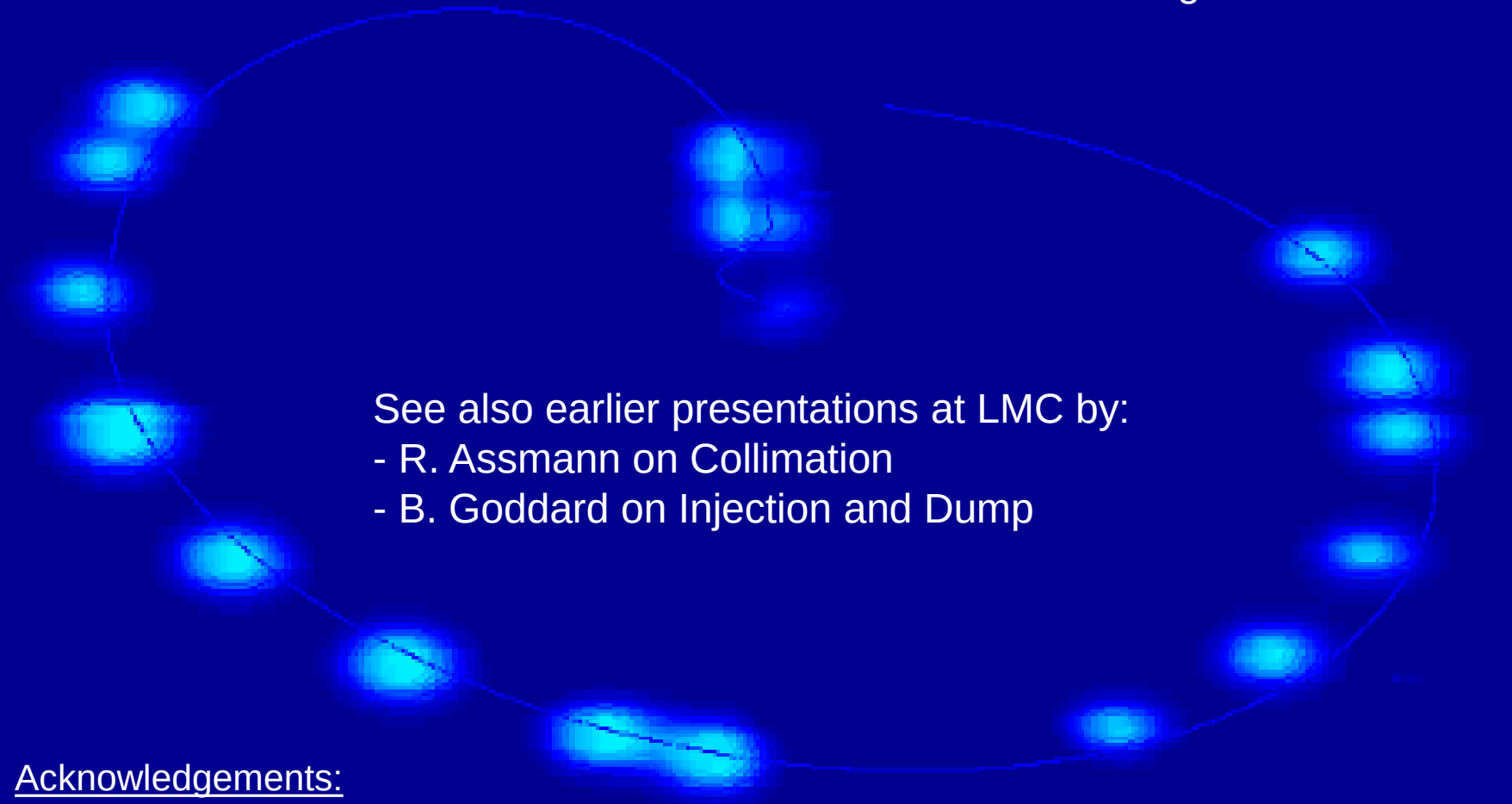
Machine Protection during Beam Commissioning

J. Wenninger



See also earlier presentations at LMC by:
- R. Assmann on Collimation
- B. Goddard on Injection and Dump

Acknowledgements:

B. Puccio, B. Todd, M. Zerlauth, B. Goddard, J. Uythoven & LBDS + injection team, M. Meddahi, R. Assmann & Collimation team, B. Dehning M. Sapiski & BLM team, A. Macpherson, S. Redaelli, V. Kain, R. Schmidt, R Appleby, the EICs, the Post-Mortem team, and many more.

Special thanks to Brennan & BI for the dump BTV images

Beam Interlock System

- BIS is running with almost nominal configuration.
  - Only a few missing inputs, ~1/2 of them due to the ‘absence’ of client (ATLAS RP, CMS magnet, transverse damper).
  - Behind the ~180 inputs to the BIS there are ~20k-40k individual interlock channels (QPS, PIC, BLM…).

- BIS operation fault free.
  - In the STABLE BEAMS periods all connected interlocks were active.
  - Masking facility proved essential for availability in first days and MPS tests (see later).

Safe Machine Parameters

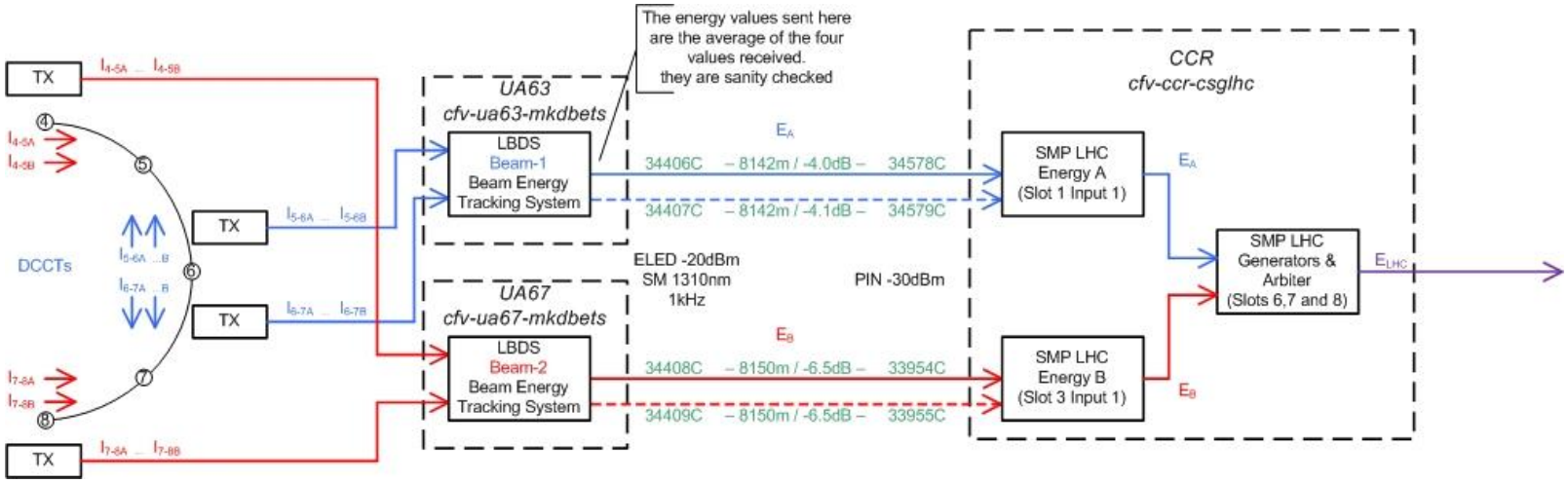
- SMP system responsible for generation of:
  - ✓ SPS Probe Beam Flag
  - ✓ SPS Safe Beam Flag
  - ✓ LHC Beam Presence Flag
  - Safe Energy
  - LHC Setup(Safe) Beam Flag (SBF)
  - Safe Stable Beams Flag
  - Movable Devices Flag

- All parameters are generated and distributed, but the Safe Energy and LHC SBF are affected by a lack of redundancy (→ next slide).

>> OK for present low intensity/energy

Safe Energy

- Energy information generated by the LBDS BETS system (IR6).
- Redundant information transmitted @ 1 kHz to SMP system in CCR.



- Problems were observed in the energy value distributed in the pre-beam periods:
  - Energy set to safe value of 7864 GeV a few times per day. Internal comparison of A/B redundancy suspected to be at the origin of the issue.

>> Disable redundancy + crash program on fast internal diagnostics.

No problems observed during beam commissioning (without redundancy).

The internal comparison process has been upgraded and will be back for 2010.

Powering Interlocks

- Powering interlocks (PIC) link to BIS were activated in commissioning configuration:
  - Main circuits, IPD and IPQ → un-maskable beam interlocks.
  - Trim quads, sextupoles, > 60 A CODs → maskable beam interlocks.
  - Other circuits : don't care.

- Performance:
  - Very reliable.
  - Maskable inputs were occasionally masked, or the configuration was adapted when circuits were not available (almost always MCBX !).

    >> MCBX also a problem for steering, separation, real-time feedback … !
  - All dump triggers were clean and fast (no effect seen on beam before dump).

Fast Magnet Current Change Monitors (FMCM)

- All 12 LHC FMCMs were commissioned in parallel to HWC by generating powering faults on the associated circuits.
  - Performance in spec, dump thresholds:

    ~ few 10^{-4} relative current change at 450 GeV

    ~ 10^{-4} relative current change at nominal current

- FMCMs operated reliably. ‘Anomalies’:
  - FMCM of RD34.LR7 triggered a few times without associated PC fault.

    - All but one event concentrated in the 3-4 hours before 18 kV transformer problem. Precursor? M. Zerlauth is investigating…

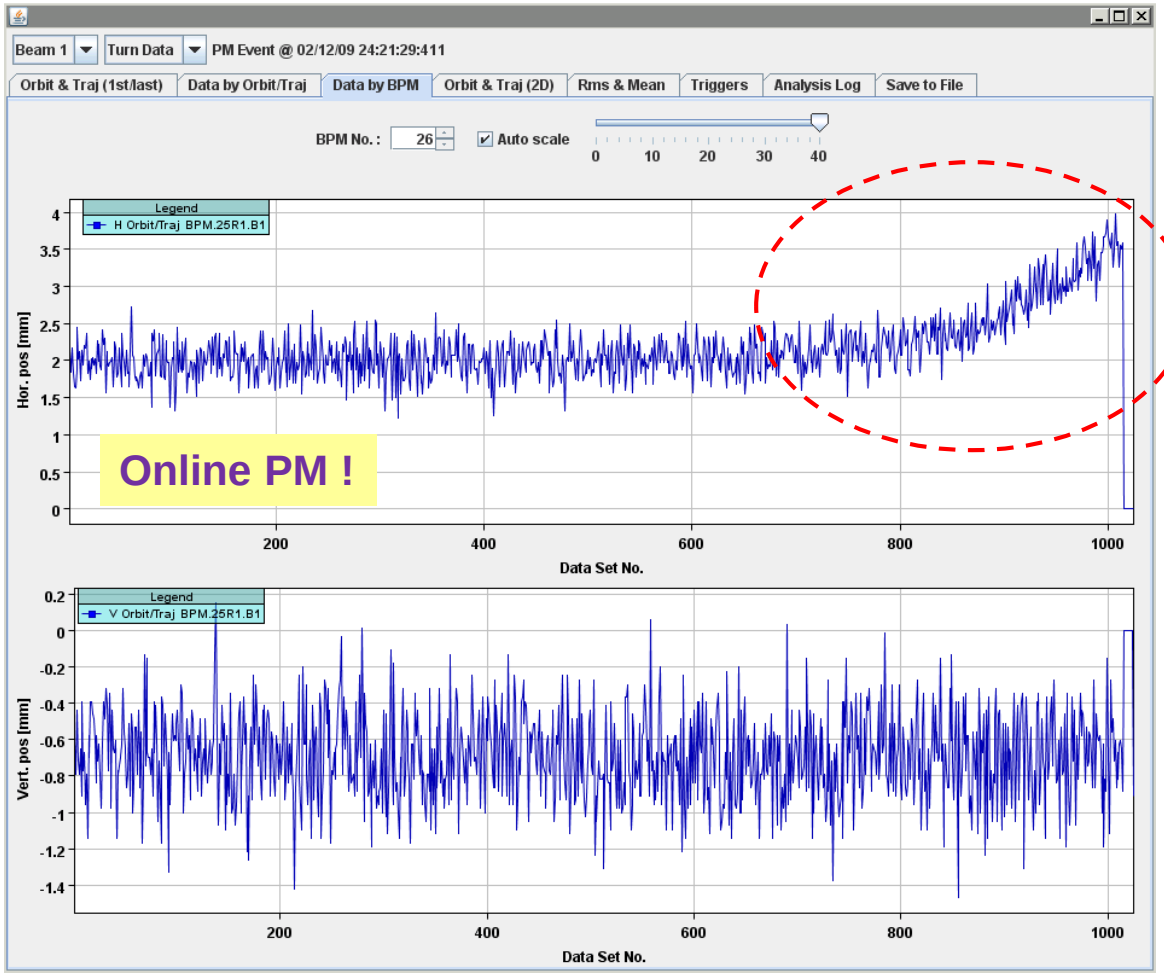
18 KV Transformer & FMCMs

- BIS interlock sequence during 18 KV transformer problem on 02.12 at 01:10.
  - FMCMs triggered one after the other within 22 ms.
  - ‘Unfortunately’ no low intensity beam to witness – but encouraging sign that FMCMs may catch the such events before the consequences on beam become a problem.

Input	Delta (ms)
FMCM RD1.LR1	0.00
FMCM RD1.LR5	3.42
FMCM RD34.LR3	4.15
FMCM RD34.LR7	5.74
FMCM RMSD.B1	8.22
FMCM RMSD.B2	10.87
FMCM RQ4.LR7	14.34
FMCM RQ5.LR7	14.42
FMCM RQ4.LR3	16.37
FMCM RQ5.LR3	22.11
WIC IR1	556.89
WIC IR5	594.40
WIC IR7	653.16
PIC IR2 (Mask+Un-Mask)	1522.70
PIC IR3 (Mask+Un-Mask)	1523.12

FMCM Beam Tests for D1 IR1/5

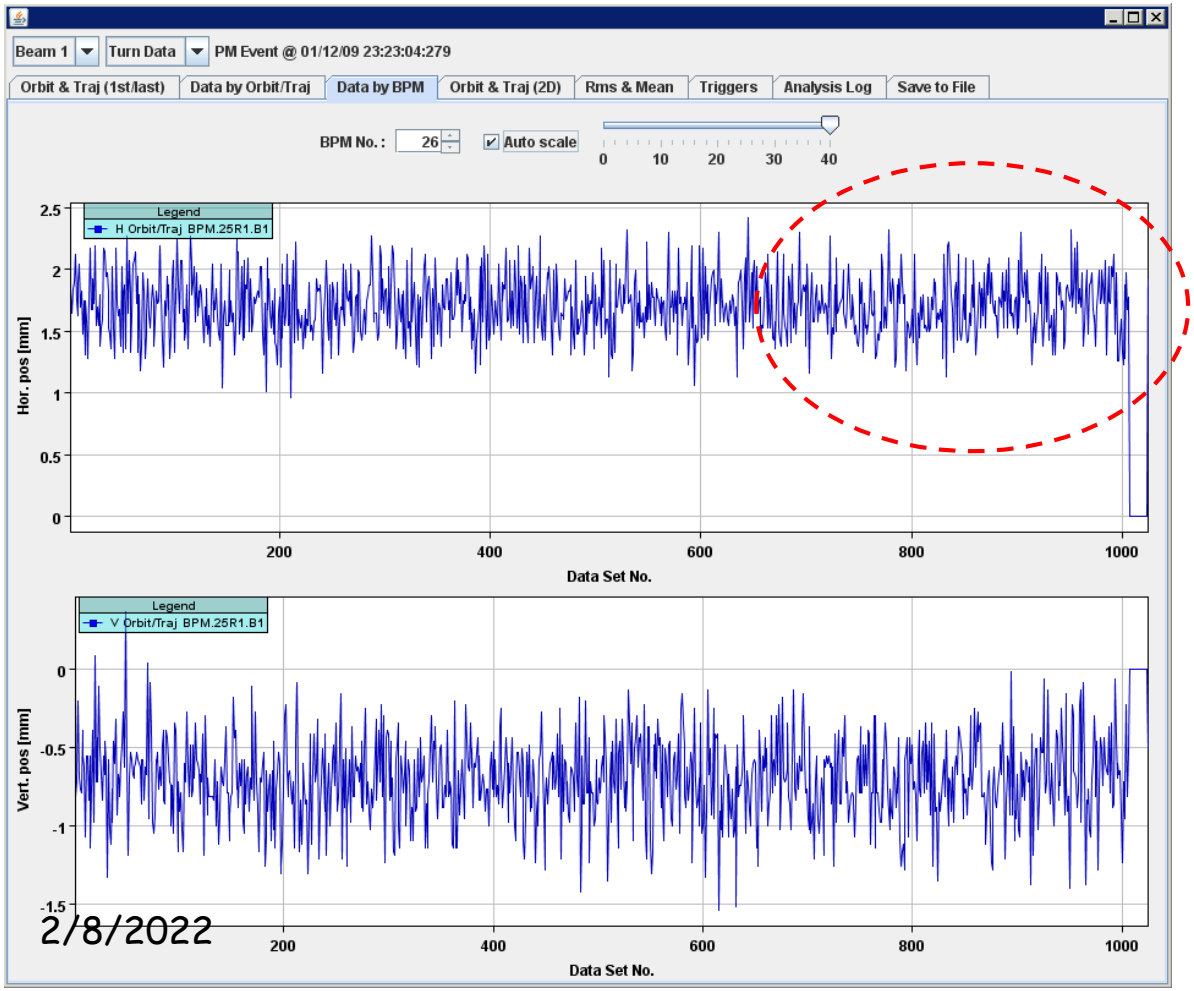
- Low intensity beam test.
- Trajectory evolution after OFF send to RD1.LR1, with FMCM masked.
- Beam dumped by BLMs in IR7.



- Trajectory over 1000 turns at a BPM.
- Position change of ~1.5 mm over last 250 turns.

FMCM beam tests

- Low intensity beam test.
- Trajectory evolution after OFF send to RD1.LR1, with FMCM active.
- Beam dumped by FMCM.



- Trajectory over 1000 turns at a the same BPM.
- No position change visible within resolution.

>> The redundant protection is working

Beam Loss Monitors

- BLM system is working reliably. It is one of the primary and very powerful observations tools (@ 1 Hz + PM analysis).
- BLM configuration for this period:
  - Arc + triplet BLMs → un-maskable interlocks.
  - LSS + warm elements → maskable interlocks.
- BLM reliability is excellent.
  - Isolated problems with noise and with connections.

  >> For 2010 more BLM will be attached to the un-maskable interlocks.
- Overall the thresholds seem OK.
  - Thresholds at TCTs and TCLA were increased by factor 50 after beam tests.
  - Thresholds at TDI were set ‘out-of-range’ for short integrations windows.
- Signal cross-talk (through particle showers):
  - Transfer line collimators → ring BLMs.
  - TDI IR8 → MQX (Q3).
  - TCP beam 1/2 → TCLA beam 2/1.

Quenches

- Quench count now at 4.
- All quenches were 450 GeV ‘Quench-inos’.
- All quenches were associated to beam injection – ultra-fast loss.
  - Latest event related by injection while trimming bumps for aperture scans.

  >> Importance of :

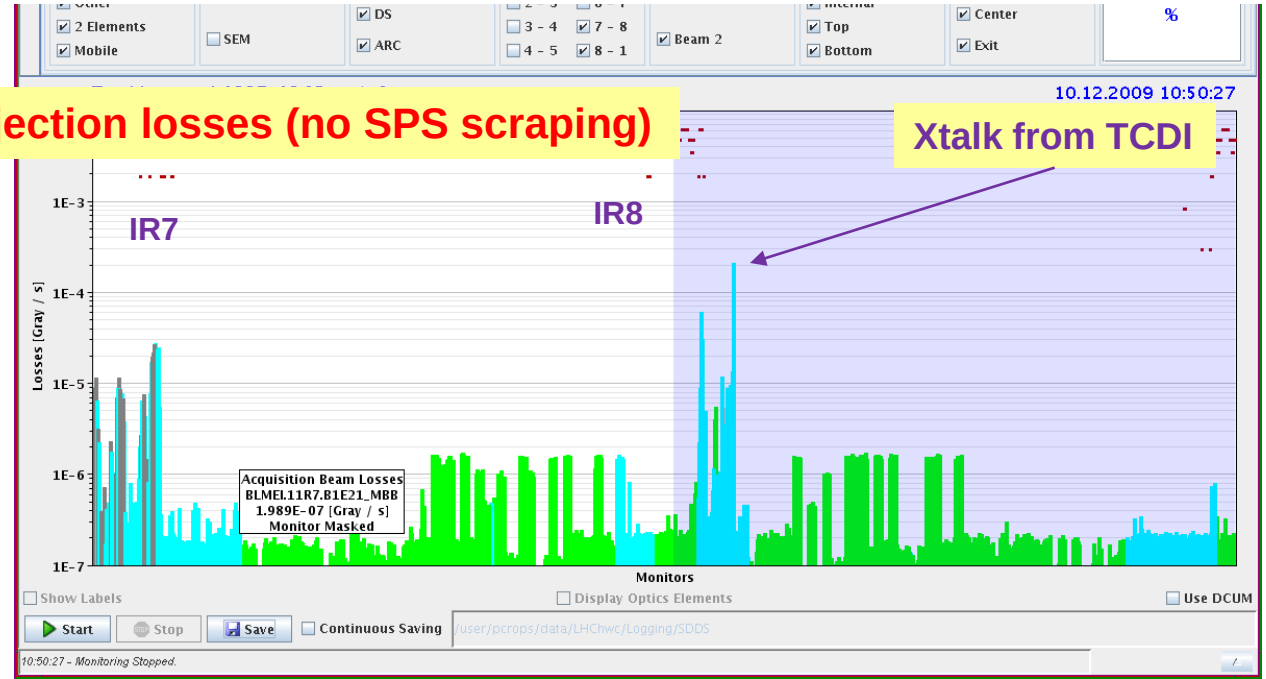
  - Low intensity injection into empty ring.
  - Orbit corrector interlocking by SIS !

Injection Protection

- Transfer line interlocks fully commissioned and active for first injection.
  - Only missing item: TL collimators.
- Injection protection (TL collimators TCDI, TDI, TCLI) setup for stable beams with 2e10 p/injection.
  - Abort gap protection (inj kicker) – not perfectly timed, but OK for now.
  - BLM cross-talk TL collimators → ring.

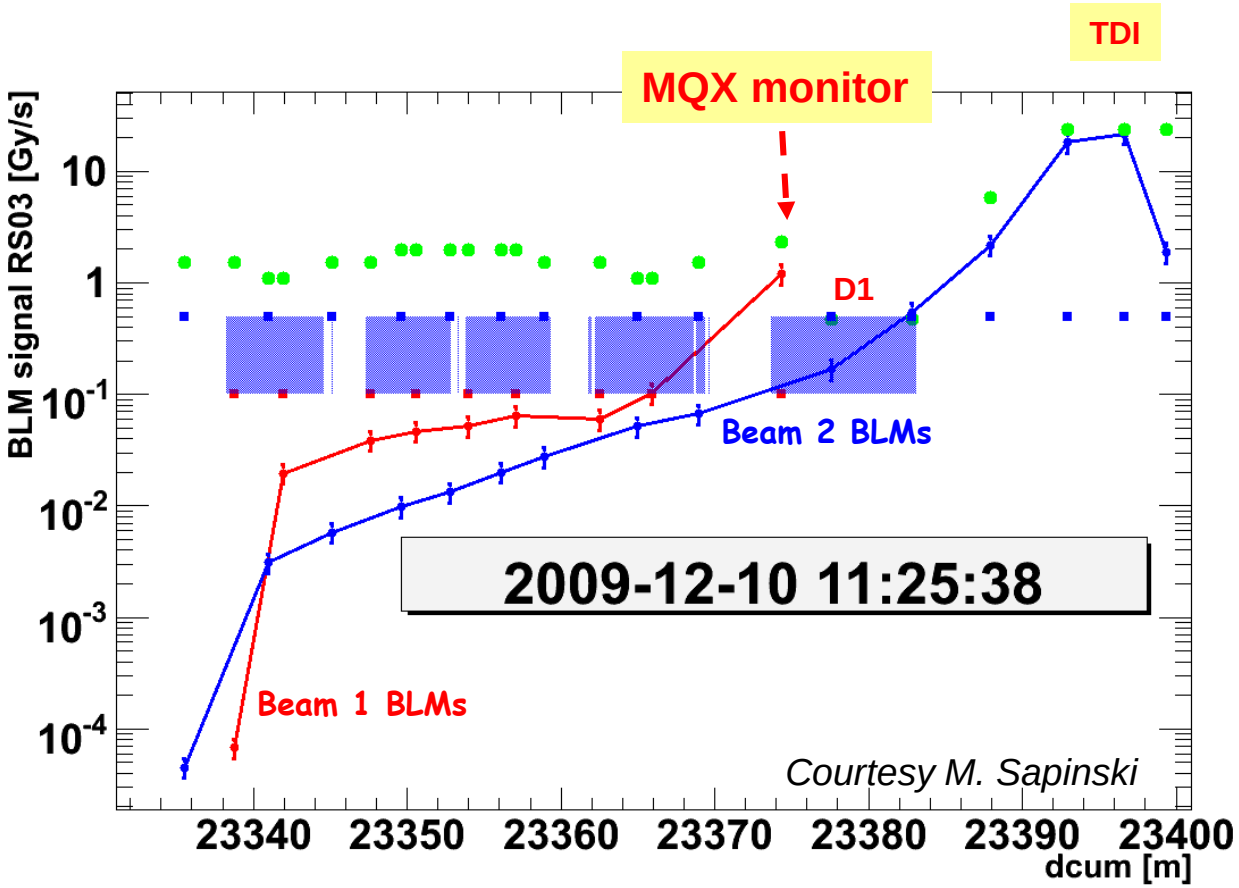
>> H collimators to 6 sigma (instead of 4.5), V collimators to 4.5 sigma

>> Beam scraping in the SPS (H plane).



IR8 TDI Losses

- Monitor on D1 (for protection of MQX3 from beam1) close to or over threshold when beam 2 is dumped on TDI.
  - Not present in IR2 (layout …?).
  - Must understand the 'path' of the showers (inside/outside vac. chamber).
  - Prevents over-injection of beam 2 for the moment.



Scraping in the SPS

- Fast (ISR !!) scraper worked for ~ 3 days before it ‘failed’.
  - Scraping towards the end of the ramp.
  - Reason of failure to be understood – apparently HW issue on a motor axis. Access is required for more precise diagnostics.
- Scraping is now done at start of ramp by bumping the beam (orbit correctors) toward the SPS (static) momentum scraper (TIDP).
  - Only for H plane.
  - Must be done at low energy (orbit corr. strength).

  >> So far OK, but may not be sufficient for higher intensity.

Collimation and Passive Protection

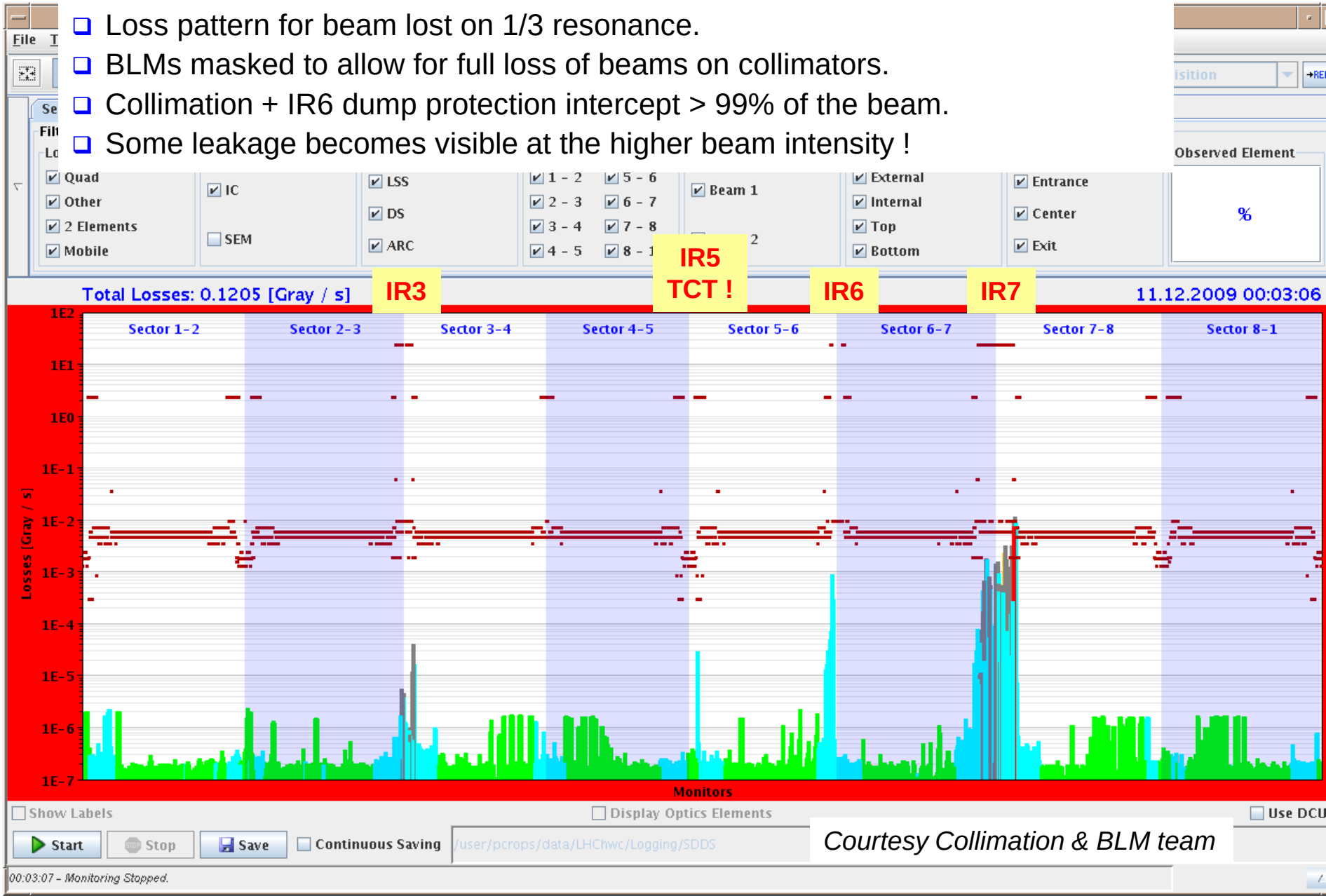
(see also LMC talk by R. Assmann on collimation)

- The LHC collimation system in the cleaning insertions provides highly efficient beam cleaning and passive protection for the LHC beams.
- Validation of the collimation efficiency and protection done by:
  - moving tune over 1/3 order resonance,
  - changing RF frequency (energy error)

  >> Proved to be very powerful !
- Passive protection by collimators and absorbers is tested at the same time! Requirement: all primary beam losses at collimators!
- The tests were fully successful in terms of passive protection (cleaning not discussed here):
  - Leakage at the level of 10^{-4}
    - Losses in cold regions.
    - Losses on tertiary collimator (TCT) in IR5 – not aligned to the beam !!

Global Protection Checks with Beam

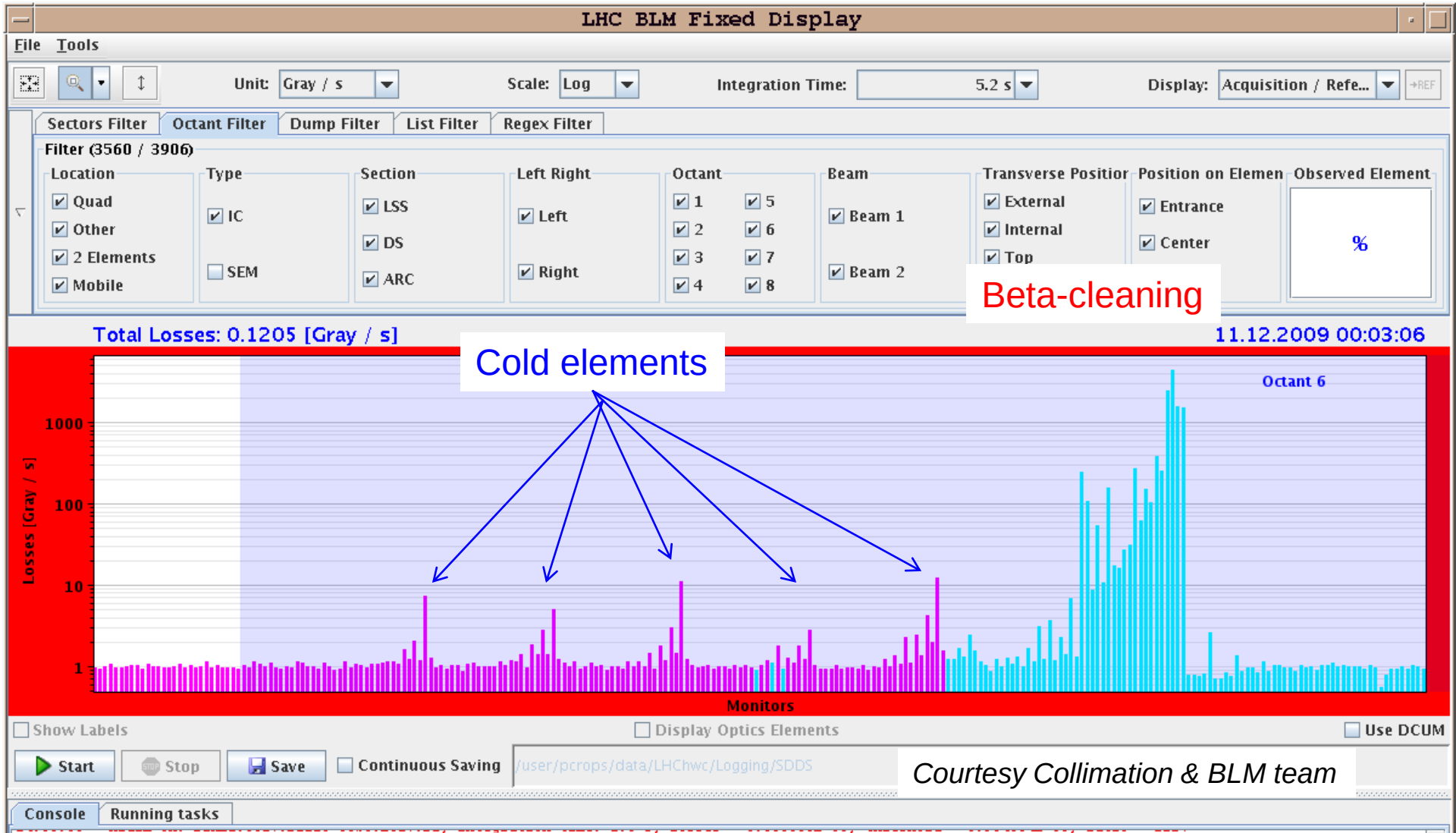
- Loss pattern for beam lost on 1/3 resonance.
- BLMs masked to allow for full loss of beams on collimators.
- Collimation + IR6 dump protection intercept > 99% of the beam.
- Some leakage becomes visible at the higher beam intensity !



Courtesy Collimation & BLM team

Global Protection Checks

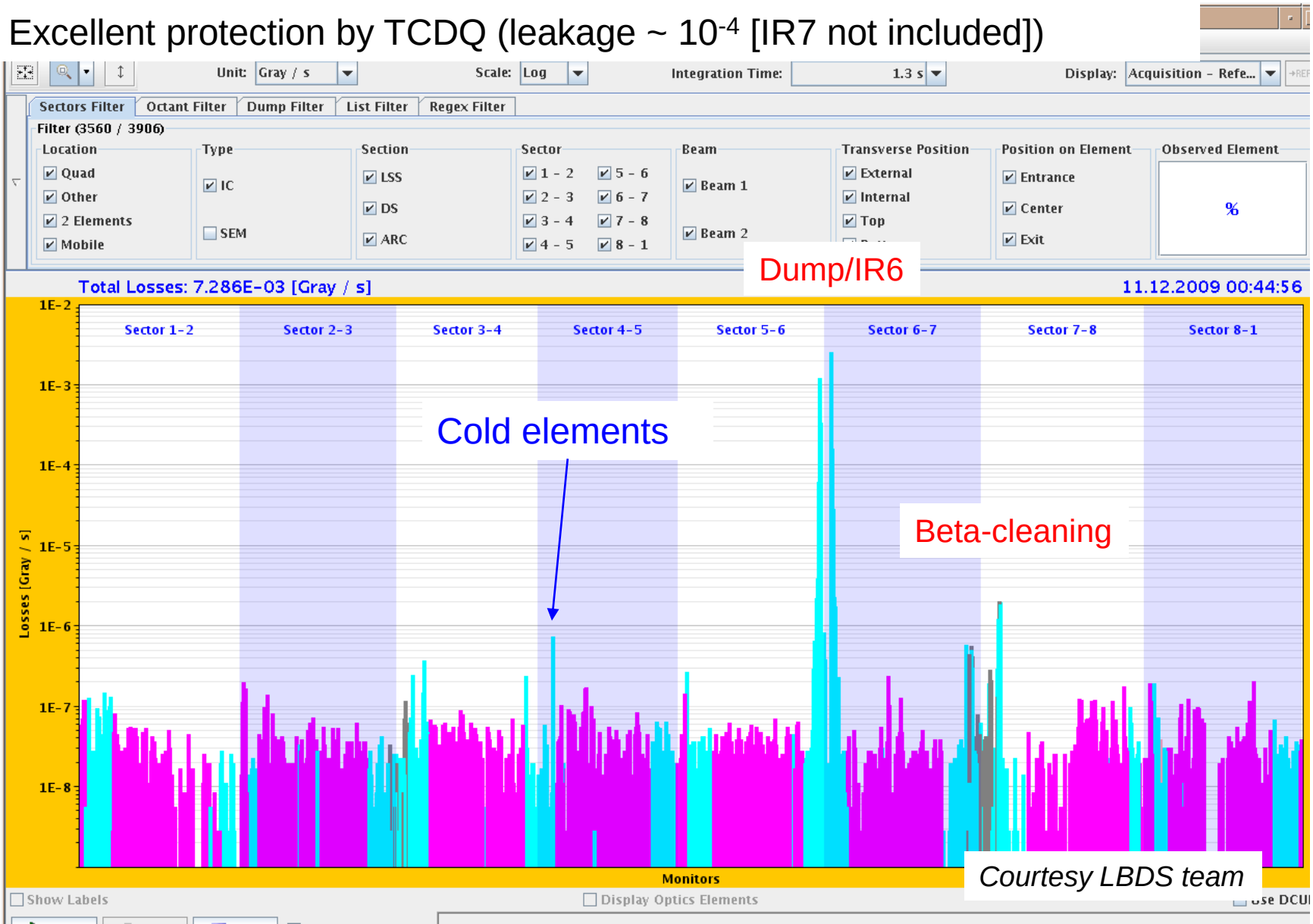
- Loss pattern for beam lost on 1/3 resonance.
- With higher intensity, the leakage into the cold parts of the machine becomes visible !



Courtesy Collimation & BLM team

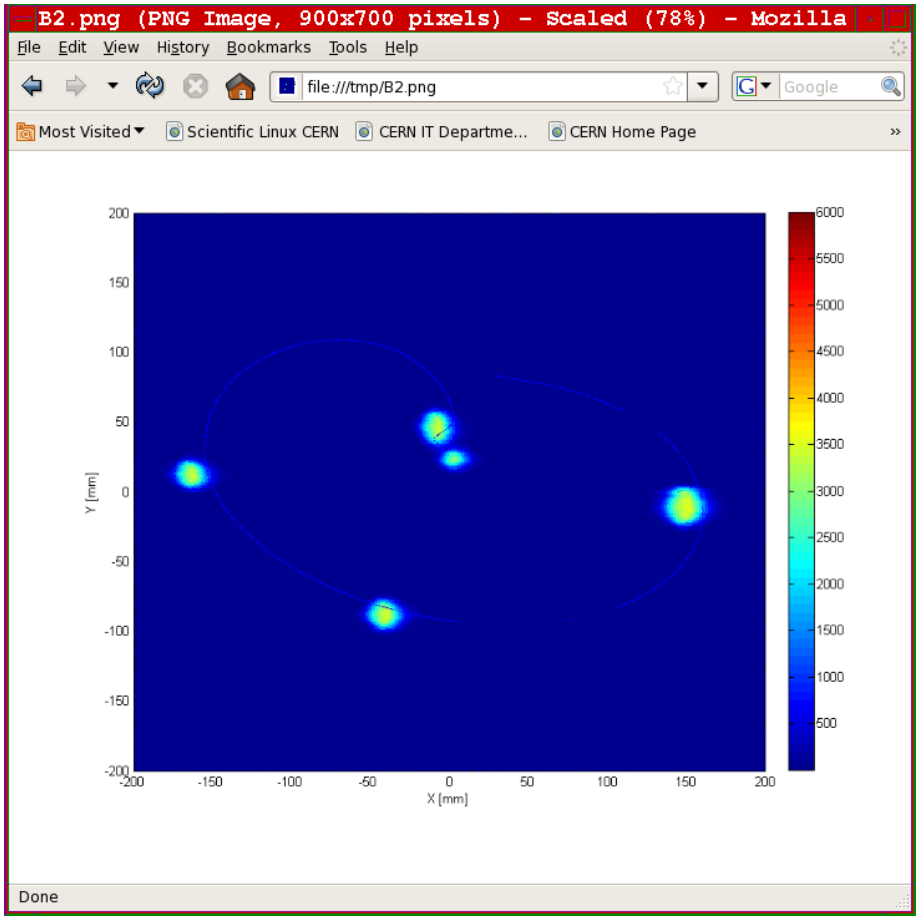
Dump of Debunched Beam

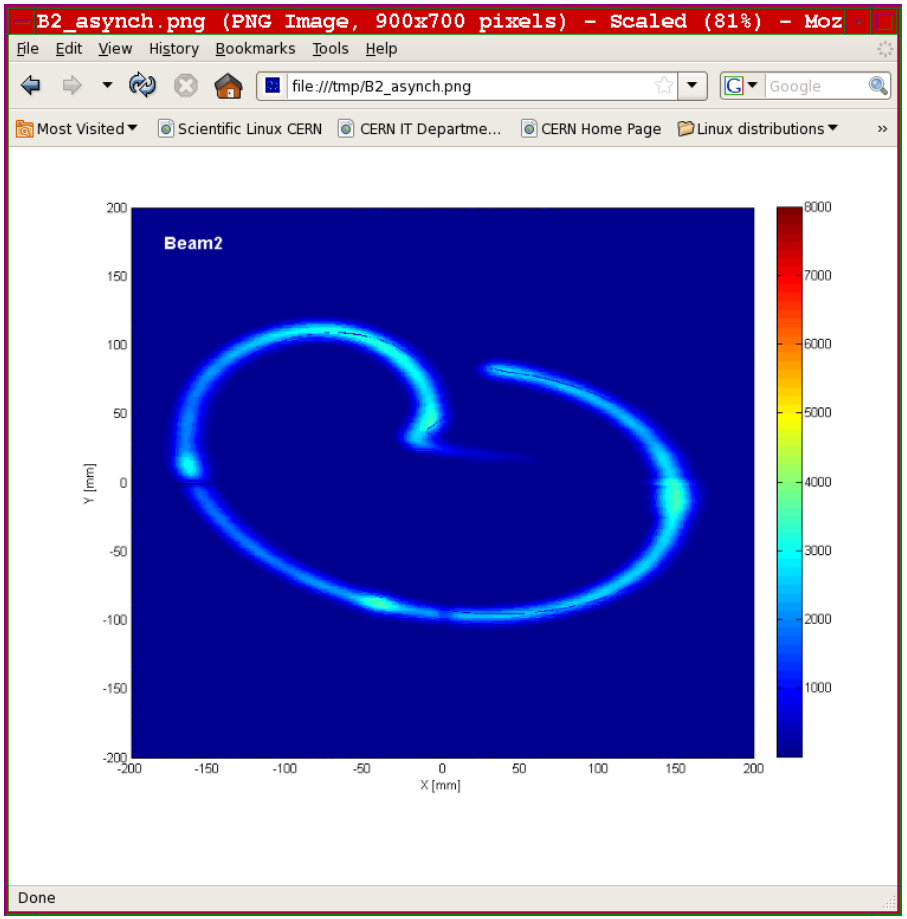
Excellent protection by TCDQ (leakage ~ 10^{-4} [IR7 not included])



Dump of Debunched Beam

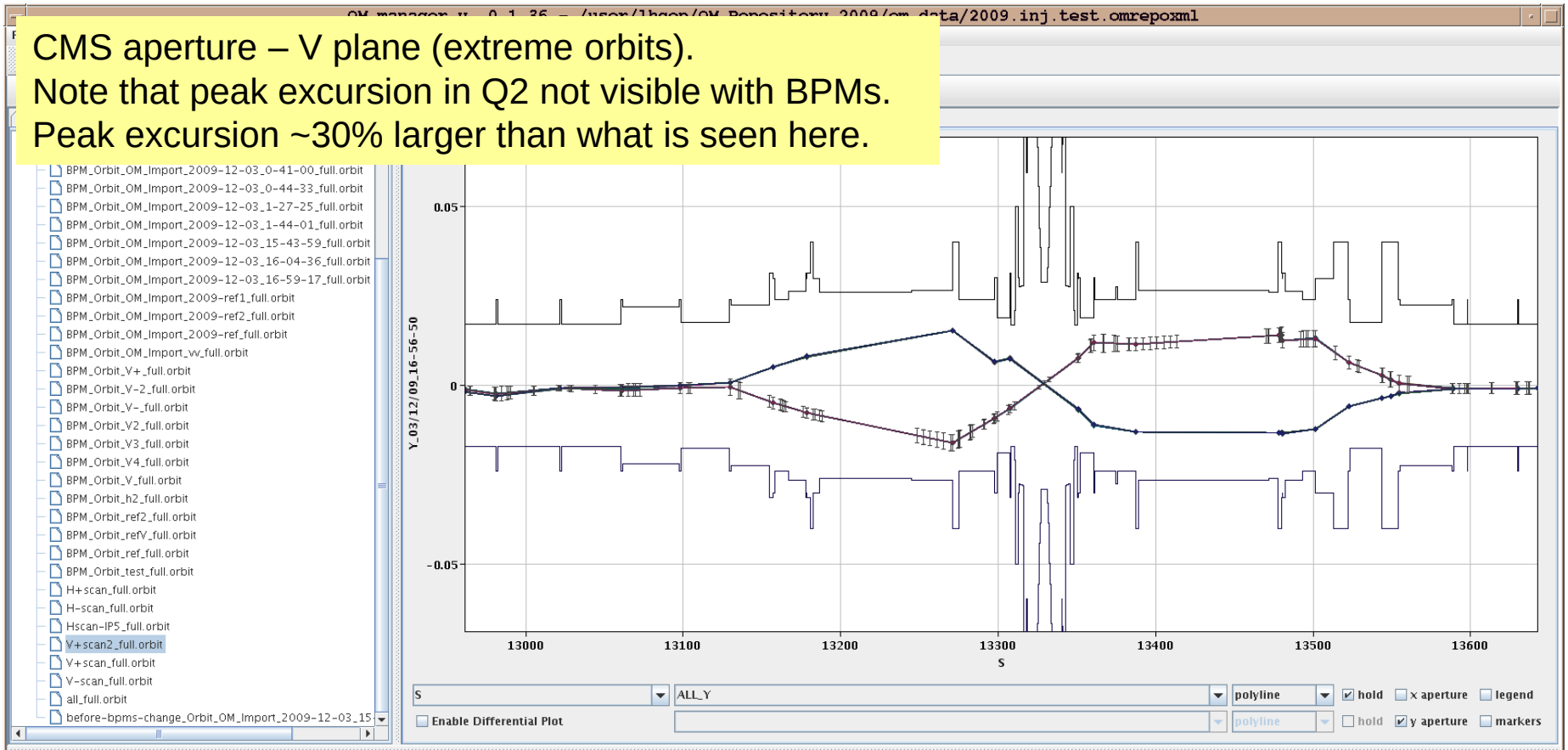
Bunched and debunched beam 2 on the dump BTV (pilot + 4x2e10)





IR Aperture Scans

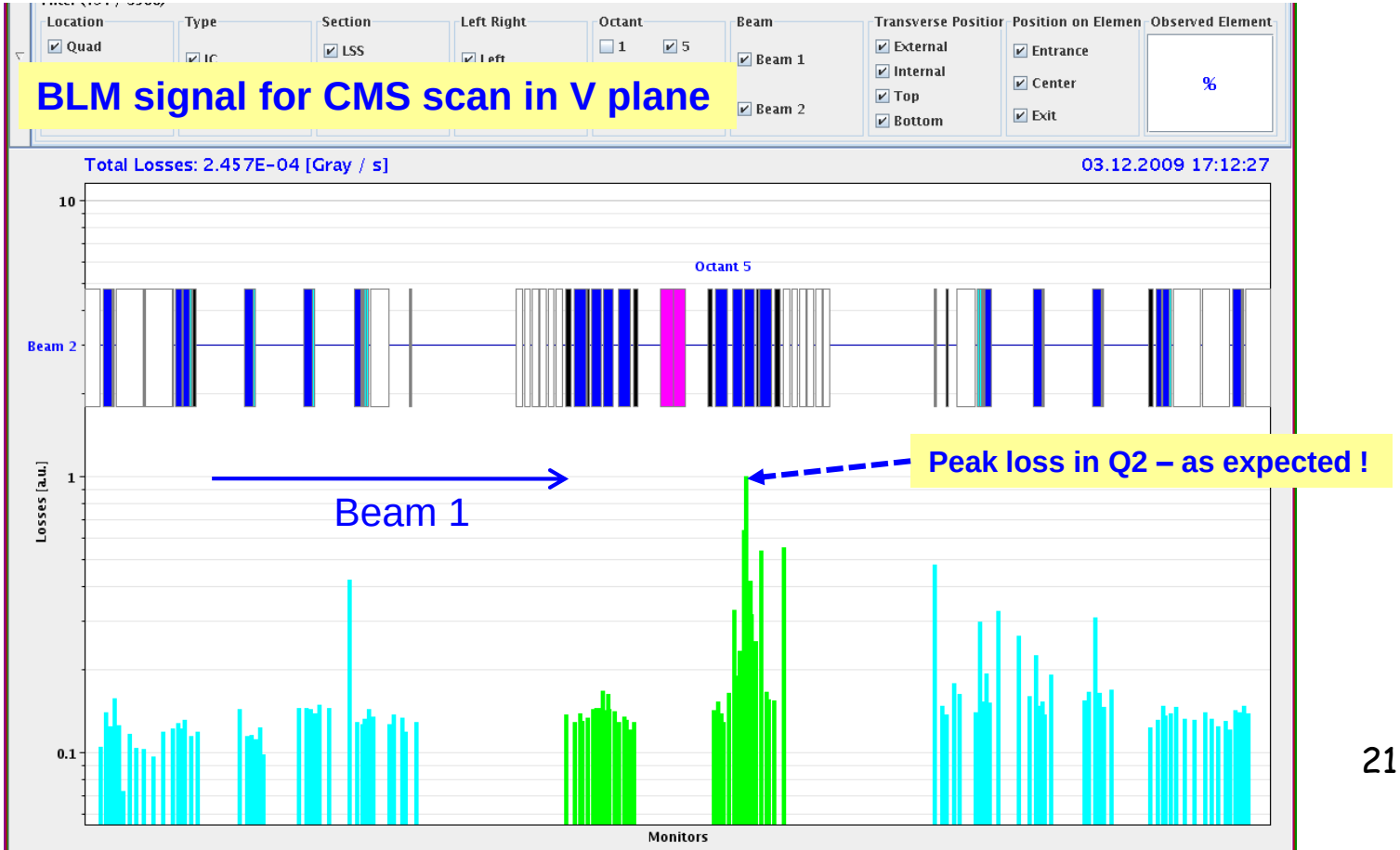
- Aperture scans in all IRs together with experiments:
  - Aperture check.
  - Rough BLM calibration - aimed to produce measurable loss (μGray to ten's of μGray over 1.3 sec) a factor 10 or more above background.
  - BCM sensitivity check.



BLM & BCMs during Aperture Scans

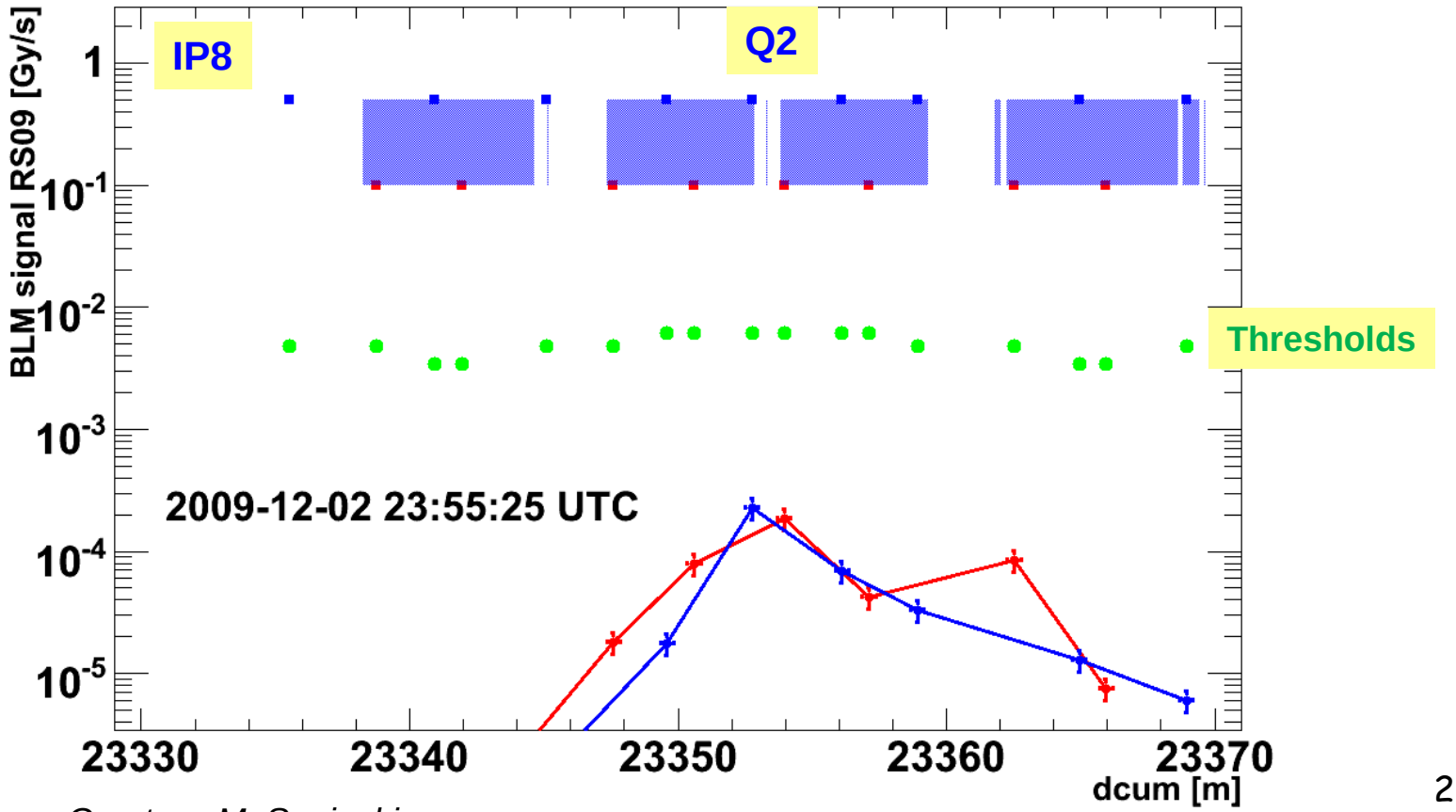
- Scans Ok for CMS, LHCb, ALICE: BCMs reach ~% of dump level – losses of ~10^8 p.
- Issue for ATLAS: beam dump by ATLAS BCM before we could see any measurable signal on BLMs in H plane (V plane OK) – did not reach the aperture !

  >> Probably combination of very low dump threshold (100 lower than other exps – tbc ?) and loss on incoming side. Offline analysis with ATLAS in progress…



BLMs during Aperture Scans

- Loss of ~10^9 p in IR8 triplet (Q2 over ~1 second):
  - BLMs signals at ~ 1/20 of dump threshold → threshold ~ few 10^{10} p ~ OK.



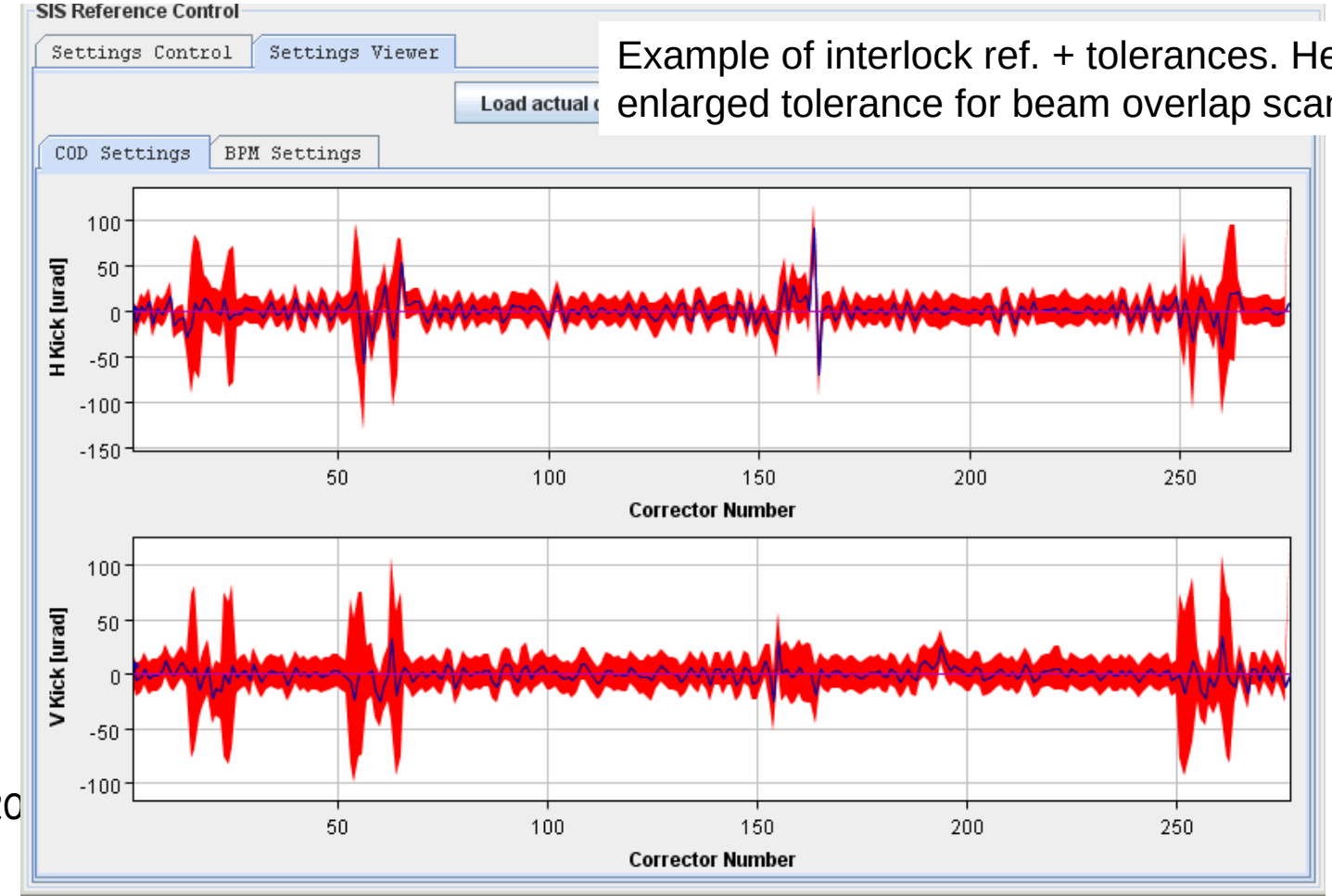
Courtesy M. Sapinski

Software Interlock System (SIS)

- SIS able to inhibit injection or dump beam.
- SIS for injection:
  - Almost fully commissioned (~ 4000 interlocks).
  - Missing : protection against over-injection, RF cryo maintain.
- SIS for dump:
  - Almost fully commissioned.
  - Only active interlock (availability): orbit corrector locking for STABLE BEAMS.

SIS Corrector Interlock

- Deflections of all CODs reconstructed from currents & energy.
- Dump is >= 2 CODs out of tolerance (bump…).
- Note : ignores CODs where PC is OFF.
- Used in all STABLE BEAM periods.

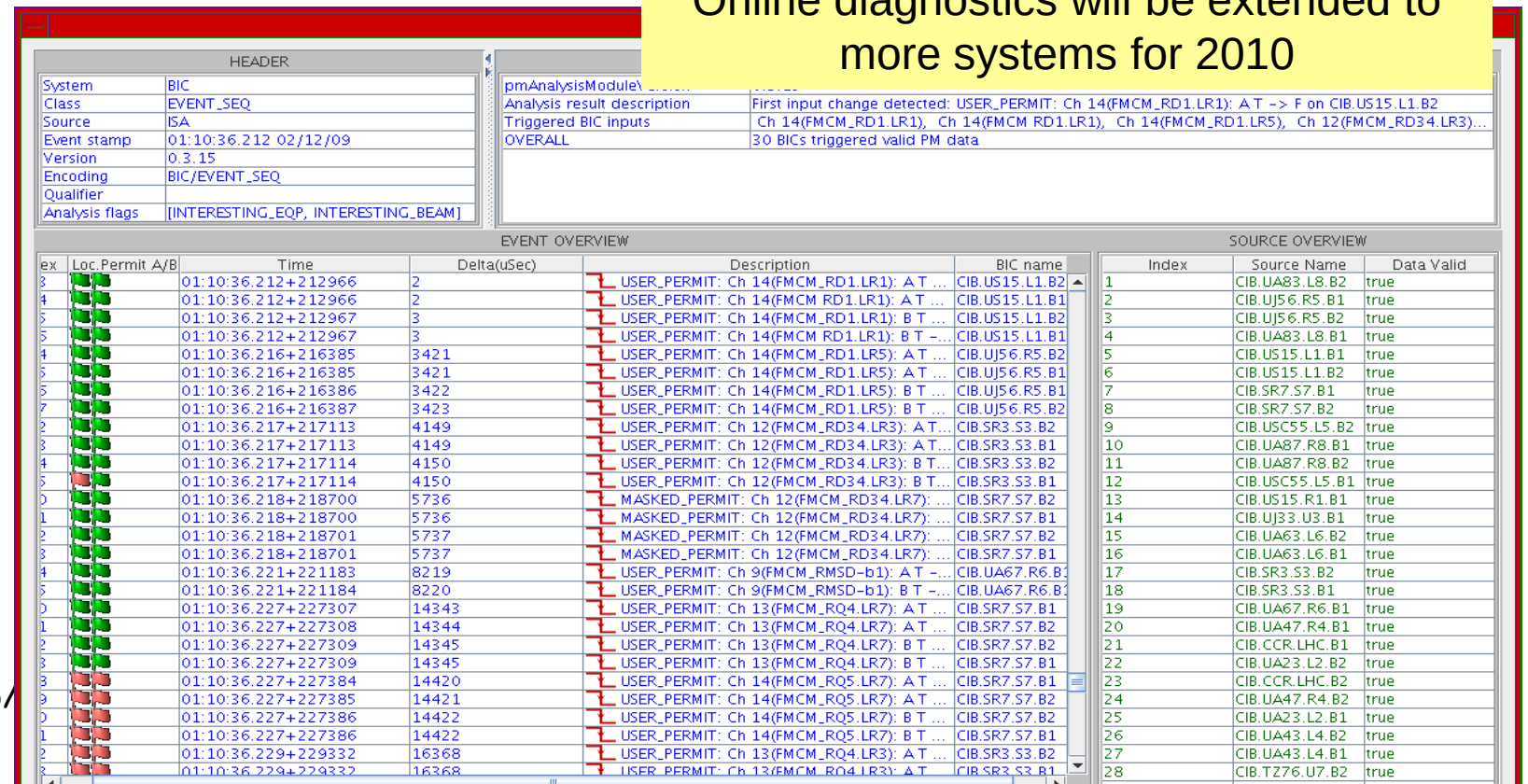


Example of interlock ref. + tolerances. Here with enlarged tolerance for beam overlap scans at IRs.

Post-mortem System

- Dump diagnostics with Post-mortem system is already a routine check in the CCC. The diagnostics is very good for:
  - BIS - who dumped and when
  - BLMs
  - BPMs
  - PIC
  - FMCM

Online diagnostics will be extended to more systems for 2010



HEADER

System	BIC
Class	EVENT_SEQ
Source	ISA
Event stamp	01:10:36.212 02/12/09
Version	0.3.15
Encoding	BIC/EVENT_SEQ
Qualifier	
Analysis flags	[INTERESTING_EQP, INTERESTING_BEAM]

Analysis result description	First input change detected: USER_PERMIT: Ch 14(FMCM_RD1.LR1): A T -> F on CIB.US15.L1.B2
Triggered BIC inputs	Ch 14(FMCM_RD1.LR1), Ch 14(FMCM RD1.LR1), Ch 14(FMCM_RD1.LR5), Ch 12(FMCM_RD34.LR3)...
OVERALL	30 BICs triggered valid PM data

EVENT OVERVIEW

ex	Loc.Permit A/B	Time	Delta(uSec)	Description	BIC name
3		01:10:36.212+212966	2	USER_PERMIT: Ch 14(FMCM_RD1.LR1): A T ...	CIB.US15.L1.B2
4		01:10:36.212+212966	2	USER_PERMIT: Ch 14(FMCM RD1.LR1): A T ...	CIB.US15.L1.B1
5		01:10:36.212+212967	3	USER_PERMIT: Ch 14(FMCM_RD1.LR1): B T ...	CIB.US15.L1.B2
6		01:10:36.212+212967	3	USER_PERMIT: Ch 14(FMCM RD1.LR1): B T -...	CIB.US15.L1.B1
4		01:10:36.216+216385	3421	USER_PERMIT: Ch 14(FMCM_RD1.LR5): A T ...	CIB.UJ56.R5.B2
5		01:10:36.216+216385	3421	USER_PERMIT: Ch 14(FMCM_RD1.LR5): A T ...	CIB.UJ56.R5.B1
5		01:10:36.216+216386	3422	USER_PERMIT: Ch 14(FMCM_RD1.LR5): B T ...	CIB.UJ56.R5.B1
7		01:10:36.216+216387	3423	USER_PERMIT: Ch 14(FMCM_RD1.LR5): B T ...	CIB.UJ56.R5.B2
2		01:10:36.217+217113	4149	USER_PERMIT: Ch 12(FMCM_RD34.LR3): A T...	CIB.SR3.S3.B2
3		01:10:36.217+217113	4149	USER_PERMIT: Ch 12(FMCM_RD34.LR3): A T...	CIB.SR3.S3.B1
4		01:10:36.217+217114	4150	USER_PERMIT: Ch 12(FMCM_RD34.LR3): B T...	CIB.SR3.S3.B2
5		01:10:36.217+217114	4150	USER_PERMIT: Ch 12(FMCM_RD34.LR3): B T...	CIB.SR3.S3.B1
0		01:10:36.218+218700	5736	MASKED_PERMIT: Ch 12(FMCM_RD34.LR7): ...	CIB.SR7.S7.B2
1		01:10:36.218+218700	5736	MASKED_PERMIT: Ch 12(FMCM_RD34.LR7): ...	CIB.SR7.S7.B1
2		01:10:36.218+218701	5737	MASKED_PERMIT: Ch 12(FMCM_RD34.LR7): ...	CIB.SR7.S7.B2
3		01:10:36.218+218701	5737	MASKED_PERMIT: Ch 12(FMCM_RD34.LR7): ...	CIB.SR7.S7.B1
4		01:10:36.221+221183	8219	USER_PERMIT: Ch 9(FMCM_RMSD-b1): A T -...	CIB.UA67.R6.B1
5		01:10:36.221+221184	8220	USER_PERMIT: Ch 9(FMCM_RMSD-b1): B T -...	CIB.UA67.R6.B1
0		01:10:36.227+227307	14343	USER_PERMIT: Ch 13(FMCM_RQ4.LR7): A T ...	CIB.SR7.S7.B1
1		01:10:36.227+227308	14344	USER_PERMIT: Ch 13(FMCM_RQ4.LR7): A T ...	CIB.SR7.S7.B2
2		01:10:36.227+227309	14345	USER_PERMIT: Ch 13(FMCM_RQ4.LR7): B T ...	CIB.SR7.S7.B2
3		01:10:36.227+227309	14345	USER_PERMIT: Ch 13(FMCM_RQ4.LR7): B T ...	CIB.SR7.S7.B1
8		01:10:36.227+227384	14420	USER_PERMIT: Ch 14(FMCM_RQ5.LR7): A T ...	CIB.SR7.S7.B1
9		01:10:36.227+227385	14421	USER_PERMIT: Ch 14(FMCM_RQ5.LR7): A T ...	CIB.SR7.S7.B2
0		01:10:36.227+227386	14422	USER_PERMIT: Ch 14(FMCM_RQ5.LR7): B T ...	CIB.SR7.S7.B2
1		01:10:36.227+227386	14422	USER_PERMIT: Ch 14(FMCM_RQ5.LR7): B T ...	CIB.SR7.S7.B1
2		01:10:36.229+229332	16368	USER_PERMIT: Ch 13(FMCM_RQ4.LR3): A T ...	CIB.SR3.S3.B2
3		01:10:36.229+229332	16368	USER_PERMIT: Ch 13(FMCM_RQ4.LR3): A T ...	CIB.SR3.S3.B1

SOURCE OVERVIEW

Index	Source Name	Data Valid
1	CIB.UA83.L8.B2	true
2	CIB.UJ56.R5.B1	true
3	CIB.UJ56.R5.B2	true
4	CIB.UA83.L8.B1	true
5	CIB.US15.L1.B1	true
6	CIB.US15.L1.B2	true
7	CIB.SR7.S7.B1	true
8	CIB.SR7.S7.B2	true
9	CIB.USC55.L5.B2	true
10	CIB.UA87.R8.B1	true
11	CIB.UA87.R8.B2	true
12	CIB.USC55.L5.B1	true
13	CIB.US15.R1.B1	true
14	CIB.UJ33.U3.B1	true
15	CIB.UA63.L6.B2	true
16	CIB.UA63.L6.B1	true
17	CIB.SR3.S3.B2	true
18	CIB.SR3.S3.B1	true
19	CIB.UA67.R6.B1	true
20	CIB.UA47.R4.B1	true
21	CIB.CCR.LHC.B1	true
22	CIB.UA23.L2.B2	true
23	CIB.CCR.LHC.B2	true
24	CIB.UA47.R4.B2	true
25	CIB.UA23.L2.B1	true
26	CIB.UA43.L4.B2	true
27	CIB.UA43.L4.B1	true
28	CIB.TZ76.U7.B2	true

Post-mortem Analysis

- MPP team is now looking at all dumps.
  - Majority is well understood and shows no anomalies
  - Few isolated cases are not understood, for example:
    - Beam lost over few turns at injection during MPS setup for 2e10p / bunch.
    - Two consecutive events, but rather different signature.
    - In both cases losses on TCT in IR1, ATLAS dump.

>> highlights the importance of only injecting low intensity into empty ring !!

- For next year.
  - Database of dumps with main characteristics.
  - Offline analysis team for un-explained events (starting…).

General Remarks

- Fast progress in beam commissioning:
  - MPS quickly becomes a bottleneck – strong pressure to commission as fast as possible.
  - Mixing of beam commissioning and STABLE BEAMS at same energy raises protection issues (procedure to switch from one mode to another…). This is made even worse by the fact that sequences are not well established, change rapidly…

  >> OK for this year – could be major issue when beams become unsafe !
- If the excellent state of the machine at 1.18 TeV reproduces at 3.5 TeV, MPS setup is likely to dictate progress in 2010.
  - 'Quiet beams' period should not become a standard OP mode!

  >> Give time for MPS setup to establish low intensity collisions (~ 4 pilot style) in STABLE BEAMS asap to avoid 'Quiet beams'.

  Then run at fixed intensity until MPS qualifies for more beam…

Summary

- No major problems in the MPS commissioning – some issues to be investigated & fixed for 2010.

  The system is already very safe – but the intensity is also very low.

- As expected MPS requires a lion's share of beam time in the early phases, in particular because the machine works well.
- So far we are working with ~1 permill of nominal beam, but things will rapidly change next year when beams will become unsafe. Besides completing the tests we need:
  - Well defined OP sequences for CCC.
  - More post-operational checks for critical systems – port-mortem acknowledge, BIS, LBDS, BLM tests… some of this is active or ready to go.
- We will re-evaluate 'quiet beam' – preference in MPP to go quickly to a safe low intensity OP rather than 'abusing' of quiet beams.