BEAM LOSS IN THE LHC AND ITS INJECTOR

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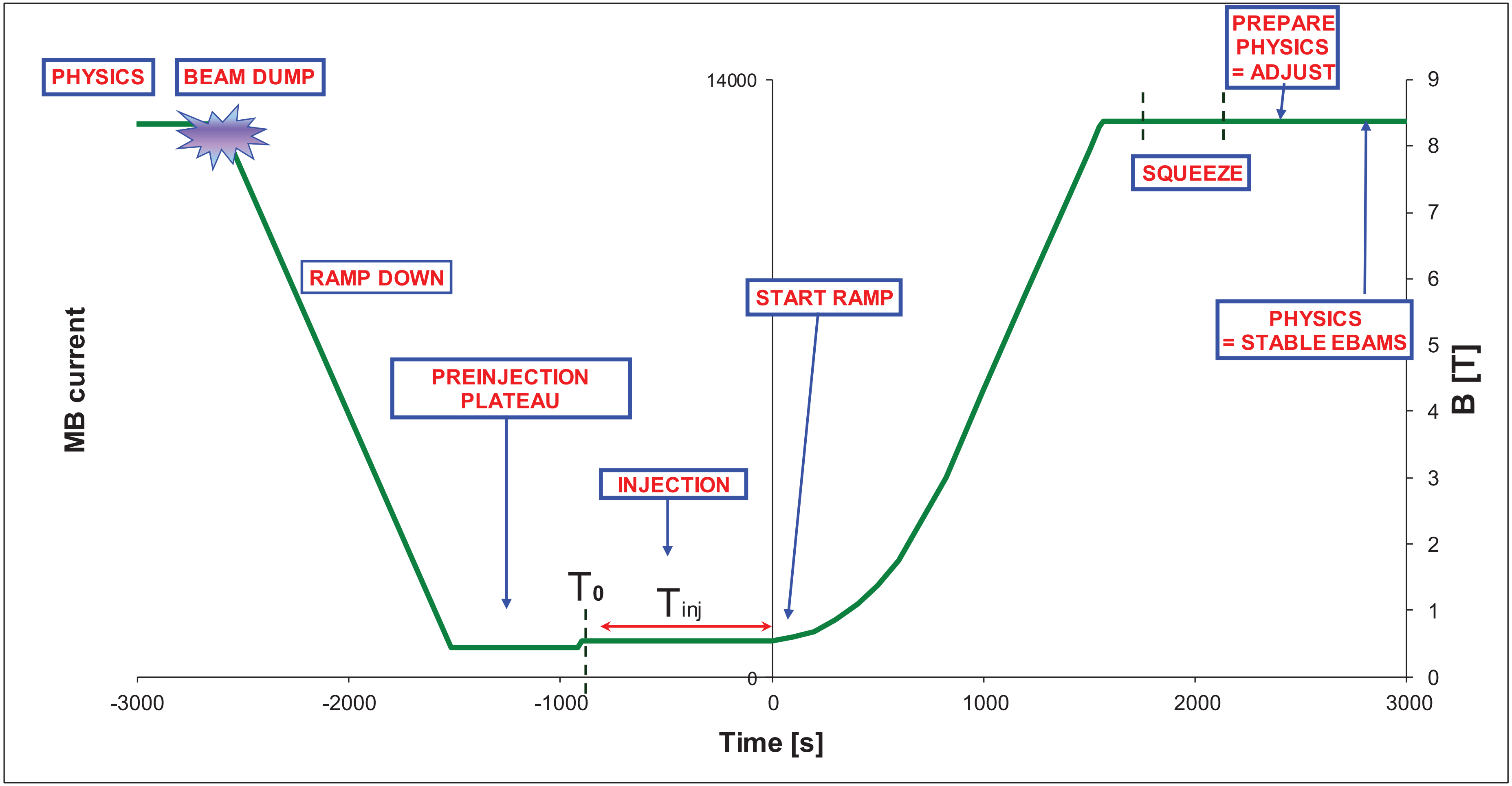
CERN, LHC Beam Operation

Acknowledgements: J. Wenninger, T. Baer, W. Bartmann, C. Bracco, M. Pojer, L. Drosdal, Karel Cornelis, V. Kain and OP

LHC hypercycle

➢ Nominal LHC hypercycle divided in phases (= beam processes) between 15 and 30 min (45 min for ramp down)

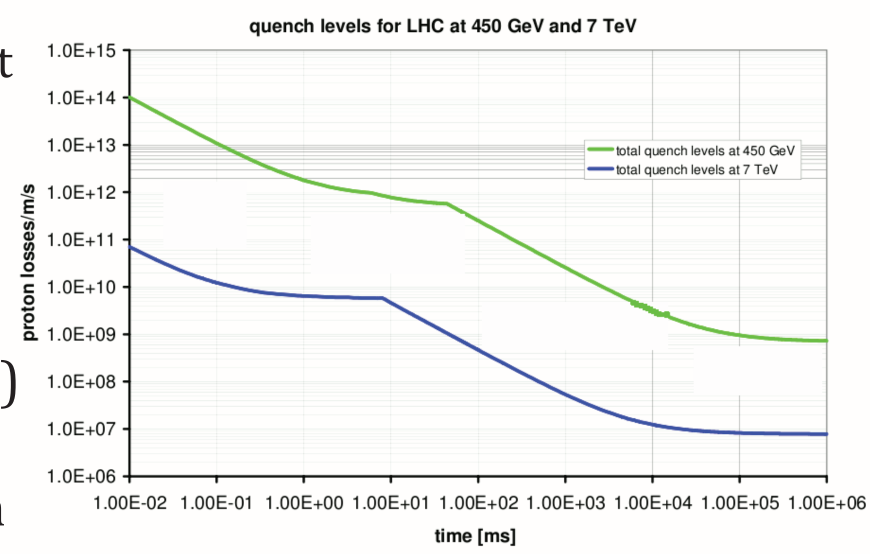


Outlines

- Losses at injection
  - Injection region layout
  - Standard injection losses
  - Injection failure examples
- Losses along the cycle
  - Typical loss pattern during ramp
  - Orbit excursion during the squeeze
  - instabilities
- Losses when in collisions
  - Luminosity fragment
  - UFOs
- *Losses due to abort gap population*

LHC BLM system

- Some 4000 BLMs : 3600 IC and 400 SEM for higher loss intensities
- Part of Machine Protection:
  - The only system to protect LHC from fast losses and to prevent quench
  - **All BLMs are interlocked** and send a beam dump request via the BIS if signal over threshold or one of the tests failed

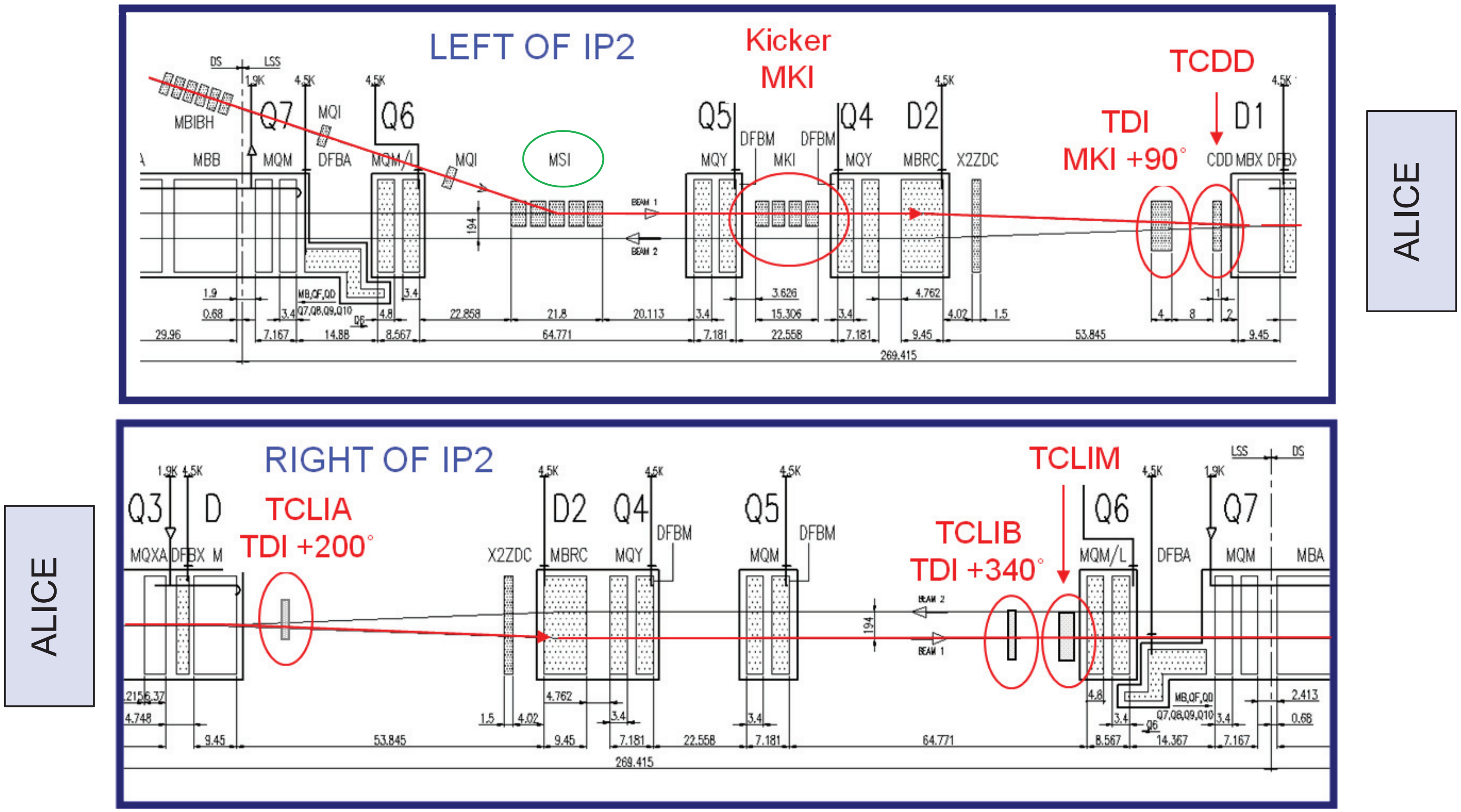


- 12 time windows (from 40 us to 83.88 s) and 32 different energy levels to cover the different loss duration and the beam energy => ~1’500’000 thresholds values
- Initial thresholds settings derived from particle shower and BLM response simulations.
- Several modifications (i.e increase) based on beam operation experience

BLM fixed display

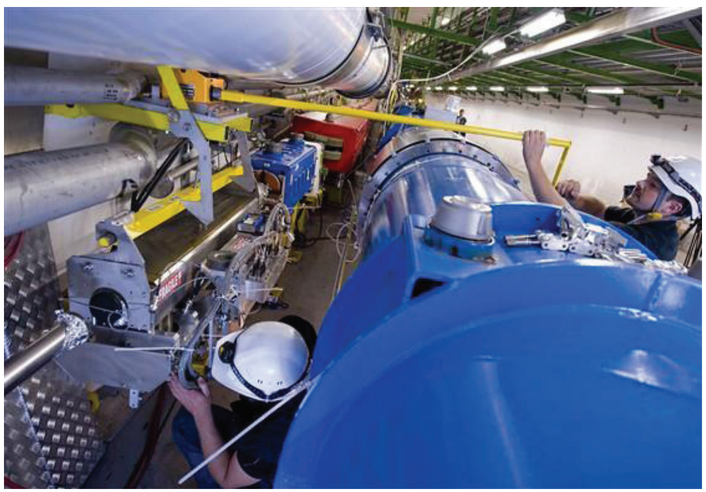
LHC injection layout

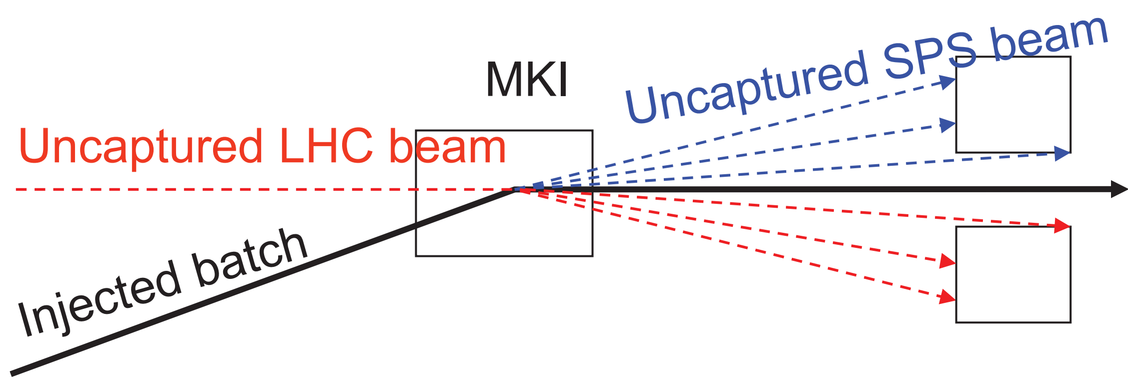
- LHC injection: horizontal injection septum MSI (12 mrad), vertical injection kicker MKI (0.85 mrad); vertically off-centre through the LHC quadrupole (Q5)
- Protection against kicker failures: TDI + TCLIs
- Experiment detector in the middle: ALICE or LHCb



Injection losses : regular losses

Loss reason	where
1) Transfer line collimators (TCDIs) cutting transverse beam tails	loss shower on cold elements: Q6,Q7,Q8, MSI
2) Uncaptured beam LHC	TDI lower jaw, showers on equipment downstream (TCTVB, MQX, MBX, TCLI)
3) Satellites, uncaptured beam from SPS	TDI upper jaw, showers on equipment downstream (TCTVB, MQX, MBX)





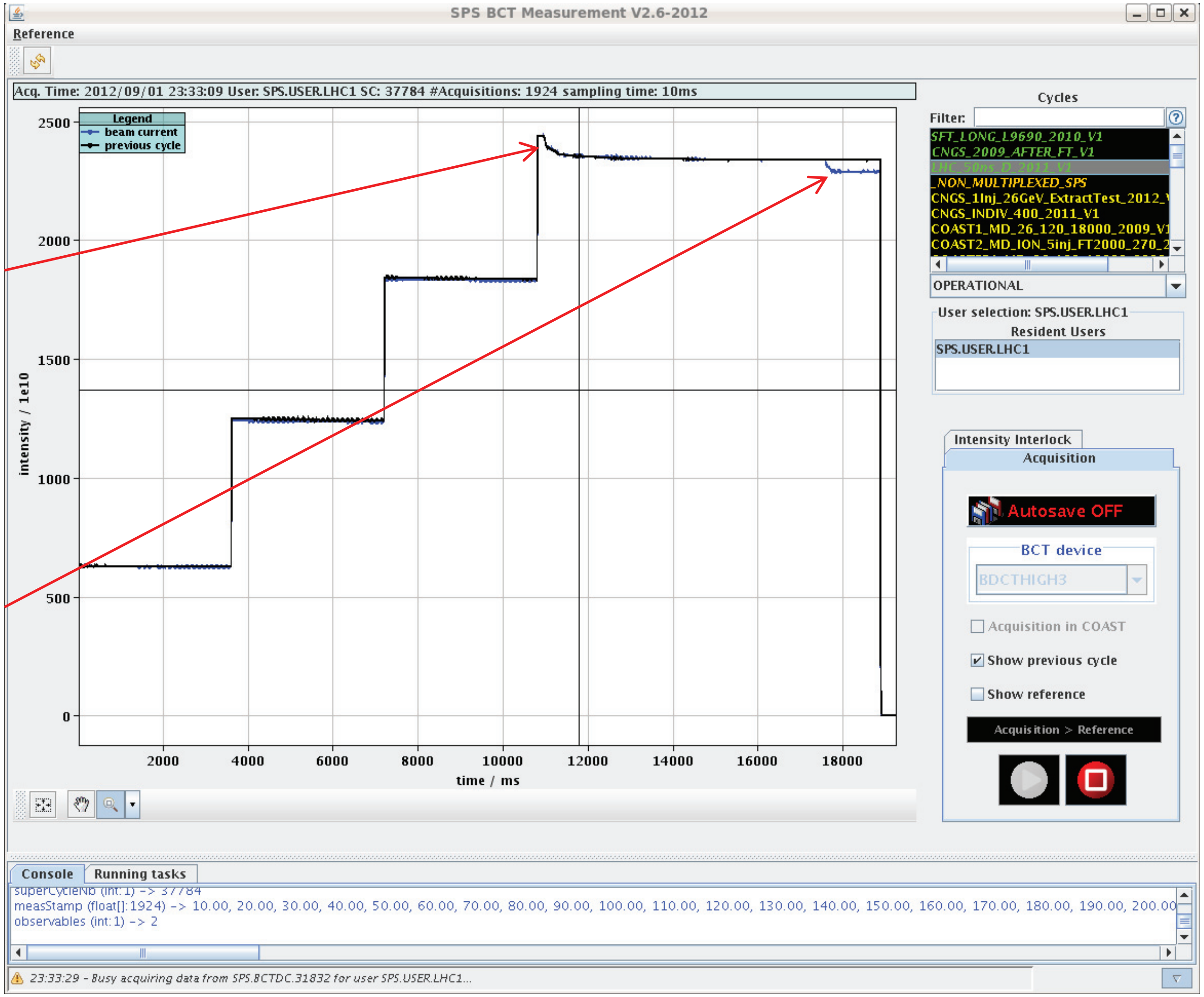
➢ Transfer line collimators partly close to superconducting magnets.
➢ LHC BLM trigger with TCDI shower from the outside.

➢ Circulating uncaptured beam is kicked out onto the lower jaw of the TDI each injection.
➢ TDI showers reach LHC BLMs on TCTVB, triplets,… from the outside – and experiments' beam condition monitors

Losses in SPS cycle

Two types of losses:

- Capture losses at start of acceleration (beam is lost on momentum scraper) (4%)
- Tail scraping before extraction. Beam lost on dump bloc in injection region.(3%)

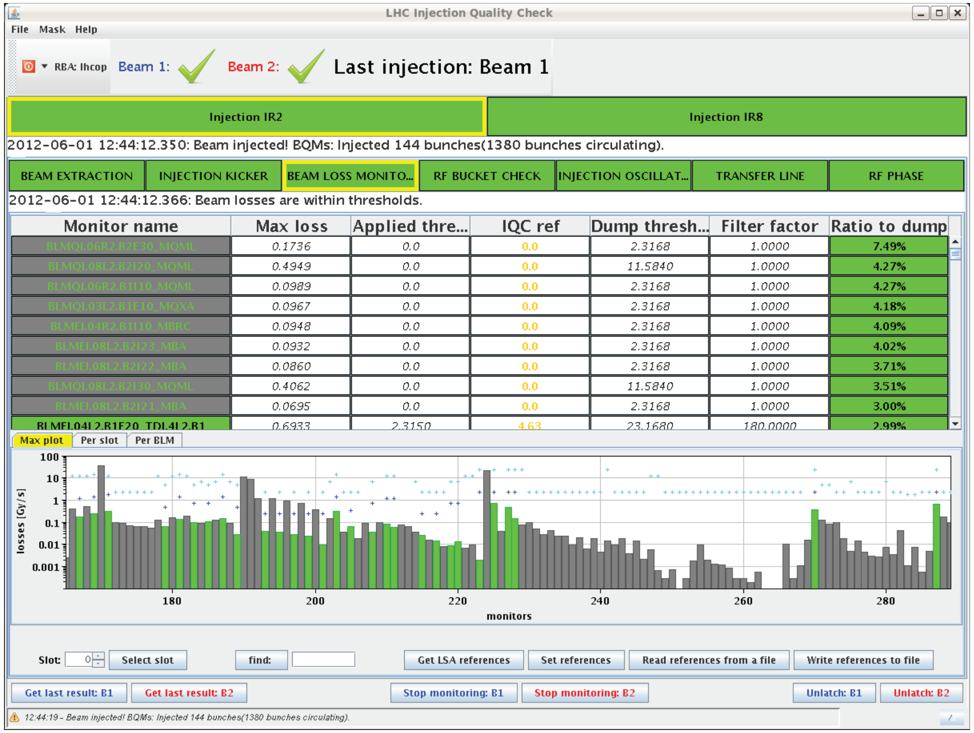


Courtesy K. Cornelis

Injection Losses and Intensity Limitations

- Based on extrapolation from 2010 performances, mitigations techniques needed
- Transfer Lines showers:
  - Local shielding between TCDIs and LHC
  - Beam scraping (transverse) in SPS
- Uncaptured beam
  - Local shielding at TDI
  - Minimization of capture losses
  - Injection and abort gap cleaning

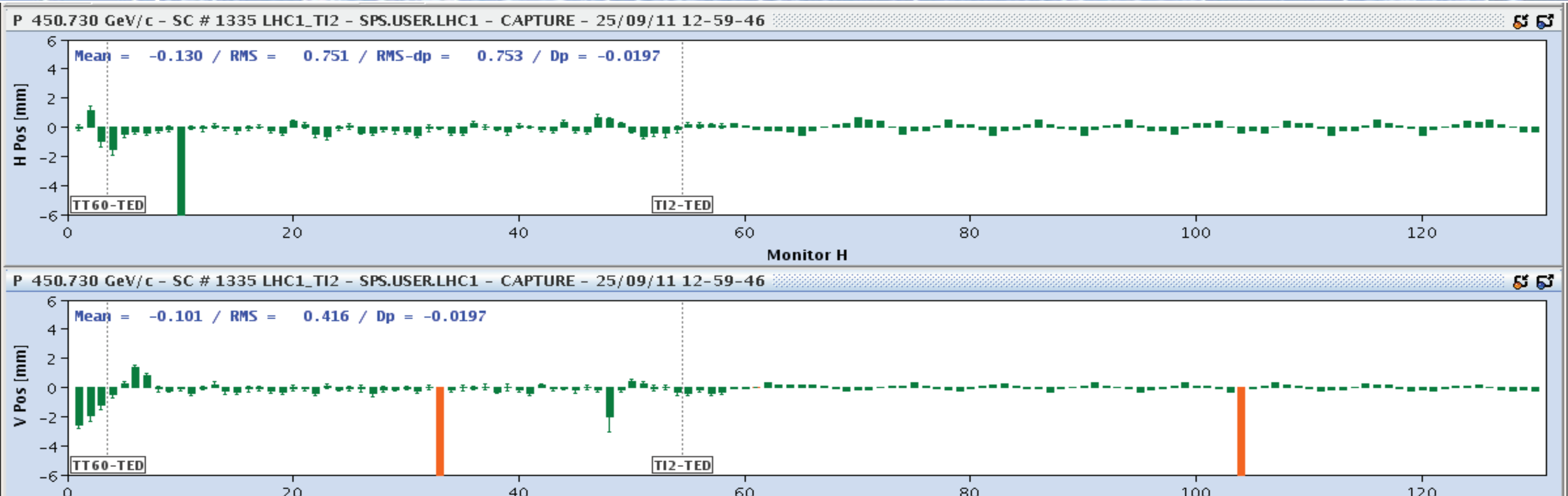
Loss type	Losses in % of dump threshold B1/B2				
	8b	16b	24b	32b	48b
TCDI shower	1/2	3/5	4/6	5/8	23/24
Uncaptured beam	4/2	12/3	12/5	16/8	20/8



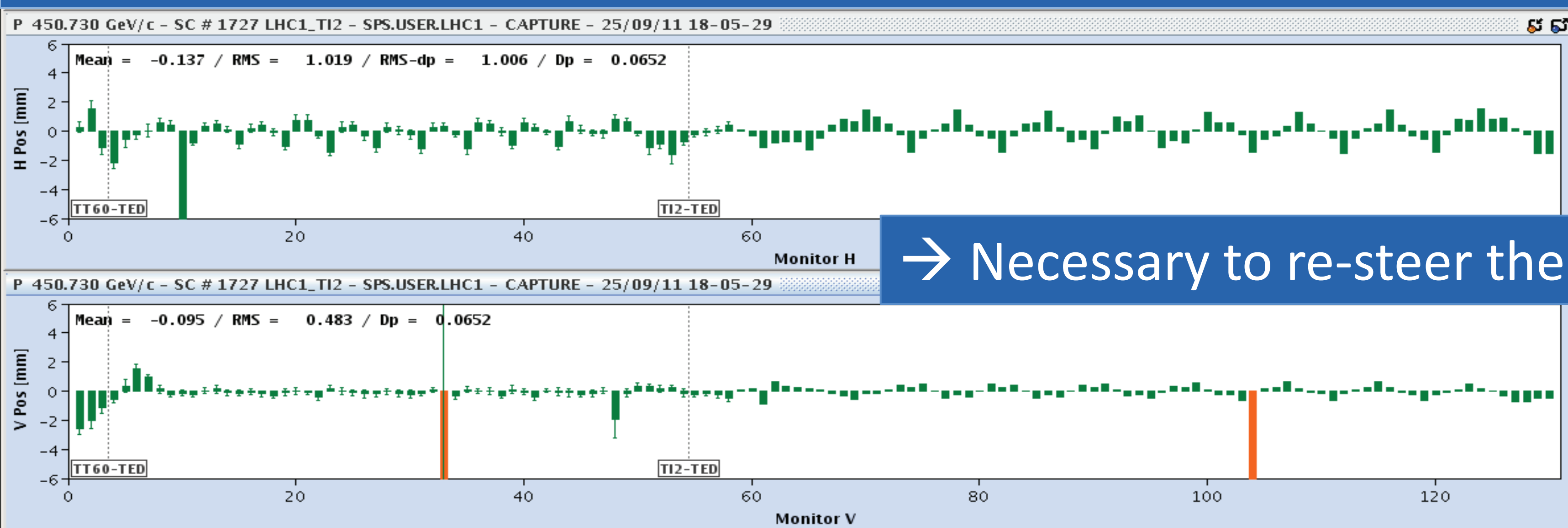
- In 2012, clean injections :
  - 144 bunches (~1.5e11 protons per bunch, ~2 um emittance) in normal operation (< 10% of dump threshold)
  - 288 bunches (1.05e11, 2.5-2.7 um) injected with 30 % of dump threshold during MD

Courtesy C. Bracco

TL stability problem



5 h later – same super cycle composition → Trajectory has changed



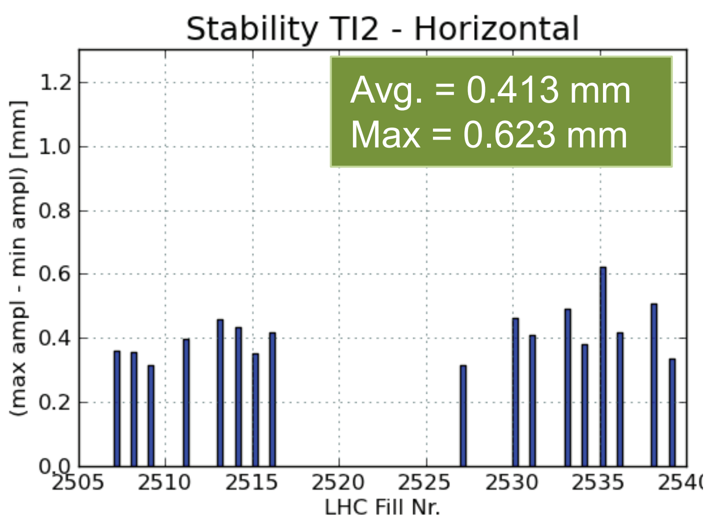
→ Necessary to re-steer the line

2012 stability

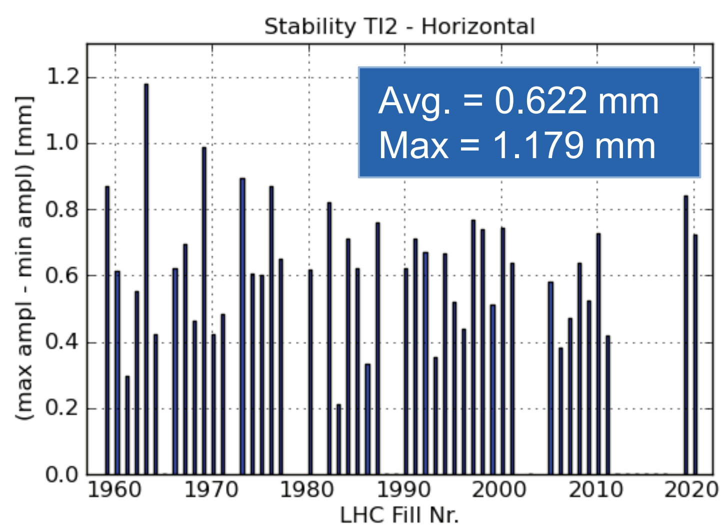
- Along 2011, study on to point out sources of instabilities
  - Shot by shot variations up to 760 um(H plane, both lines) : MSE power converter ripple
  - Bunch by bunch variation up to 1 mm peak difference (Beam 2 H plane)MKE
- power converter ripple of TI2 MSE reduced to half : Horizontal injection oscillation variations in TI2 reduced
- + relaxed collimators settings

TI 2

2012



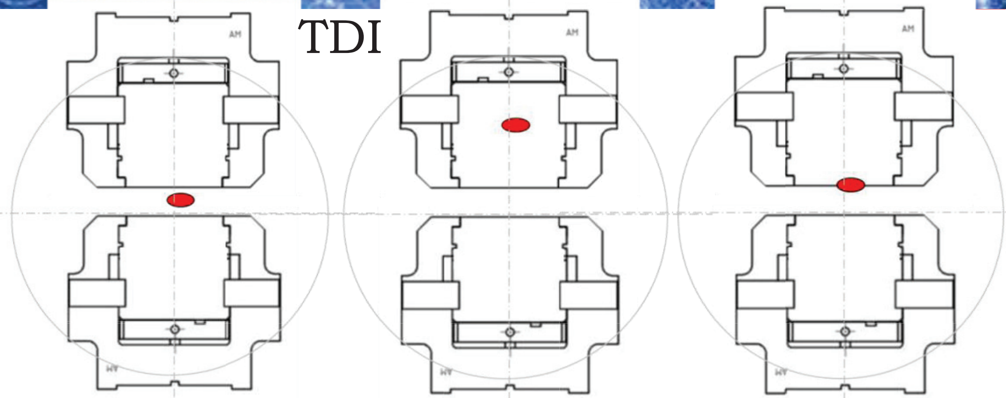
2011



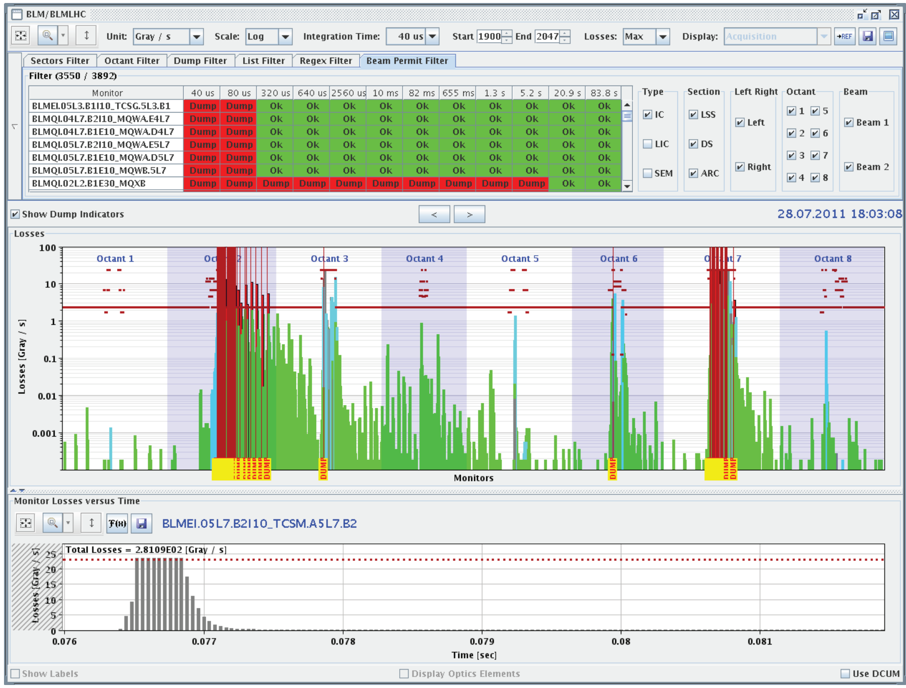
Courtesy of L. Drosdal

Injection failure

- Different types of failure:
  1. Injected beam not kicked
  2. Circulating beam hit
  3. Injected beam partly kicked

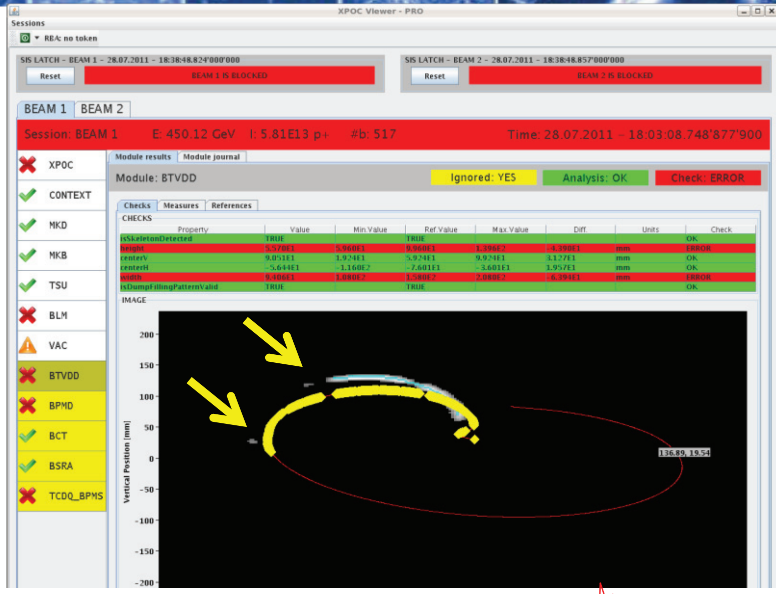


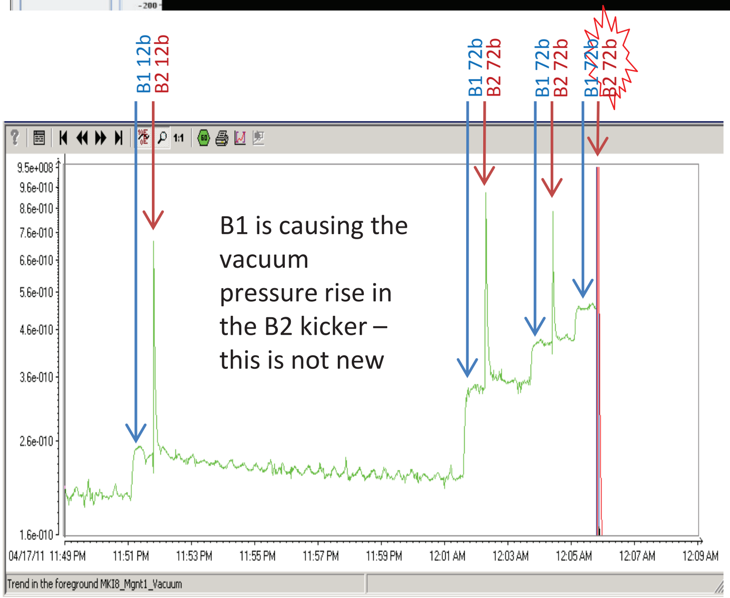
- Jul 28: erratic on the MKI
  - Erratic on the main switch detected by interlocks -> discharge
  - But too late to inhibit extraction
  - 144 bunches dumped on TDI in point 2
  - Circulating beam was not hit
  - Heavy losses in IR2, but NO quench



Injection failure

- July 28: second erratic on the MKI
  - During charging process, not detected by interlocks
  - Circulating beam swept over aperture (17% of normal kick)
  - 173 bunches missing in dump --> on TDI
  - Some grazing bunches quenched 3 magnets and hit ALICE (permanent damage)
  - Important leakage to S23 (but no quench)
- April 28: flashover in the MKI
  - Injection of 2 × 36 bunches spaced by 2.2 μs
  - Breakdown after ~2 μs ➔ All 36b of 2nd batch were kicked with 110-125% nominal MKI deflection
  - Beam was on LOWER TDI jaw and over-kicked, i.e. breakdown in second half of magnet (LHCb signals support this)
  - Nearly all p+ of the 36b impacted on the TDI/TCLIB (grazing) -> 11 magnets quenched

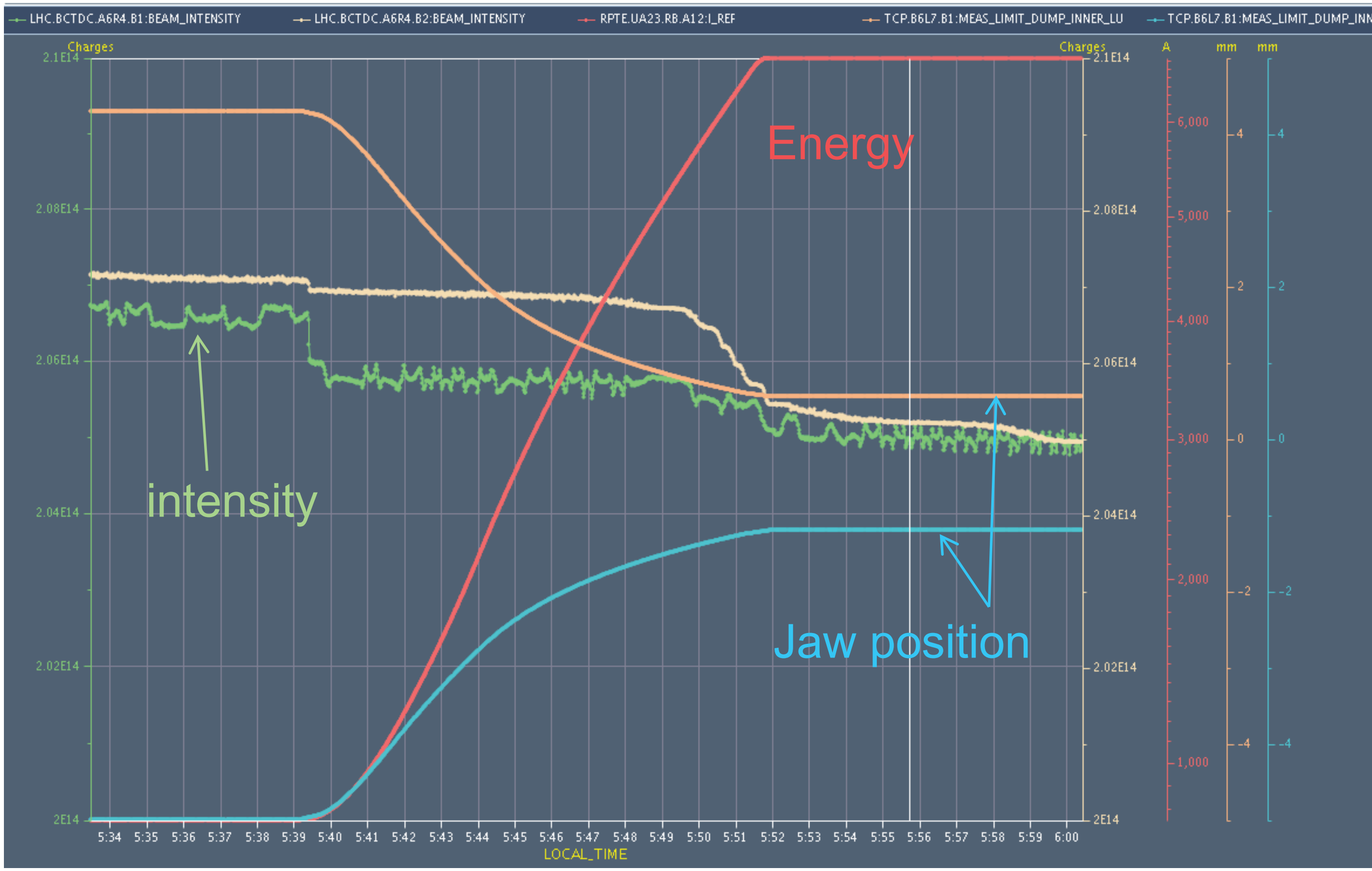




Losses during the ramp

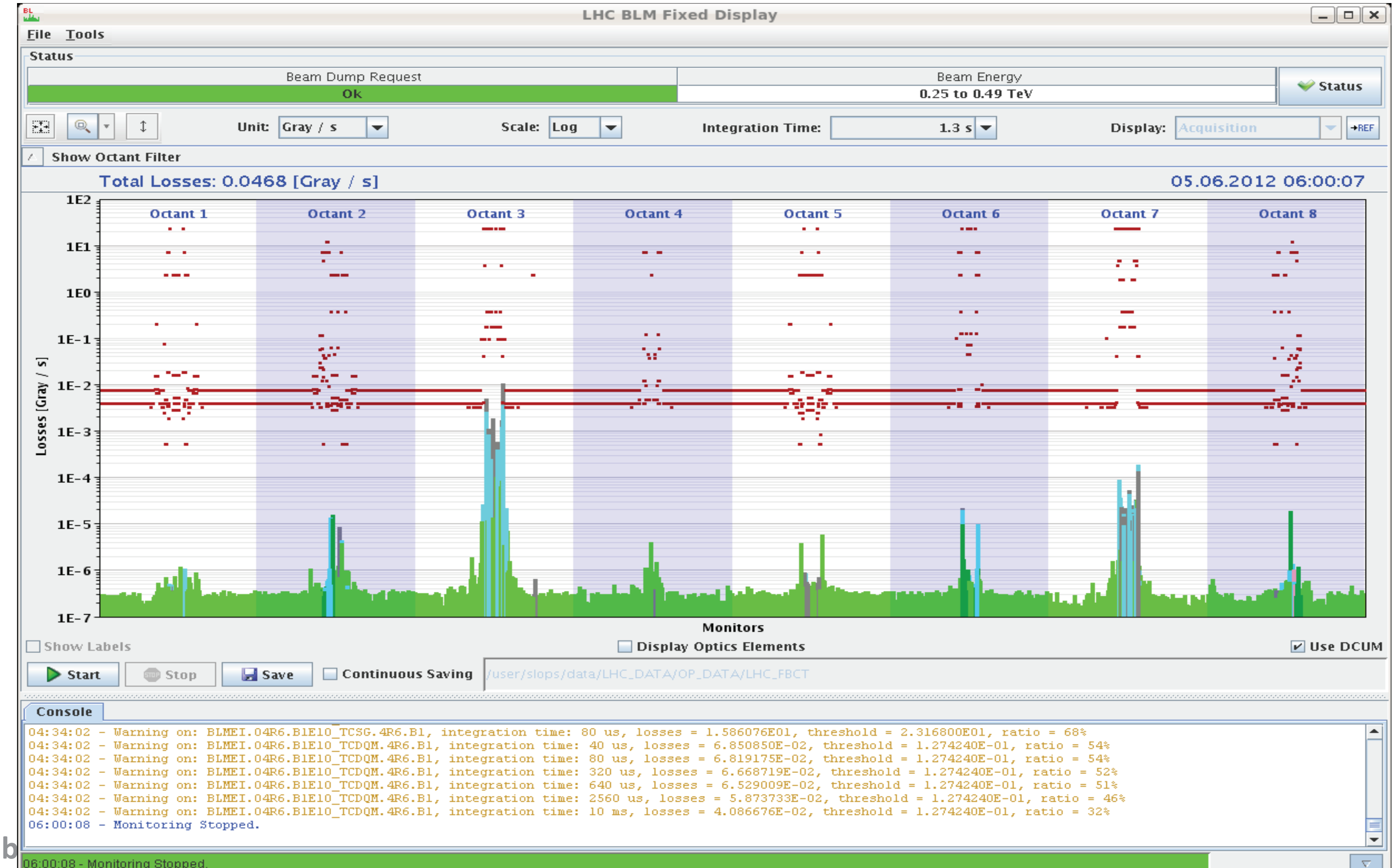
- Uncaptured beam lost at the beginning of the ramp
- Losses at the end of the ramp when tight collimators settings are put in

Transmission ~ 98%



Losses start of ramp

- Losses in momentum collimation region : up to ~50 % of dump threshold
- For intensity increase, BLM thresholds adapted in IR3



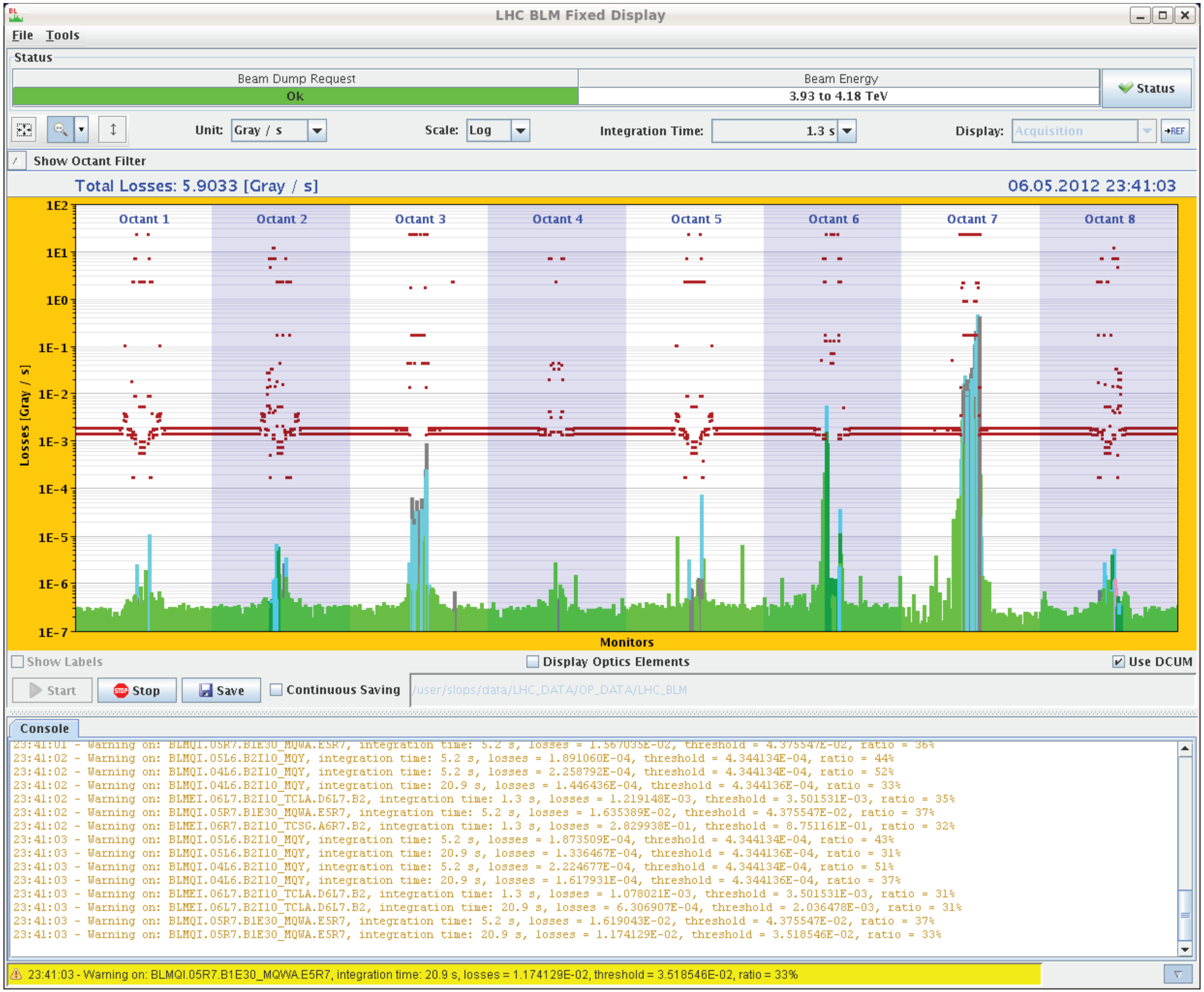
Losses during the squeeze

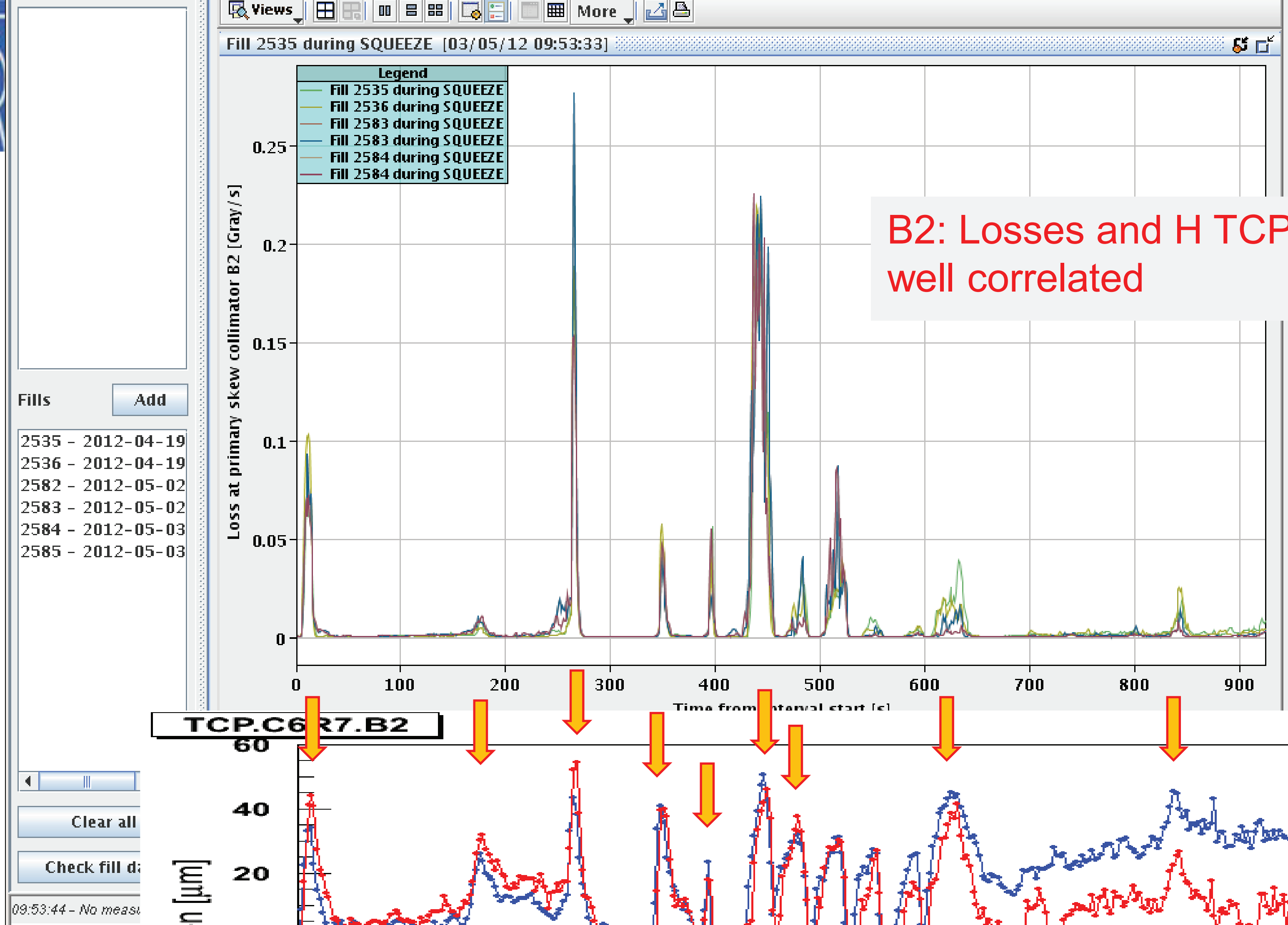
- Several fills dumped during the intensity ramp up in the squeeze with tight collimators settings.
- Observations from orbit correction indicate:
  - Orbit shift of 50 um at primary collimators → > 30% of BPM dump threshold.
  - Orbit shift of 100 um at primary collimators → high risk of beam dump by BLMs.
  - For losses on time scales of few seconds.
  - Corresponds to 5-10% of collimator ½ gaps.

- Together with the increased tail population the orbit excursions were pushing the losses towards/above threshold.

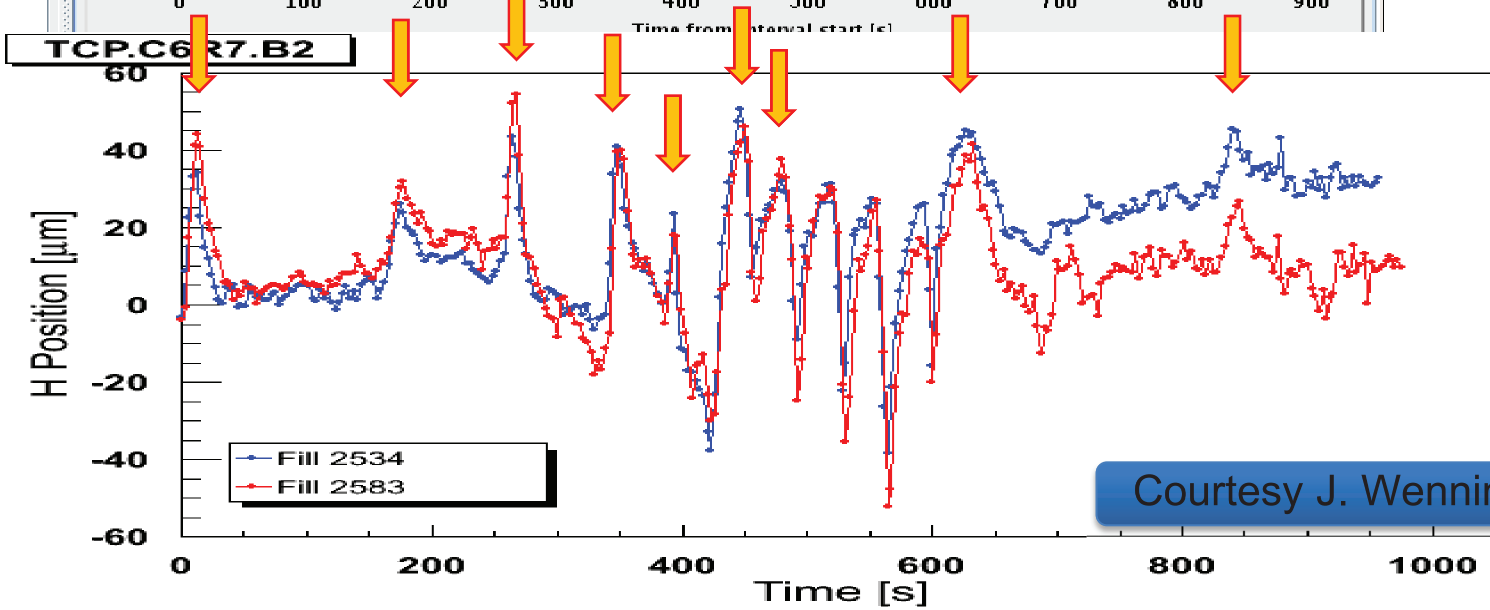
Losses at 2m beta*

Up to 45% of dump threshold





B2: Losses and H TCP orbit well correlated



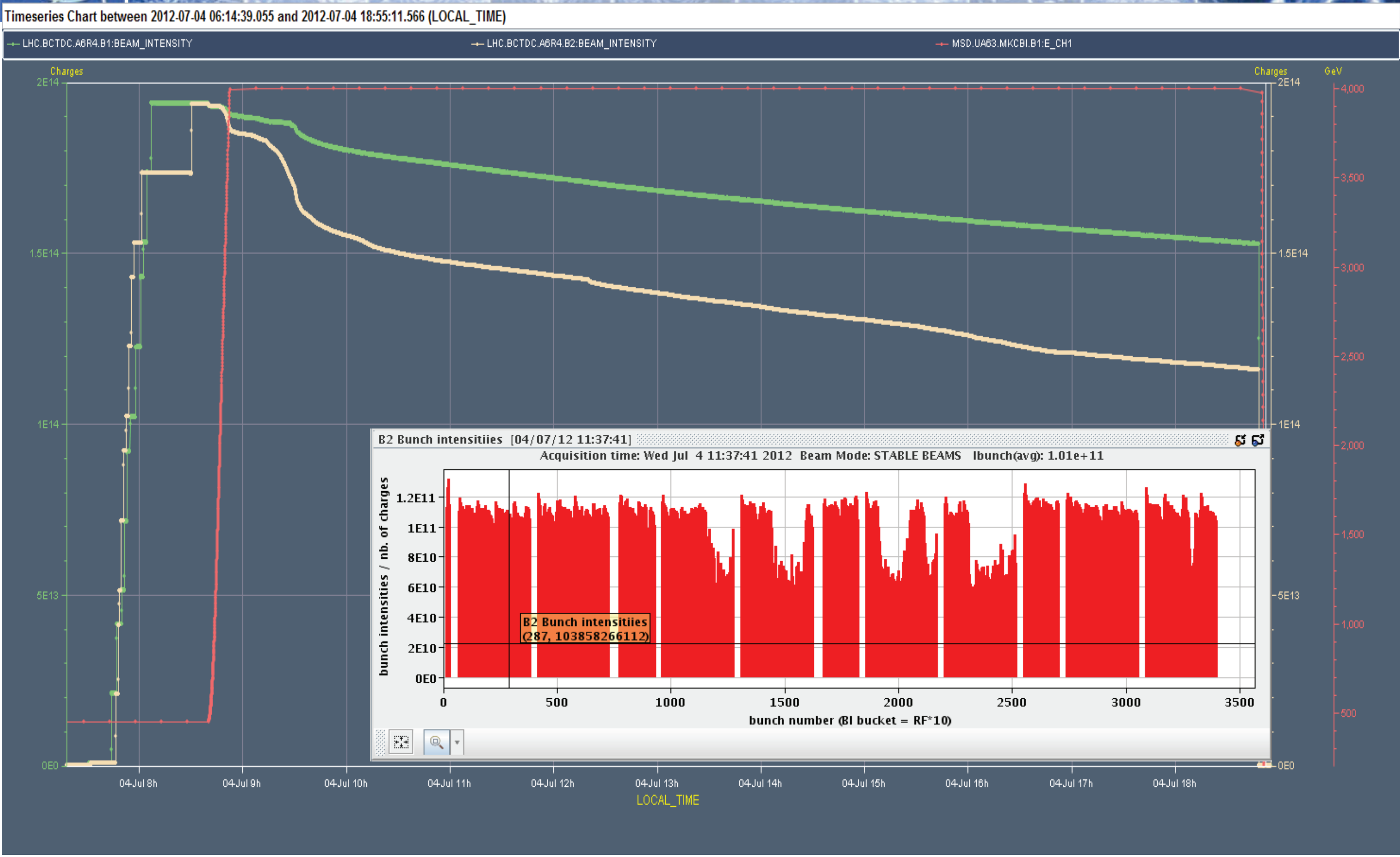
Courtesy J. Wenninger

Losses when going in collisions

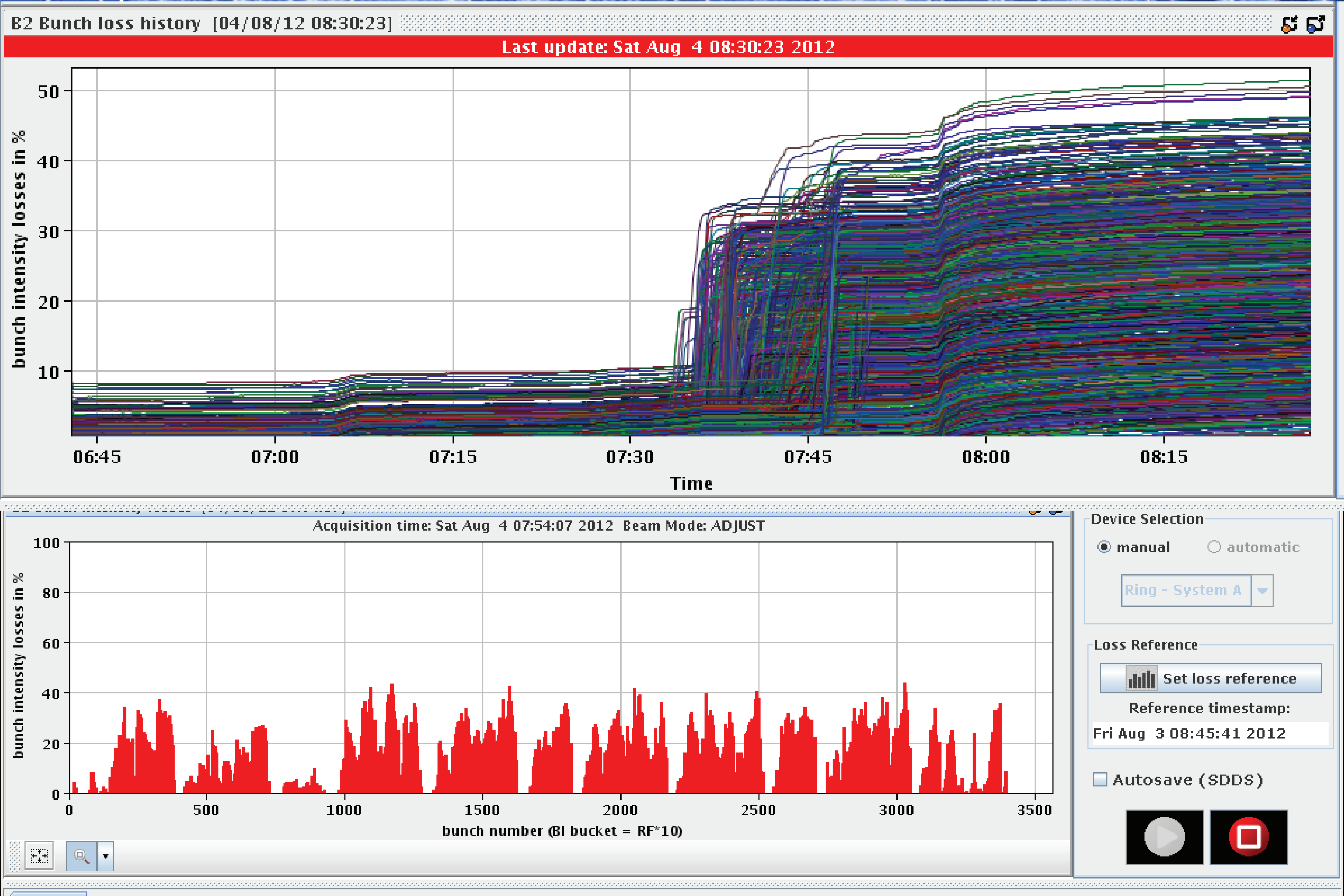
- Instabilities observed in 2011 when going in collisions (and end of squeeze) cured all along the run by transverse feedback, octupoles and chromaticity adjustment
- Increased number of beam dumps in 2012, especially in Summer when bunch intensity was pushed up
- **3 Main cases:**
  - Instability during end squeeze (after IP2 & 8 at 3 m)
  - Instability during first minutes of Adjust
  - Instability during Adjust luminosity
- Used to be in the horizontal plane, but also have some example in the vertical plane

See B. Salvant's oral presentation on WG-A Wednesday

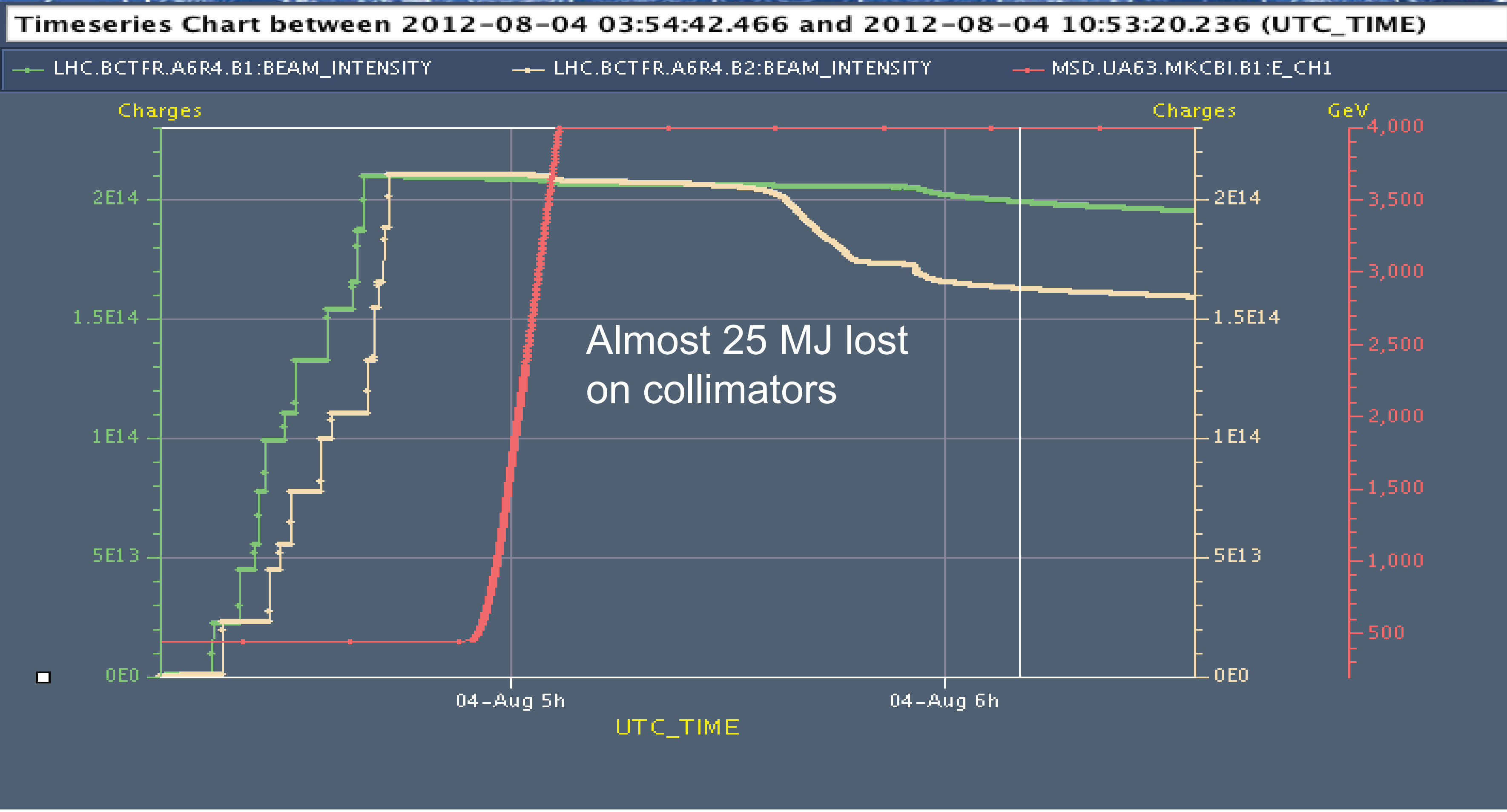
Losses on selection of bunches



Losses on all bunches



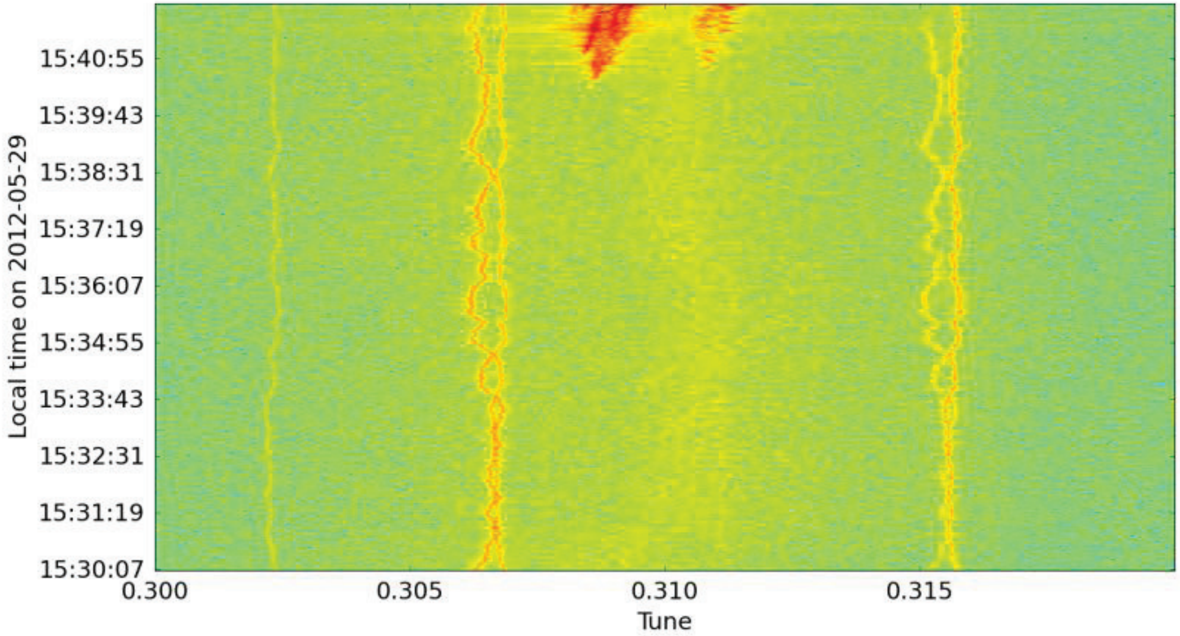
Losses on selection of bunches



- Beams life time stabilized by increasing chromaticity by 5 units
- Octupole polarity changed since that fill and chromaticity increased by more than 15 units

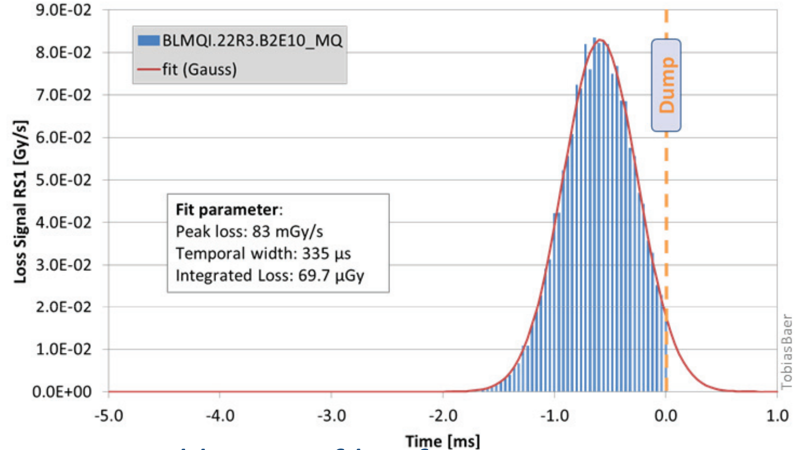
An example of instabilities

- Just before going into collisions, 2 octupoles (out of 16) tripped at the end of the squeeze (one already missing)
- Octupole individually not linked in the beam interlock : beam not dumped
- Instability produced slow losses on beam 1 eventually dumping beam
  - 83.8 second running sum on TCLA.A7R7.B1
  - Sharp peak seen on beam 1 (and beam 2)

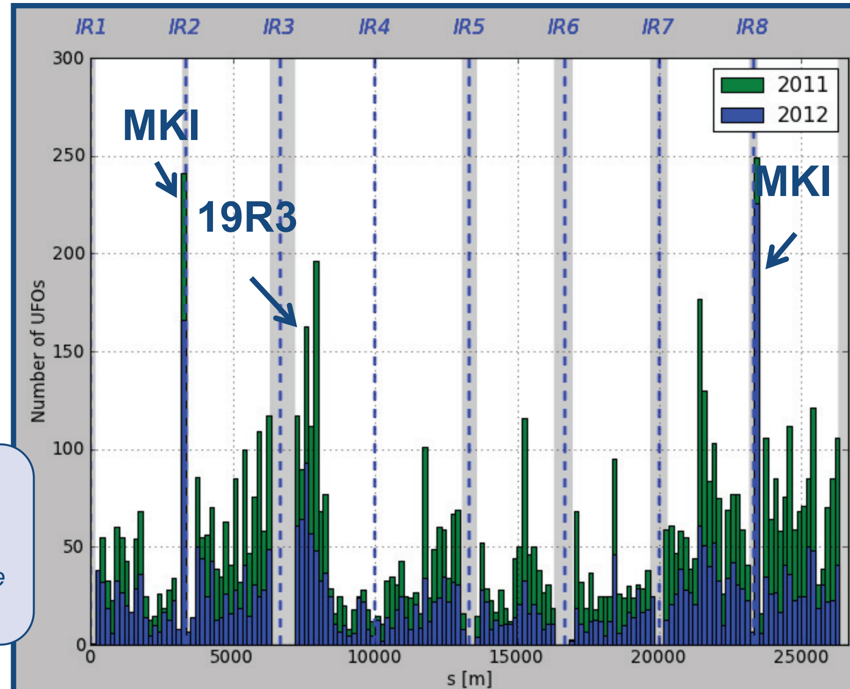


UFOs in the LHC

- 39 beam dumps due to (**U**n)identified **F**alling **O**bjects
  - Loss duration : about 10 turns
  - Throughout 2011: mitigation by increase and optimization of BLM dump thresholds (17 dumps first half of 2011, 4 in 2012)
- 18000 candidate UFOs below BLM dump thresholds found, ~ 8000 in 2012)
- UFOs occur all around the LHC,
  - Unconventional loss location (arcs)
  - Particularly many around MKIs



temporal loss profile of UFO on 23.08.2010



2011: 7668 UFOs at 3.5 TeV.
2012: 3719 UFOs at 4 TeV.
Signal RS04 > 210^{-4} Gy/s.
Gray areas around IRs are excluded from the analysis.

Courtesy T. Baer

Arc UFO Size

- 44 UFOs over 10% of dump threshold in 2012 so far (at 4 TeV).
- At 7 TeV, BLM thresholds are 5 times smaller and UFO signal amplitude simulated to be 3-4 times bigger
- Energy extrapolation to 7 TeV:
  2011 arc UFOs would have caused **112 beam dumps.**
  2012 arc UFOs would have caused **50 beam dumps so far.**
- A lot of effort put in better understanding localization and temporal resolution, simulation and MD studies (quench limit, UFO production mecanism at MKI...)
- Different mitigation solutions being investigated:
  - MKI : Change MKI.D5R8 in TS#3 (heating problems), coating…
  - Arc UFOs: Increase BLM thresholds towards quench limit and refine the BLM distribution

See E. Nebot Del Busto oral presentation on WG-E and M. Hempel poster on diamond detector

Conclusions

- Quick list of the different losses observed in the LHC.
- Injection was really the bottleneck in 2011, going in collisions is the one in 2012
- Losses along the cycle under control: still no beam induced quench above injection energy
- But BLM thresholds have been increased in several location to stand losses rate in collisions (TCT and IP7)
- 2012 operation less comfortable than 2011, and we still have a long way for 7 TeV operation