Machine Protection Experience and Issues at the SPS in 2007

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- New SPS ring BIS
- SPS SIS
- Experience from CNGS operation
- Machine protection incidents

Interlock Big Bang 2007

The SPS interlock systems when through their Big Bang in 2007 :

- New LHC-like BIS system for the ring : 6 BICs and a beam permit loop.
- The new SIS took over all software interlocks of the SPS.
- New TT60/TI2 interlock system.

Only the CNGS & TI8 interlocks systems : ~'same as before' !

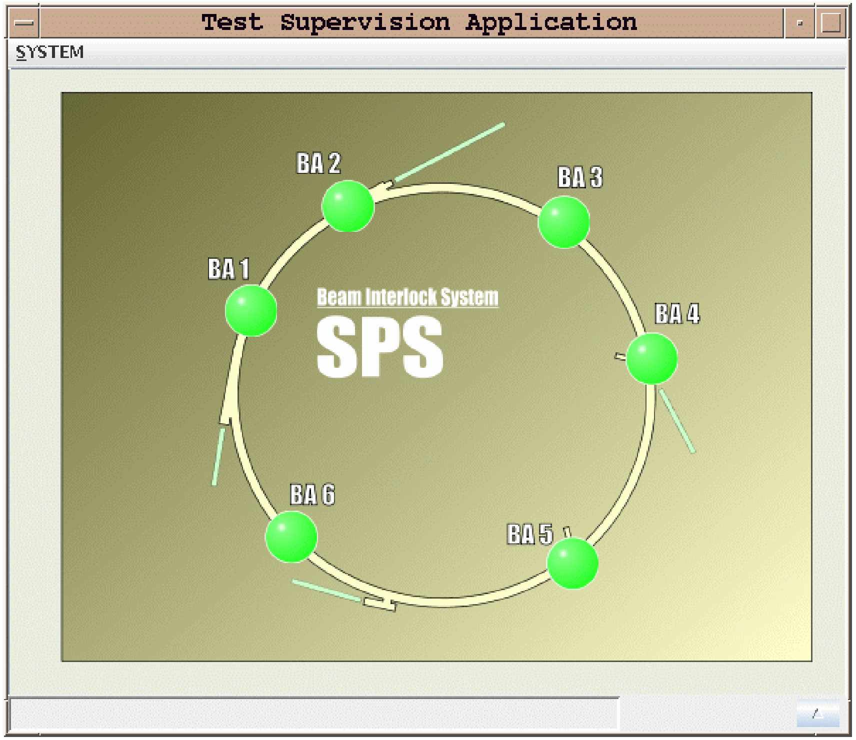
SPS Ring BIS

SPS started up with the new ring BIS (6 BICs + associated beam permit loop):

- Totally smooth transition !!!!
- The 'most difficult' issue for the operators was to get used to the fact that no reset was required after a beam dump !!!

  Contrary to the old BIS, no latching in order to 'decouple' beams.
- We profited (see later) from the additional diagnostics, for example the history buffer.

Perfect job by Bruno's team !!



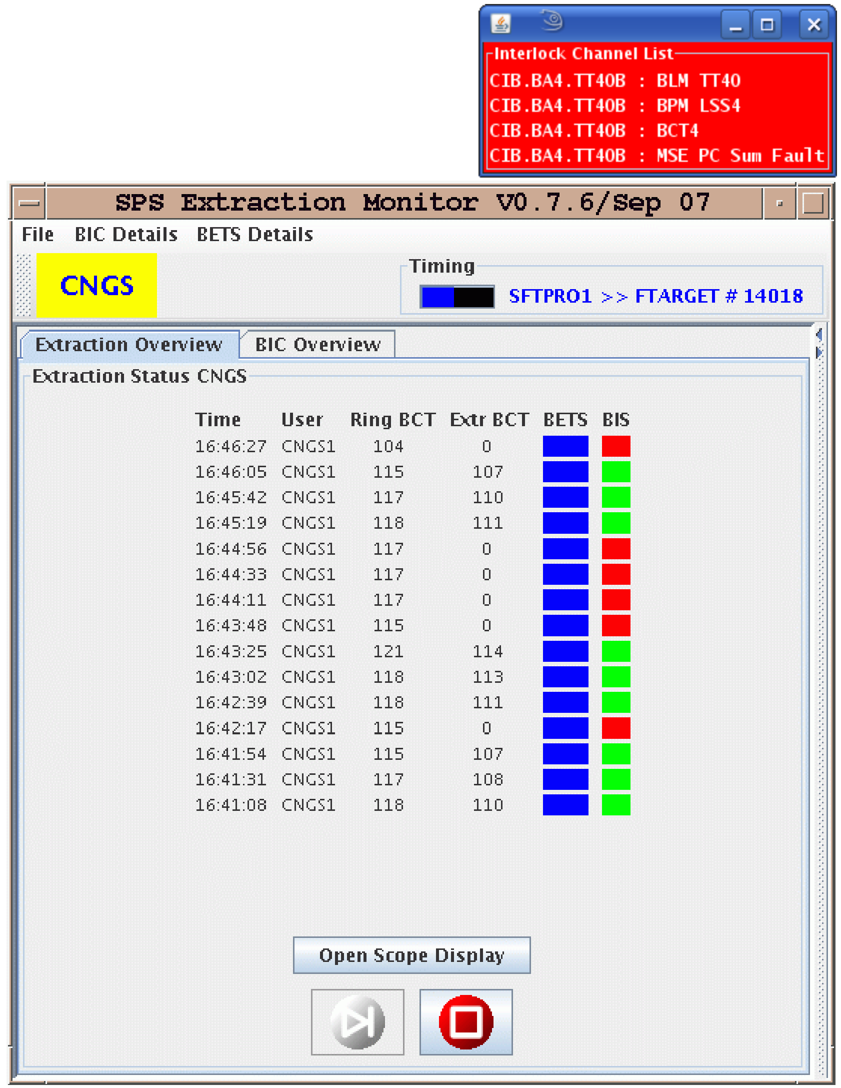
BIS Diagnostics

To ease the diagnostics for extraction with a large number of rapidly varying interlock signals, a special monitoring program was written to:

- monitor all state transitions in one SPS cycle,
- analyze the time sequence of all signals,
- provide a summary of the extraction interlock system over the last 15 selected SPS cycles,
- provide BCT information,
- provide detailed diagnostics in case of problems.

CNGS & LHC 'extraction versions', SPS ring version.

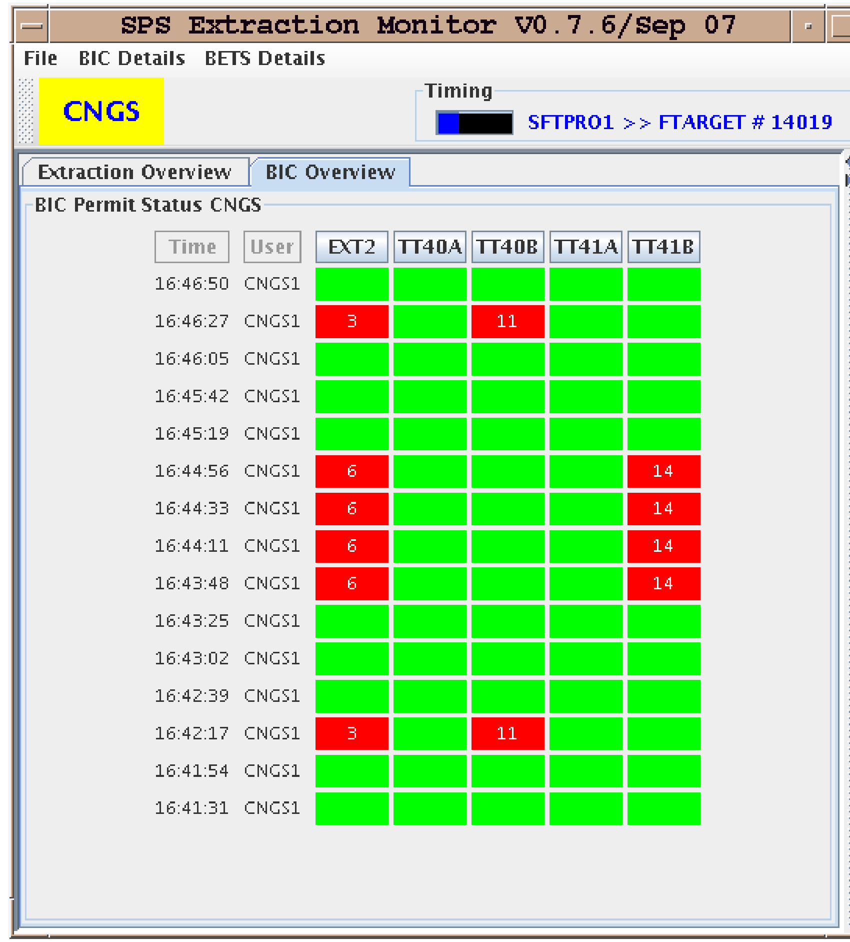
Program can also digest and analyze (from output to file) logging data.



More detailed diagnostics…

A more detailed overview panel with all BICs provides:

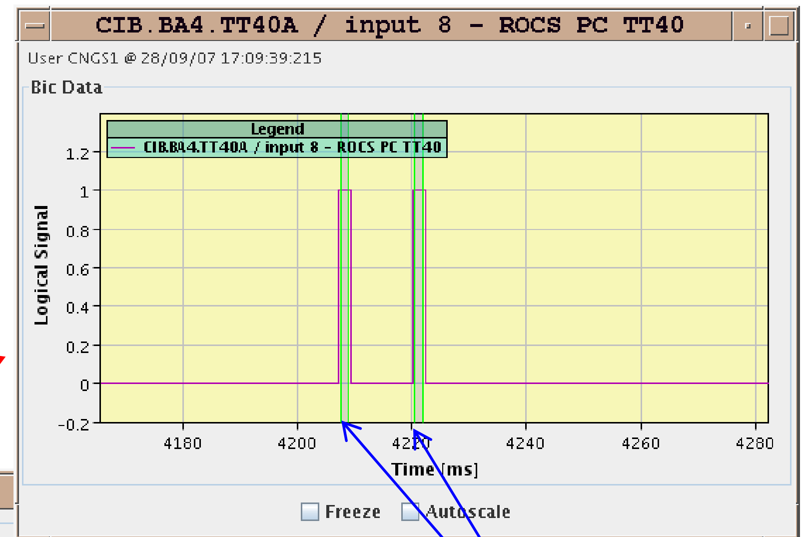
- information on the ID of the first faulty input,
- summary of the BIC outputs over the last 15 selected SPS cycles,
- 'pop up' with list of interlocks and name of the inputs.

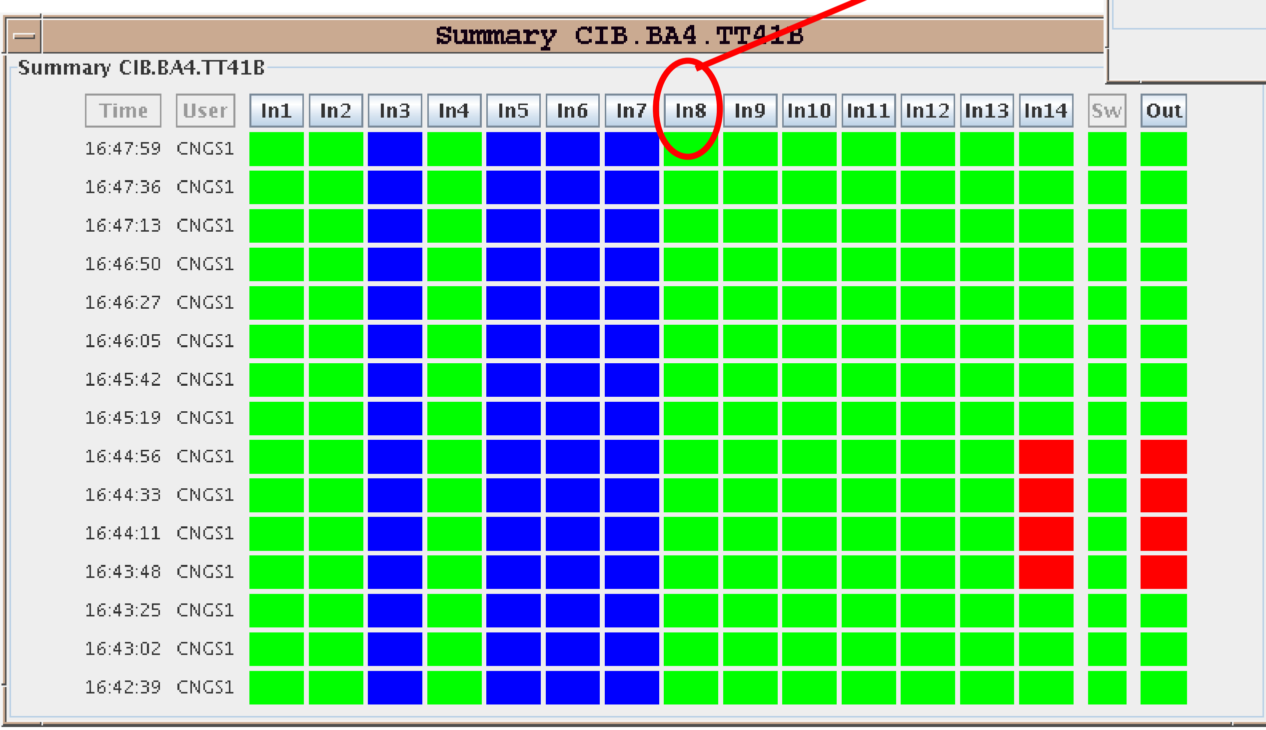


Another level down…

Detailed overview panel for each individual BIC provides:

- information on all faults,
- configuration information of each channel by 'tooltip text',
- possibility to view time evolution with PM freze options etc…





Analysis interval : signal must be = 1 for extraction to take place

SIS

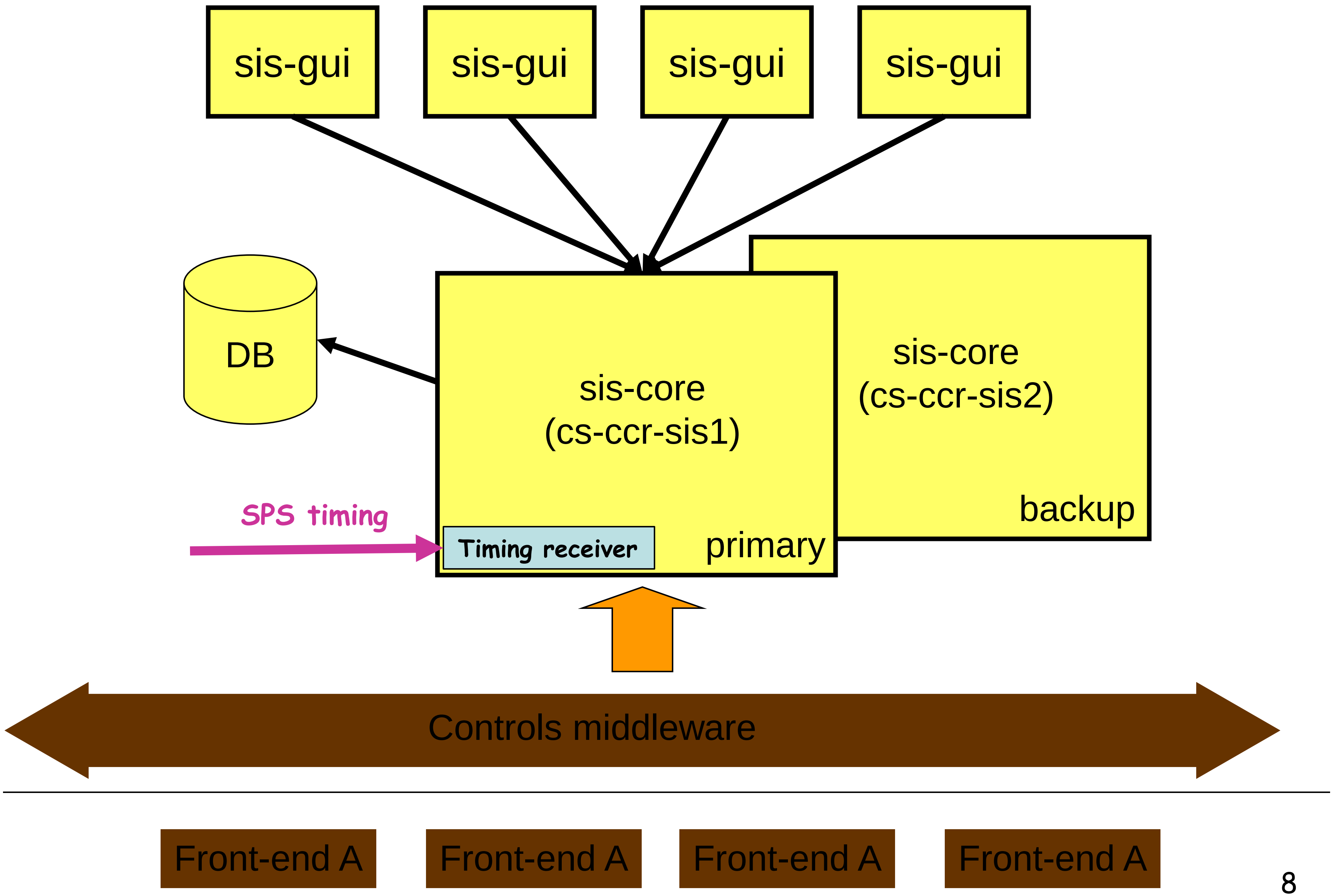
- SIS development started in 2005 (JW, V. Baggiolini, J. Wozniak) to replace legacy SPS Software Interlock System (SSIS).
- Milestones :
  - First version ready for 2006, to be applied to the CNGS transfer line.
  - Operational version for 2007, to be run in parallel with SSIS.
  - End of SSIS 'sometimes' in 2007…
- During the startup of 2007, SSIS was in trouble with its (rather old) HW.

  → Decision : don't waste time on SSIS, all effort concentrated on SIS.

  → SPS started up in 2007 with SIS 'in charge' of all SW interlocking.

- Present CO project leader is J. Wozniak (more or less on his own in CO).

SIS Architecture (1)



SIS Interlock Tree

The SIS tests grouped in a tree structure:

- Parameter tests are at the base:
  - Generic tests on values, strings, arrays…
  - Complex tests by JAVA classes
- Test outputs may be grouped logically to form a tree.
- The top of the tree is the **PERMIT** that is exported to BIS, Timing, Alarms.
- SPS Beam mode information is included as specific tests in the tree to mask 'irrelevant' interlocks. Mode info is checked against equipment state (mobile dump positions..).
- Permits are updated at the end of each SPS cycle.

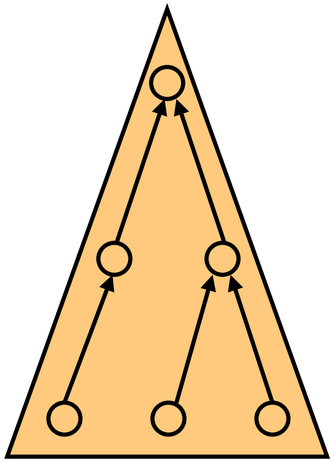
Also:

- Able to monitor ANY FESA property/field.
- Interlocks can be added within 15 minutes.
- Local test environment.
- Configuration in XML+macro language, encoded in the project JAVA library (jar).

SIS is decoupled from LSA (except for mode info).

Status end of 2007 : **~ 900 base tests (SPS)**

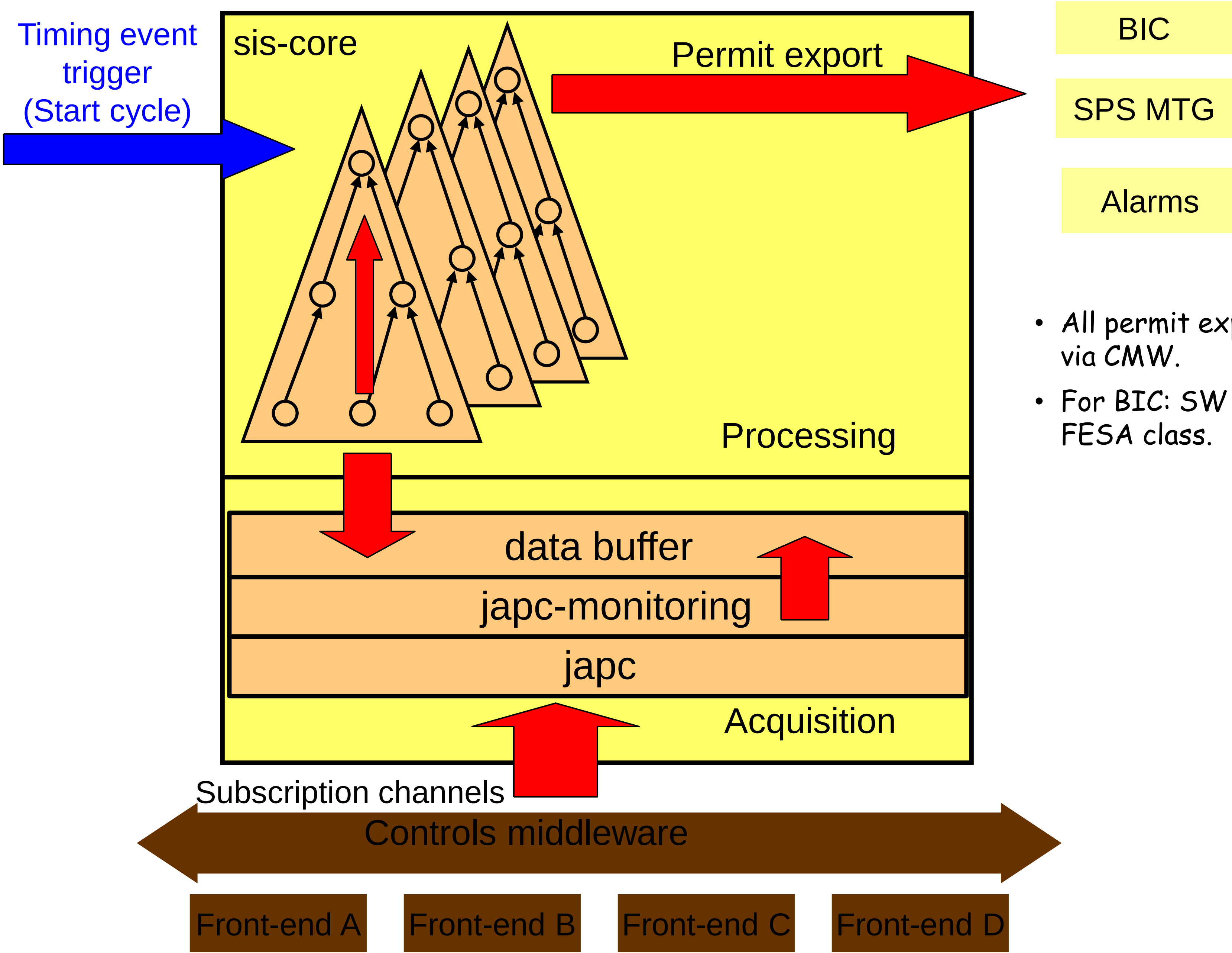
Permit tree



SPS SIS permit trees:

- **SPS ring & injection line**
- **LSS2 extraction + TT20 line**
- **LSS4 extraction + TT40 line**
- **TT41 line**
- **TI8 line**
- **LSS6 extraction + TT60 line**
- **TI2 line**

SIS Architecture (2)



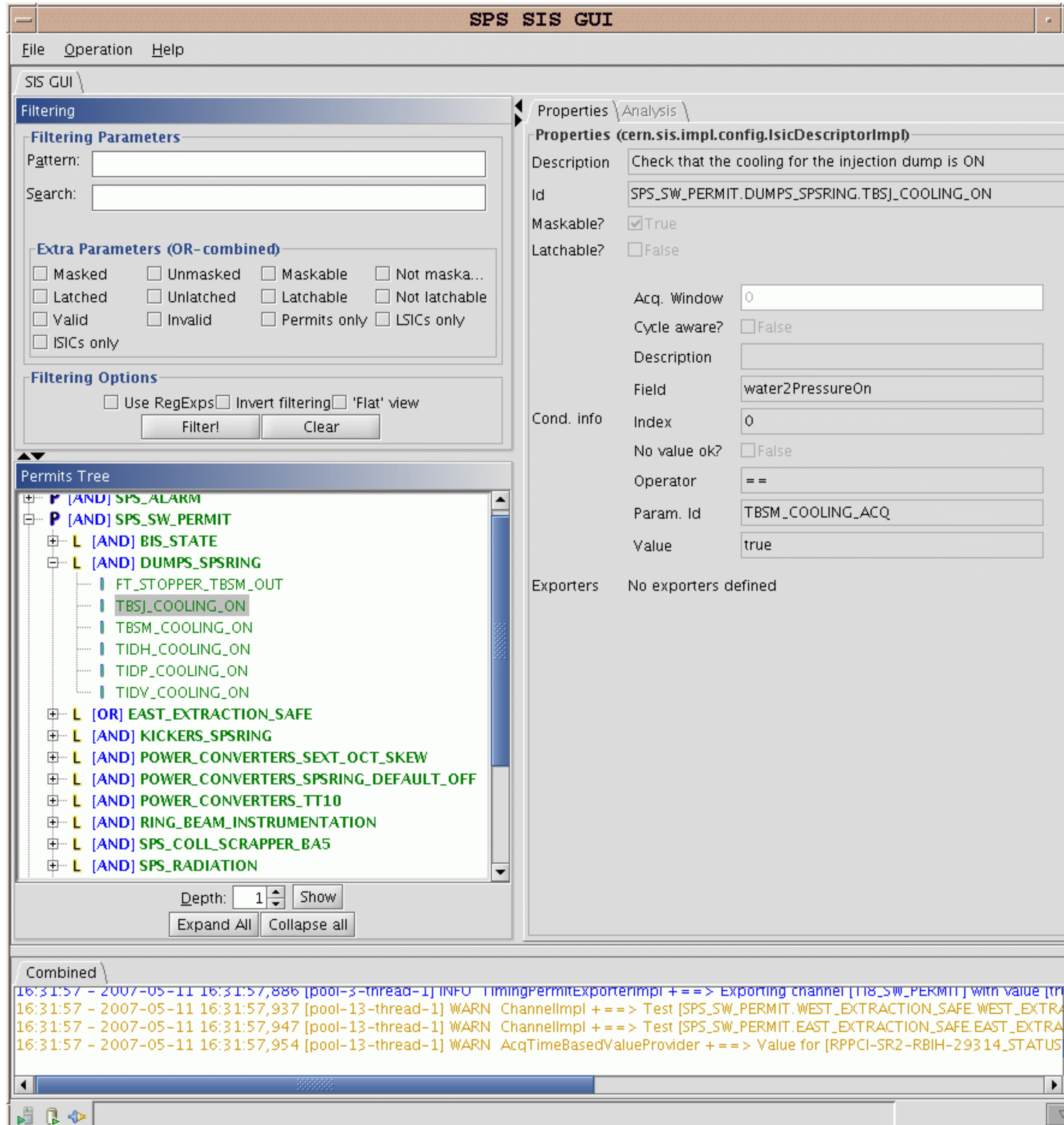
- All permit exports are via CMW.
- For BIC: SW Input in FESA class.

SIS GUI

- Browsing of permit/test tree.
- Search of trees with filters…
- Masking/unmasking.
- Reset of latched interlocks.
- Test/node description.
- 'Logging' consoles for diagnostics, spying on parameter acquisitions…

On the 'todo list':

RBAC for masking?



SIS & Timing

- In the SPS every beam has a property called DESTINATION (defined within the timing system). Possible destinations:
  - SPS-DUMP
  - FTARGET
  - CNGS
  - TI8-DUMP
  - TI8 (→ ring2)
  - TI2-DUMP
  - TI2 (→ ring1)
- Within the SPS MTG, inhibits are defined for a geographical zones:
  - Inhibit SPS-RING
  - Inhibit TT20
  - Inhibit TT40
  - Inhibit TT41
  - Inhibit TI8
  - Inhibit TT60
  - Inhibit TI2
- To reach its DESTINATION, each beam has to pass one or more zones:

  example : CNGS ->> SPS-RING + TT40 + TT41
- If an inhibit is set on a zone that has to be passed to reach a certain DESTINATION, the timing system will stop that beam (switch to 'spare' beam).
- SIS Permits may be associated to one of the inhibits, and SIS is able to stop the production of a beam by acting on the inhibits.
- Note that for safety reasons + faster reaction time, SIS is configured to always act on a BIC and on a timing inhibit in parallel.

SIS & BIS

SIS continuously monitors all the BICs to provide additional safety:

- All the BIC masks are monitored. If a BIC channel is masked, SIS will set an interlock. The SIS interlock can of course be masked if the BIC mask is needed. Protects against accidental masking of BIC channels.
- SIS observes the BIC inputs associated to ring BLM and BPM interlocks. When it detects more than N (default=3) consecutive interlocks on the same input for the same SPS cycle, it stops the corresponding beam(s) by raising it own latched interlock. Must be reset the OP crews.
- When SIS detects that a BIC interlock with a 'long "repair" time-constant' is set, it stops all the beams that are affected by the interlock to avoid un-necessary dumps and minimize activation.

  Example of 'long "repair" time-constants' interlocks :

  - **Main power supplies**
  - **Vacuum**
  - **Dumps**
  - …

When such interlocks are present, it takes minutes to hours to solve the problem → it is worth stopping the affected beams.

SIS experience in 2007

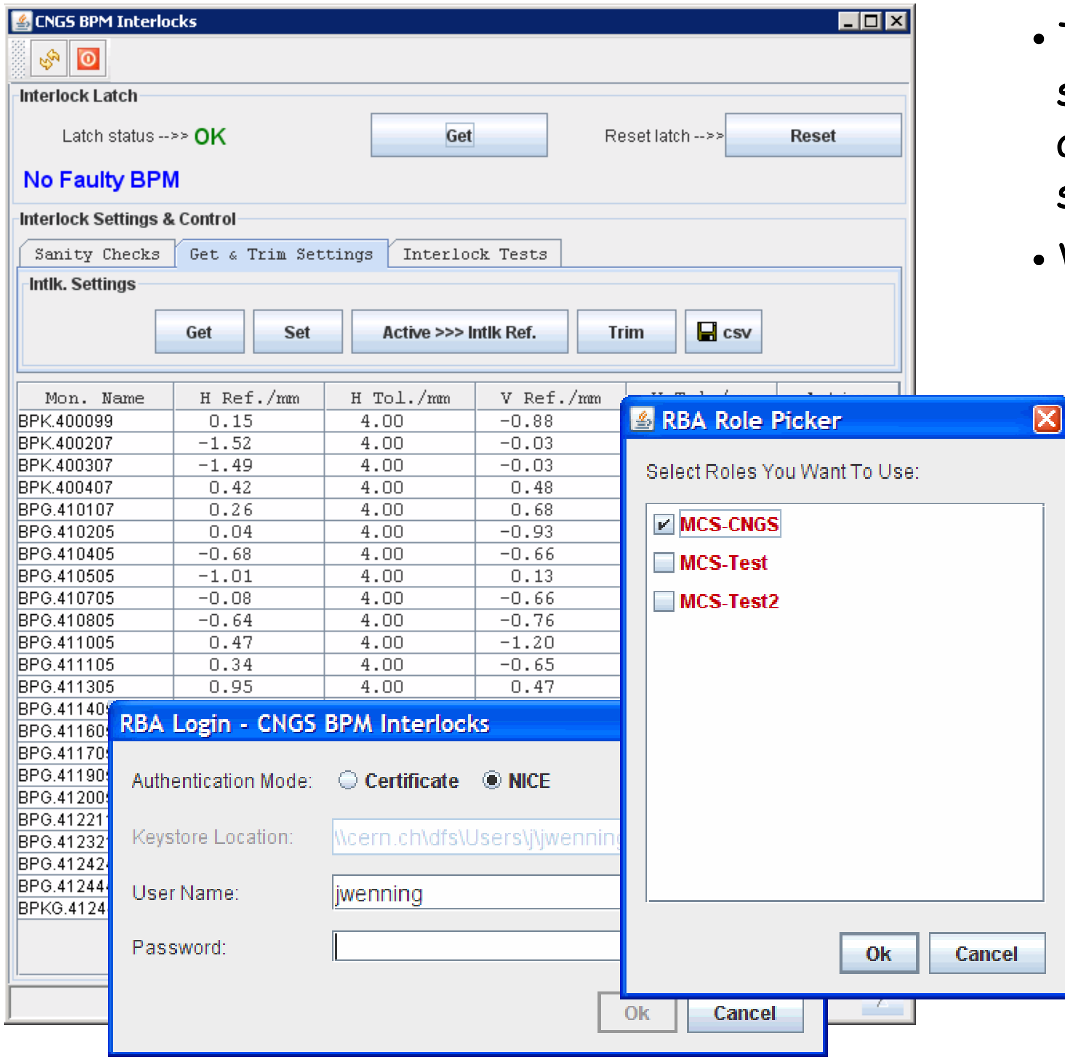
- The SIS core itself never created any problems.
- On one occasion, problems appeared in the core-GUI communication (fixed).
- But SIS 'suffered' from insufficient client reliability:
  - Data loss & CMW disconnects:
    - → tended to improve during the run.
  - Problems were dominated by access problem to PC front-ends:
    - → hope for improvements in 2008 (legacy → FESA).

Client reliability will be a major concern for LHC !!

CNGS Setting up

- CNGS extraction & transfer setup was done under 'ideal' conditions:
  - Small team (E. Gschwendtner, V. Kain, J. Wenninger).
  - Plenty of low intensity beam time for setup and checks (beam, optics, interlocks, etc).
  - No stress !!
- Interlock tests were performed much more rapidly than in 2006:
  - Experience, all HW ready at the same time (→ more efficient).
  - For PCs and screens (lengthiest tests) : automated test SW with detailed log output that is kept on the SPS MP web site.. Very large gain in time.
  - Interlock system ready for high intensity ~ 4 days after startup (includes a WE).
- Beam commissioning:
  - First beam on target Friday 21st September ~ 17:00.
  - Beam on target at first shot, trajectory easily corrected in a few steps.
  - Settings for large dipole strings, septa and quads fully reproducible wrt 2006. Could re-use the SAME interlock settings of PC currents that were used in 2006 (tolerances are at the level of ~0.1% !).

MCS for CNGS

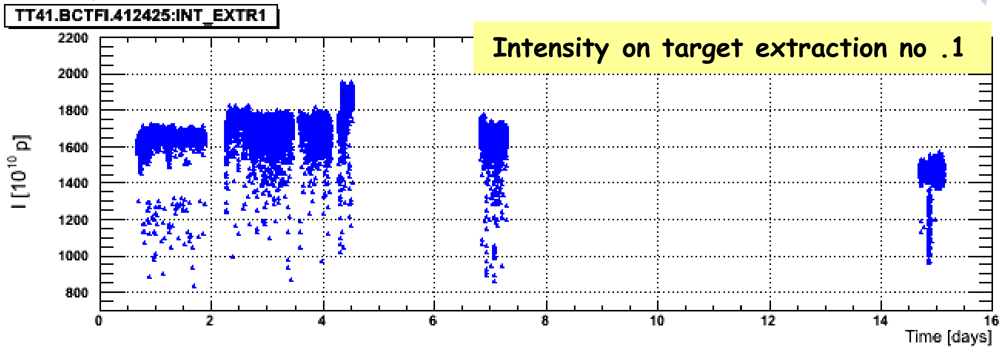


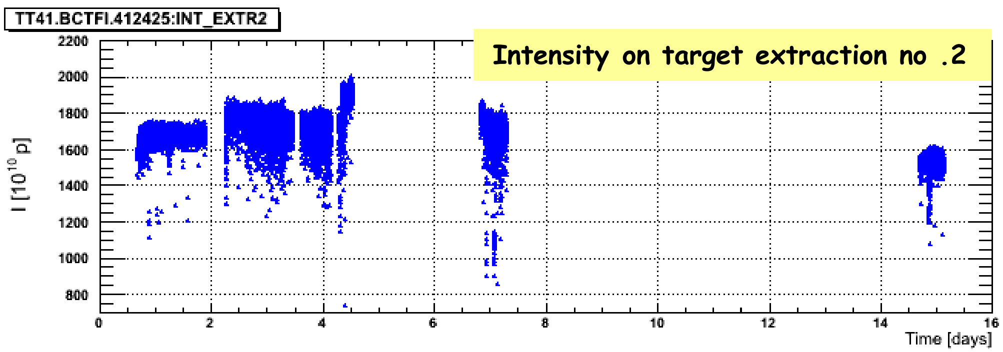
- The CNGS beam position interlock settings (references, tolerances & active status) were the first OP setting to be used with MCS. scheme.
- Worked fine after a few iteration.

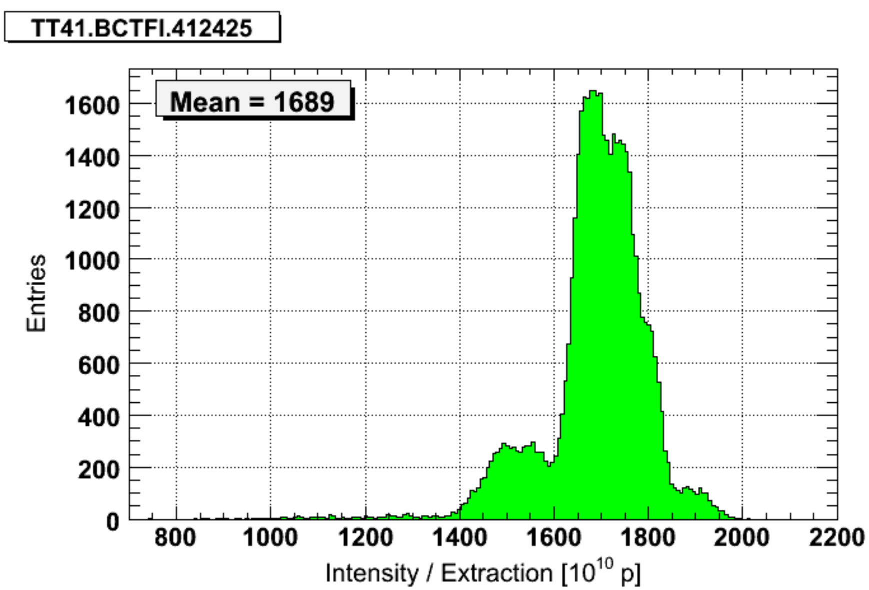
CNGS HI Run

October 5th

October 21st

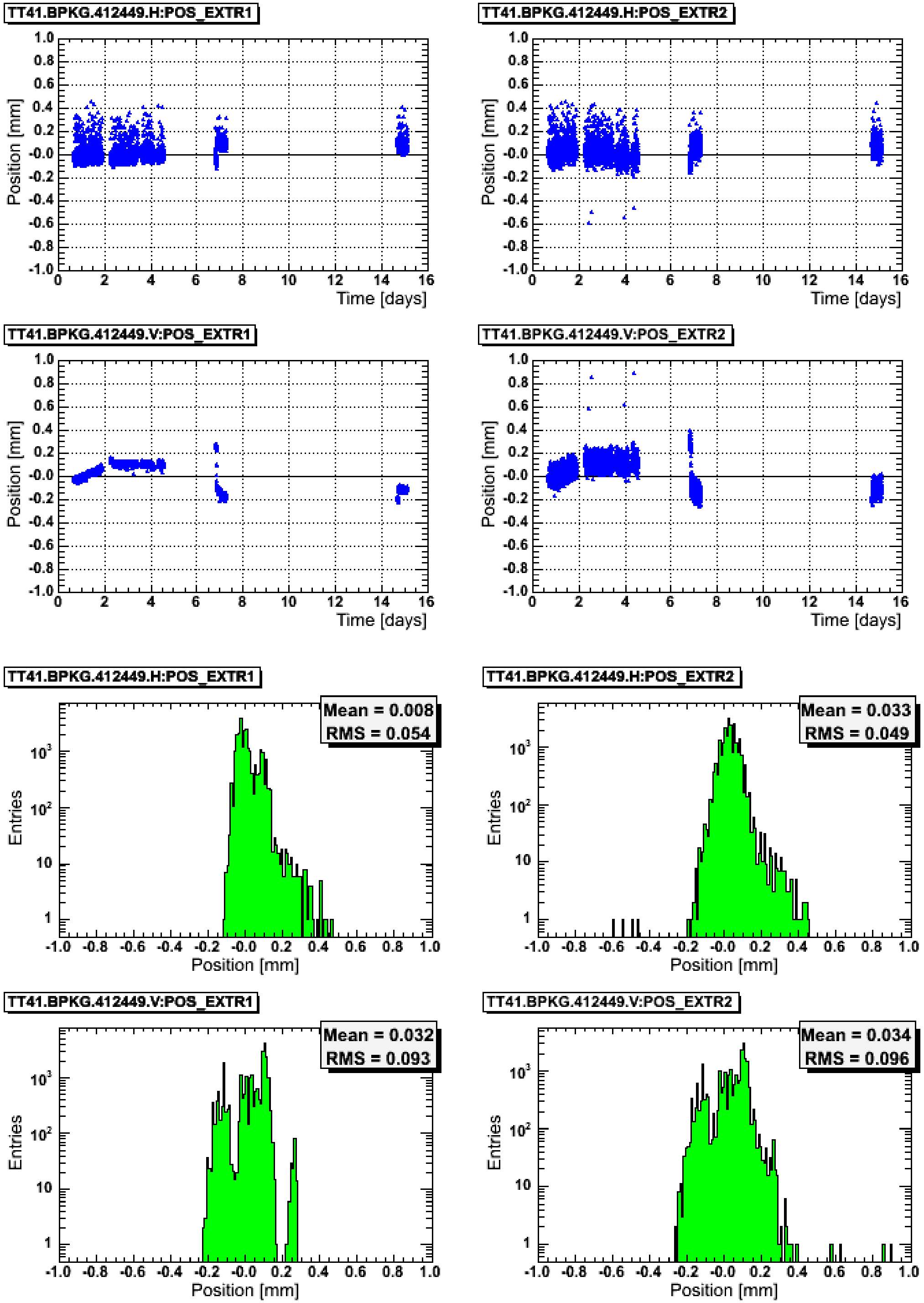






- The CNGS high intensity run was shortened due to the radiation problems in the target area.
- The ~ 15 day period of high intensity was analyzed for stability and interlock performance:
  - 46’500 extraction in 23’700 cycles.
  - Peak intensity ~ 2×10^{13} p /extraction. Nominal ~2.4×10^{13} p /extraction
  - Intensity on target : 7.8×10^{17} p

Beam Stability

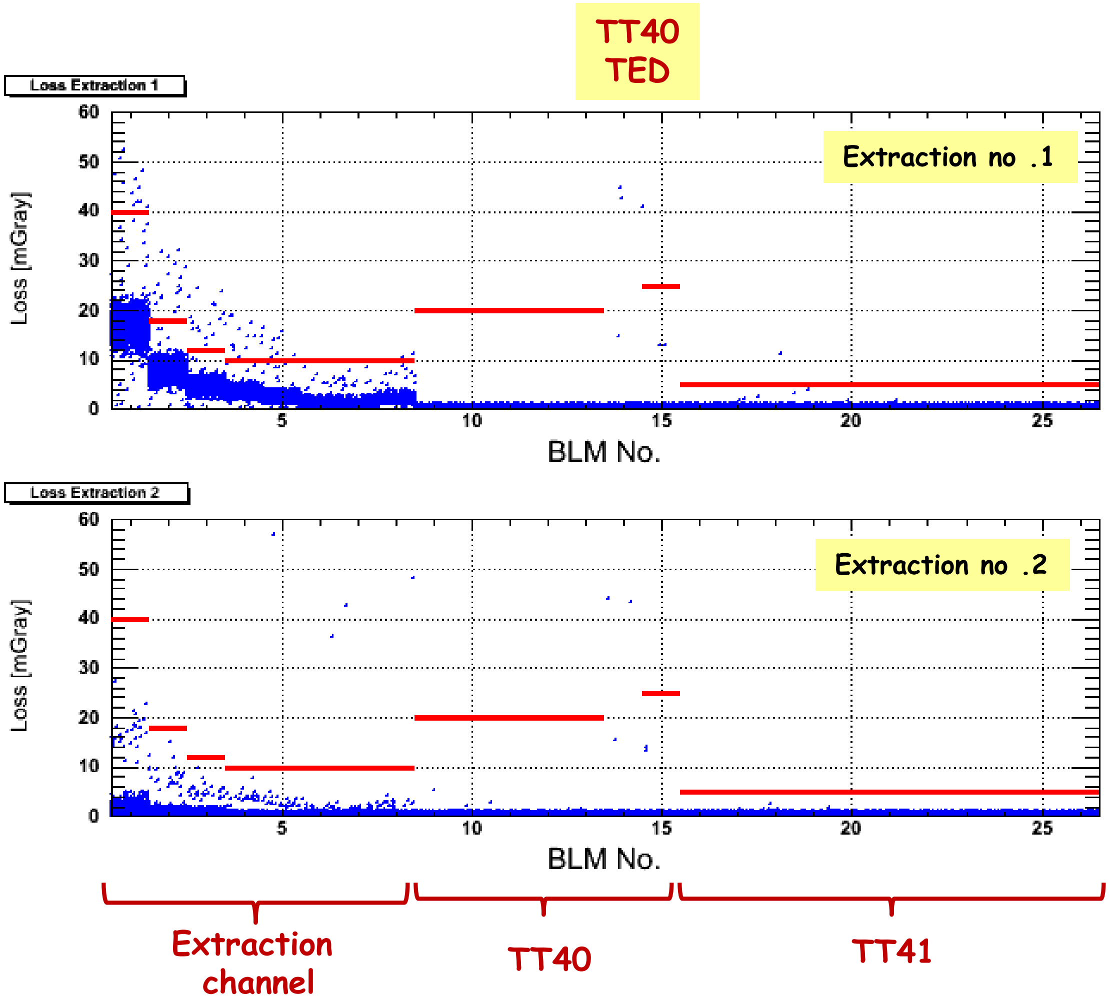


Stability of the beam measured with the last BPM in front of the target.

- All extractions well within the 0.5 mm tolerance. Includes some steering.
- 4 outliers : wrong readings (and interlocks !!) from the BPMs.
- Some steering at the target sufficient to keep the muon beam well centered.

Beam Losses

- Beam losses stable over period, some poorer cycles.
- With one exception (see later) no beam loss in the TT41 transfer line!

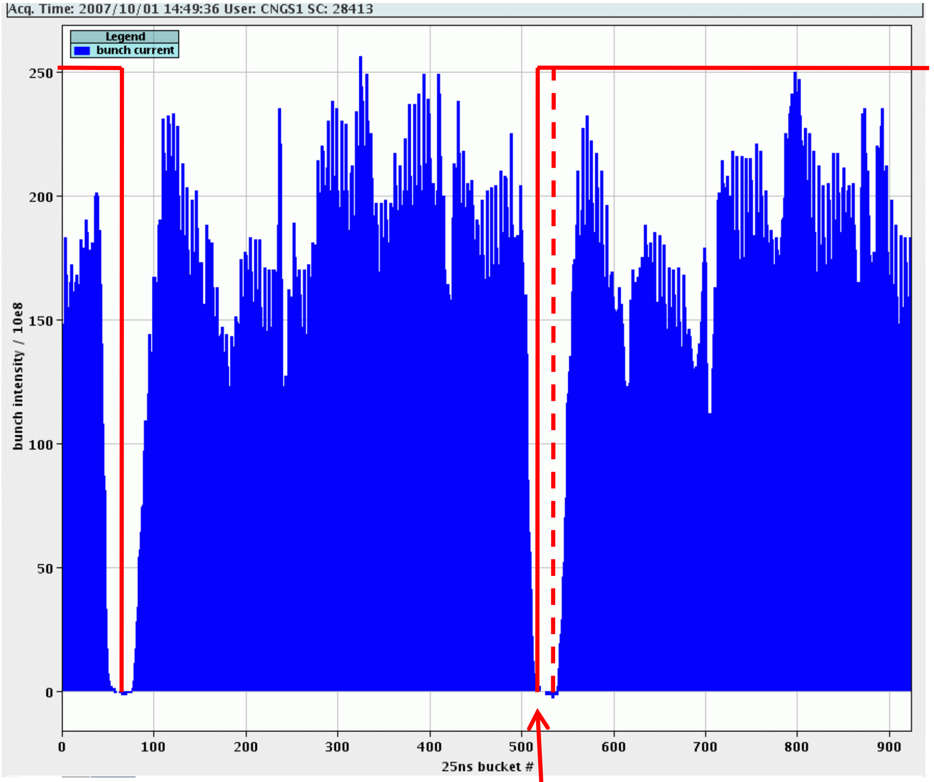


Beam losses for all 47'000 extractions

CNGS Beam Structure & Beam Gaps

CNGS beam :

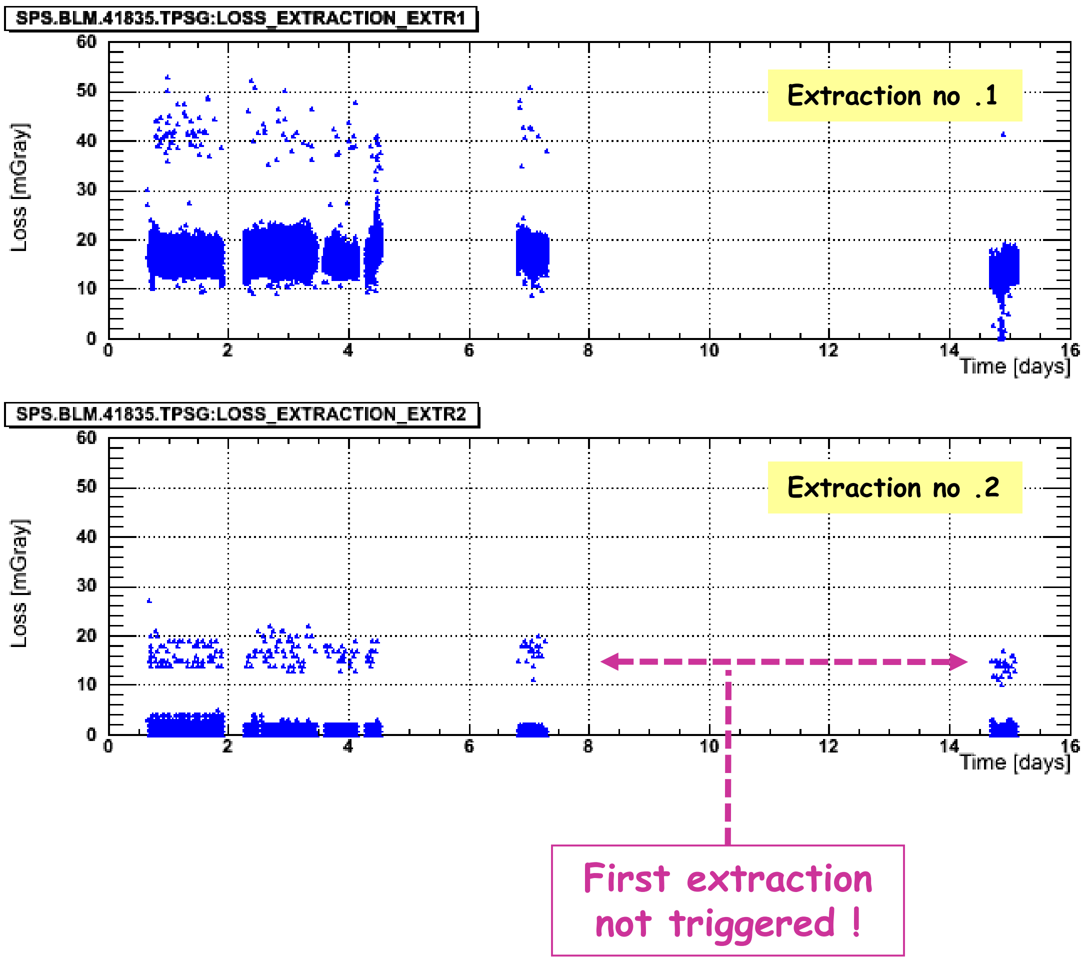
- **two 10.5 μs batches, 1 μs gaps.**
- **injected at an interval of 1.2 s.**



- Poorly captured beam of the first batch has time to drift into the gaps.
- May be minimized by appropriate RF manipulations & settings, proved not to be sufficiently reproducible in 2007..
- In 2007 the gaps were kept clean by advancing the injection kicker pulse of the second injection by 250 ns

Injection kicker pulse advanced as much as possible to kick out any beam present in gap in front of the second batch.

Beam Losses TPSG



- Highest beam losses are always at the first BLM (TPSG, absorber to protect the septum magnet).
- Typical beam losses at TPSG:
  - Extr. 1 : 17 mGray
  - Extr. 2 : 2-3 mGray

  →0.05% of the total intensity.

- When the first extraction is not triggered, the losses of the second extraction increase to the same level as for a typical first extraction.
- Higher beam losses occur in ~0.3% of all extractions. Correlated to lower intensity. Random: never 2 consecutive cycles !

Exceptional Beam Loss Events

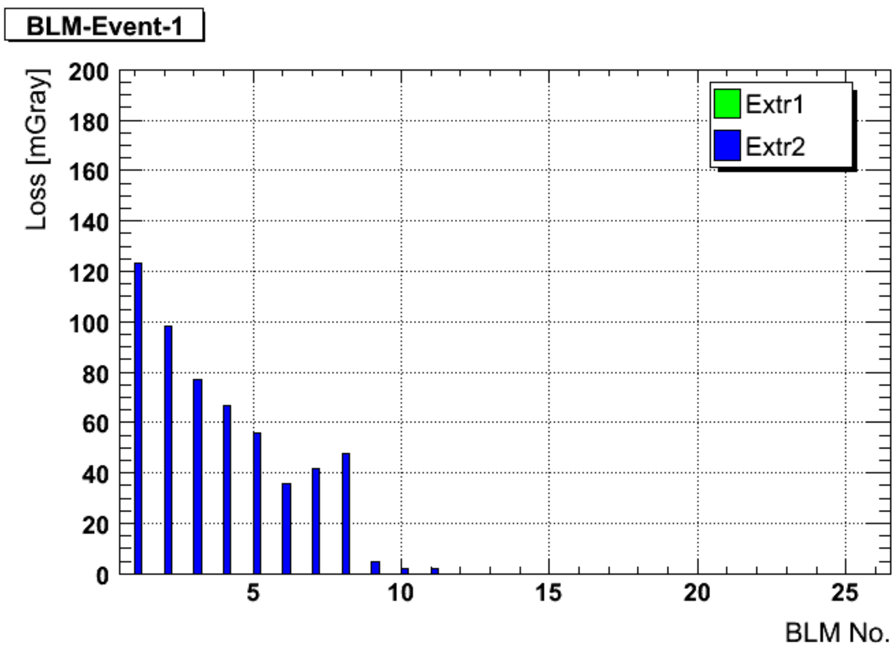
Event 1:

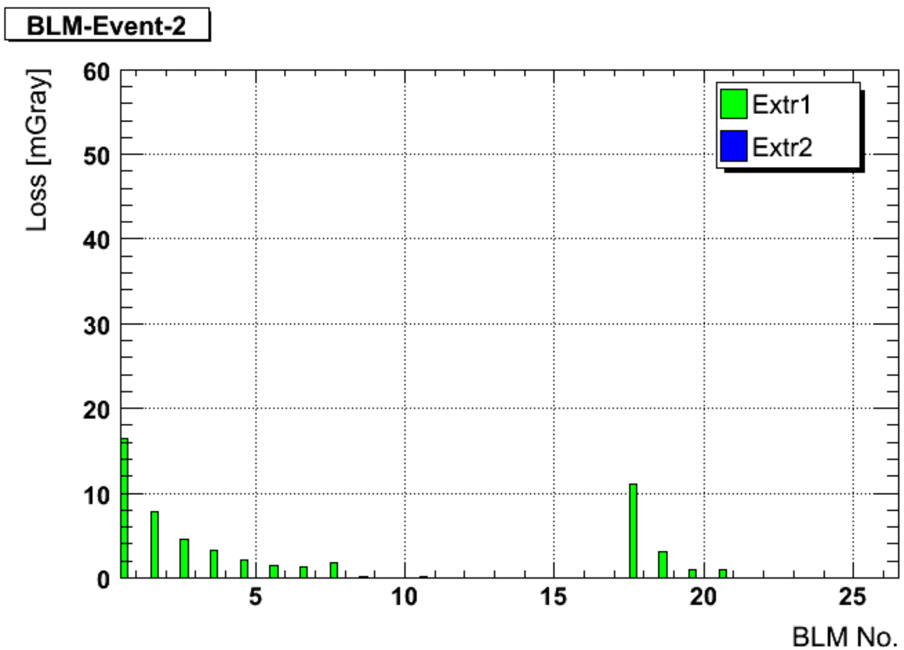
- Extraction 1 not triggered (LSS4 beam position interlock).
- Large loss on the second extraction:

  7 times more beam in gaps.
- Largest observed loss !

Event 2:

- Unique event with BLM interlock trigger from TT41.
- Extraction losses ~ normal.
- Interlock latched, reset ~13 minutes later.
- No explanation found from logging data !

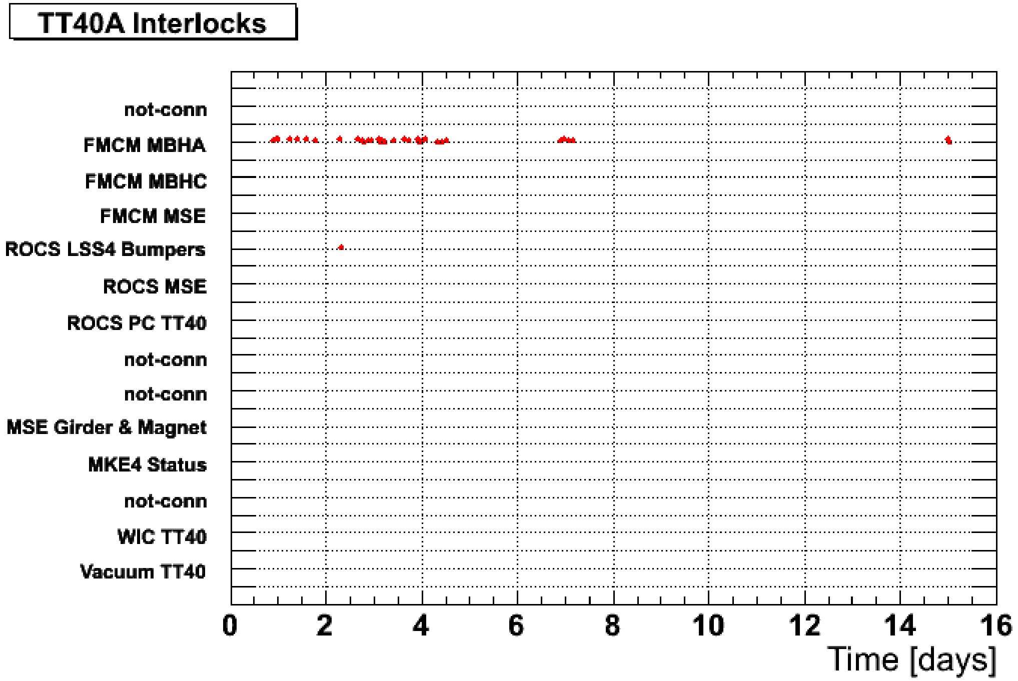


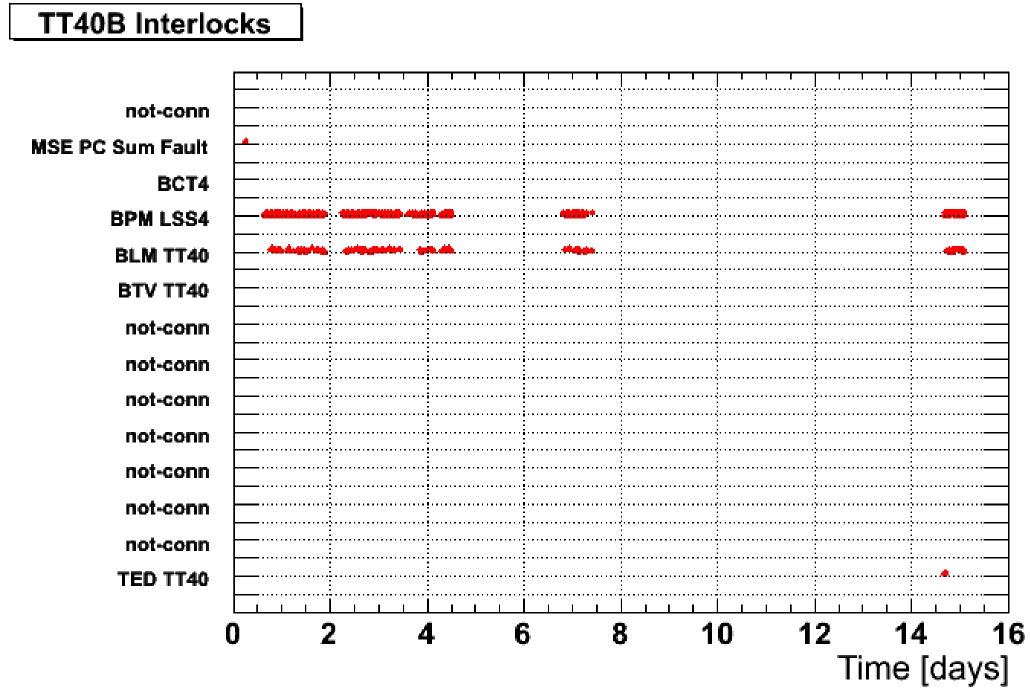


'False' Interlocks

- A closer look at the BCT data reveals that during stable running periods 2% of the first and 3.6% of the second extractions are not triggered:
  - For 1% of the cycles both extractions missing.
  - For 2.5% of the cycles second extraction missing
  - For 1.1% of the cycles first extraction missing
- The actual data (losses, beam positions…) cannot explain the lost cycles.
- The BIC data was therefore analyzed to identify possible interlocks that could explain the missing triggers. A search for isolated interlocks in the data reveals that **there are 'false' interlocks**. Main sources:
  - Beam position interlocks in LSS4 account for 2.2% of the lost extractions.
  - Beam loss interlocks in TT40 and TT41 account for ~0.5% each.
  - Beam position interlocks in TT40+Tt41 account for ~0.4%.
  - MBHA FMCM interlocks account for ~0.1% → threshold setting a bit tight…

→ the BI interlocks are due to missing or 'late' permit transitions from FALSE to TRUE (margin of ~4 ms). This was already observed online in the CCC. FESA ???



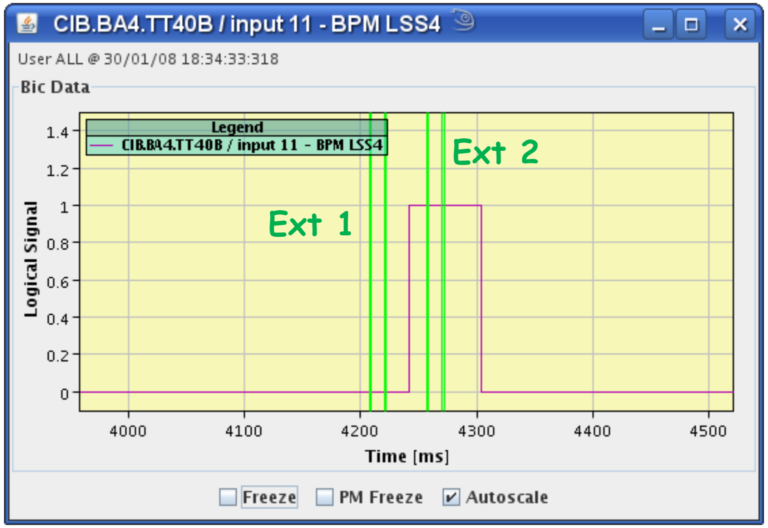


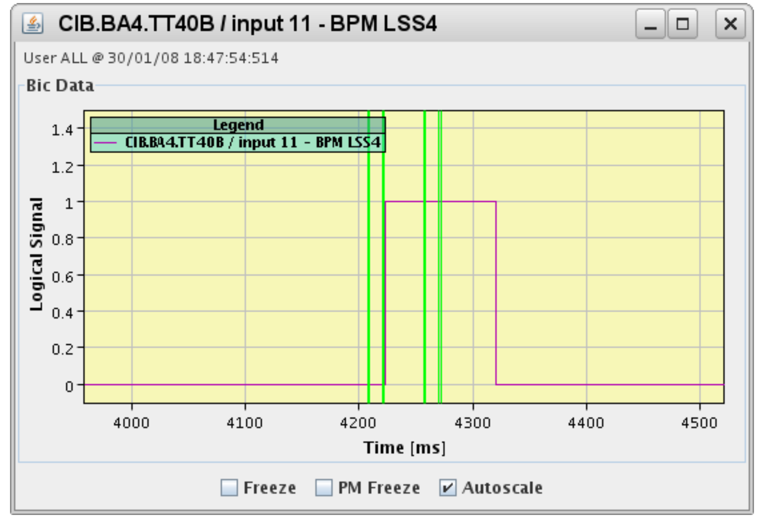
False Interlocks

Occurrence of suspected 'false' interlocks for the TT40 BICs.

False Interlocks : examples

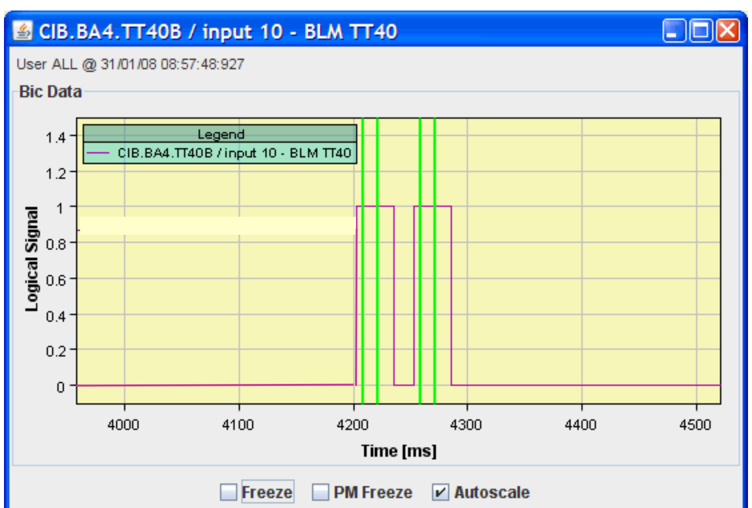
BPMs LSS4 : signal transitions too late, note the jitter.

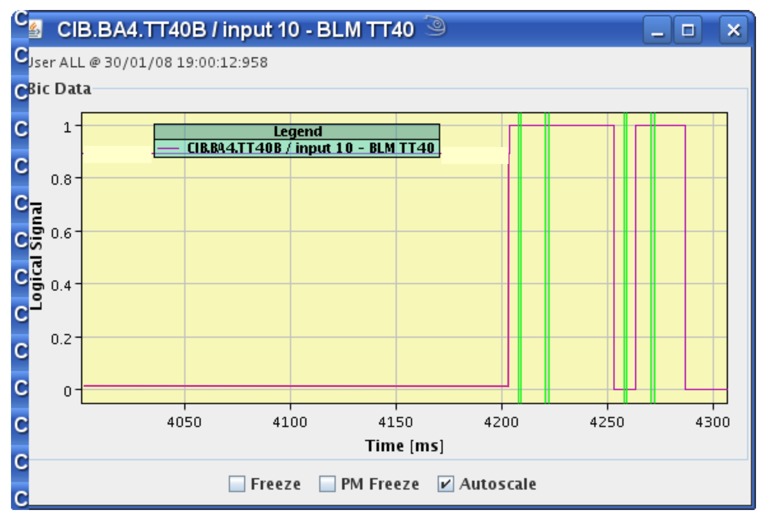




BLMs TT40 : normal transitions

transitions too late



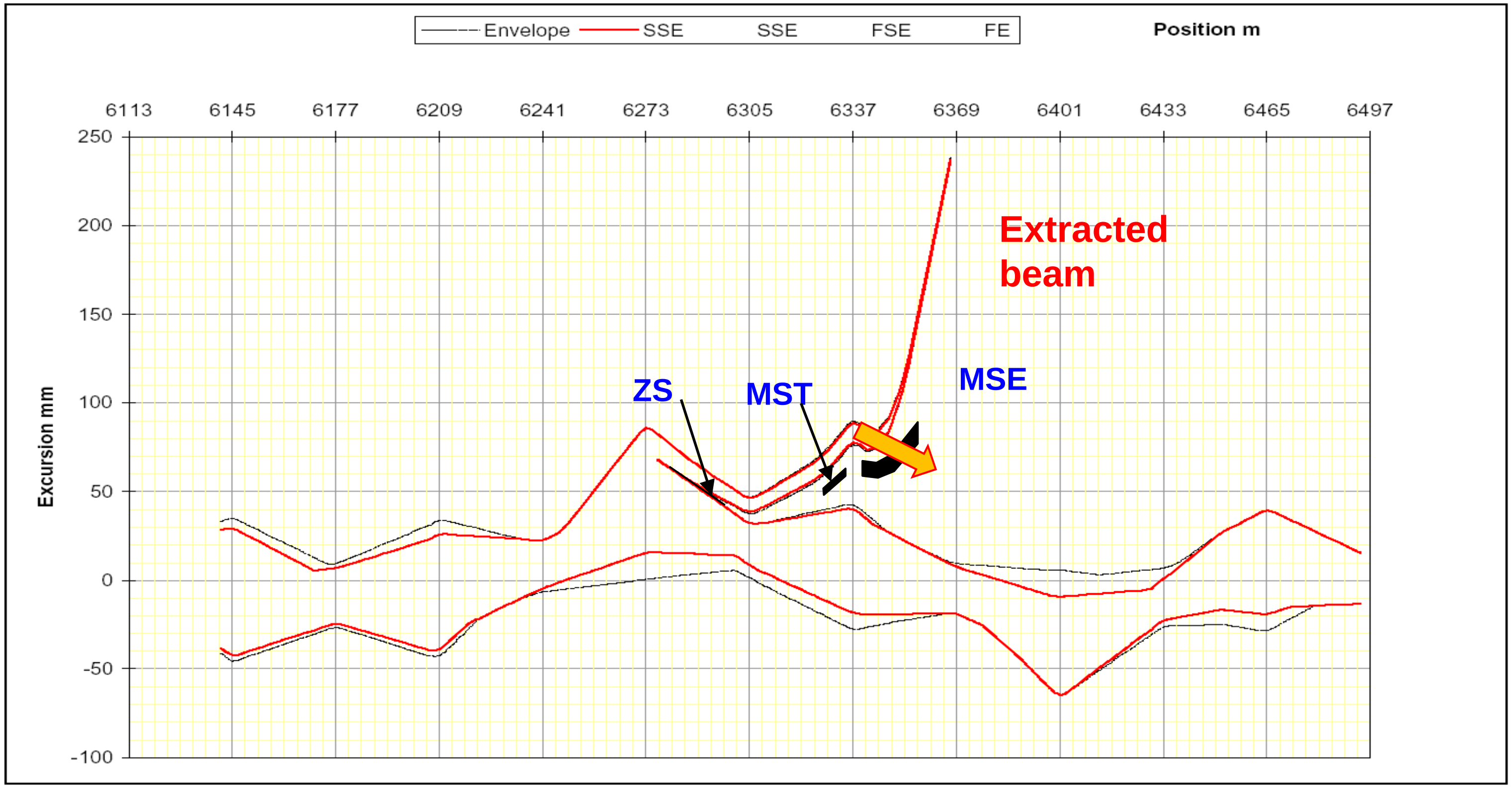


Incidents…

Incident no. 1

- Conditions : setting up of SPS slow extraction with 2-3x10^{12} p @ 400 GeV.
- Access faults interlocked the septum (MSE) converter and lead to a full beam loss inside the MSE itself (due to the strong deflection of the MSE).

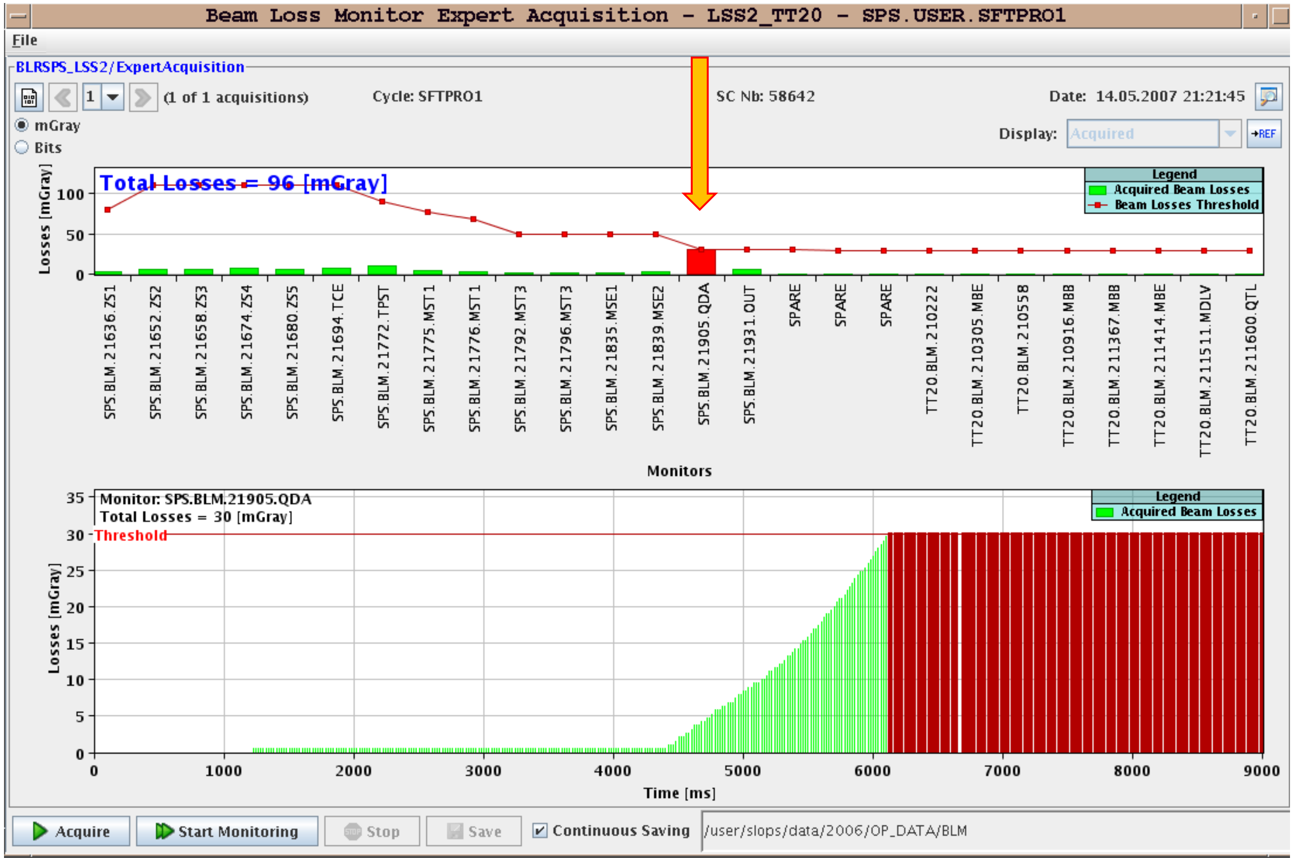
→ SIS stopped the beam, but **no BLM interlock was recorded !**



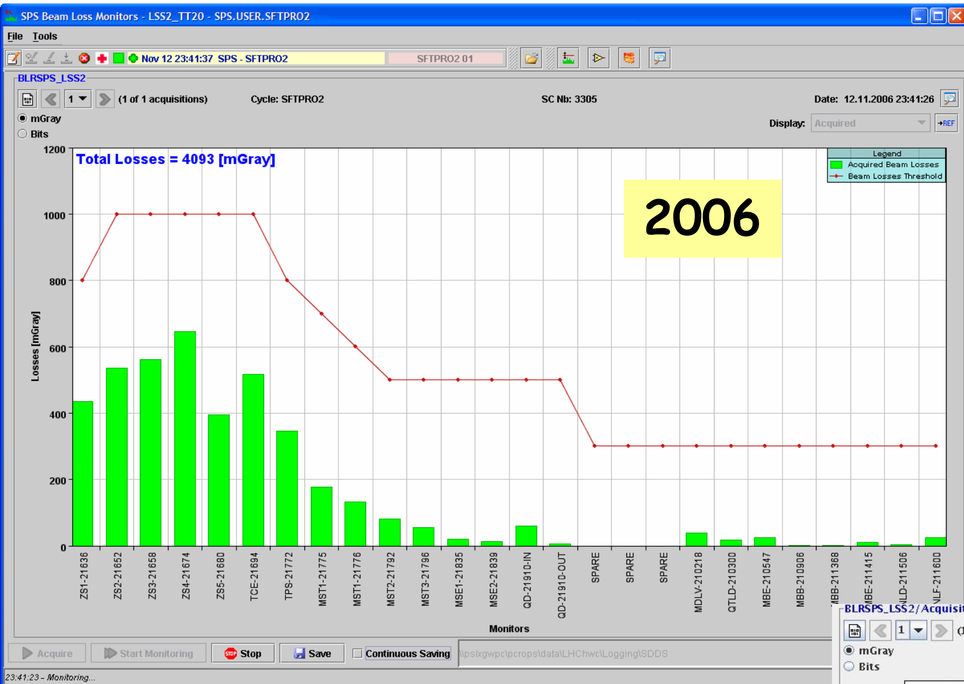
Incident no.1 : test

- A test was setup :
  - Slow extraction tuned to ~10^{12} p extracted @ 400 GeV.
  - BLM thresholds lowered factor 10.
  - MSE PC switched off, SIS surveillance of PC state masked.

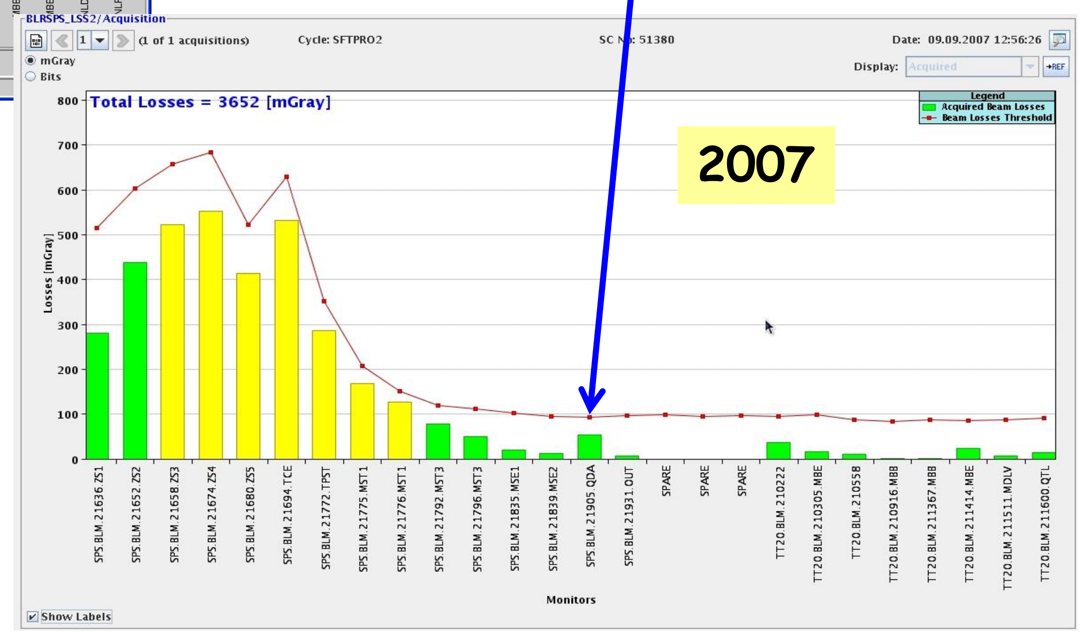
→ Only one BLM is very sensitive to the fault. Its threshold was set to high to react on a loss of $3x10^{12}$ protons.



Incident no. 1 : follow up



- Thresholds of LSS2 extraction channel & TT20 transfer line were lowered significantly wrt 2006.
- Threshold of critical monitor is surveyed by SIS to ensure it remains < 200 mGray (⇔ 2×10^{12} p).



Incident no. 2

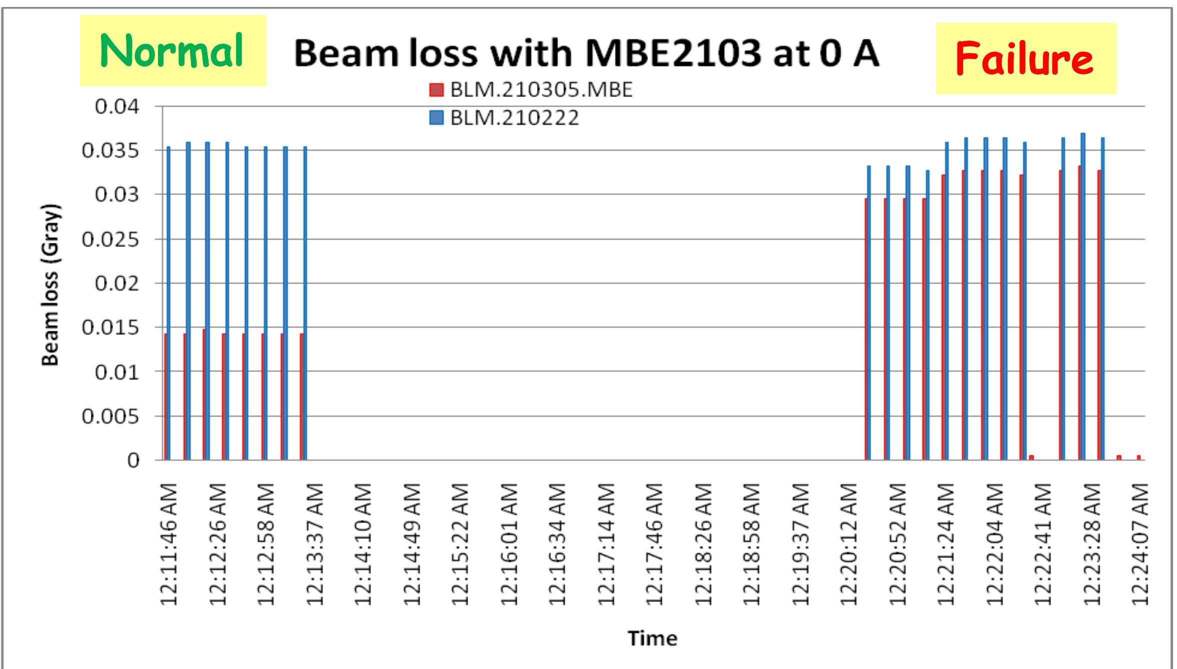
- Conditions : Fixed target with slow extraction of ~2.4×10^{13} p @ 400 GeV.
- Following a bad manipulation, the settings of the TT20 main dipole string was set to 0 A, but PC still ON.

→ No reaction from SIS since PC is ON (only state surveyed).

→ No BLM trigger !

→ Beam stopped by vacuum interlock after a few cycles !

Got very close to drilling a hole !!



BLM problem:

- Only one BLM at the entrance (210305) and one at the exit (210222) of the dipole string:

  13 magnets, 8 mrad each.

>> beam is lost inside the string, no loss visible at the exit !

Incident no. 2 : follow up

'Short' term:

- Implementation of a current surveillance of some critical dipoles by SIS for the slow extraction channel and the TT20 transfer line.
- Unfortunately the number of surveyed circuits had to be minimized because the CMW server that accessed the (legacy) PC front-end interface could not cope reliably with the data requests from SIS.

2007-2008 shutdown:

- A new BLM will be added within the dipole string to catch such a failure (spare channel + cable available).
- PC front-ends will run FESA servers in 2008 which should lift the limitations and problems from the CMW interface server. It will also make the interlock more robust.To be confirmed…

Incident no. 3

- Conditions : Setting up of a new slow extraction schema, slow extraction of ~9x10^{12} p @ 400 GeV at the moment of the incident.
- After a bad manipulation while testing knobs for the new extraction schema, the extraction bump was accidentally set to TWICE its nominal value.

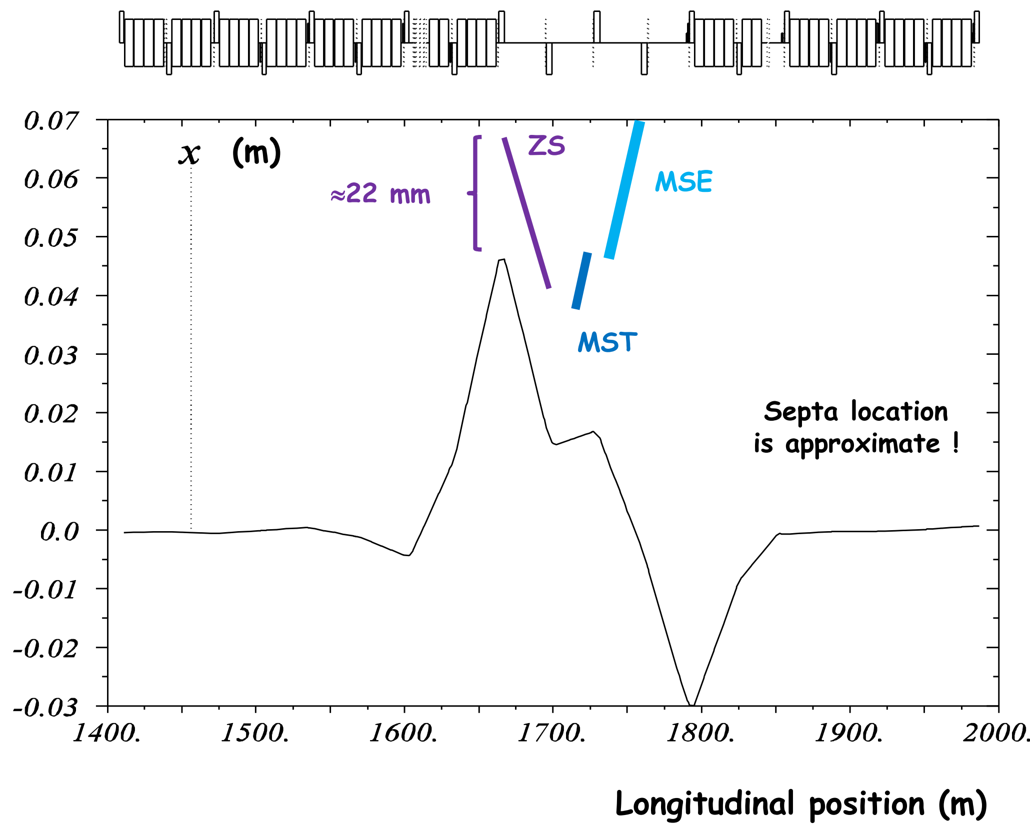
→ Beam was swept over the electrostatic septum (ZS) wires within ~10 ms.

→ BLMs triggered, but too late !

→ Beam stopped by failure of ZS HV system.

→ First ZS damaged (sparking), replaced in the shutdown

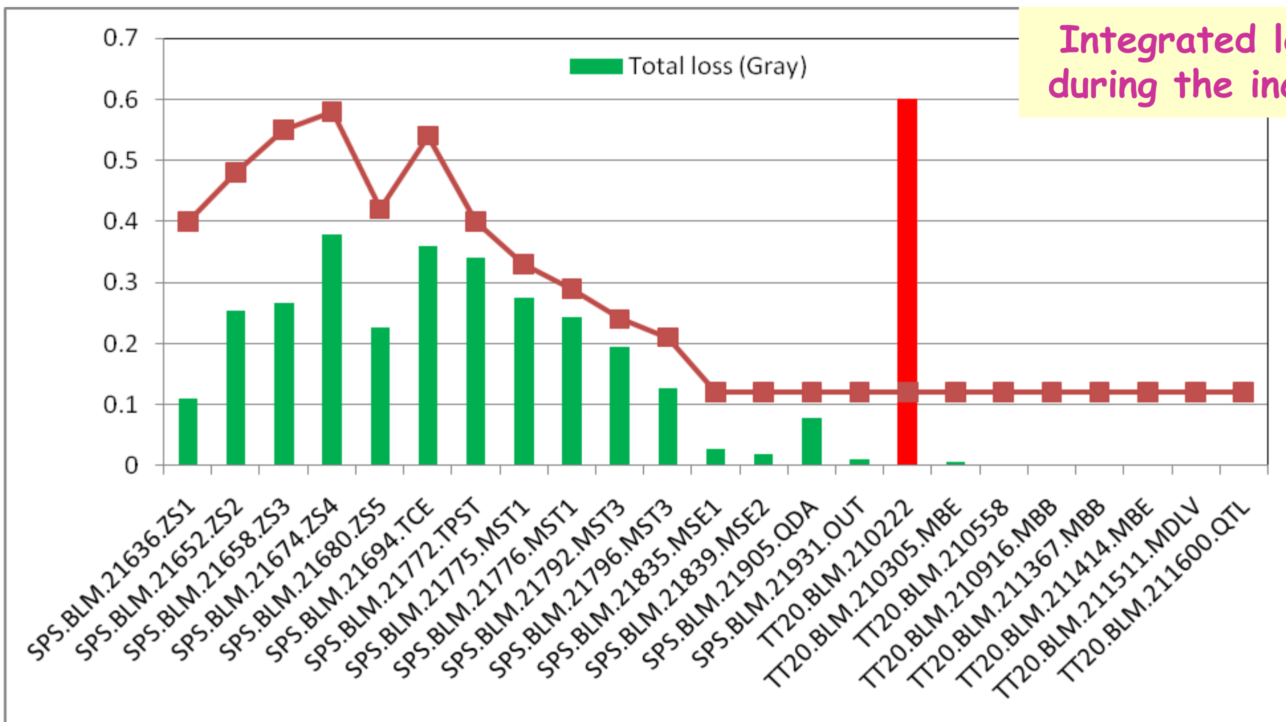
Nominal extraction bump, amplitude ~ 50 mm.



Incident no. 3 : follow up

- **Current surveillance by SIS of the extraction bumper magnets**.
- Trim limits on the extraction bumpers within LSA control system.
- Beam loss monitors:
  - The BLM that triggered was a 'slow' SPS ring type BLM with a sampling period of 20 ms.
  - By the time it triggered, the loss was 5 x over threshold.

  → **The BLM will be 'converted' into a fast extraction BLM (reaction in μseconds) since a spare channel is availiable.**



Integrated losses during the incident

Summary

- ✓ Both new ring BIS and SIS performed to full satisfaction.
- ✓ SIS proved very powerful and is now a first line diagnostics for the SPS.
  - ➢ More improvements will be added for 2008 (also for the LHC).
  - ➢ A first version of the LHC SIS exists. It monitors ALL ~1600 LHC PCs and already implements the current surveillance for the D1, D2 & MCBX new the experiments.
- ✓ CNGS high intensity operation was smooth (from the beam and interlock point of view).
  - ➢ We will have to look again at the 'false' interlocks in 2008.
  - ➢ The analysis results will be published as note/report soon.
- ! Three incidents related to the FT beam, the last one being 'fatal'.
  - ➢ Improvements have been implemented / will be implemented for 2008.
  - ➢ Documented in detail in CERN-AB-Note-2008-003. Also available at https://sps-mp-operation.web.cern.ch/sps-mp-operation/
  - ➢ Highlights the weakness of MP for the SPS fixed targets beams.
  - ➢ Highlight the absence of proper failure simulations : "learn by breaking".
    - >> foresee some interlock tests with safe beam for SPS startup