - $1\text{-}2 \times 10^{-3}$ on dipole strings, quadrupoles and bumpers (26 converters).
  - For TI8 tests the orbit correctors were not surveyed.
  - For the high intensity tests orbit correctors were surveyed to ensure beam excursions < 1-2 mm.
- The bumped beam position :
  - Tolerance of ±0.5 – ±2 mm (depending on conditions).
- Beam loss : not effective for TI8 (interlock arises AFTER beam passage).
- Warm magnet interlocks (WPIC) for all TT40 and TI8 magnets.
- Added at '½ time' : interlock on the MSE magnet.

An interlock on beam loss in the extraction channel was part of the SPS ring interlock system.

Intensity interlocks

Two interlocks to limit the intensity that is extracted :

SPS ring intensity limitation :

- Based on the SPS hadron BCT (resolution 10^{10} charges).
- The beam is dumped in the realy part of the ramp if the total intensity exceeds a preset threshold.

Extraction intensity limitation :

- Based on the SPS ion / high sensitivity BCT installed in LSS4.
  - resolution is 10^{8} charges.
  - saturation at 7×10^{11} charges.
- An extraction permit signal is generated if the intensity is BELOW a preset threshold.
- The extraction permit is used as NON-MASKABLE client of the TT40 interlock.

For the TI8 line tests :

- Ring intensity threshold : 2×10^{11} charges.
- Extraction intensity threshold : 5×10^{10} charges.

BIC Layout

BIC – LSS4 master :

- BIC – TT40 permit
- BIC – TI8 upstream permit
- BIC – TI8 downstream permit

BIC - TT40 :

- TT40 Vacuum
- Kicker magnet
- Beam Pos (BPCE) → later : MSE PLC interlock
- Beam intensity (BCT)
- MSE PC surveillance
- Bumper PC surveillance
- TT40 & TI8 upstream PC surveillance
- Beam Loss → later Beam Pos

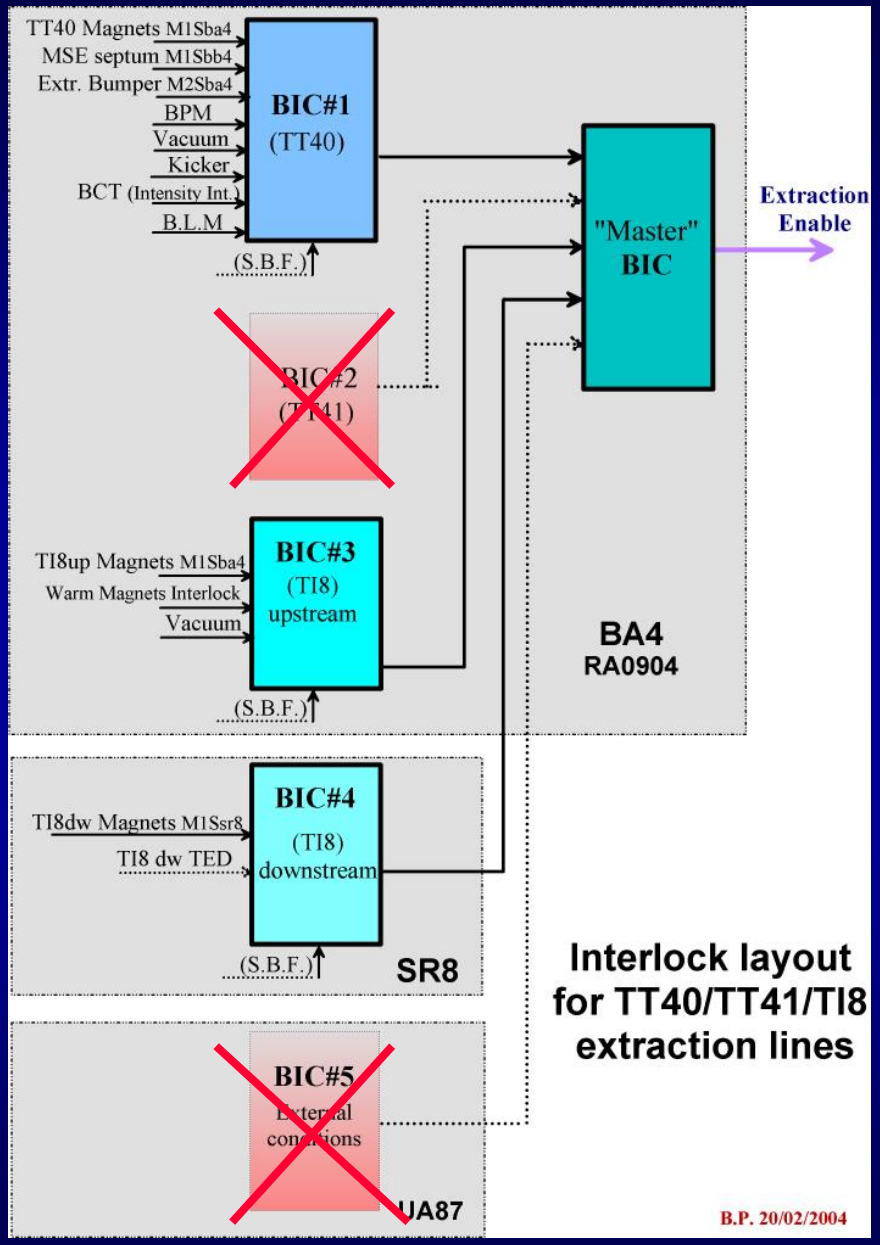
BIC – TI8 upstream :

- Warm magnet interlocks TT40+TI8
- TI8 vacuum
- Later : Beam Loss

BIC – TI8 downstream :

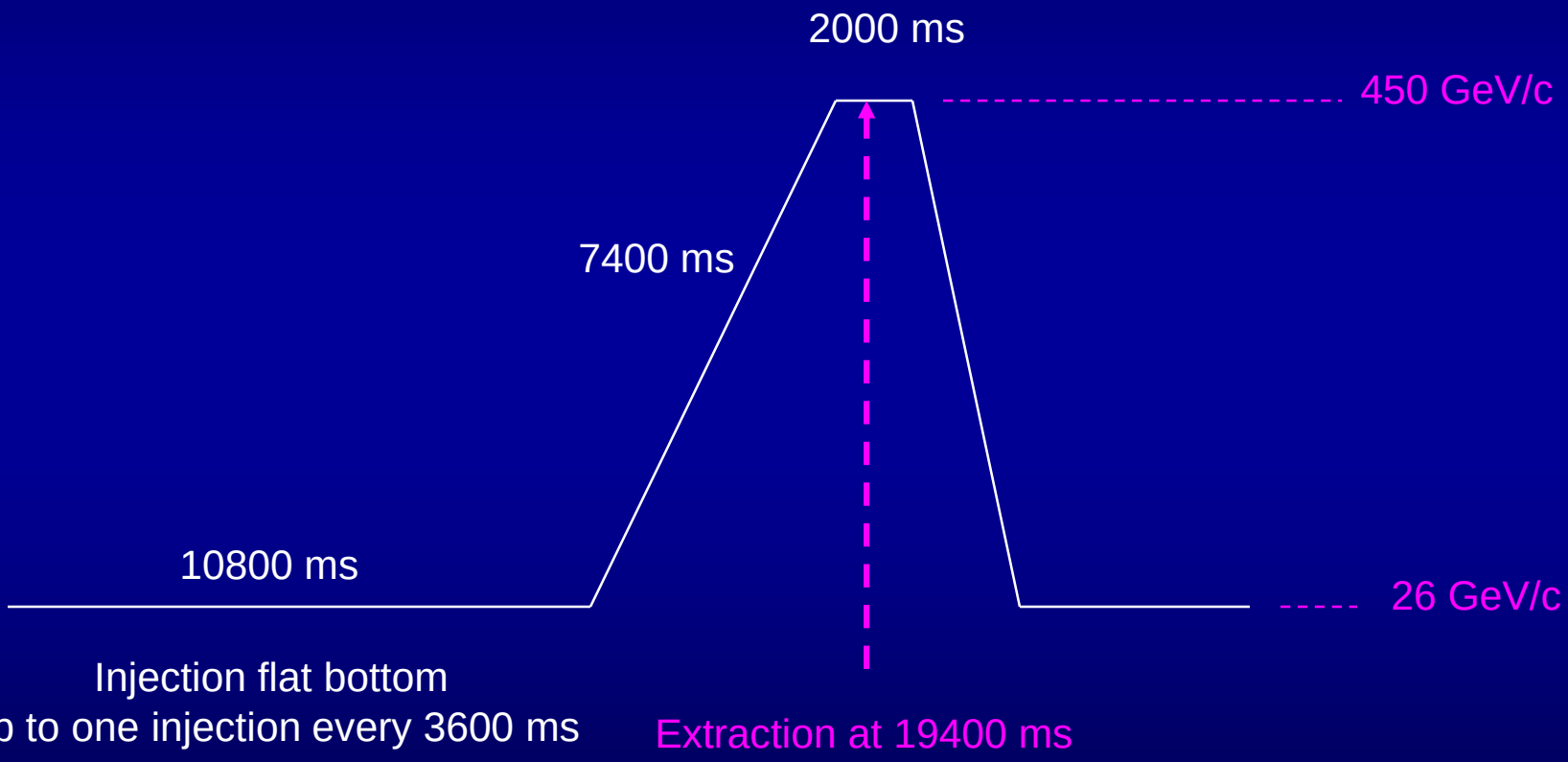
- TI8 downstream PC surveillance

RED = NOT MASKABLE



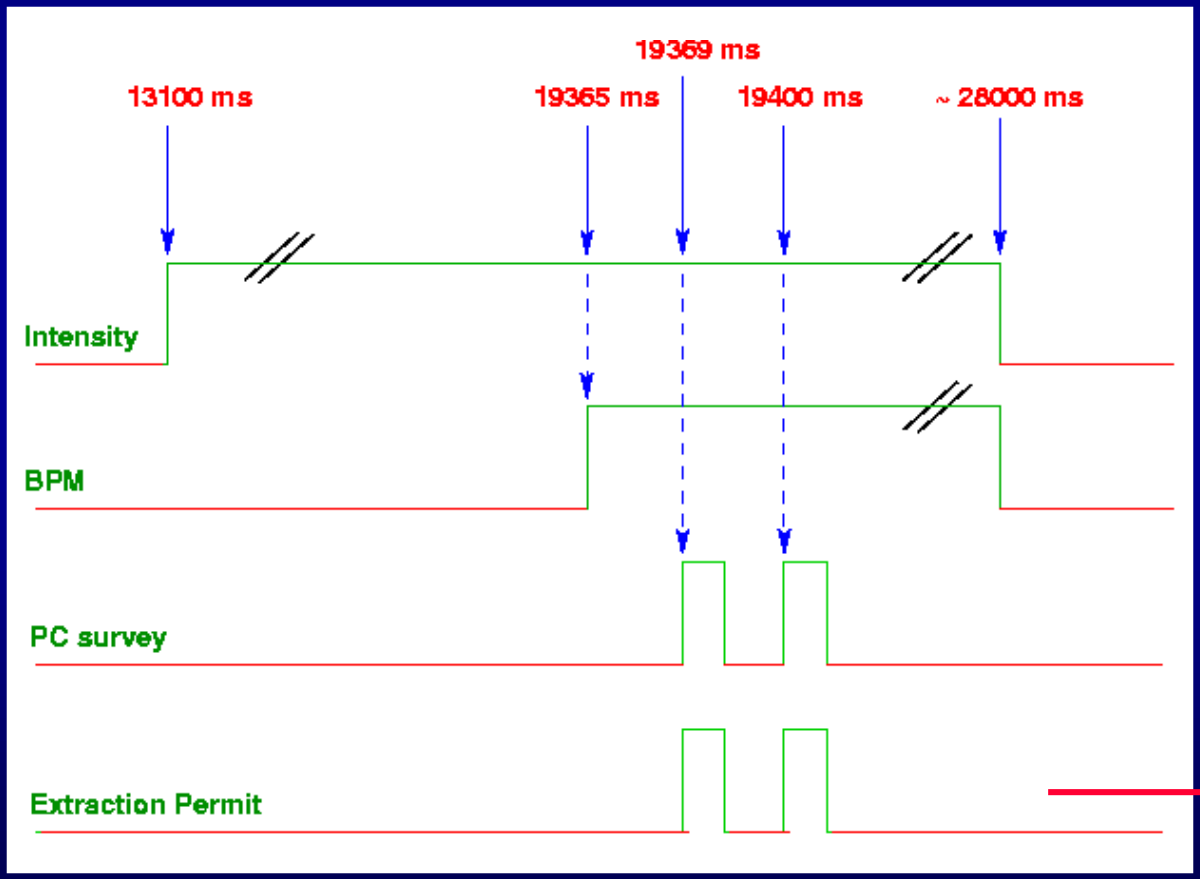
SPS cycle for LHC injection

Total cycle length 28.8 s



Extraction timing / 1

- The extraction interlock system gives a (short) permit signal at extraction time.
- The beam intensity, beam position and PC surveillance clients each give a permit signal of varying length that is reset before the next cycle.
- The other clients give ‘permanent’ permits – similar to the LHC situation.

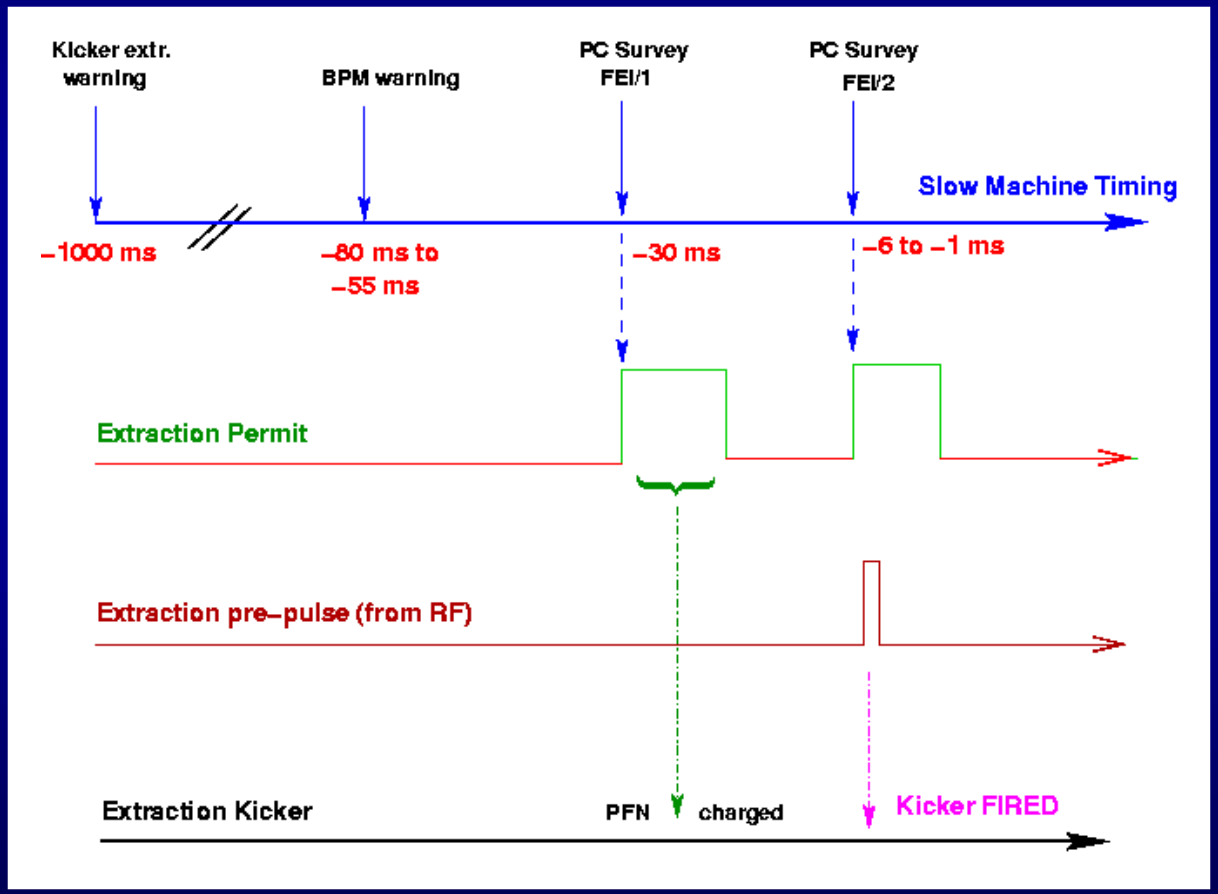


The extraction permit signal is the logical AND of all client inputs.

The PC survey gives 2 short permits → see next slide.

Extraction timing / 2

- The first PC surveillance permit is used to charge the Pulse Forming Networks of the extraction kickers – only done if all is OK at that time.
- The second PC surveillance permit is given just before extraction.



Timing jitter on permit signals :

BPM	**200-800 μs**
Intensity	**100-200 μs**
PC survey	**10-20 μs**

Occasionally the BPM permit arrives with a delay of 10-20 ms.

Beam incident 25th October 2004

Beam impact on the vacuum chamber in the TT40 line : details will be given in J. Uythoven's presentation.

Cause of the problem :

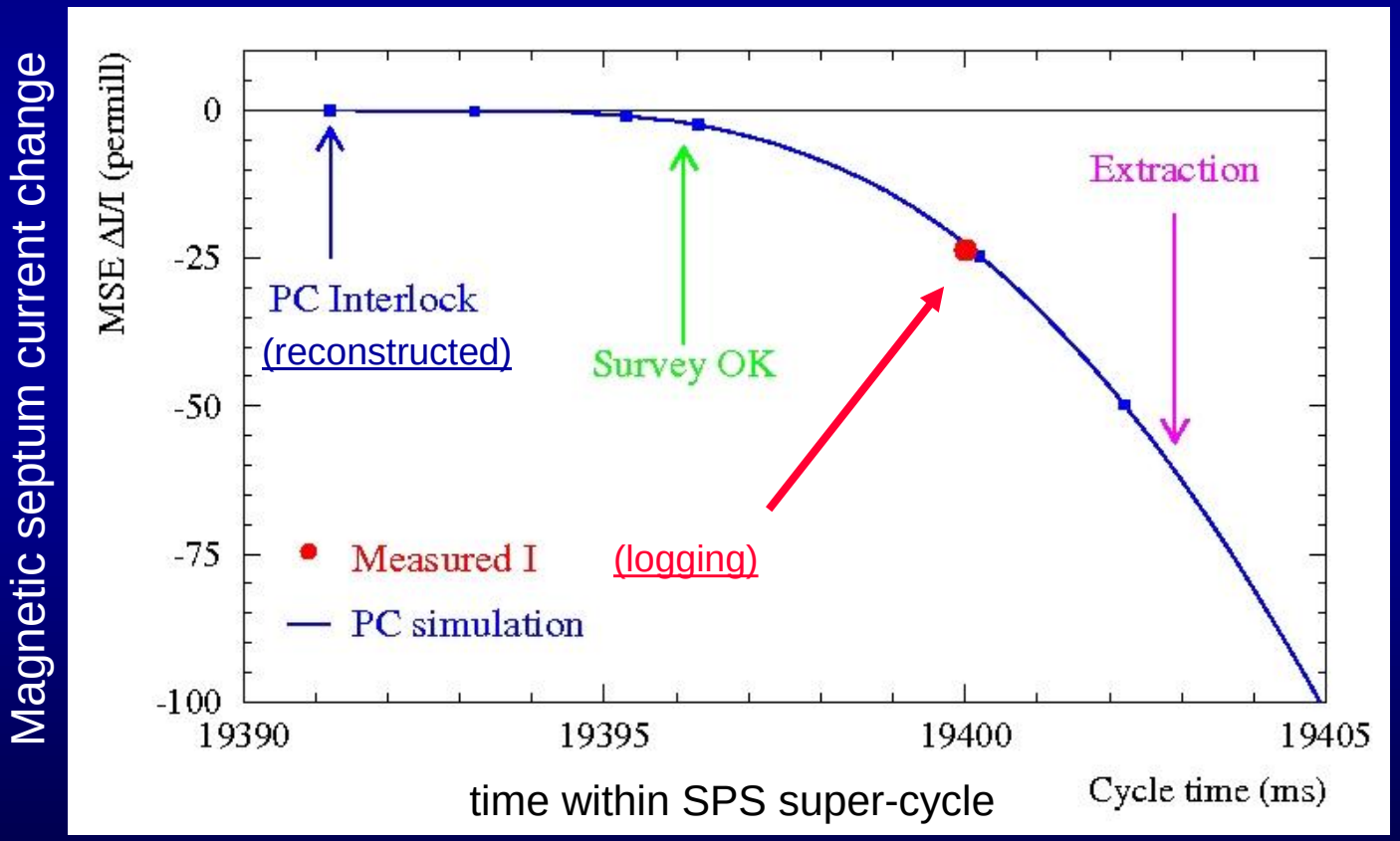
- Interlock on the MSE power converter due to a SPURIOUS magnet fault that fell inside the time interval between the last current surveillance and the extraction.

Cure :

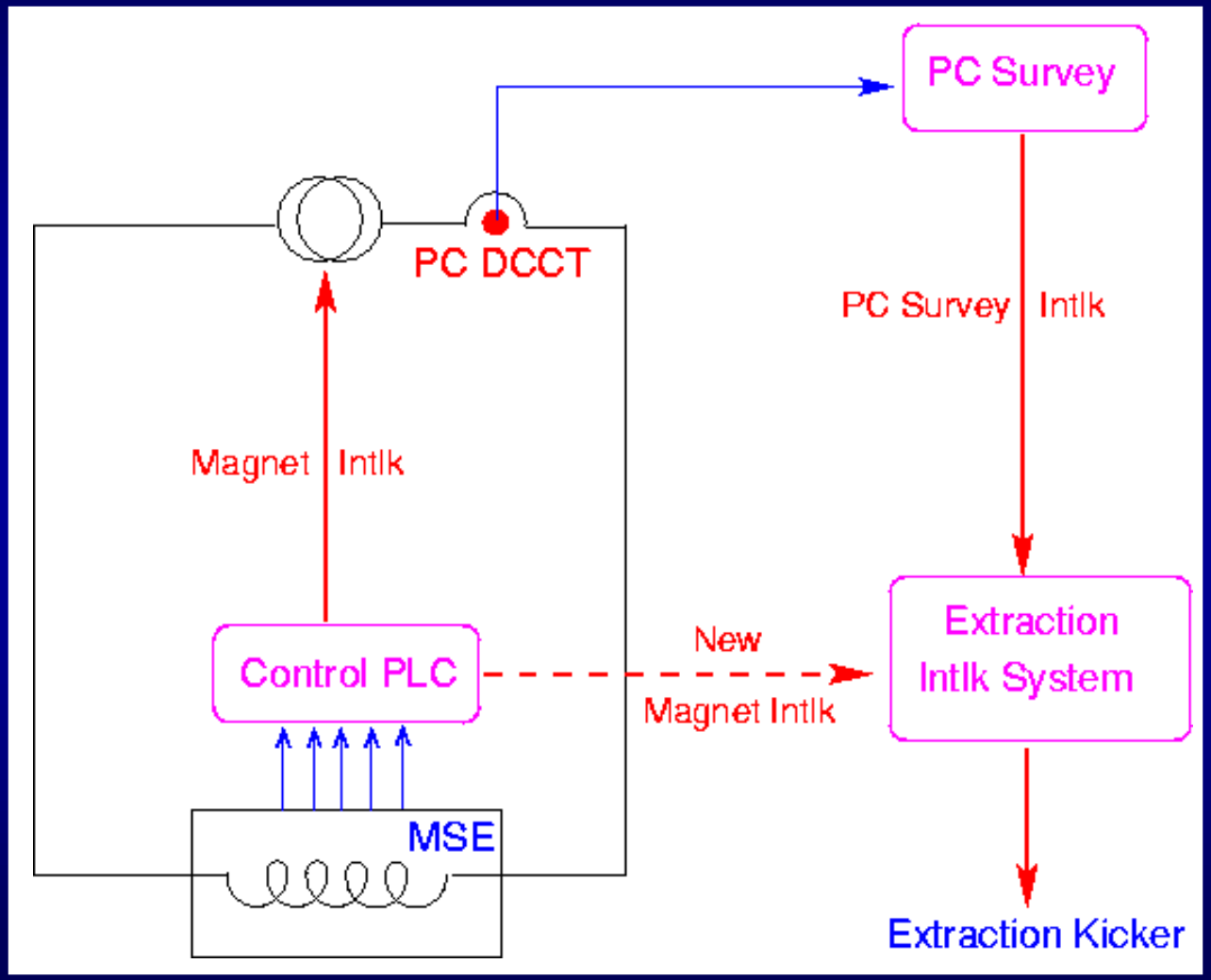
- Additional interlock between the PLC that surveys the state of the MSE magnet (temperature, water…) and the TT40 BIC.
- New interlock logic for the MSE magnet :
  - First an interlock is send to the BIC → inhibits extraction.
  - 10 ms later the PC is switched off.
- Improved and tigher current surveillance.

Beam incident timing

- The BLUE curve is obtained from a PC simulation (PC off) by AB/PO.
- The timing of PC current survey (0.1 % tolerance) and of the precise extraction time is obtained from the Beam Interlock System logging.
- This reconstrction is consistent (within ~ 0.5 ms) with the beam impact point.



New MSE magnet interlock



PC surveillance

Initial settings – first TI8/TT40 test :

- Current readings were averaged over 10 samples (10 ms) – we were uncertain about ripple / accuracy of the DCCT readings.
- Permit was given nominally 3 ms before extraction. In fact due to a delay of the extraction pre-pulses, the permit actually arrived ~ 6 ms before extraction.
  → surveillance gap of 6 ms + delay due to averaging.

Second test series :

With the experience of the first test and an analysis of the PC current stability the 'surveillance gap' was significantly reduced :

- Current readings were based on ONE sample.
- It was also discovered that the latest sample used previously was actually 2 SPS cycles old (double buffering in the PC control system).
- The current tolerances could be reduced to ≤0.1% on all PCs.

For more details → M. Jonker's presentation

Other interlock issues

Bumped beam position interlock :

- The first high intensity test revealed a very large (~ 10 mm) systematic reading error due to excessive signal with high intensity beams.
  → fixed for second test period (attenuator).
- There are residual systematic shifts of the measured beam position between high and low intensity beams due to gain changes…
- These systematic shifts may prevent us form obtaining an operational interlock with tight ±0.5 mm tolerances.
- Follow up in … 2006.

EMC

Electro-Magnetic Coupling was observed on the interlocks signals.

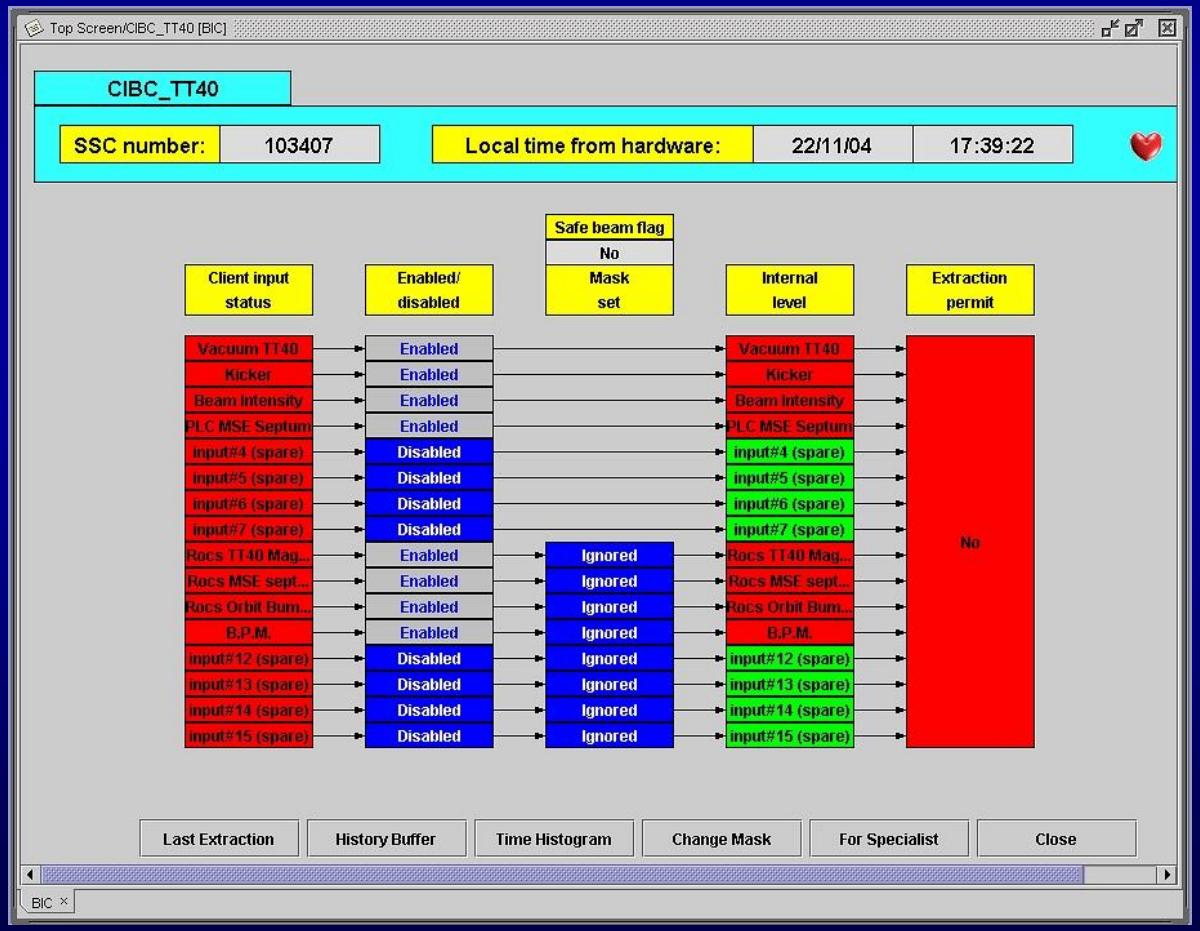
- Each time the extraction kicker pulsed, a short transient appeared on ONE of the TWO interlock signals between kicker and BIC (note that all client signal transmissions are redundant).
  - → This turned out to be an excellent diagnostics for the kicker triggering.
  - → In 2006 we should add the information of the extraction pre-pulses to the interlock system logging.

- When the MSE PC is switched on (main cicuit breaker ?) there are transients on a number of interlocks channels connected to the TT40 BIC.

→ design will be improved !

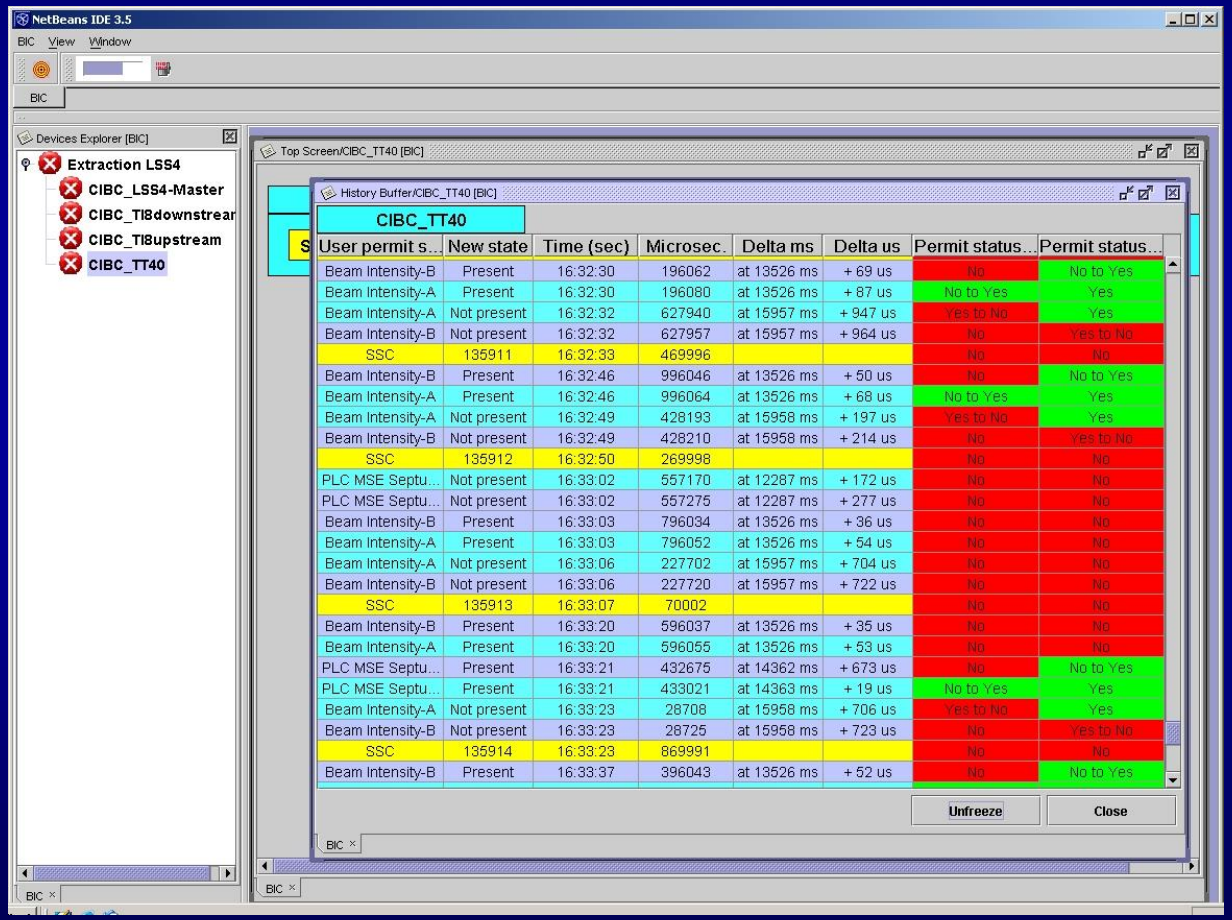
BIC User Interface

- Basically same UI than for 2003.
- Improved functionality – essentially OK for the LHC that is very ‘static’.
- Fast SPS cycling and very short (~ few ms) permit signals make the display more complicated at the SPS than at the LHC – not yet optimal.



Interlock history

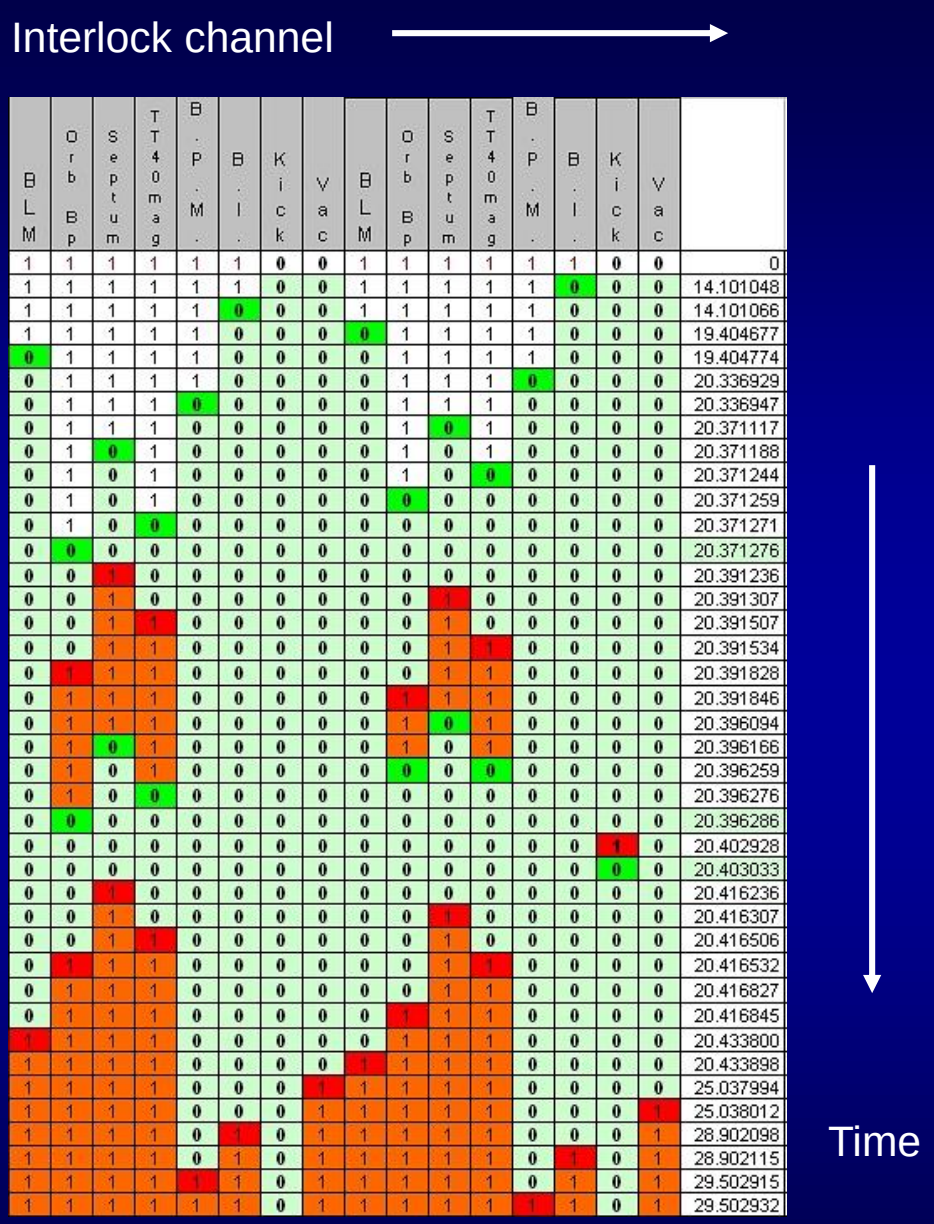
- History turned out to be the most usefull/used diagnostics by the experts.
- Difficult to read by non-experts !



User permit s...	New state	Time (sec)	Microsec.	Delta ms	Delta us	Permit status...	Permit status...
Beam Intensity-B	Present	16:32:30	196062	at 13526 ms	+ 69 us	No	No to Yes
Beam Intensity-A	Present	16:32:30	196080	at 13526 ms	+ 87 us	No to Yes	Yes
Beam Intensity-A	Not present	16:32:32	627940	at 15957 ms	+ 947 us	Yes to No	Yes
Beam Intensity-B	Not present	16:32:32	627957	at 15957 ms	+ 964 us	No	Yes to No
SSC	135911	16:32:33	469996			No	No
Beam Intensity-B	Present	16:32:46	996046	at 13526 ms	+ 50 us	No	No to Yes
Beam Intensity-A	Present	16:32:46	996064	at 13526 ms	+ 68 us	No to Yes	Yes
Beam Intensity-A	Not present	16:32:49	428193	at 15958 ms	+ 197 us	Yes to No	Yes
Beam Intensity-B	Not present	16:32:49	428210	at 15958 ms	+ 214 us	No	Yes to No
SSC	135912	16:32:50	269998			No	No
PLC MSE Septu...	Not present	16:33:02	557170	at 12287 ms	+ 172 us	No	No
PLC MSE Septu...	Not present	16:33:02	557275	at 12287 ms	+ 277 us	No	No
Beam Intensity-B	Present	16:33:03	796034	at 13526 ms	+ 36 us	No	No
Beam Intensity-A	Present	16:33:03	796052	at 13526 ms	+ 54 us	No	No
Beam Intensity-A	Not present	16:33:06	227702	at 15957 ms	+ 704 us	No	No
Beam Intensity-B	Not present	16:33:06	227720	at 15957 ms	+ 722 us	No	No
SSC	135913	16:33:07	70002			No	No
Beam Intensity-B	Present	16:33:20	596037	at 13526 ms	+ 35 us	No	No
Beam Intensity-A	Present	16:33:20	596055	at 13526 ms	+ 53 us	No	No
PLC MSE Septu...	Present	16:33:21	432675	at 14362 ms	+ 673 us	No	No to Yes
PLC MSE Septu...	Present	16:33:21	433021	at 14363 ms	+ 19 us	No to Yes	Yes
Beam Intensity-A	Not present	16:33:23	28708	at 15958 ms	+ 706 us	Yes to No	Yes
Beam Intensity-B	Not present	16:33:23	28725	at 15958 ms	+ 723 us	No	Yes to No
SSC	135914	16:33:23	869991			No	No
Beam Intensity-B	Present	16:33:37	396043	at 13526 ms	+ 52 us	No	No to Yes

Improved history display

- In 2006 we need a better display of the interlock history.
- A graphical representation turned out to more delicate to use than foreseen :
  cycles >> longer than permit signals.
- A possible (and surely better) options is the presentation on the right (B. Puccio).
  - Note : 0 = permit, 1 = no permit



BLM	Orb Bp	Septum	TT40mag	B.P.M.	B.I.	Kick	Vac	BLM	Orb Bp	Septum	TT40mag	B.P.M.	B.I.	Kick	Vac	
1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0
1	1	1	1	1	1	0	0	1	1	1	1	1	0	0	0	14.101048
1	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	14.101066
1	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	19.404677
0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	19.404774
0	1	1	1	1	0	0	0	0	1	1	1	0	0	0	0	20.336929
0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	20.336947
0	1	1	1	0	0	0	0	0	1	0	1	0	0	0	0	20.371117
0	1	0	1	0	0	0	0	0	1	0	1	0	0	0	0	20.371188
0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	20.371244
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	20.371259
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20.371271
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20.371276
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	20.391236
0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	20.391307
0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	20.391507
0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	20.391534
0	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	20.391828
0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	20.391846
0	1	1	1	0	0	0	0	0	1	0	1	0	0	0	0	20.396094
0	1	0	1	0	0	0	0	0	1	0	1	0	0	0	0	20.396166
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	20.396259
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20.396276
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20.396286
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	20.402928
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20.403033
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	20.416236
0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	20.416307
0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	20.416506
0	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	20.416532
0	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	20.416827
0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	20.416845
1	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	20.433800
1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	20.433898
1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	0	25.037994
1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	1	25.038012
1	1	1	1	0	1	0	1	1	1	1	1	0	0	0	1	28.902098
1	1	1	1	0	1	0	1	1	1	1	1	0	1	0	1	28.902115
1	1	1	1	1	1	0	1	1	1	1	1	0	1	0	1	29.502915
1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	29.502932

BIC Logging

All state changes in the BIC were logged together with the time (to the μs).

The SPS super-cycle number was logged & used to identify the start of a new cycle.

Logging problems to be fixed :

- About 1 out of 20 cycles was ‘missing’ : contains the data from the previous cycle or is partly ‘corrupted’.
- Masked channels are forced to the PERMIT state in the logging : not possible to verify the changes of masked signals.

The logged information was crucial

- to analyse the beam incident.
- to analyse the system performance (timings…).

Analysis tools were essential to scan the logged data for abnormal conditions, make statistics on the signals…. For the SPS I will have to develop them and make them more ‘operational’ for online diagnostics - to be evaluated.

Interlock references

A number of interlock clients require reference values and tolerances :

- For the tests the settings were set with ‘expert’ programs. This provided some ‘protection’ (limited number of users) but will not work in the long term.
- There was no logging of the references and tolerances.

In the future we need better control :

- SW to control parameter settings.
- Protection against ‘absurd’ settings, excessive changes (mistyping….)…
- Logging of all reference / tolerance changes.
- Multi-cycling of the SPS implies that references depend on the beam type.
- …

Summary

- The first ‘large scale’ performance test of the interlock system including a number of BICs was performed during the TI8 commissioning.

- The BIC system itself performed very well. To be improved :
  - EMC.
  - Control room user interface.
  - Logging errors must be fixed.
  - Logging information for masked channels must be added.

- The beam incident highlighted once more…
  - …the criticality of powering problems on circuits with short time constants. It also showed that it pays off to catch interlocks at the earliest possible stage in order to get rid of the beam before the fault influences the beam.
  - … the interest to develop a fast current/voltage surveillance of critical D1- or MSE-like circuits.

For the future / 1

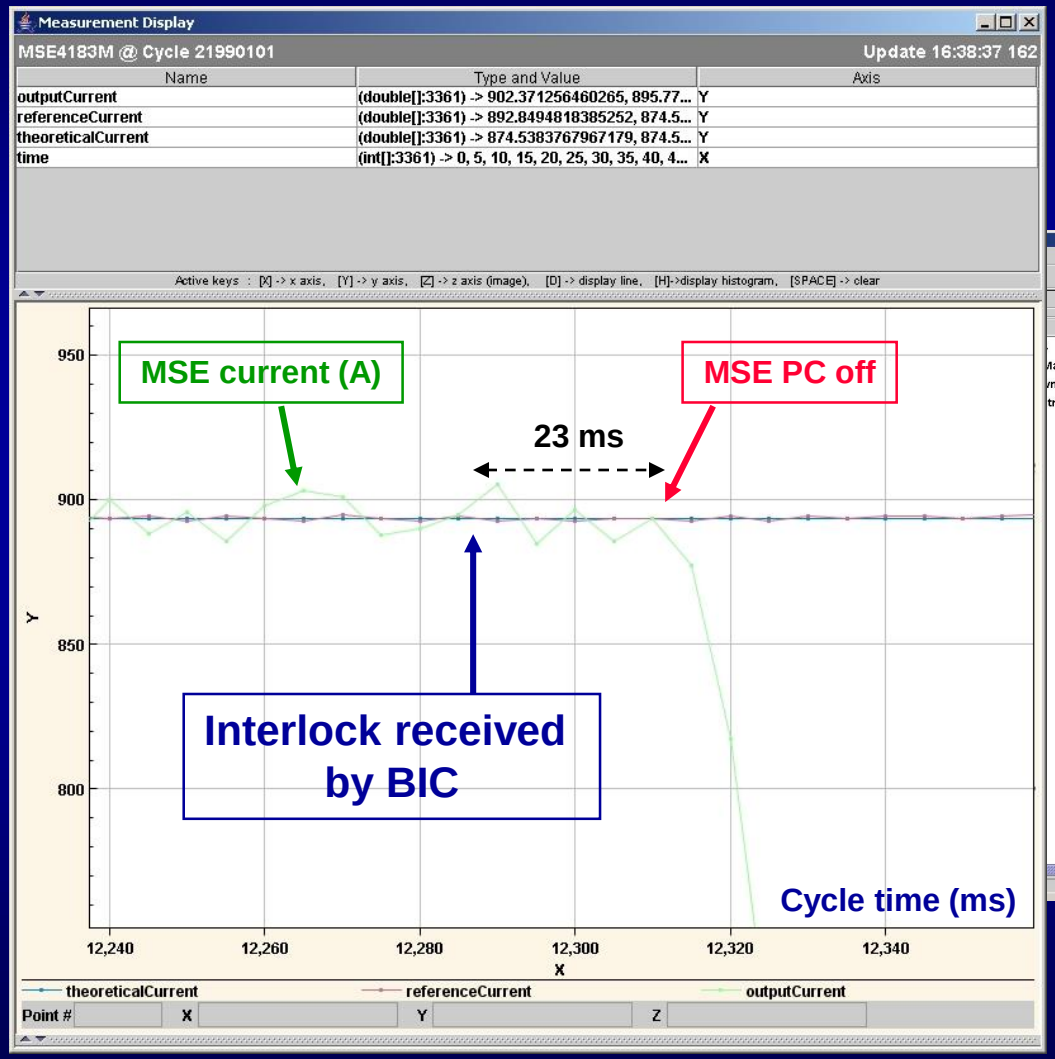
- We must start to tackle issues related to interlock references and settings:
  - SW to set the parameters.
  - Logging and tracing of changes.
- Together with the InjWG the presently defined tolerances on PCs will be re-checked.
- An additional interlock channel must be foreseen for the MSE girder.
- A connection of the extraction system with the SPS emergency beam dump must be established for 2006.
- Proper ‘actions’ following ‘abnormal situations’ for the extraction kicker must be defined / finalized :
  - PFNs charged but kicker was not triggered.
  - First CNGS extraction inhibit.
  - …

For the future / 2

- For 2006 we need a Safe Beam Flag for the SPS.
- The fast current surveillance for circuits with short time constants should be developed and tested in 2006 on the MSE – an excellent training ground for the D1
- In the future we must foresee suficient time to test and analyse the interlock system before moving on to high intensity beams → see also Jan's presentation.

Septum PLC timing test

Current history of the MSE PC



Interlock recording by the BIC