"WHAT YOU GET" INJECTION & DUMP SYSTEM

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Acknowledgments: M. Di Castro, G. Le Godec, A. Lechner, R. Losito, A. Masi

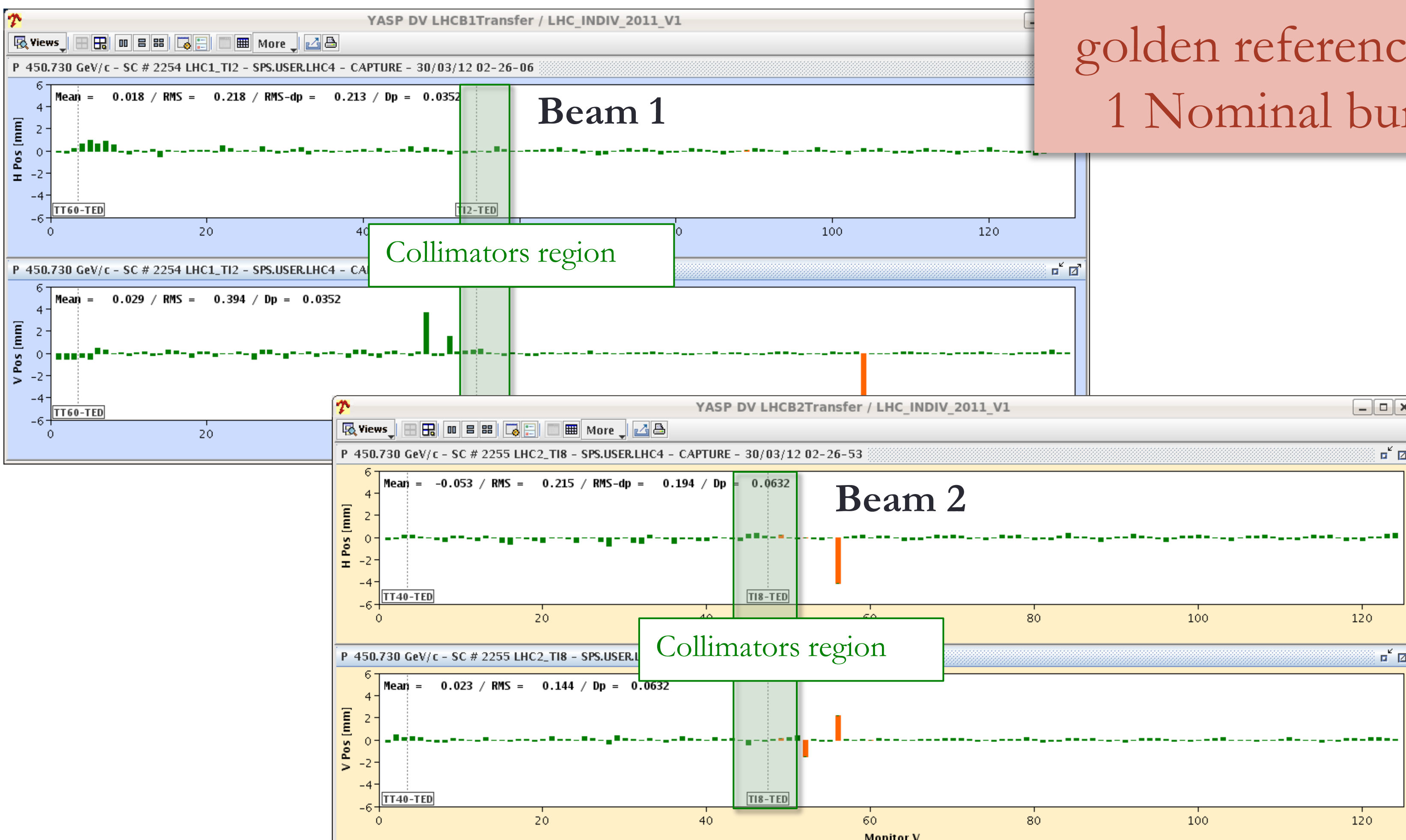
Outline

- Injection:
  - Performance during 2012 operation
    - Steering
    - Transfer Line stability
    - Injection of 25 ns beam
    - Injection HW (MKI, TDI and TCDI): problems encountered (Operation and Machine Protection), mitigations applied and foreseen actions for LS1
- LHC Beam Dump System (LBDS):
  - Performance during 2012 operation
    - Problems encountered (TCDQ, LBDS logic)
    - Applied mitigations and foreseen actions for LS1

Transfer Lines Steering

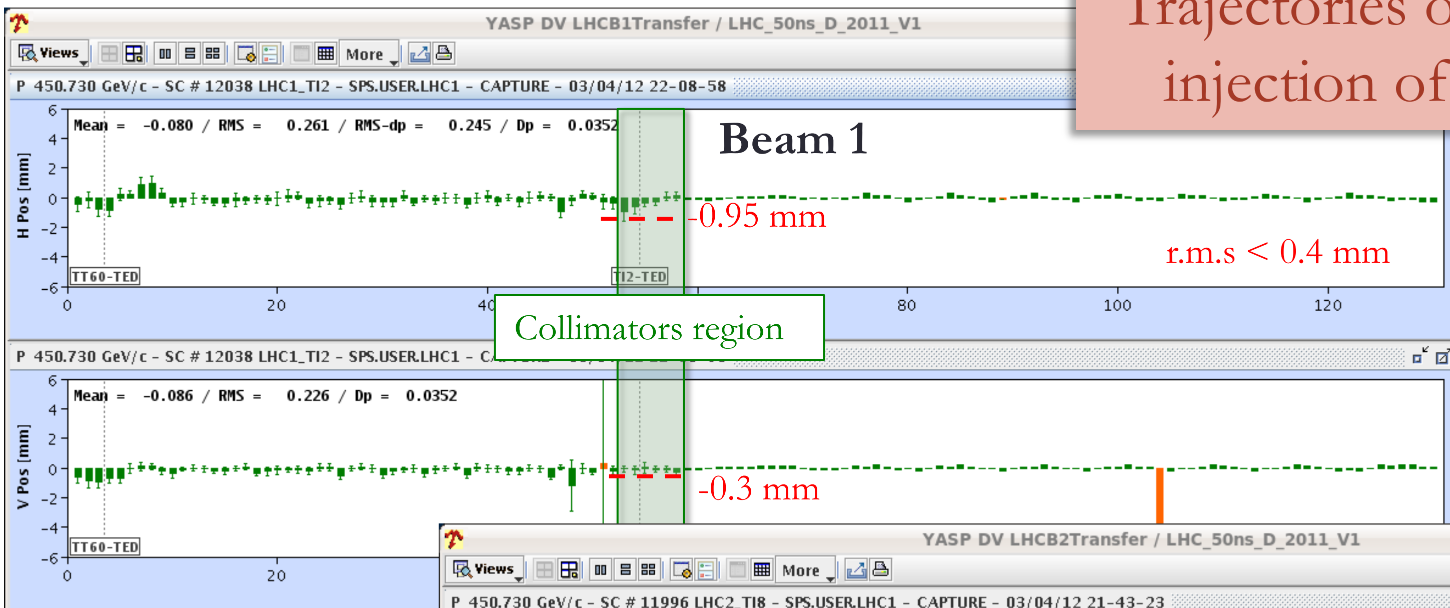
- **Golden reference trajectory** was established on **March 25th** minimise both **losses** and **injection oscillations**

Difference wrt golden reference for 1 Nominal bunch

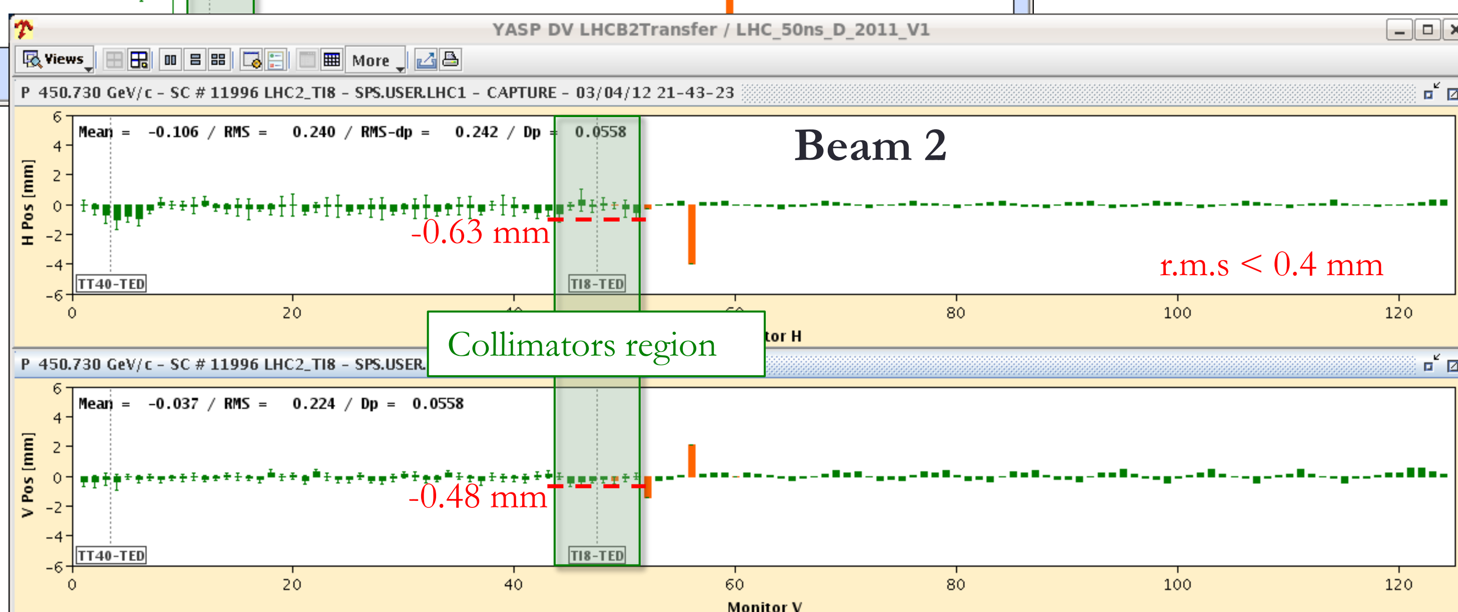


Transfer Lines Steering

Trajectories on April 4th first injection of 144 bunches



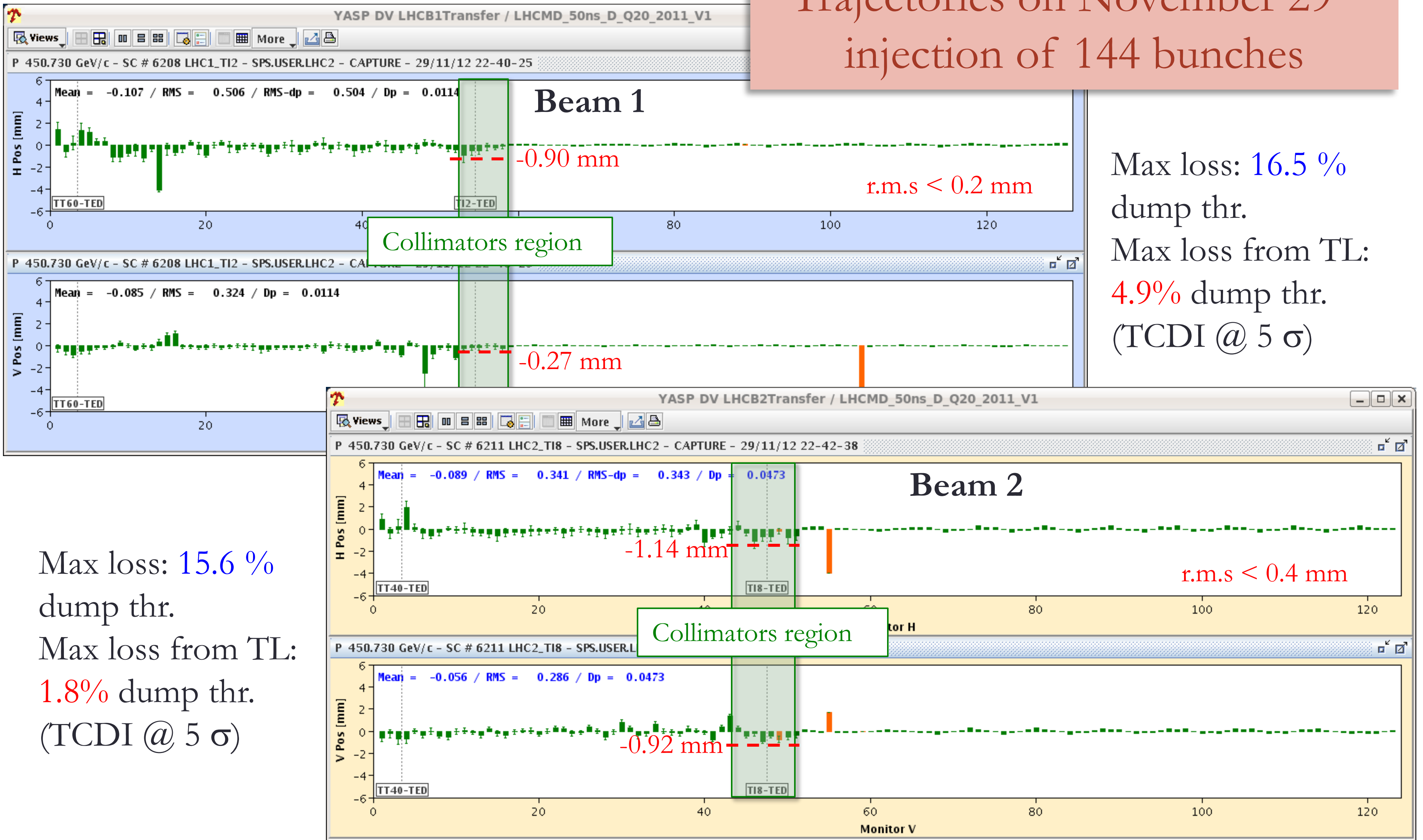
Max loss: 24.1 % dump thr.
Max loss from TL: 15.8% dump thr.
(TCDI @ 4.5 σ)



Max loss: 8.8 % dump thr.
Max loss from TL: 3.21% dump thr.
(TCDI @ 4.5 σ)

Transfer Lines Steering

Trajectories on November 29th injection of 144 bunches

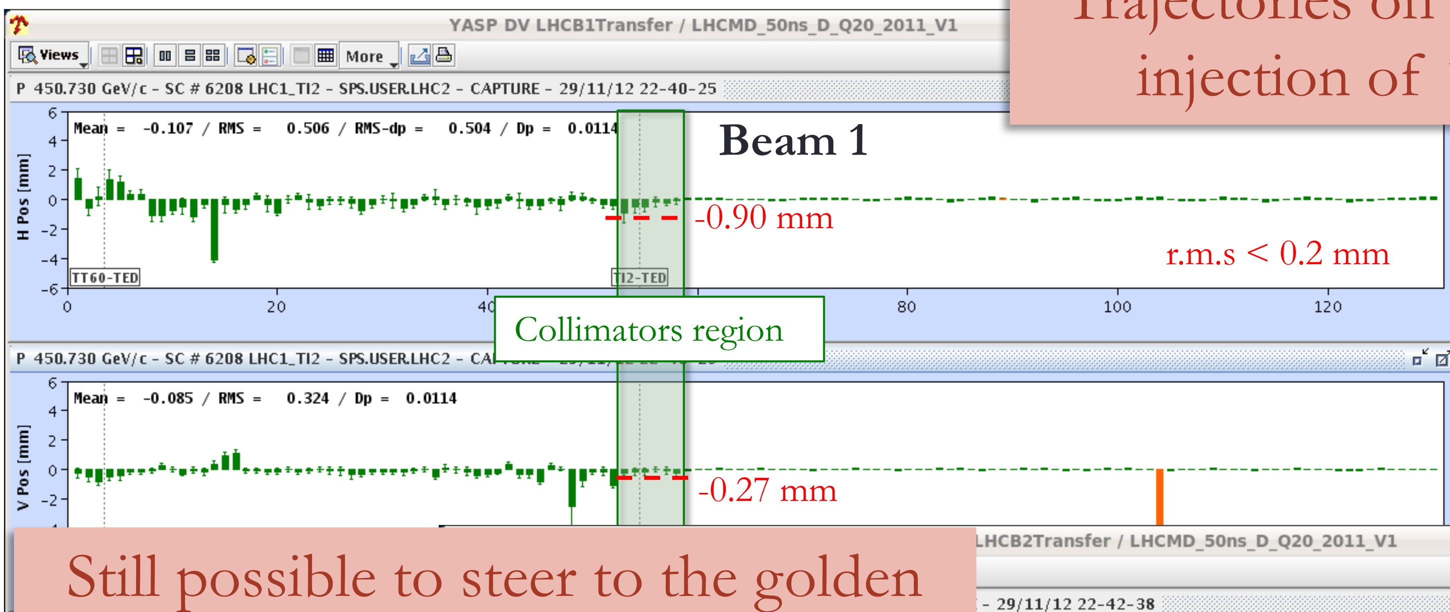


Max loss: 16.5 % dump thr.
Max loss from TL: 4.9% dump thr.
(TCDI @ 5 σ)

Max loss: 15.6 % dump thr.
Max loss from TL: 1.8% dump thr.
(TCDI @ 5 σ)

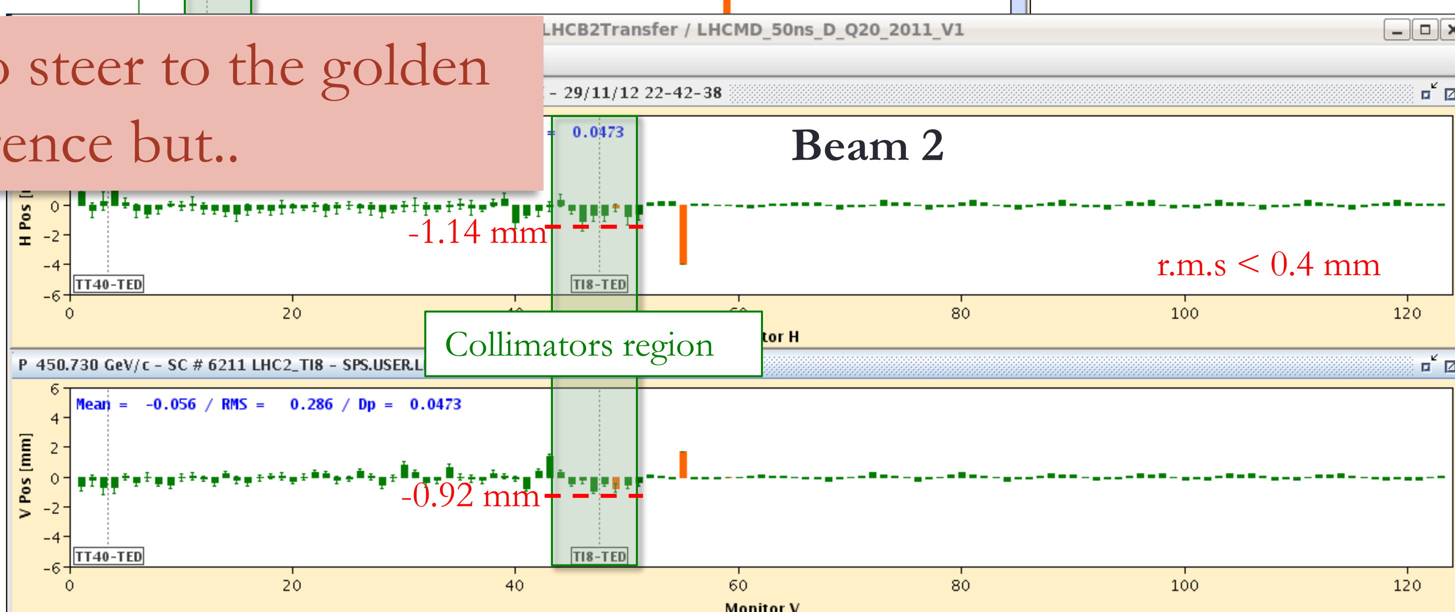
Transfer Lines Steering

Trajectories on November 29th injection of 144 bunches



Max loss: 16.5 % dump thr.
Max loss from TL: 4.9% dump thr.
(TCDI @ 5 σ)

Still possible to steer to the golden reference but..



Max loss: 15.6 % dump thr.
Max loss from TL: 1.8% dump thr.
(TCDI @ 5 σ)

Transfer Lines Steering

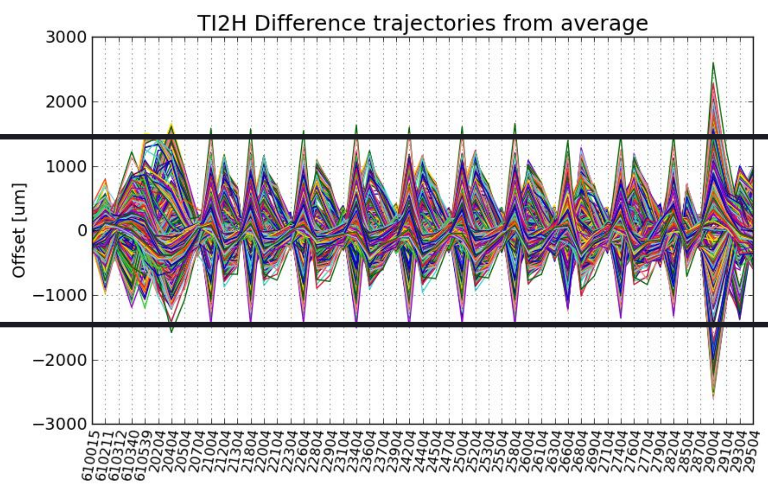
- Need for steering became **more and more frequent:**
  - **Once**, maximum **twice per week** until **end of September**
  - **Every 1-2 days** in **October and November** (**Q20 optics**)
- **Injection oscillations** were the main reason for steering
- More time spent for steering:
  - When injection oscillations ok, still high losses **BUT** mainly **from debunched beam** (independent from transfer line steering). For operation after LS1 we could **improve the IQC to give a clearer indication of when steering is needed** (i.e. highlight region where TL collimators are installed and reference BLMs in the injection region)
  - **Not same trajectory for 6 bunches and 144 bunches** injection ➔ corrections have to be calculated with 144 bunches ➔ 6 bunches have to be injected after every correction ➔ time needed to change beam in the SPS. Still not known why this is more critical than before

Transfer Lines Stability

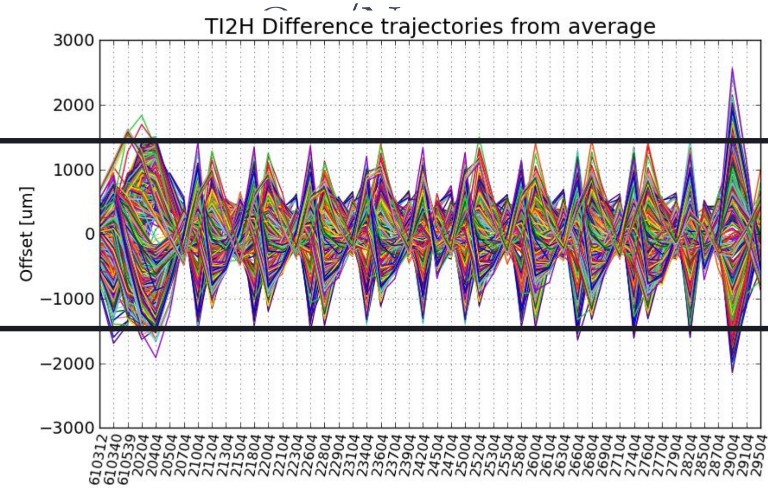
Why steering is needed more frequently with Q20 optics?

- L. Dorsdal analysed **transfer line uncorrected trajectories for 144 bunches injection** since beginning of October (Q20 period) and a similar period in May/June (Q26 period)
- Model Independent Analysis (MIA) used to **define sources of variations** from the different trajectories

Q26 May/Jun



Q20



L. Dorsdal

Transfer Lines Stability

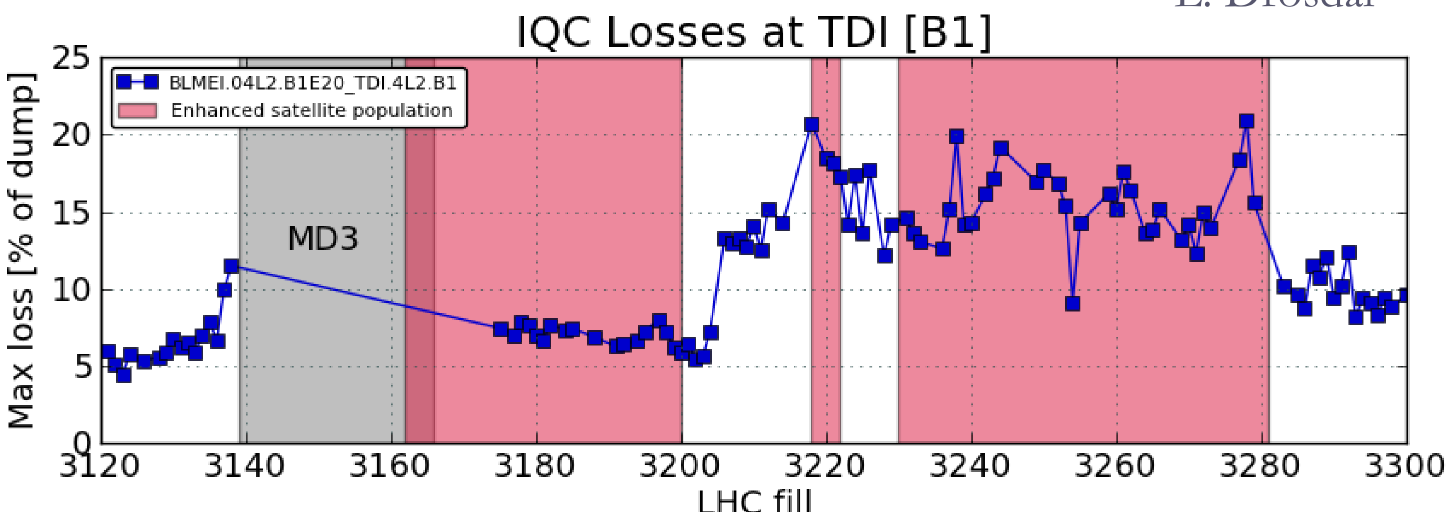
- **No or only a small worsening** of the trajectory variations was observed for the Q20 optics

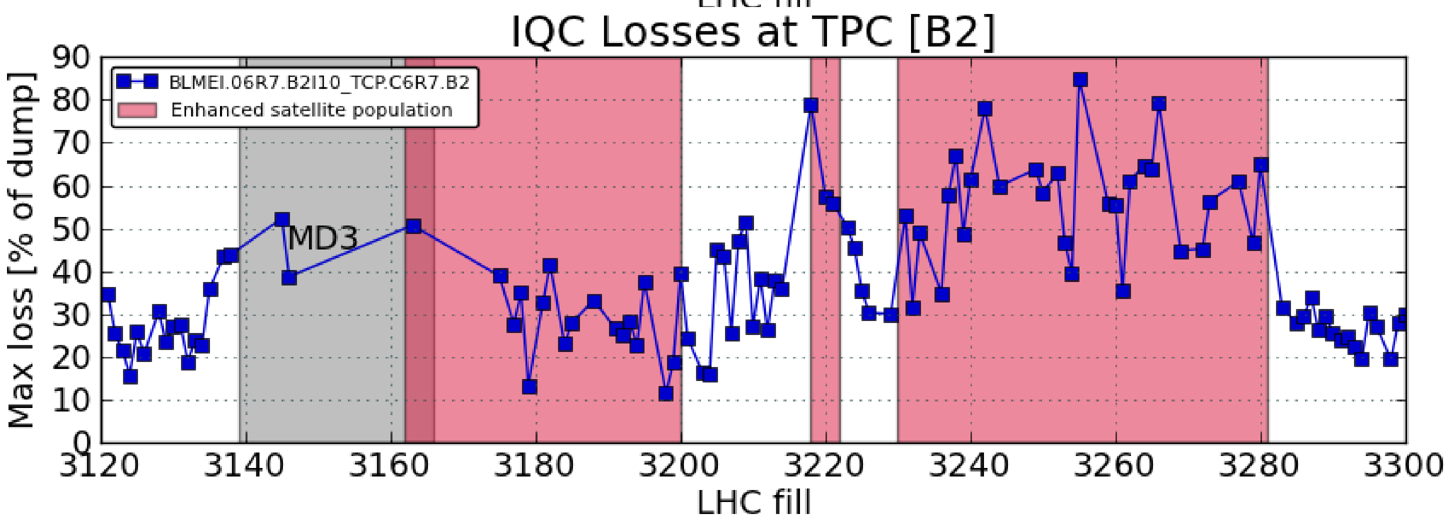
- **Two main sources** for trajectory variations were identified:
  - **Current ripples in the SPS extraction septum** (MSE) are **the main source of shot-by-shot variations** (already mentioned in Evian 2011). Currents were changed by 5-8% to match Q20, but **ripples** are **not larger** than for Q26.
    - During TS4, further checks are foreseen to investigate any eventual deterioration of the system (visual inspection of the septum and a test campaign for the Power Converter units). Possibly a new type of converter (capacitor discharge) will be installed during LS1.
  - **Orbit variation in the SPS**. These variations were **only monitored for the Q20** optics while a reasonable statistic for Q26 is missing ➔ not possible to say if any worsening was introduced when moving to the new optics

Losses from Unbunched Beam

- Some effect from **satellite enhancement** but **not only contribution** (batch-by-batch blow-up, injection cleaning?)

L. Drosdal



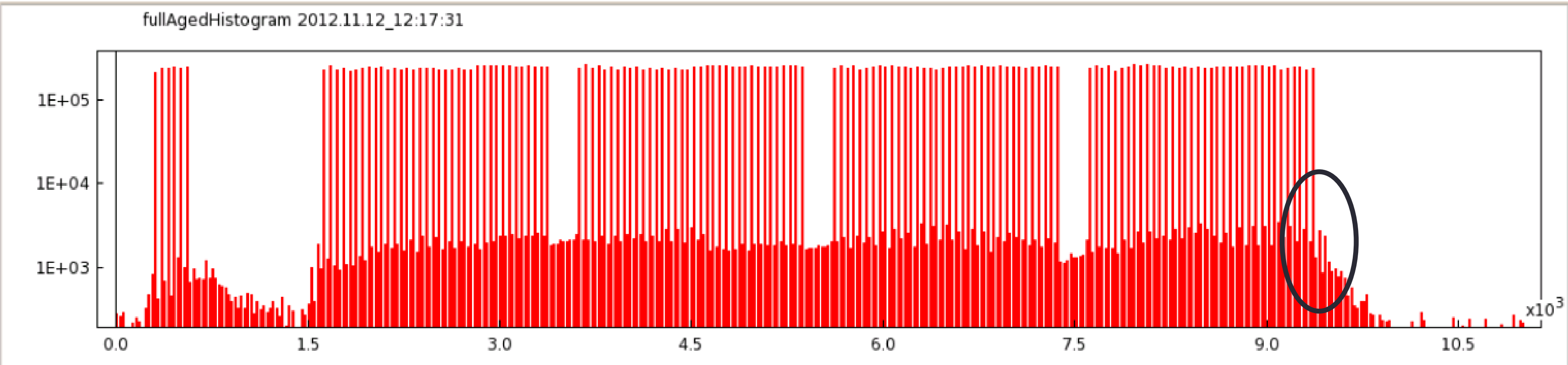


Losses from Unbunched Beam

- Some effect from **satellite enhancement** but **not only contribution** (batch-by-batch blow-up, injection cleaning?)

- **Beam was dumped twice by LHCb BCM** at injection because of two trailing 50ns bunches (11/11 and 12/11)
- Situation was improved by shortening the **PS extraction kicker** pulse length

T. Bohl



25 ns Scrubbing Run

- Injection setup 6/12/2012:
  - Straightforward steering of both lines
  - Clean injections with trains of up to **288 bunches** (first injection: Beam 2 max. loss 10.8%, Beam 1 max. loss 15.3%)
- Re-steering of the lines on 9/12/2012
- Injection of several trains of **288 bunches** for scrubbing run:
  - Worst injections for both beams losses at ~**50%**
  - For Beam 1, in average: max. losses at ~**17%**, max. losses from TL at ~**10%**
  - For Beam 2, in average: max. losses at ~**17%**, max. losses from TL at ~**3%**

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Equivalent to "good" injections of 144 bunches separated by 50 ns

About a factor 2 higher then for injections of 144 bunches separated by 50 ns

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  - For Beam 1, in av
  - For Beam 2, in av

We are not limited by injection losses but:

- **Several BLM monitors with RC filters in the injection region (including @ TDI) ➔ sensitivity reduced by up to a factor 180 and signal delayed**
- **TCDI @ 5σ instead of nominal 4.5σ (better protection of LHC aperture ➔ more margin for orbit variations)**

Need for sunglasses after LS1 is confirmed (LICs under evaluation by the BLM team)

Hardware Problems: TDI in IR8

- Two **spurious glitches** on the **RU end-switch** when moving to parking (7/8/2012 and 8/8/2012)➔ switch active ➔ motor stopped ➔ huge **tilt** of the jaw (22 mrad – 11 mrad) ➔ suspected plastic deformation

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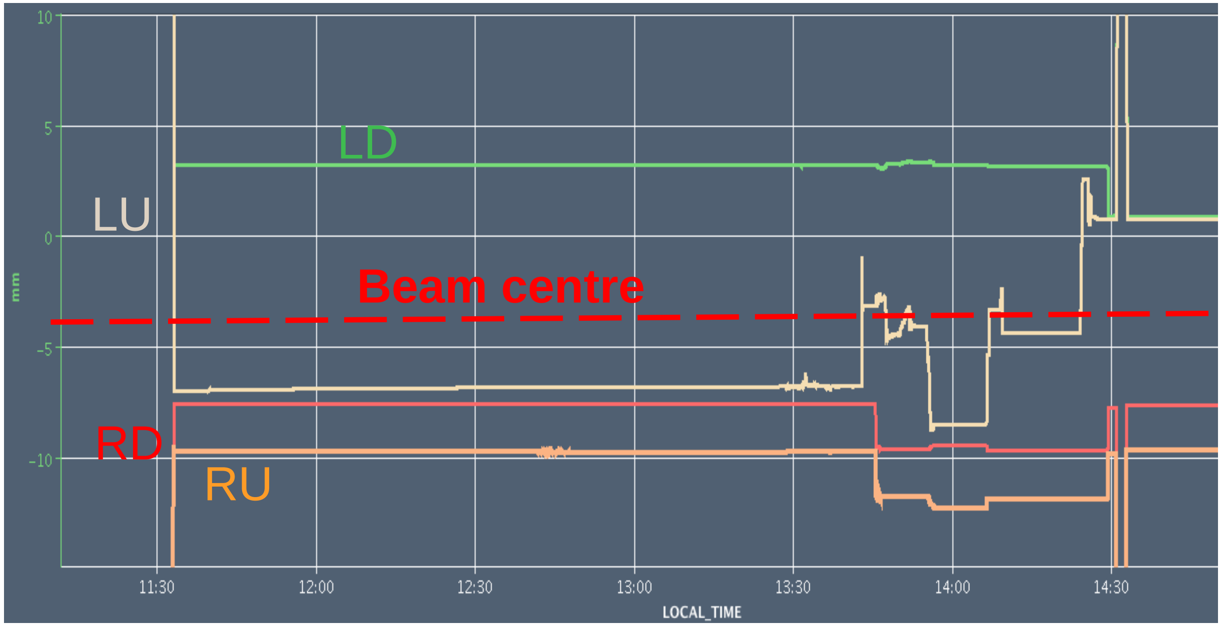
  - Control module of the switch exchanged (9/8/2012)
  - TDI alignment re-checked and validated!
  - **Maximum allowed angle of 5 mrad** (check of the requested position and warning if bigger than specifications, low level control on position measured by resolvers and motors stopping if angle > 5 mrad)
  - Added a task in the sequencer to check TDI position before the energy ramp

- Left (upper) jaw stuck at parking position during the **25 ns scrubbing run**. Hypothesis: **beam induced heating** + frequent **cycling** of the jaw from injection to parking position ➔ **mechanical degradation** of the motorization system
  - Increased current to augment motor torque
  - Exchange of full motorization block for the upstream axis of the upper jaw (during TS4)

Hardware Problems: TDI in IR2

- **Failure** of the **LVDT** of the upstream corner of upper jaw (14/10/2012)
  - Moved controls to LVDT(2)
  - Position and energy interlock thresholds setup around the new LVDT ➔ introduced an **offset of ~200 µm between settings and LVDT readings**

- While moving from parking to injection position (without beam) the LU side of **TDI upper jaw fell across the beam axis** onto the lower jaw (3/12/2012).



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- While moving from parking to injection position (without beam) the LU side of **TDI upper jaw fell across the beam axis** onto the lower jaw (3/12/2012).
  - Jaw put back into correct position plus hardware consolidation
  - Re-checked TDI alignment (both jaws) ➔ no significant change in settings was measured but **a further offset of 100 μm was introduce between LVDT and settings** (closer to inner position interlock limit)
- **LU LVDT drifted beyond inner dump limit** when at injection position ➔ not possible to move the jaw to parking (11/12/2012)
  - Re-checked TDI alignment ➔ defined new settings and thresholds. A **total offset of 530 μm between LVDT readings and settings** persists
  - Exchange of full motorization block for the upstream axis of the upper jaw (during TS4)

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  - Re-checke **530 μm b**
  - Exchange

- In total TDI alignment had to be re-checked 3 times.
- About 1 shift needed for setup and validation (downtime BUT only protection in case of MKI failures)
- During LS1:
  - New beam screens
  - Both TDIs fully dismounted and reassembled + 2 spares
  - Possible to reduce heating? (B. Salvant talk)

Wrong TCDI Settings for Q20 Optics

- SPS changed to Q20 optics (after TS3) ➔ **transfer lines re-matched** and **change of β–function** at TCDIs (end of the lines) was **expected to be negligible**
- **Trajectories** could be **steered to the golden reference** defined with Q26 optics ➔ no need to change the TCDI centring ➔ no explicit verification of TCDI settings was done
- Changes in β at the TCDIs were quantified in preparation of an LMC (1.5 months after moving to Q20) ➔ **differences in settings up to +1.3σ at 1 collimator per line** ➔ **loose protection**
- TCDIs immediately moved to corrected settings and validated with beam (**~14 hours**)
- Defined procedures to avoid repeating such mistakes
- Discussions on-going to find a way to improve the **detection of wrong settings/thresholds** (topic for 2013 MPS workshop)
- An **automatic tool for TCDI setup** was tested during an MD and is working ➔ **safer** (new beam centers automatically in TRIM) but **not** necessarily **faster**
- Present **validation is very lengthy procedure** ➔ try to define a better procedure for after LS1

MKI Erratics and Flashovers

Date	Problem	Magnet	Beam
26-Mar-12	MS erratic during PFN charging	MKI8 C	1 nominal bunch on TDI
9-April-12	Flashover, 4.4 μs pulse length (instead of 8 μs)	MKI8 D	12 bunches injected and correctly kicked
15-April-12	Flashover, 3 μs pulse length (instead of 8 μs)	MKI8 D	**108 bunches on TDI**, quenches, vac valves closed, cryo cond. lost
22-June-12	Flashover during UFO MD (anti-ecloud solenoids off)	MKI8 C	MKI pulsed in empty gaps; dump due to vac interlock
24-Sept-12	Flashover during Q20 injection tests, 1.3 μs pulse length	MKI8 D*	No beam extracted from SPS
13-Oct-12	Flashover, 6 μs pulse length	MKI8 D*	6 bunches injected and correctly kicked
31-Oct-12	Flashover, 4 μs pulse length	MKI8 D*	No beam extracted from SPS

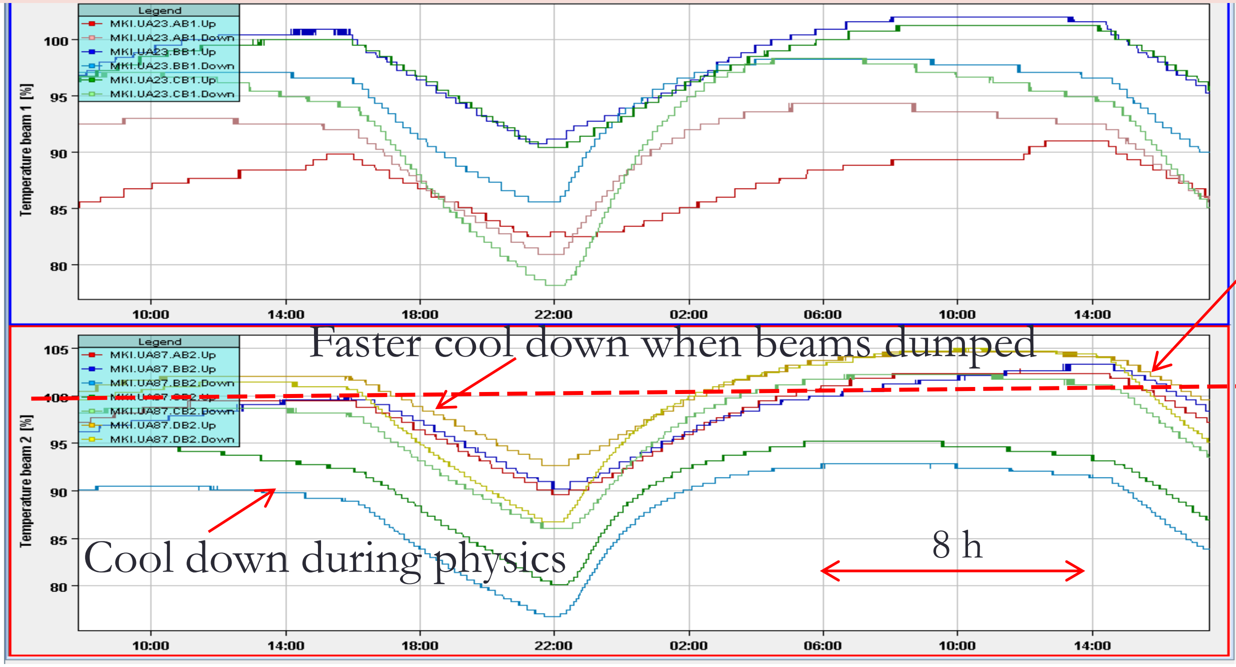
Timing issues during H=9 ➔ 48 bunches dumped on the TDI (D. Wollmann's talk)

No flashover during 25 ns scrubbing run!
(Time for conditioning and complete set of anti-e-clouds coils. Vacuum interlock thresholds in the MKI tanks at 4E-9 and at the interconnects at up to 4.5E-8)

* New Hardware

Injection kicker MKI heating

MKI injection kicker measured ferrite yoke temperatures (relative to SIS threshold)



Wait before injection

Injection limit

MKI-8D
Replaced in TS3, more beam 'screens': OK. Full systems exchange during LS1

- On about **10 occasions** required to wait > 1 hour for an injection kicker (normally **MKI8D)** to cool down
  - Happened after a series of long fills with efficient turn around to refill
- In **TS 3 replaced the hottest kicker** (MKI8D) with version with more screening wires: now amongst lowest measured temperatures.
- All MKIs to be upgraded during LS1 with more screen conductors
  - Don't expect any waiting time for kicker cool-down after LS1
  - See presentation B. Salvant

LHC Beam Dumping System

- **No big operational problems or long downtime induced by the TCDQs** (only a minor issue for the Beam 1 TCDQ but no impact on operation). New hardware (2×3 m C jaw → **3×3 m CFC jaw**) will be installed during LS1 for operation at **6.5 TeV**.
- **No asynchronous beam dump with beam**
- **Two Asynchronous dumps without beam** due to failures of WIENER power supplies (February-April).
  - Re-defined logic for cabling and powering of the LBDS
  - During LS1: modify the UPS electrical distribution and upgrade the circuit breaker technology + replace WIENER crates with crates with internal protection.
- Operation at **6.5 TeV** → "real" risk of switch erratics
  - Complete overhaul of all MKD and MKB switches to increase reliability (less sensitive to radiation) during LS1

LHC Beam Dumping System

- **A common mode failure in 12-V DC power feed line,** which would not allow to dump (if that failure occurs) the beam when requested, was discovered
  - Implemented an external monitoring of the 12 V line with asynchronous dump request (**no further async. Dumps since April 2012**)
  - LBDS review on 20/06/2012 ➔ several recommendations for additional actions to be taken during LS1, i.e. BIS for triggering a delayed asynchronous dump as ultimate protection ➔ increased risk of asynchronous beam dump…

- Failure of a compensation power supply (13/10/2012) ➔ replaced ➔ **offset** in energy tracking system **BETS (0.9%)** ➔ few empirical runs in order to validate the adjusted set point over the 450Gev-4Tev range (tolerance window: 0.1-0.5%) ➔ test ramps (1 without and 1 with beam) and system ok!

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- **A common mode failure in 12-V DC power feed line,** which would not allow to dump (if that failure occurs) the beam when requested, was discovered
  - Implemented an extern request (**no further asy**
  - LBDS review on 20/0 be taken during LS1, i.e protection ➔ increase

> - **Details on the modifications of the logic and architecture of the LBDS will be discussed at the 2013 MPS workshop**

> - **After the LBDS problems were discovered ABT asked to stop high intensity operation to allow implementing mitigation solutions**
> - **Back to operation after ~6 hours + validation**

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> - **Downtime for power supply replacement and system validation: ~8 hours**

Conclusions 1/2

- Operation with **50 ns**:
  - **Reference golden trajectory** for TI 2 and TI 8 defined in **March 2012** and **still valid** but **steering** became **more frequent and lengthier** after moving to **Q20 optics**.
  - **No evident explanation** found for this worsening (SPS orbit, MSE ripples, losses from debunched beam, enhanced satellites, injection cleaning, etc.)
- Scrubbing run with **25 ns**:
  - **Steering** of the TL to 50 ns golden reference and **clean injections** of trains of up to **288 bunches**
  - **No MKI flashovers** (continuous monitoring of vacuum)
  - **Enhanced TDI heating** (also effect of frequent cycling)
  - **Need for Sunglasses/LICs after LS1 con**firmed
- TDI:
  - **several problems** (mainly induced by heating and frequent cycling) but **interlocks always worked as by design**.
  - Mitigations applied and further **consolidations foreseen for LS1** + completely **new design for LS2**

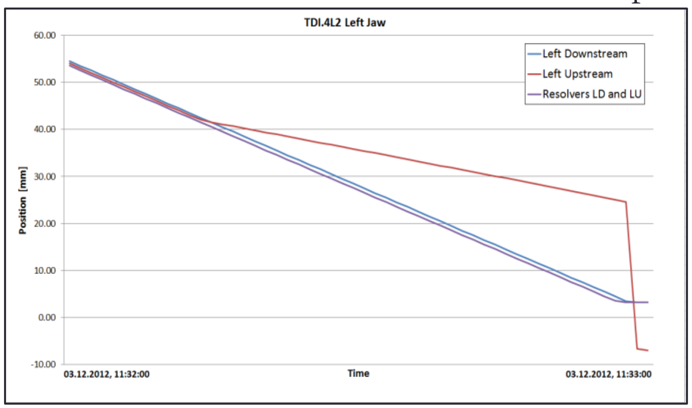
Conclusions 2/2

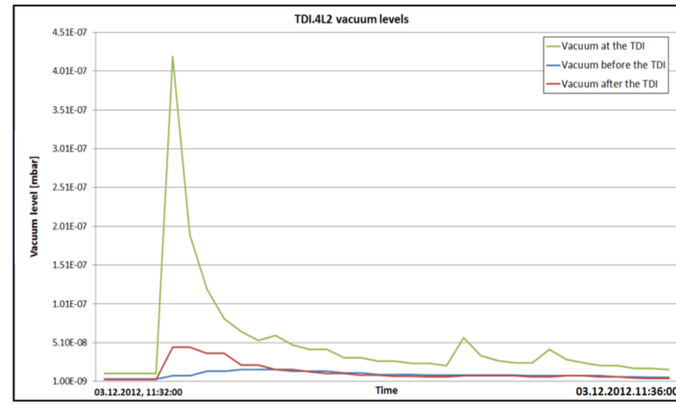
- MKI:
  - **6 flashovers and 1 erratic** ➔ up to 108 bunches mis-kicked (quenches, valves closed, cryo..)
  - Heating: ~10 times **>1 hour waiting** before injecting for cooling down of MKIs (normally MKI-8D) ➔ all MKIs will be upgraded during LS1 ➔ no more waiting time
- TCDI:
  - **Wrong settings** after Q20
  - Safer procedure and additional checks
- LBDS: **2 major events** causing **downtime** (12 V and offset in BETS after replacement of a compensation power supply failure)
  - **New more robust TCDQ** hardware for operation at 6.5 TeV installed during LS1
  - **Weaknesses** identified in the powering **logic of the TSU** ➔ important improvements foreseen for LS1
  - Additional safety net: link BIS → re-triggering ➔ increased risk of async. dumps
  - More reliable MKD and MKB switches


Thank you!

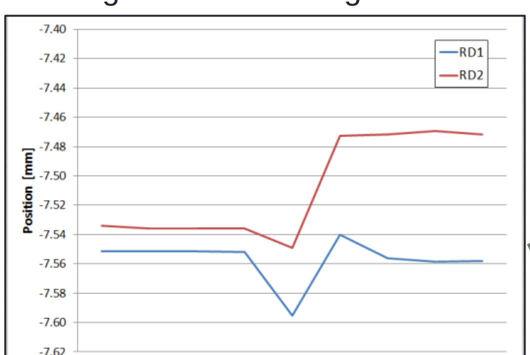
Cotter pin problem on the TDI.4L2 LU

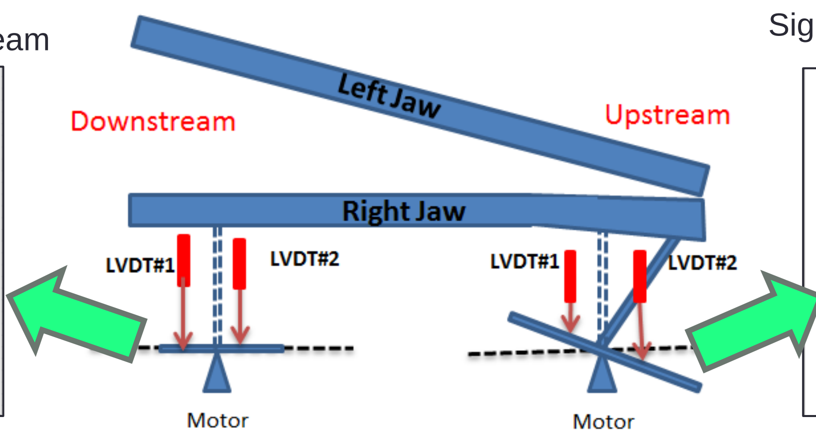
- On the 3.12.2012, during a motion, the Left Upstream axis cotter pin “jumped out” from its position
- The LU first changed the moving speed and, at the end of the movement, fell down of approx. 30 mm
- Signs of a suspected impact between the jaws at the upstream
  - ✓ LVDTs readings on the right jaw, “jumping” on the downstream, deformation on the upstream (200 μm for RU1 and 50 μm for RU2)
  - ✓ The vacuum level at the TDI raised up from 1.1E-8 to 4.2E-7 mbar





Bouncing LVDTs on the right downstream





Sign of force applied on the right upstream