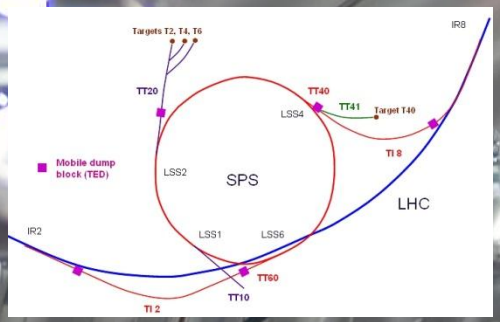
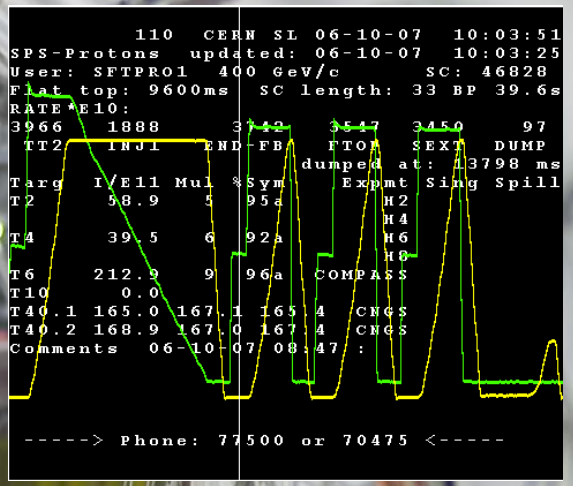
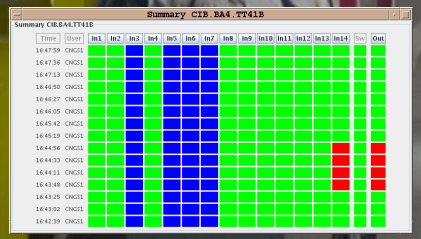
Changes in SPS interlocking







J. Wenninger

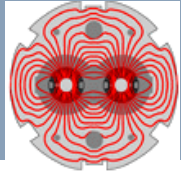
Beams Department

OP/ LHC

Acknowledgements: J. Uythoven, V. Kain,

K. Cornelis, G. Pappoti, E. Carlier and many others

Introduction and scope



This presentation has 3 different objectives.

- Information: SPS MP is not well known (on the LHC side).
- Recollection of issues and possible improvements.
- Changes to the SPS (MP, control, machine etc) that will impact MP at the SPS.

SPS MP Information Mine

https://sps-mp-operation.web.cern.ch/sps-mp-operation/

This WEB page contains all information on SPS MP 2006-2011

(tests, configurations etc)

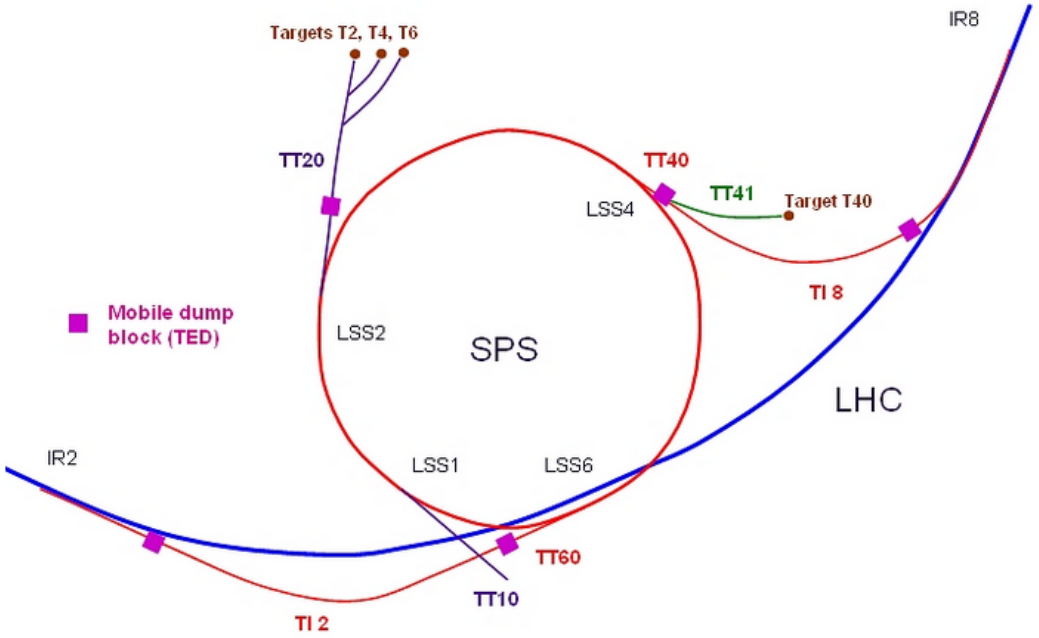
Home

- Configuration: Ring Extraction
- Timing aspects
- SPS Long MD recovery
- CNGS OP: 2009-11 2008
- LHC OP: 2009-11 2008
- North OP : 2009-11 2008
- RBI.816 PC (TI8/CNGS)
- SIS
- SPS Injection
- SPS BLMs
- Beam Dump
- Tests: 2009-11 2008 2007 2006
- Training/help docs
- Documents

SPS Machine Protection

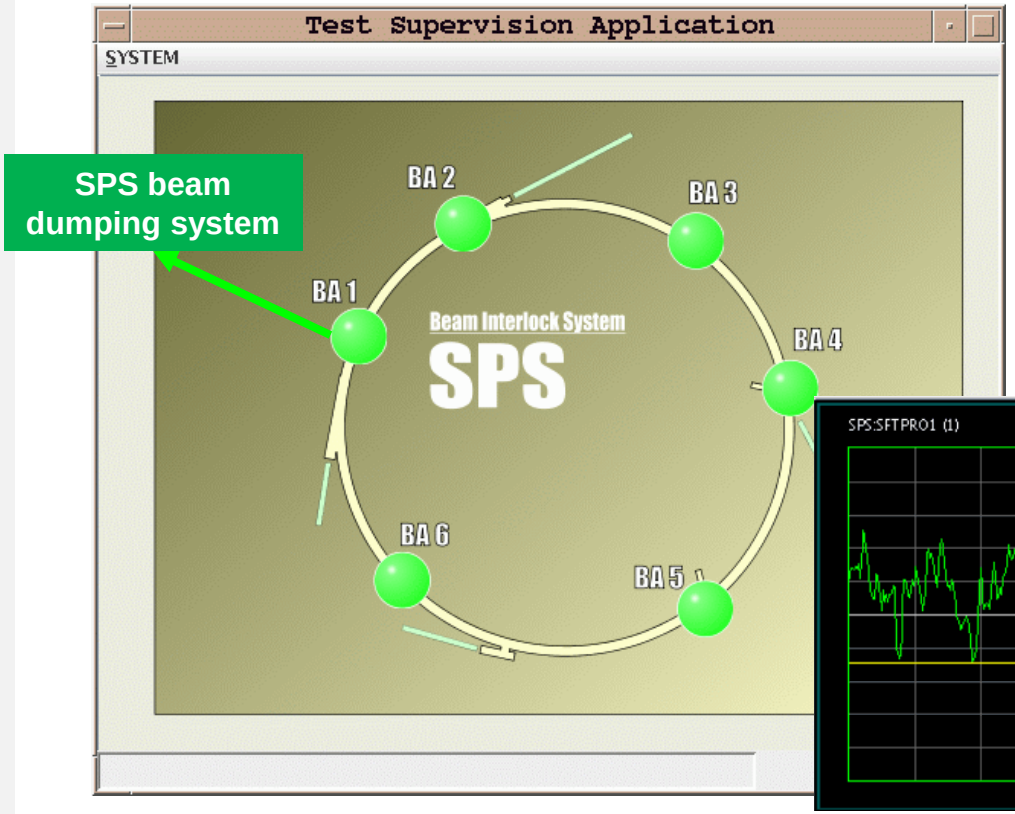
Commissioning and Operation

J. Wenninger AB-OP



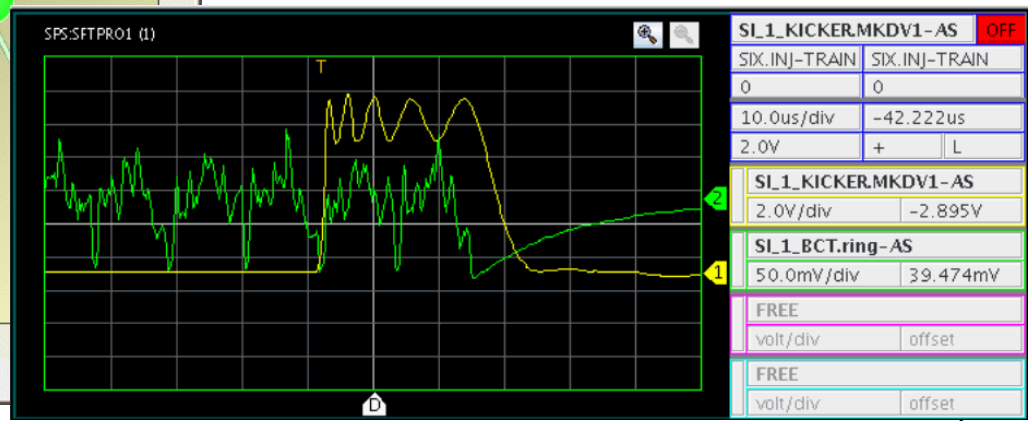
SPS Beam Interlock System

- First ring BIS at CERN with new 'LHC' design – 2006/2007.
- Contrary to the LHC, the SPS BIS rearms automatically as soon as all interlocks cleared ↔ multi-cycling nature of SPS.
  - *Safe Beam Flag (SBF) not used for SPS ring – SBF = always TRUE.*

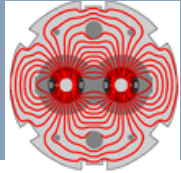


'Accepted risk' of masking certain interlocks with unsafe beam

SPS MKDV pulse (+beam)

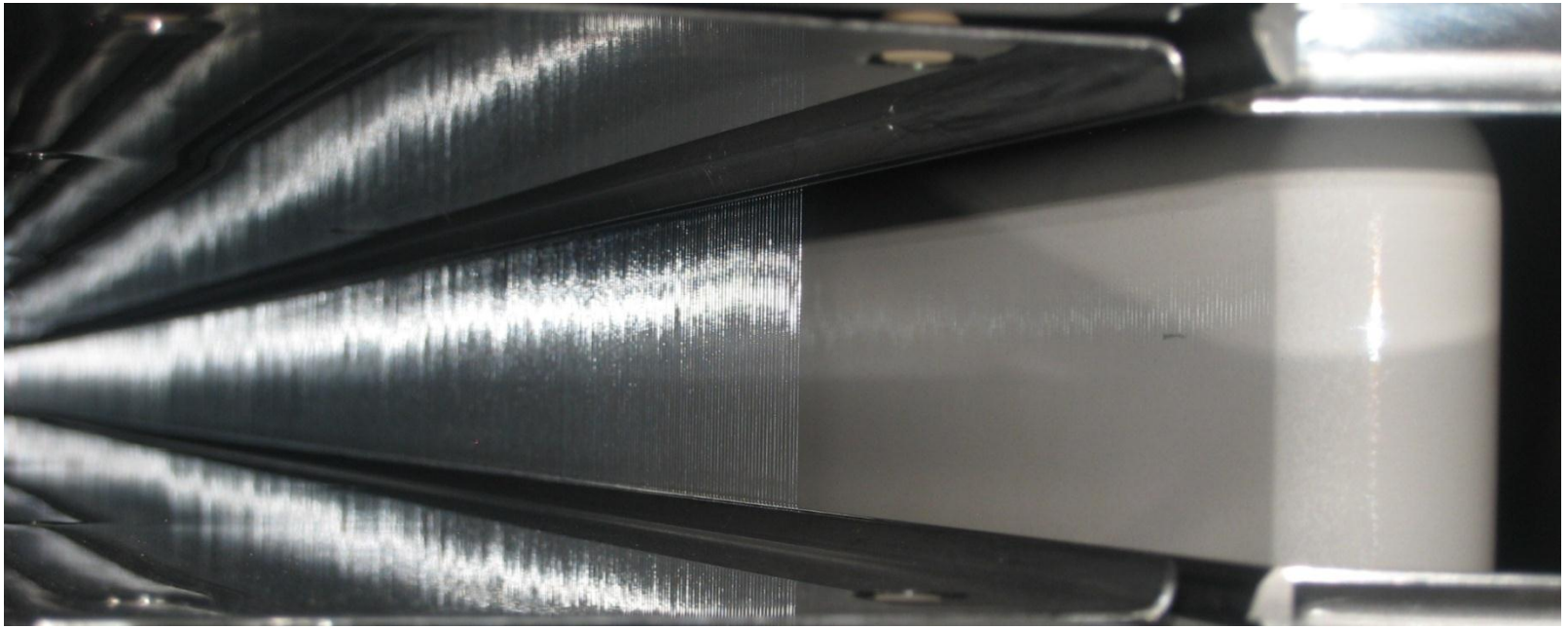


SPS Machine Protection



- SPS Machine Protection is not as tight as LHC MP - but the risk is also much reduced (max ~2 MJ / beam).
  - *Very basic protection by BLMs and BPMs (H plane only) for most failures.*
  - *MP is relying heavily on SIS – SIS was initially designed for SPS !*
  - *Multi-cycling poses a real challenge to MP (cycle dependent settings…) to both BIS and SIS.*
- The period 2006-2013 saw ~5 MP incidents.
  - *2 incidents resulted in equipment damage (ZS and MBB), the others were near–misses.*
- In the short term (up to LS2) no major improvements are foreseen for the SPS ring MP system.
  - *Next major change would be the LIU BLM electronics (with multiple integration windows – a bit a la LHC).*
  - *Improvement of the BPM interlock system (new design, H+V planes) did not work out – reliability issue – work by T. Baer.*

Illustration : ZS Incident - 2007



Electrostatic septum (ZS1) wires cut by slow extracted beam (~9x10^{12} p).

- Cause: controls 'problem' turned a slow into a fast-slow extraction.
- MPS issue: BLMs too slow / threshold too high (slow extraction).
- Action:
  - control system protections (limitations) and SIS.
  - one BLM: reaction time of 20 ms to few μs.
- See AB-Note-2008-003.

Partial solution

Illustration : ZS incident

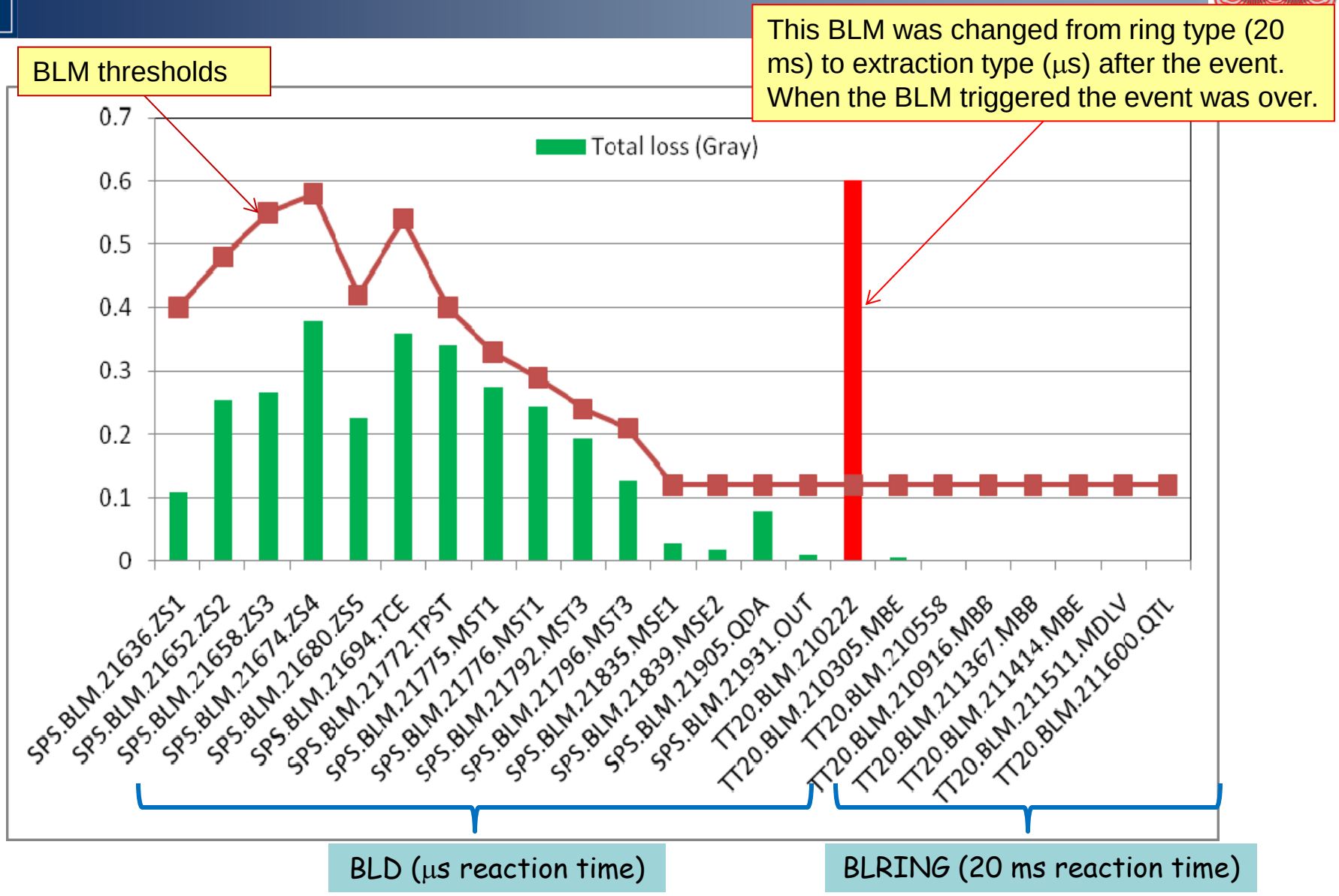


Illustration : CNGS Beam Incident - 2008

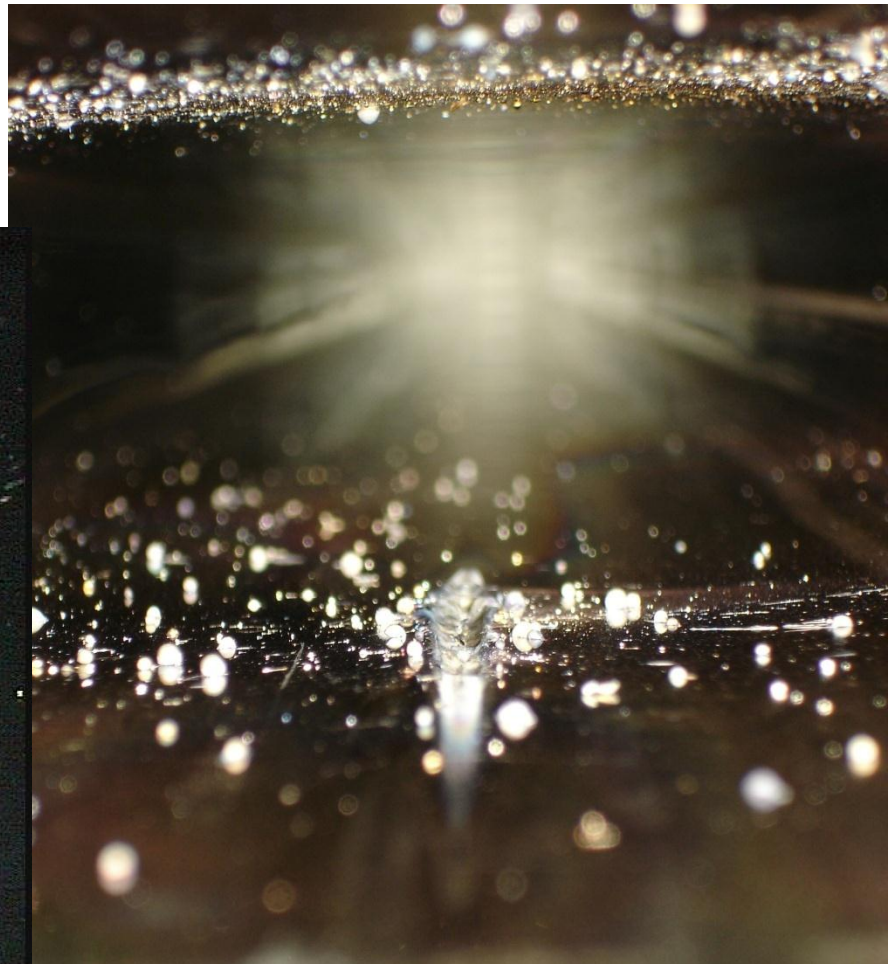
Beam impact in MBB.12530 of CNGS beam – vac. chamber ripped open (~3×10^{13} p).

- Cause: timing system problem ('freeze'), end of cycle dump not executed.
- MPS issue: BLMs too slow/thresholds too high, no fast position interlock in vertical plane.

- Action:
  - 3 protection layers against such timing failures.

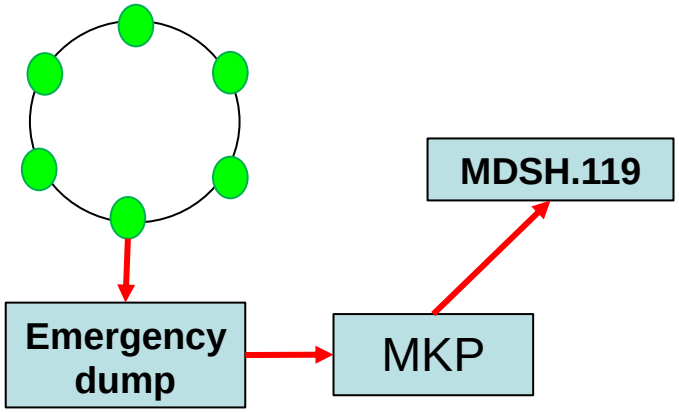
Partial solution

- See BE-Note-2009-003.

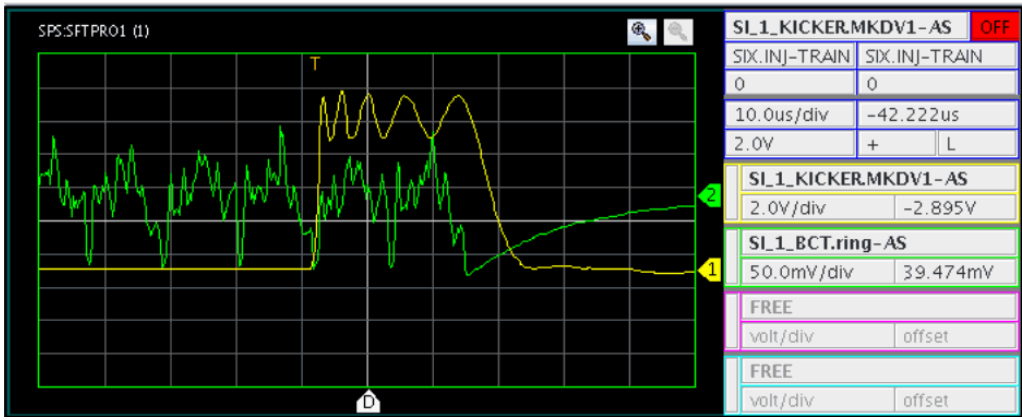


SPS Emergency Dump

- Currently the SPS emergency dump in BA1 is not synchronized to the beam (gap) – always asynchronous dump !
  - *Installation of a TSU (like in the LHC) is foreseen after LS1. It will however induce a delay of up to 1 turn of the dump – seems to be acceptable.*
  - *In the SPS the injection kicker MKP is directly inhibited by the dump system (and not across the BIS loop like in the LHC) → complicates situation.*
  - *In addition the MKP is connected to a dedicated PC / dipole corrector (MDSH.119 , 2-4.5 mrad) that is pulsed when the MKP has an inhibit → send the beam cleanly on the injection dump.*



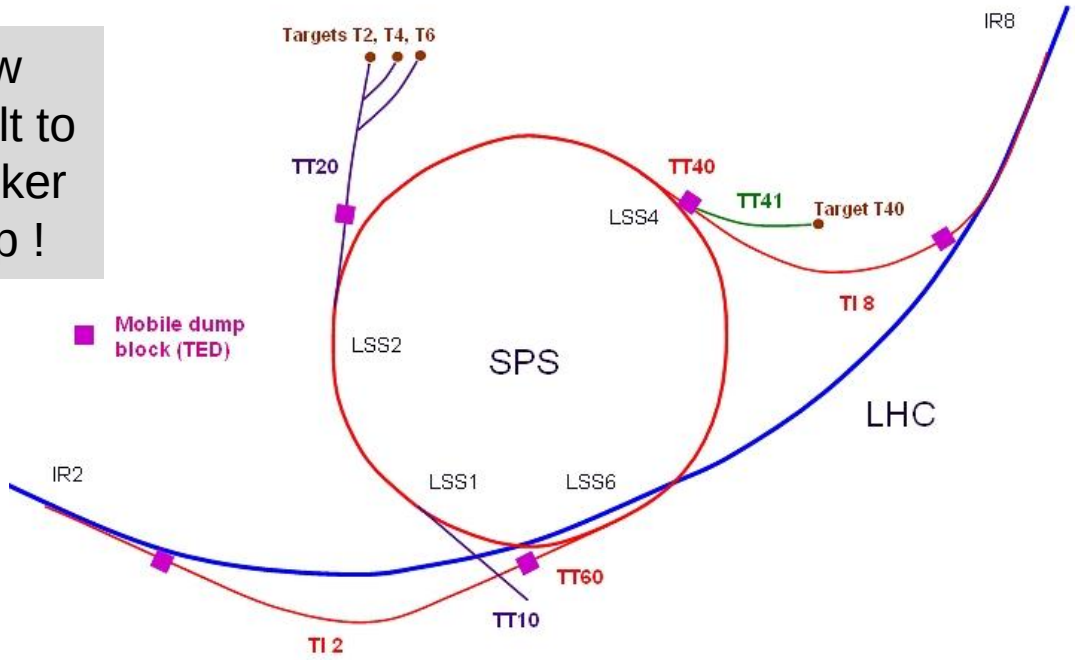
SPS MKDV pulse (+beam)



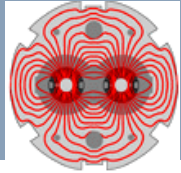
SPS Extraction Interlock Systems

- SPS extraction interlocks systems in 2012/3:
  - *LSS4 : CNGS and LHC,*
  - *LSS6 : LHC and Hiradmat.*
- Changes after LS1 (new extractions to be confirmed, both ~2016):
  - *LSS4 : exit CNGS, replaced by AWAKE (proton plasma accel.),*
  - *LSS2 : SBLNF with fast extraction using the MKP.*

Note the absence of the slow extraction (LSS2) that is difficult to interlock (no element like a kicker that can be inhibited) → dump !



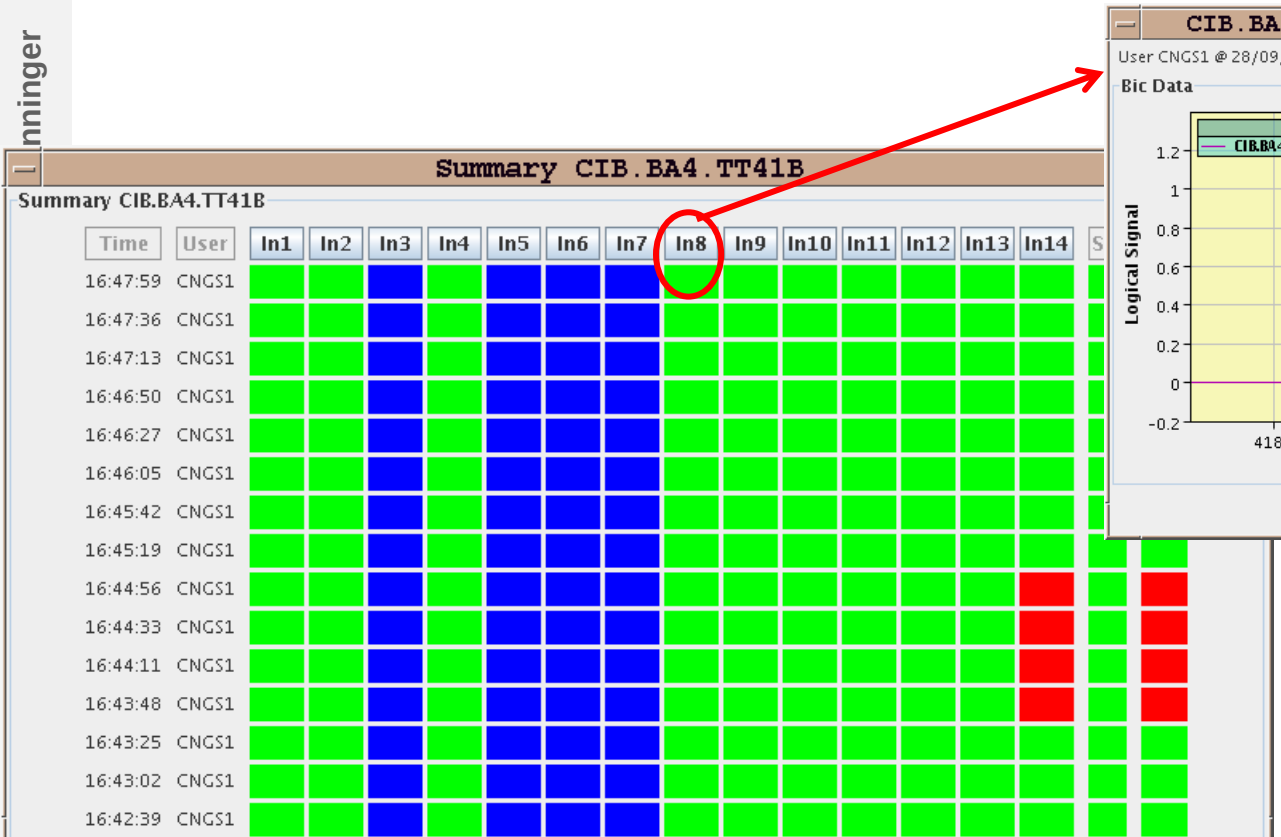
SPS Energy Flags

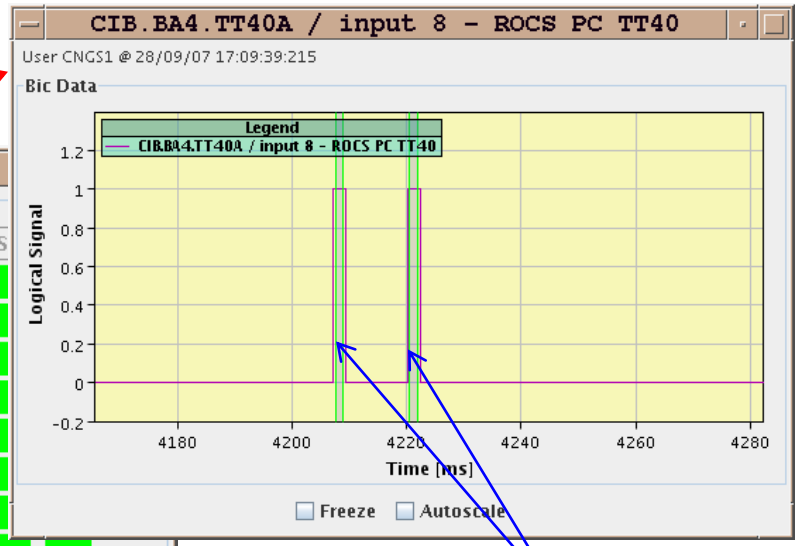


- Selection of the right extraction for the interlock systems is based on energy flags (generated by SPS SMP, windows ~ ± 2.5 GeV):
  - *CNGS : 400 GeV,*
  - *LHC : 450 GeV,*
  - *Highradmat : 440 GeV.*
- This concept has turned out to be simple and very reliable.
- (New) energy windows will have to be defined for:
  - *AWAKE: ~400-430 GeV,*
  - *SBLNF: ~100 GeV.*

Software for SPS Extraction BIS

- The fast pulsing interlock signals (based on failsafe logic) required special applications to digest the BIS states for OP.
  - *Top to bottom approach – 'OP view' : Kicker signal → BIC → Input*
  - *Summary and history per cycle (and per channel).*
  - *Special extension for the SPS and its lines – plans to merge this GUI back into main BIS application after LS1.*

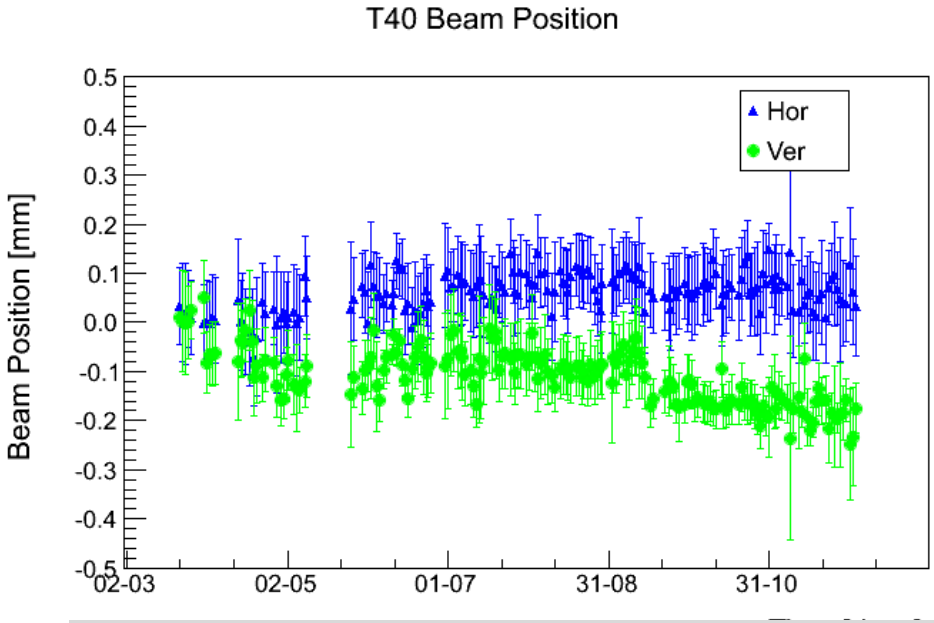




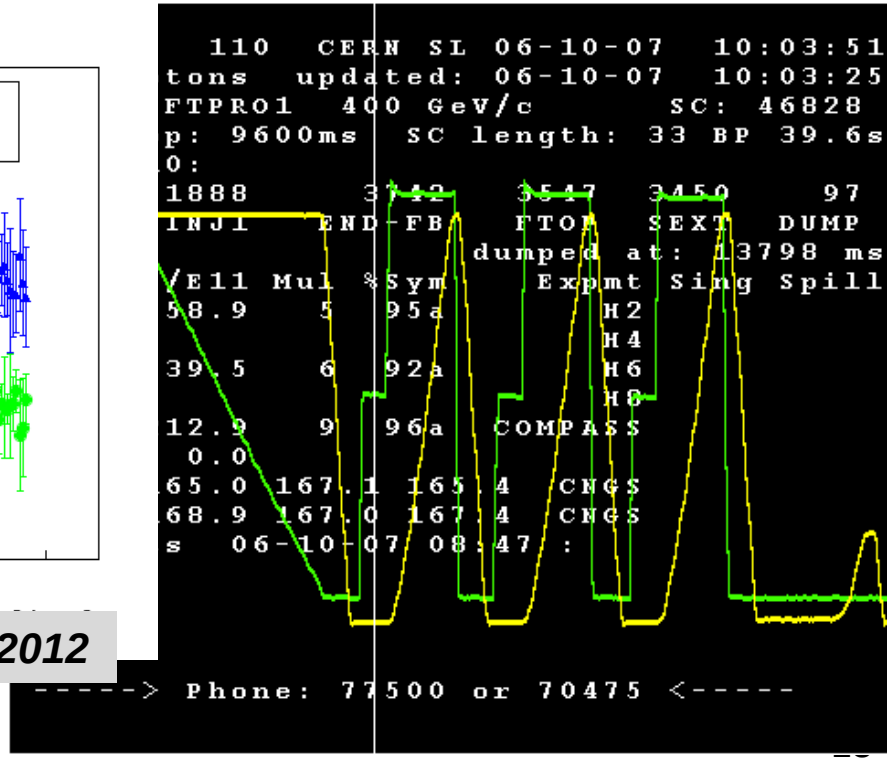
Analysis interval : signal must be = 1 (TRUE) for extraction to take place

The CNGS Success Story

- CNGS has been with us from 2008-2012, with 1.5 MJ beams extracted routinely with high efficiency and without damage.
  - *10 million extractions, 1.8x10^{20} protons on target, 7.5 PJ.*
  - *RMS beam stability on target 40-100 μm (interlock at 500 μm).*
  - *Losses in the TT41 transfer line ~un-measurable with BCTs (but some μSv visible just above natural background at high dispersion).*



Long term beam stability on target / 2012



CNGS near miss

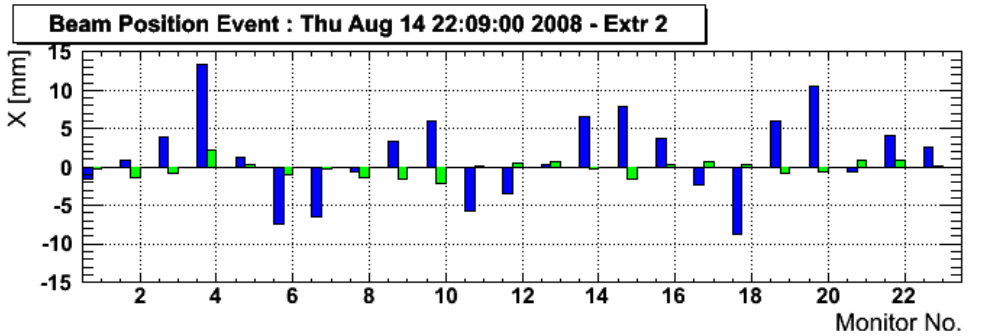
Evening of 14th August 2008 : 2 events
>> Problems with MKE control

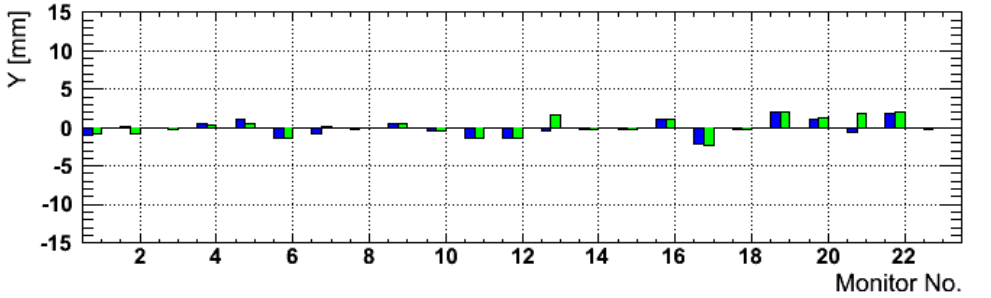
- The beam is extracted asynchronously and with significant kick error during piquet intervention

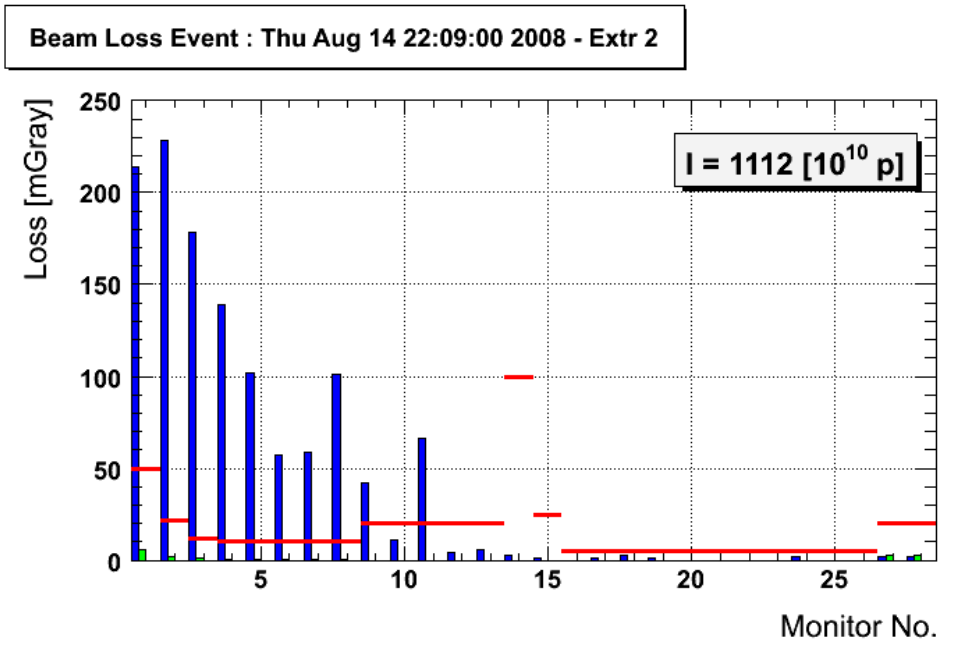
1. Very large trajectory excursions of almost **15 mm** **>> BPM interlock!**
2. Extraction losses almost 100 larger than normal,
   >> LSS4 & TT40 BLM interlock!
3. Only half of the beam intensity measured on target.

- **MPS reacted correctly and stopped the extraction.**

Blue : Event data
Green : Reference/normal extraction
Red : BLM interlock thresholds



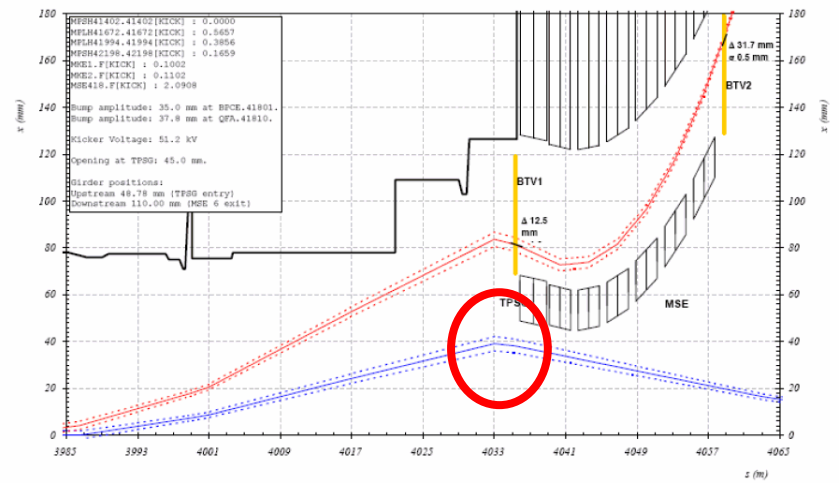




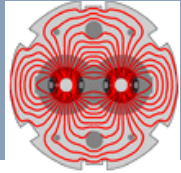
What did not work so well?

- The overall reliability and safety of the extraction interlock system was excellent.
  - *In particular the interlocking of over 200 PCs in the LHC and CNGS transfer line was crucial to ensure safe operation – worked very well !*
  - *Based on MCS settings.*
- The interlock on the beam position at extraction (~max of extraction bump) is the only one that '<u>under-performed</u>'.
  - *Just Ok for CNGS (200 MHz beam),*
  - *Not so good for LHC beams (limits had to be opened to 2-3 mm).*

  → *Due to the MOPOS orbit system (which has difficulties with LHC beams).*



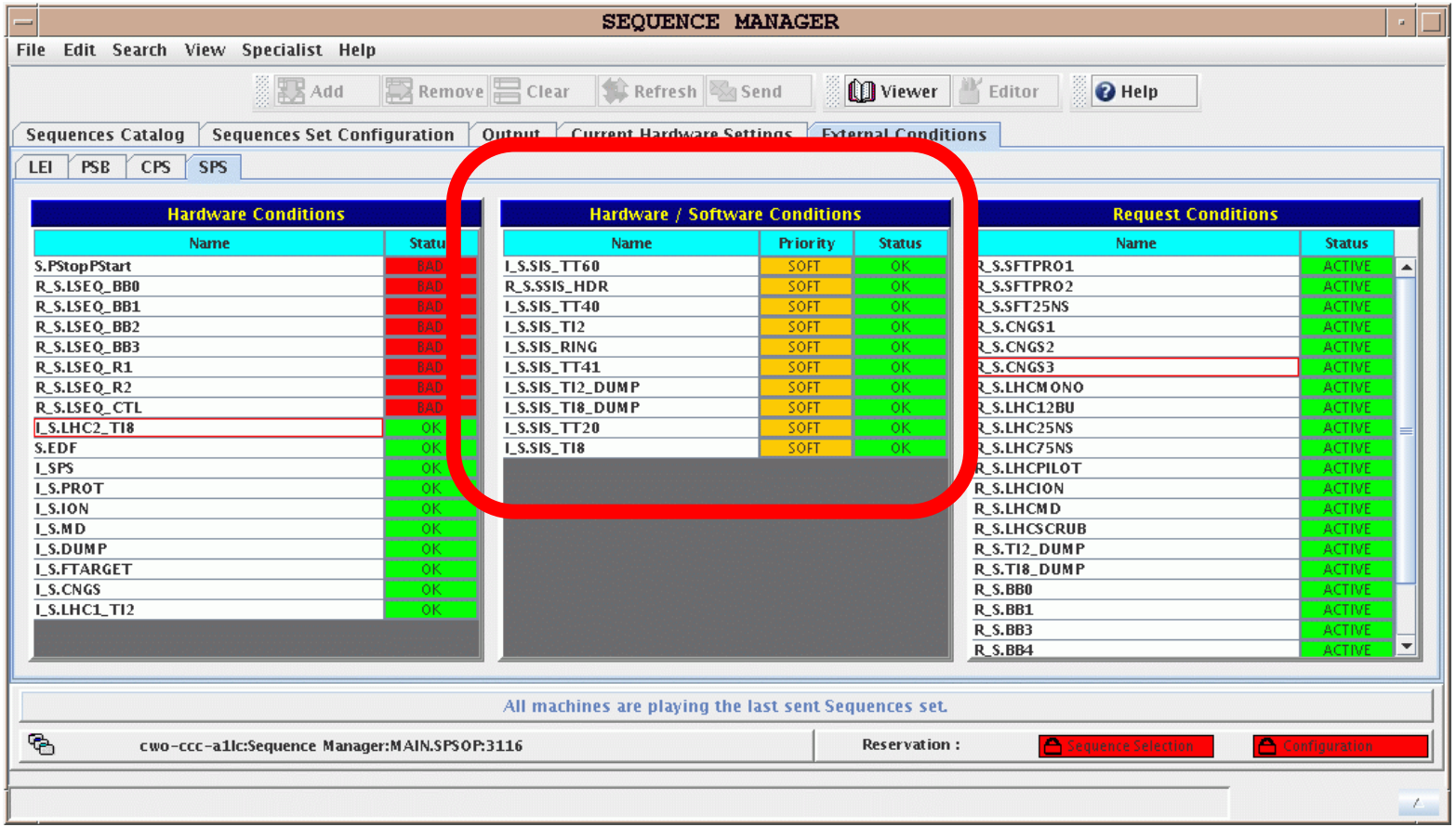
SIS @ SPS



- SIS was initially designed for the SPS – to replace an existent system that could not cope with LSA, JAVA, FESA etc.
- SIS plays a crucial role for SPS protection, and it is structured by geographical zone (~ transfer lines, extractions).
- In the SPS SIS acts always on 2 levels:
  - *Sets/clears an SIS interlocks in the BIS (ring or extraction).*
  - *Set/clears an inhibit at the level of the MTG to stop beam production at the source according to the beam DESTINATION.*
- Difficulties of SIS in a multi-cycling environment:
  - *Relation between interlocks and beams (should this interlock be evaluated in the current cycle?) – currently done through the USER names.*
    - *Needs revision if LSA cycles names are used in the future.*
  - *Reference settings management: Ok as long as one reference per beam (LHC, FT, CNGS…), currently very difficult to manage settings at the level of each individual cycle.*
    - *Evaluate need for more flexibility (– versus complexity)!*

SPS MTG Inhibits

- SIS reaction time :
  - *at the end of the cycle (when all data has been collected)*
- MTG reaction time :
  - *typically at the next super-cycle.*



SIS – MTG Beam Inhibit 'Matrix'

The matrix below indicates which INHIBITs affect a beam with a given DESTINATION (YES).

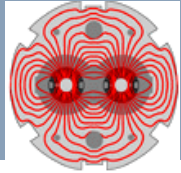
- *To be updated for AWAKE, SBNLF and end of CNGS.*

	SPS_DUMP	FTARGET	CNGS	TI8_DUMP	LHC2_TI8	TI2_DUMP	LHC1_TI2	HIRADMT
I_S.SIS_RING	YES	YES	YES	YES	YES	YES	YES	YES
I_S.SIS_TT20		YES						
I_S.SIS_TT40			YES	YES	YES			
I_S.SIS_TI8_DUMP				YES	YES			
I_S.SIS_TI8_INJ					YES			
I_S.SIS_TT41			YES					
I_S.SIS_TT60						YES	YES	YES
I_S.SIS_TI2_DUMP						YES	YES	
I_S.SIS_TI2_INJ							YES	
I_S.SIS_HIRADMT								YES

Timing

- A complex timing logic has been implemented to digest LHC beam requests and to ensure a coherent state of the machines.
  - *The diagnostics of timing problems for LHC beams remains rather tricky – more work on OP diagnostics may be welcome.*
- In 2012 a rather 'innocent looking' change of injection timings in the SPS lead to a problem where the LHC was expecting beam in one ring, and the SPS ended up sending the beam into the other ring.
  - *Wrong MKI pulsed, beam on the TDI.*
  - *Problem has been understood and will be fixed, backed probably by more SIS interlocks.*

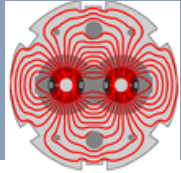
BQM and scraping



- The BQM will be based on new & better HW. Main functionality will remain unchanged, with some improvements:
  - *More diagnostics for satellites (number, location…),*
  - *And other goodies for Thomas B.*

- The existing scraper system will remain in place in BA1. A review has recommended to keep the current system.
  - *See https://indico.cern.ch/conferenceDisplay.py?confId=221617.*
  - *Some actions have been defined for the existing scrapper.*
  - *A system based on fixed absorber and magnetic bump (in LSS6) will be kept as hot spare (design !!).*

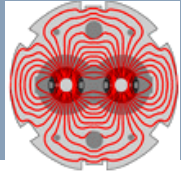
Protons versus Ions



- The mixed p-Pb operation came with the issue of ensuring that the species are send to the correct ring since RF settings (frequency) are very different.
  - *'Slow' failure (synchrotron period) – not ultra critical.*
  - *Protection by SIS:*

    Matching of the TT10 settings (17 GeV for Pb, 20 GeV for proton) and the LHC ring frequency.
- Should consider to evaluate more robust options – see also changes to SPS PC controls.

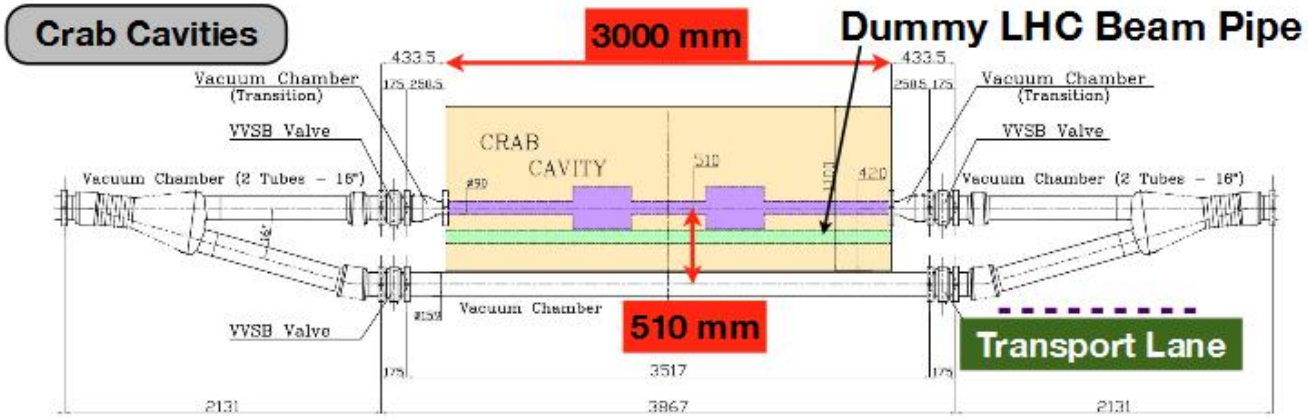
PC (Controls) Changes



- During LS1 the FEC control of the SPS power converters will be migrated from ROCS to FCG. The ramp cards that drive the actual converters stay in place.
  - *To first order this should be transparent, even if the state machine of the PCs will change (→ coasts …).*
  - *The PC interlocks with MCS will have to be re-implemented.*
  - *We should consider extensions of the PC surveillance for the fast extraction lines to the SPS ring and to FT operation of TT20.*
- A strong horizontal orbit corrector in LSS1 (MDHD.118) may be used to correct the orbit for the Q20 optics.
  - *This will require a hardware interlock.*

The Crabs are knocking on the door !

- It is planned to install proto-type crab-cavities (CC) in LSS4 (only place with cryo at the SPS) during 2015/2016 shutdown.
  - *CC will be installed on Y-chamber, can be moved in/out of beam.*
  - *Due to aperture of only 84 mm and the fact that the CC is inside the extraction bump for LSS4, it is unlikely that CCs can be in beam during regular operation – TBC.*

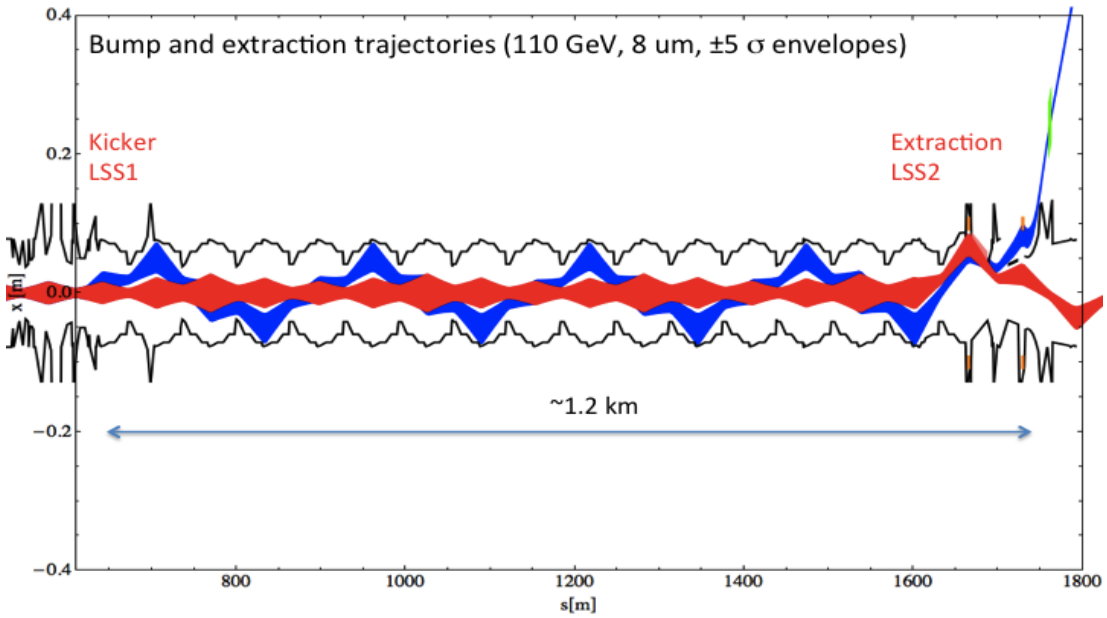


- New hardware interlocks (+ many SIS interlocks ?):
  - *Extraction interlock if CC in beam (if not compatible LHC).*
  - *Beam interlock if Y-chamber at intermediate position.*
  - *CC 'state' etc*

To be defined

New Extraction : SBLNF

- Project for a new Neutrino beam from the SPS (North Area).
  - *~100 GeV beams, FT / 200 MHz, CNGS like intensities ~4.8x10^{13} p.*
  - ***Stored beam energy ~750 kJ, extracted in 2 batches.***
  - *Non-local extraction using the SPS injection kicker MKP as fast pulsing element, with orbit oscillations along the arc from LSS1 to LSS2.*
  - *SBNLF will **NOT** operate at the same time than standard FT beams.*
- SBNLF requires a new extraction interlocking !



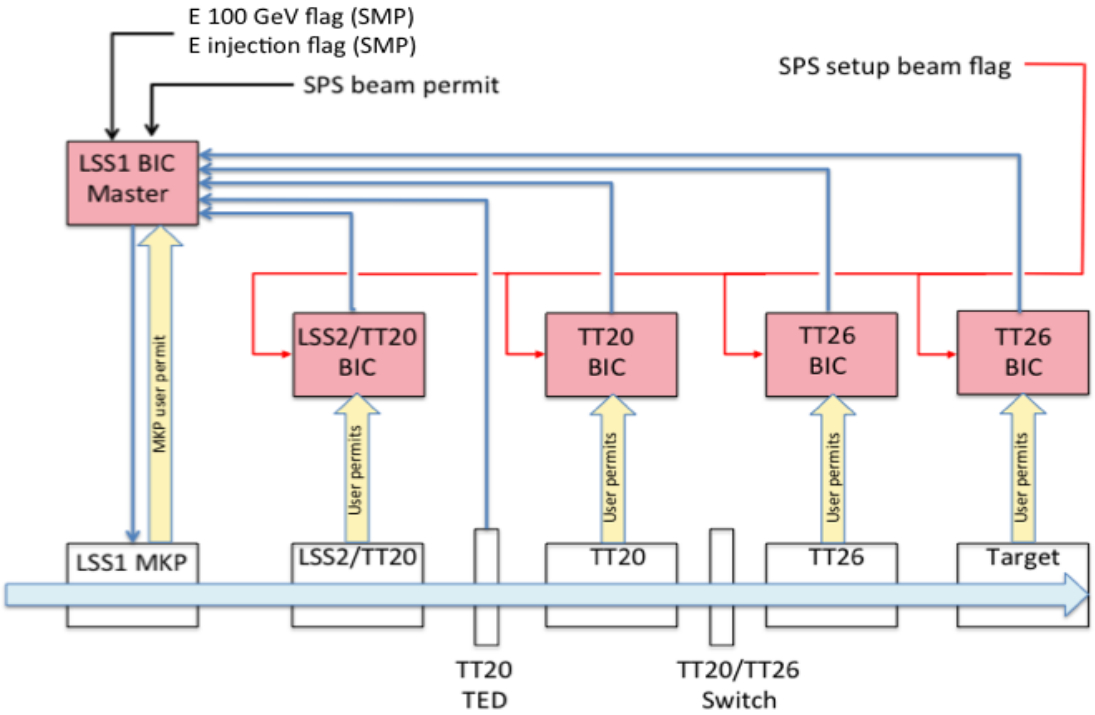
Safe beam @ 100 GeV:

~2x10^{13} p (TBC !)

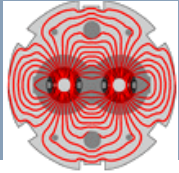
- scaled from 450 GeV with 1/E^2

SBLNF Extraction Interlocking

- Re-use our well understood concepts with slave-master BICs.
  - *Interlocking covers 3 SPS BAs (not all visible here).*
  - *Orbit correctors in sextant 1 & 2, as well as main quads (tune) and sextupoles (both BA3) must be interlocked – current level.*
- We are considering to use a 'Extraction Permit Loop' that would cover all the SPS rings and be connected to all extractions.
  - *The loop would also allow to close some gaps for LHC beam interlocking.*

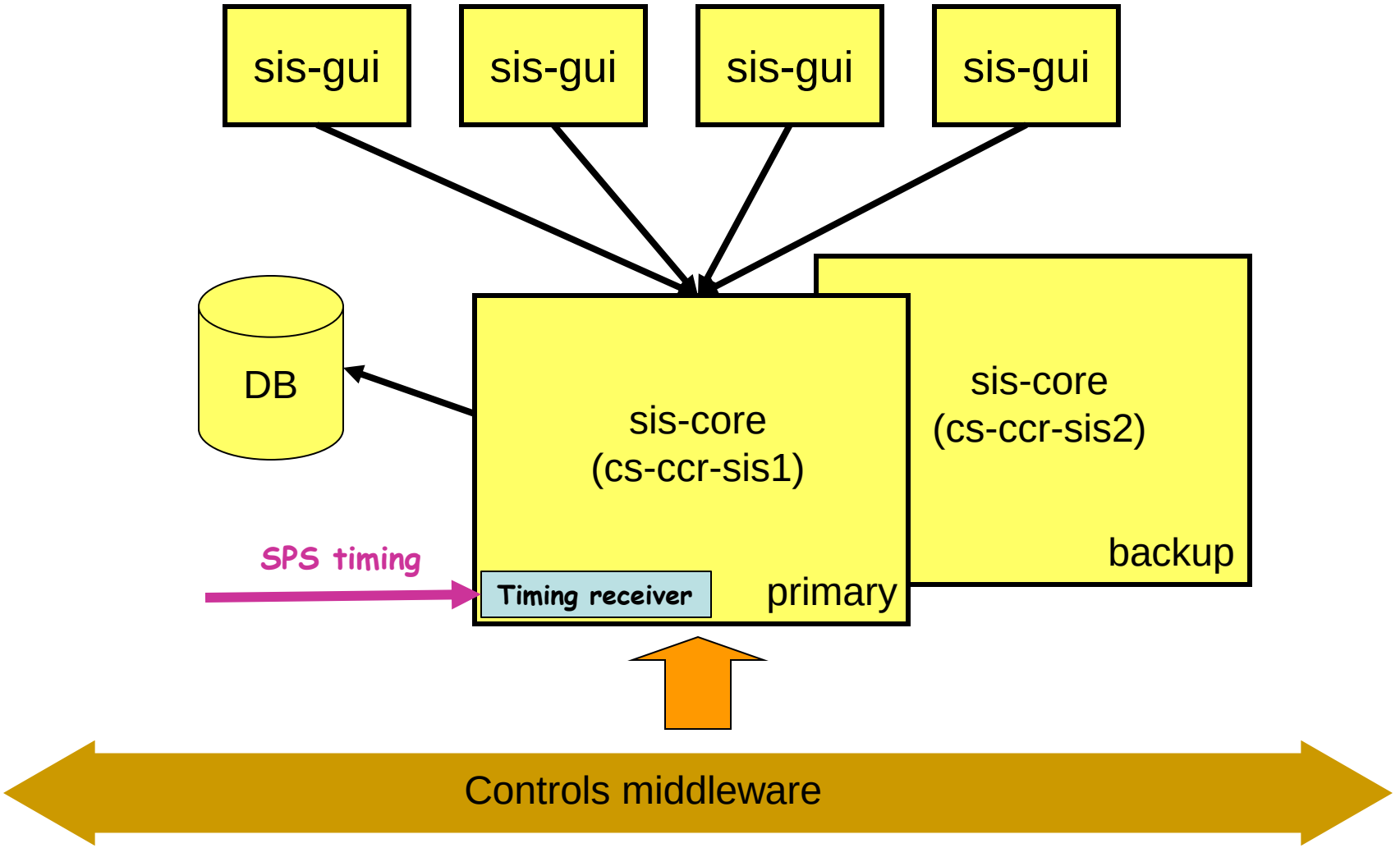


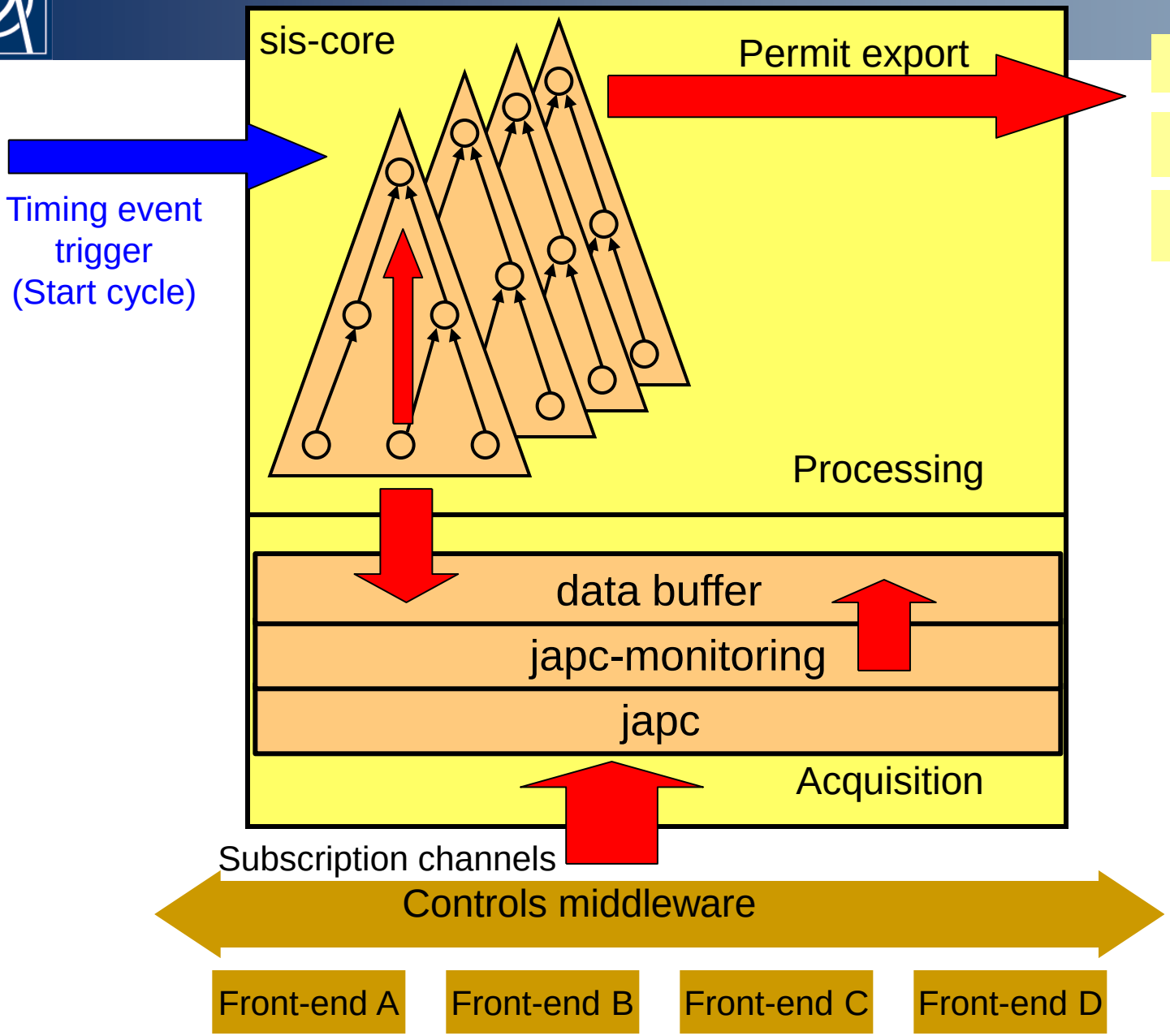
Summary

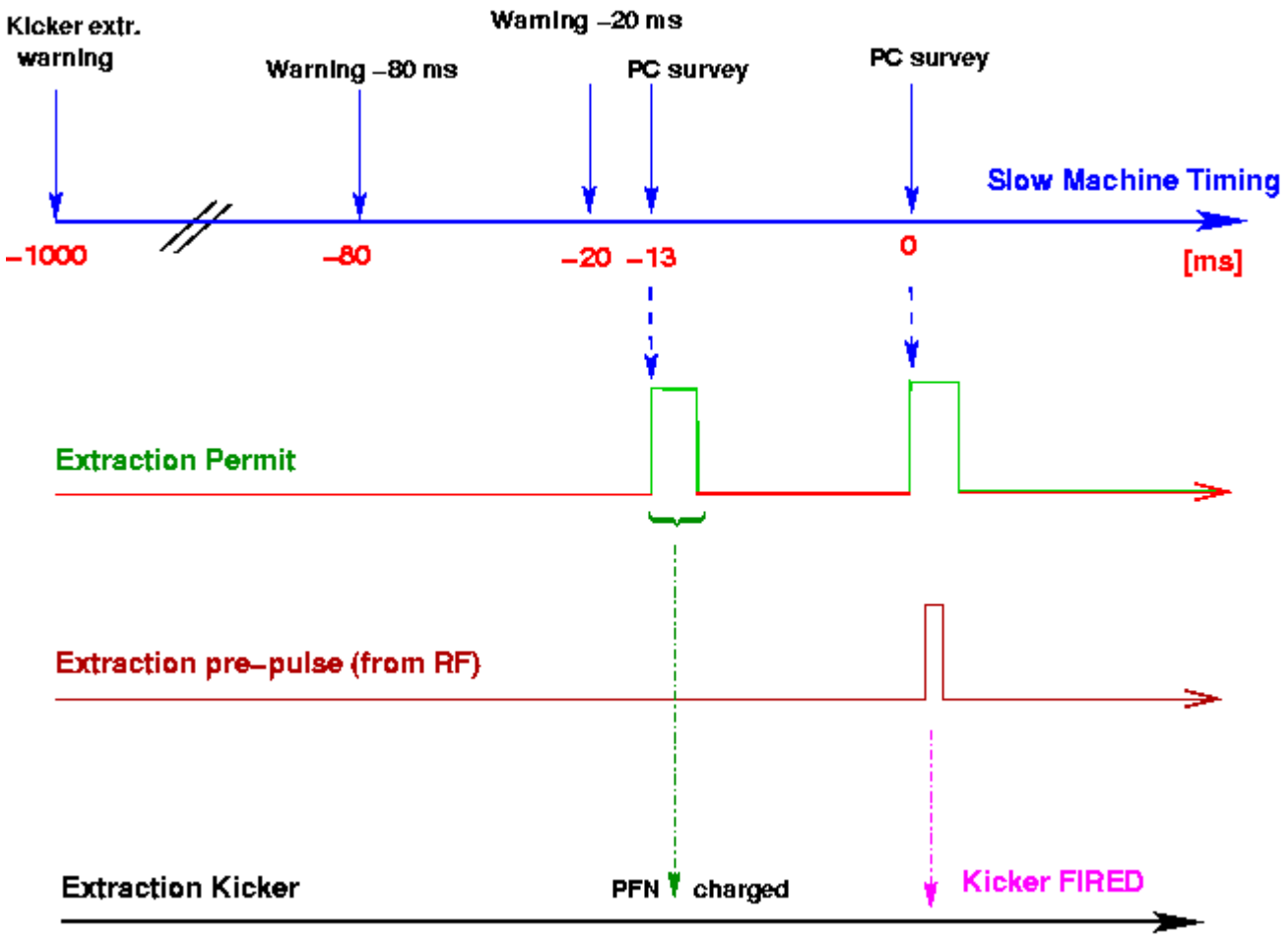


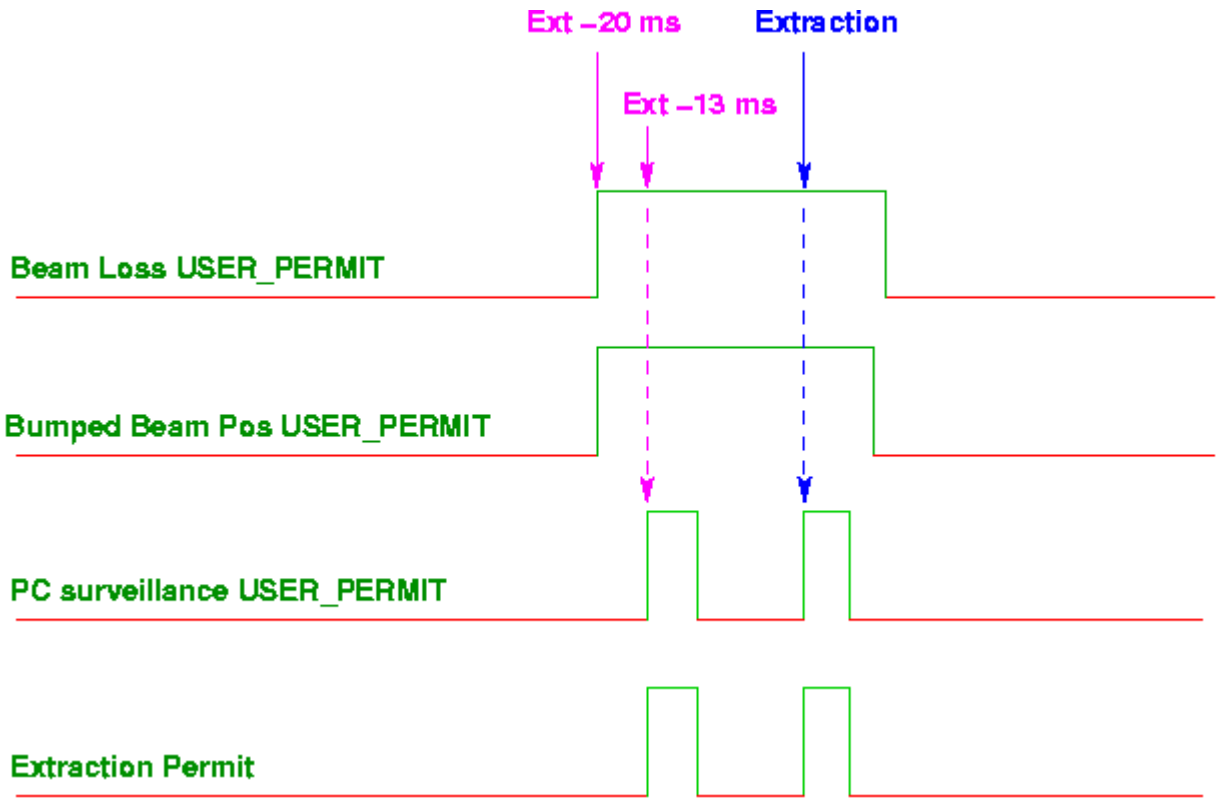
- No major changes on SPS side for MP during LS1, but a number of smaller items and a rather major change of the PC controls.
  - TSU for emergency dump,
  - PC interlocks to be re-implemented and extended under FCG umbrella,
  - What do we do with the BPM interlocks for ring and extraction?
- SIS interlocks and diagnostics must be revised.
  - USER versus LSA cycle names,
  - Settings flexibility?
- The SPS MP will have to be prepared for new extractions ~2016.
  - SBNLF in LSS2 – lot's of changes and new hardware,
  - AWAKE in LSS4 – 're-use' CNGS MP infrastructure.
- We need a new Mister / Misses MP for the SPS.
  - My term stopped naturally end of 2011.
  - Very important role in such a flexible and complex machine. A huge test campaign has to be organized after LS1, and daily issues must be followed up.

SIS Architecture

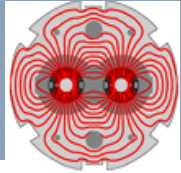



sis-core
Permit export
BIC
SPS MTG
Alarms
Timing event
trigger
(Start cycle)
Processing
data buffer
japc-monitoring
japc
Acquisition
Subscription channels
Controls middleware
Front-end A
Front-end B
Front-end C
Front-end D


Kicker extr. warning
Warning –80 ms
Warning –20 ms
PC survey
PC survey
Slow Machine Timing
–1000
–80
–20
–13
0
[ms]
Extraction Permit
Extraction pre–pulse (from RF)
Extraction Kicker
PFN charged
Kicker FIRED


Ext –20 ms
Extraction
Ext –13 ms
Beam Loss USER_PERMIT
Bumped Beam Pos USER_PERMIT
PC surveillance USER_PERMIT
Extraction Permit

SIS and FT Beams



- TT20 and the target zone of the North Area are mainly protected by SIS.
- The SIS interlocks have so far been tuned to standard 400 GeV Fixed Target beams.
  - *Operation with the variable energies for ions have been a problem, as a proper protection would have required flexible settings for certain interlocks.*