MPP Workshop: Injection System

C. Bracco on behalf of ABT

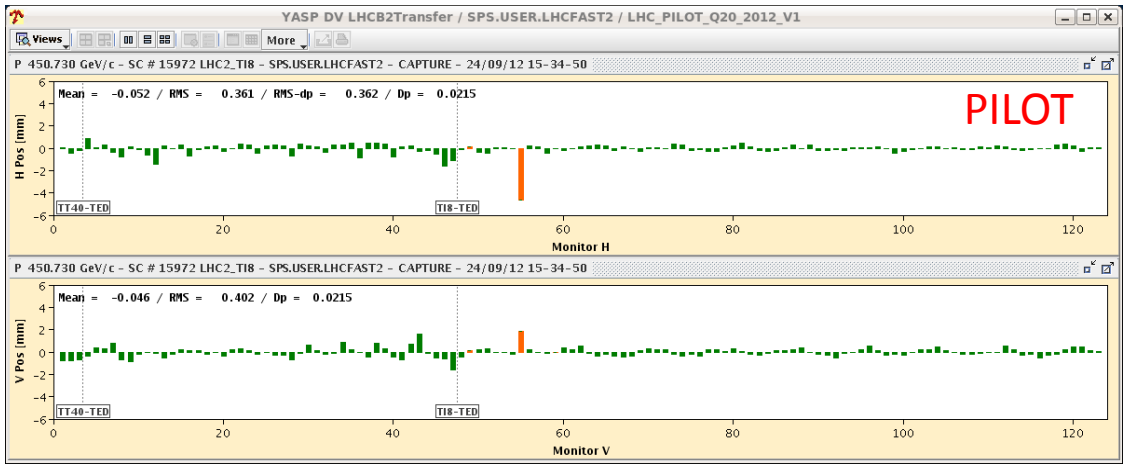
Acknowledgments: STI, ABP, BI,LHC and SPS OP

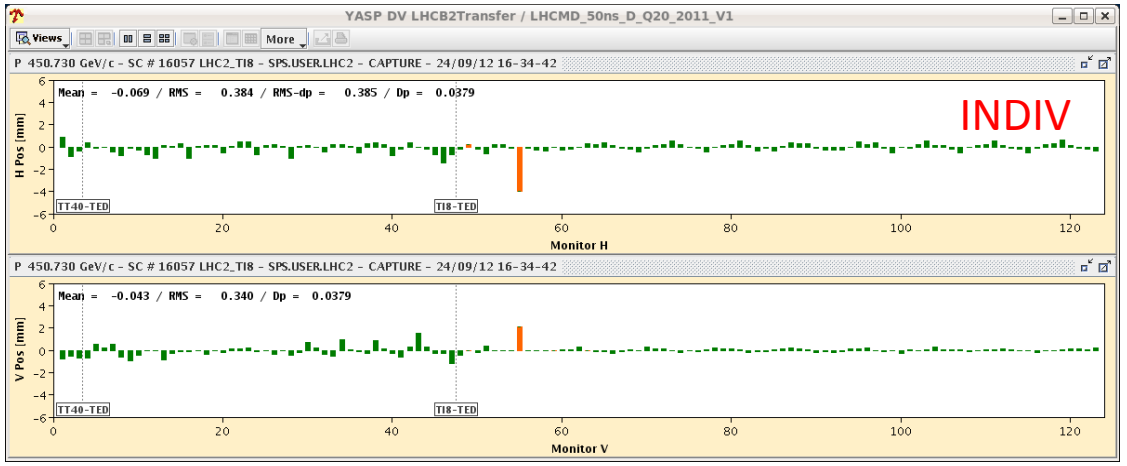
Outline

- TL steering and IQC
- Injection losses
- LSS6 extraction
- Injection protection collimators (Optics_ID)
- TDI limits
- MKI risetime

TL Steering

- Known issue: **different trajectories** for **fast-PILOT** and **slow-INDIV/25ns cycles** (slower ramp and different magnetization ➔ “different” extraction)



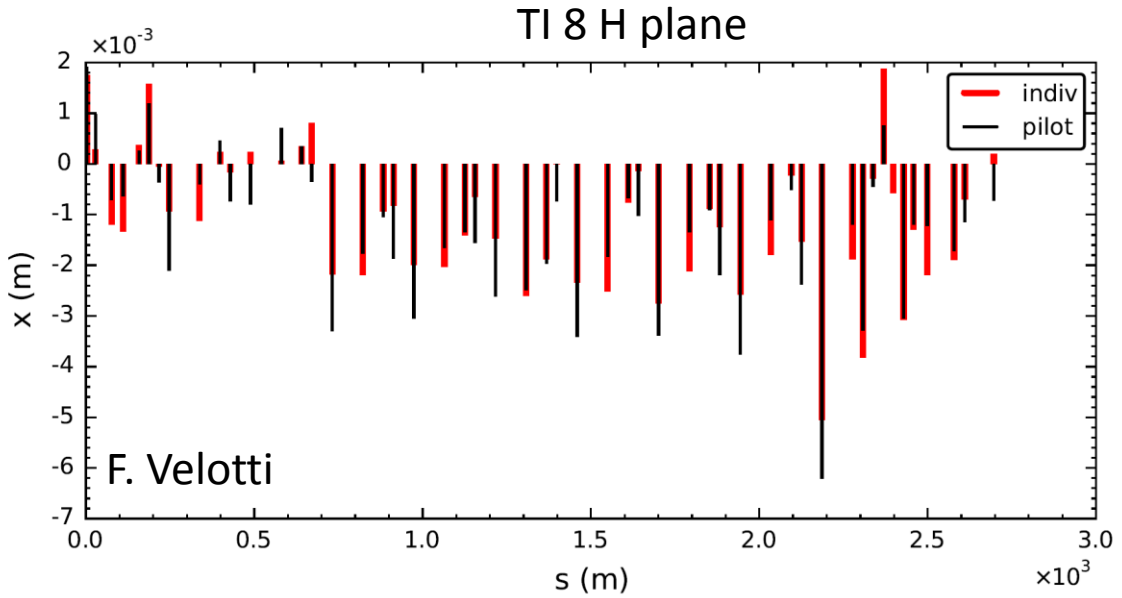


TL Steering

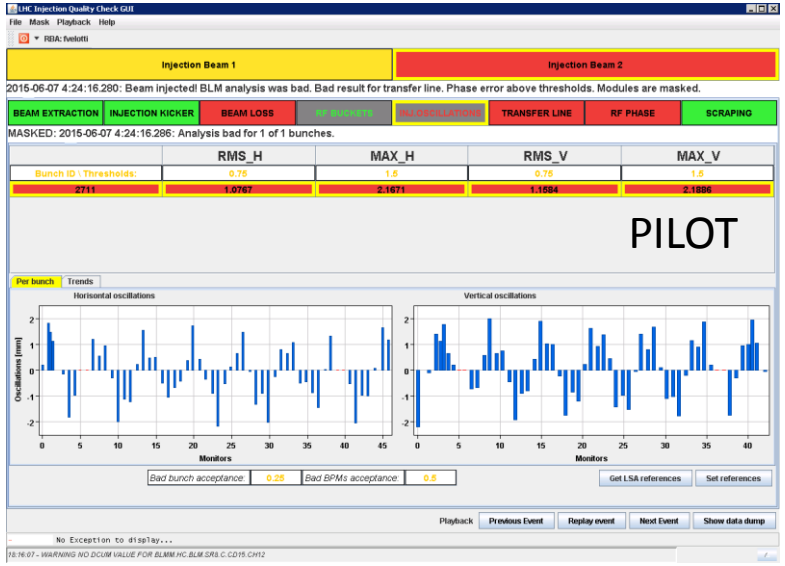
- Known issue: **different trajectories** for **fast-PILOT** and **slow-INDIV/25ns cycles** (slower ramp and different magnetization ➔ "different" extraction)
- **GOLDEN trajectory** defined with **INDIV**
- **TCDI setup and validation** done with **PILOT beam**

} Check difference in trajectory at TCDI < 0.5 σ

- "Bad" trajectory for PILOT beam in operation
- At the beginning of Run 2 the INDIV beam was on the FAST cycle ➔ almost same trajectory and injection oscillations for both beams (only difference due to BPM sensitivity) ➔ **GOLDEN trajectory established with INDIV on FAST** ➔ TCDI setup and validation done with this reference
- Moved to INDIV on SLOW beam process ➔ need to steer back to GOLDEN reference and a larger difference (>1mm) between PILOT and INDIV was observed wrt Run 1



PILOT Beam vs INDIV



Beam 2 Peak to peak injection oscillations:

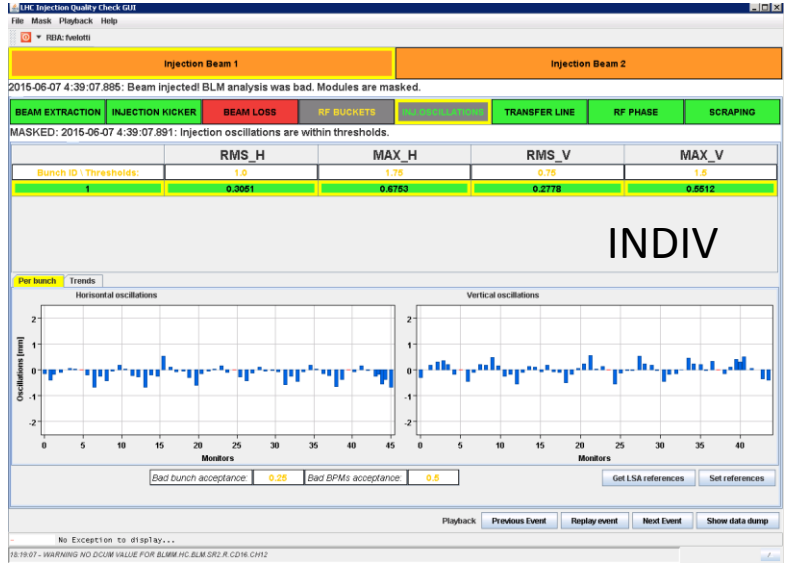
Pilot H = 3.8 mm
V = 4.1 mm

INDIV H = 1.3 mm
V = 0.6 mm

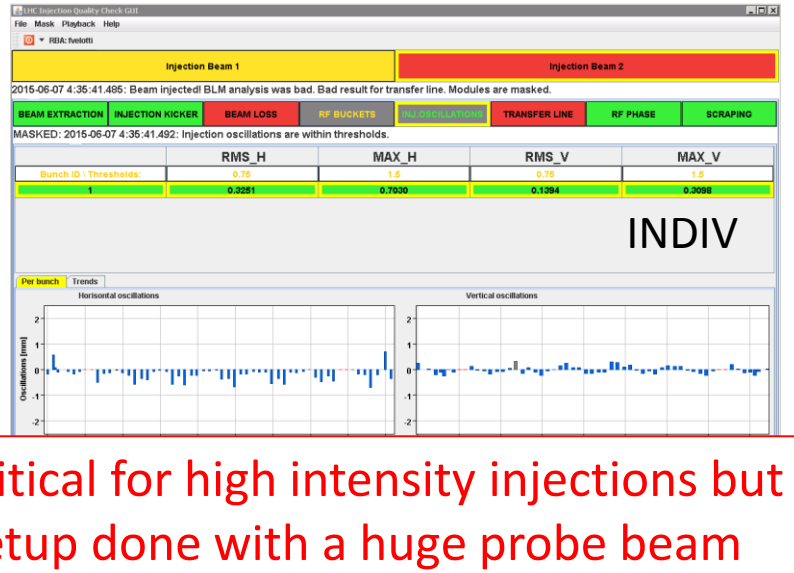
Beam 1 Peak to peak injection oscillations:

Pilot H = 8.4 mm
V = 1.6 mm

INDIV H = 1.2 mm
V = 1.2 mm



PILOT Beam vs INDIV

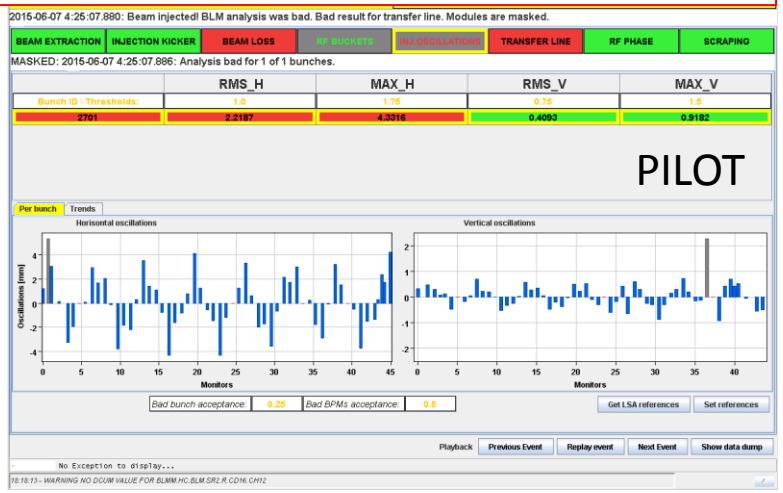


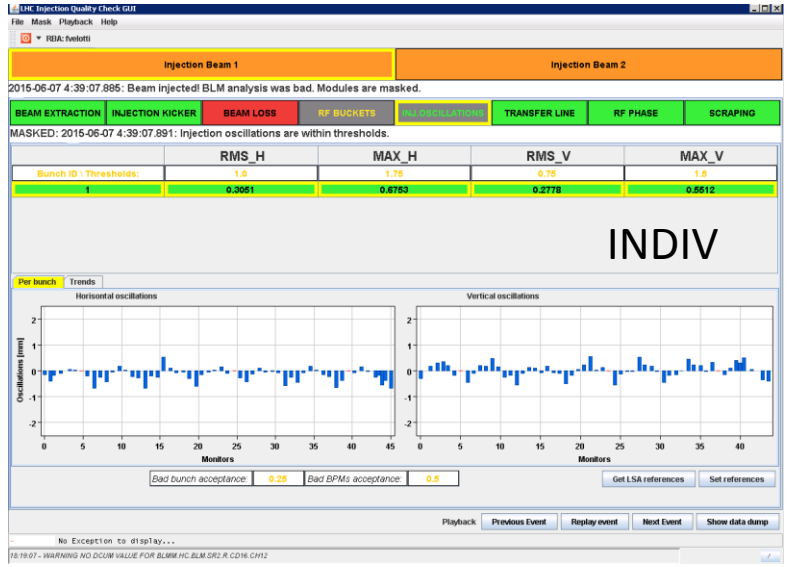
Beam 2 Peak to peak injection oscillations:

Pilot H = 3.8 mm
V = 4.1 mm

INDIV H = 1.3 mm
V = 0.6 mm

Not critical for high intensity injections but LHC setup done with a huge probe beam and IQC always failing.
Possible solution: PILOT on SLOW cycle





Beam 1 Peak to peak injection oscillations:

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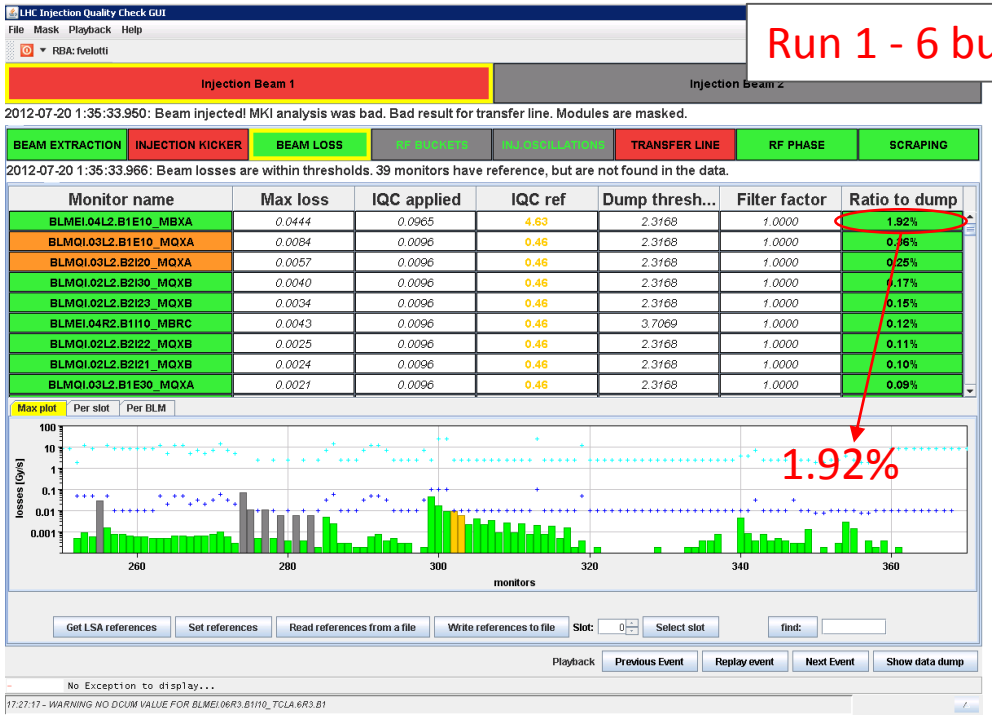
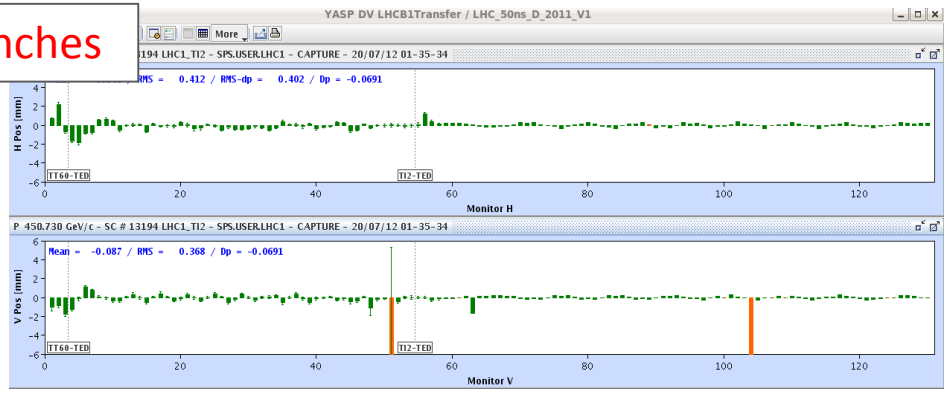
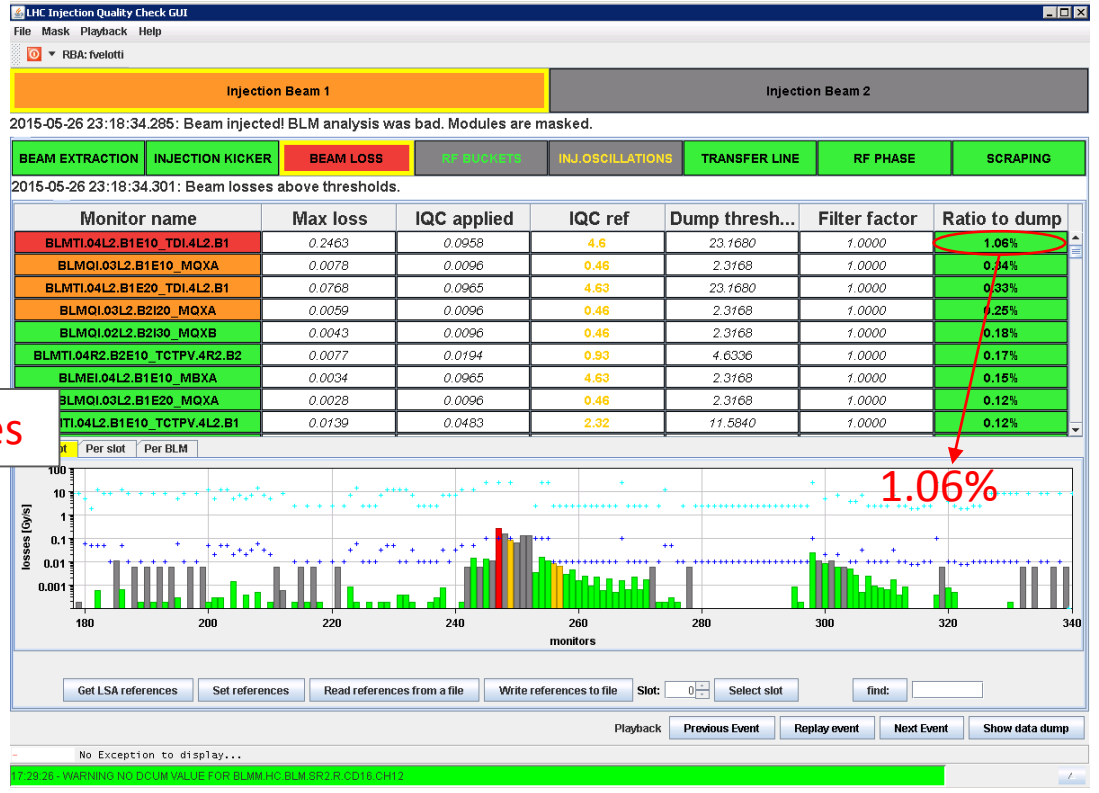
6 Bunches Injection Beam 1

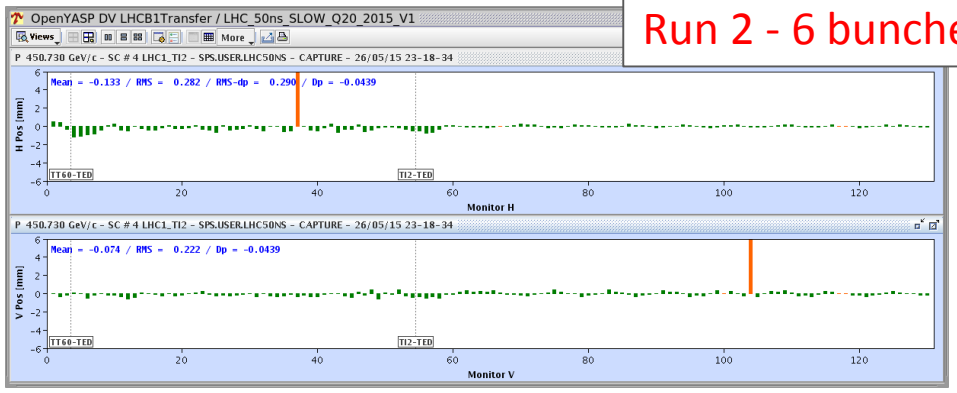
Run 1 - 6 bunches





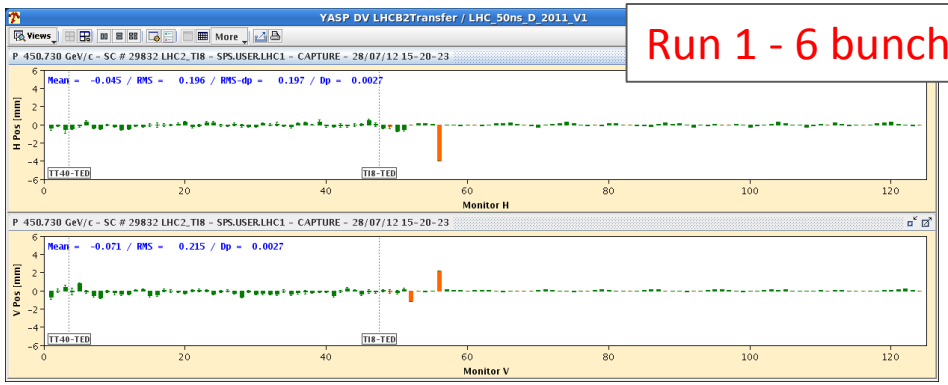
Run 2 - 6 bunches

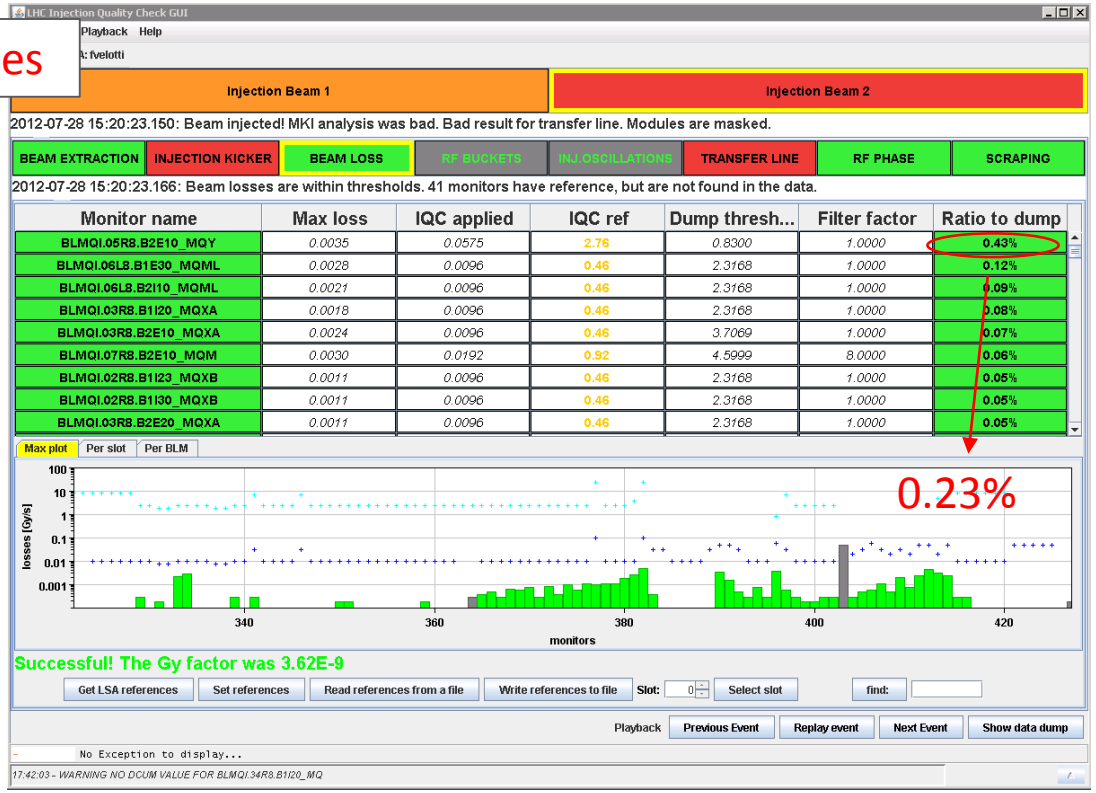




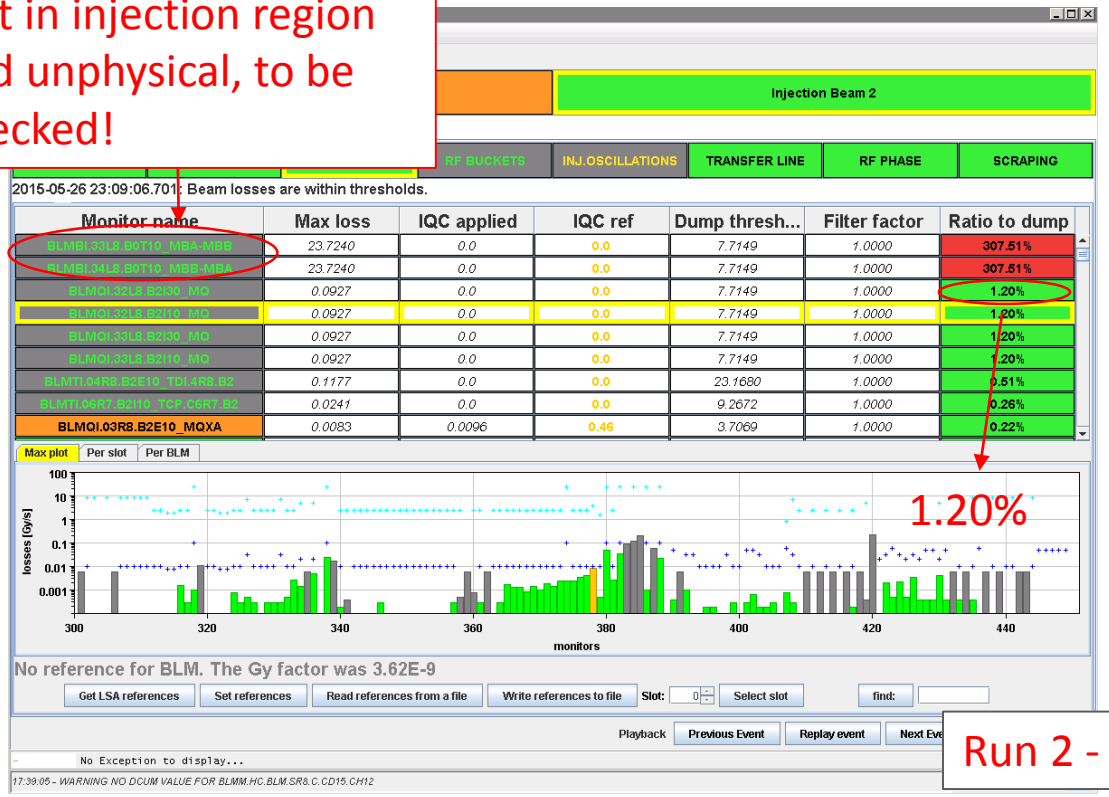
6 Bunches Injection Beam 2

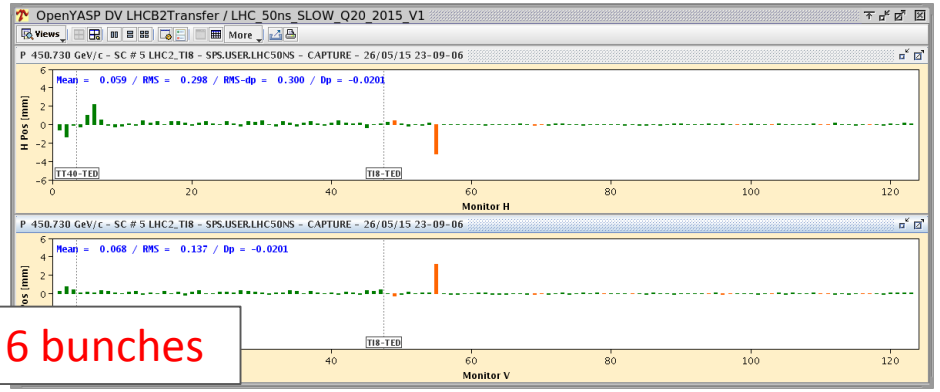
Run 1 - 6 bunches





Not in injection region and unphysical, to be checked!



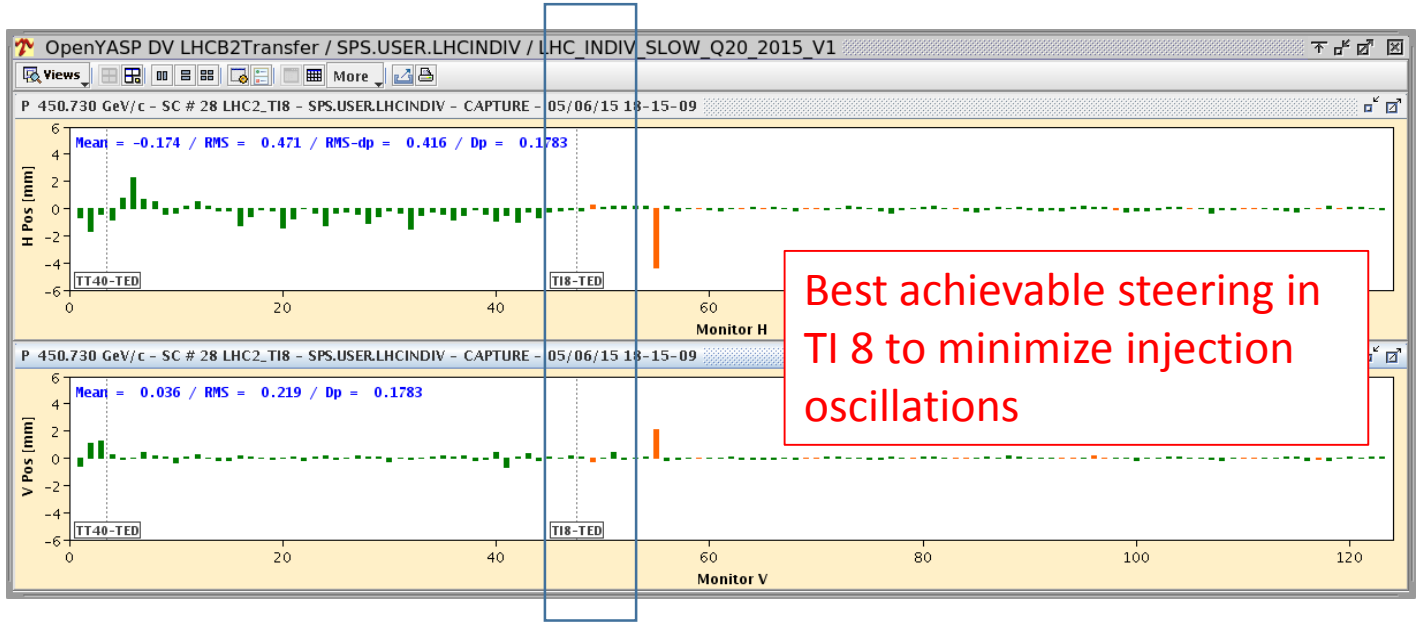


Run 2 - 6 bunches

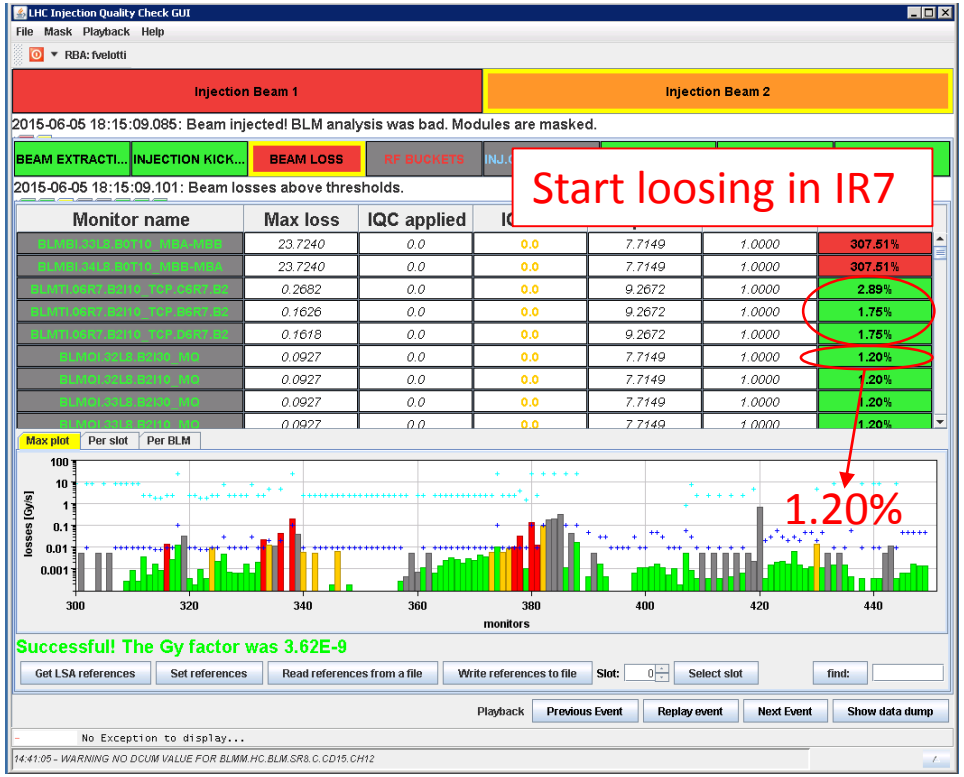
Bend Repaired in TI8

To be further investigated!!

- From LHCOP logbook 03/06/2015 14:41:
  - SPS: bend repaired in TI8. **RBI** in TI8 changed by 4 A*. To be checked next injections.



TL Collimators



* Intervention on Acquisition card to correct a 4 A offset (0.04%) between the DAQ and the Power converters to solve a FEI issue

Injection Losses: LIC vs IC

- Only up to 6 bunches injected ➔ low intensity and statistics!
- Mainly **LIC+Big filters** installed instead of the SEM
- **IC+Small filters** preferred in the injection region in view of possible need to blind most critical BLMs (removing filter!)

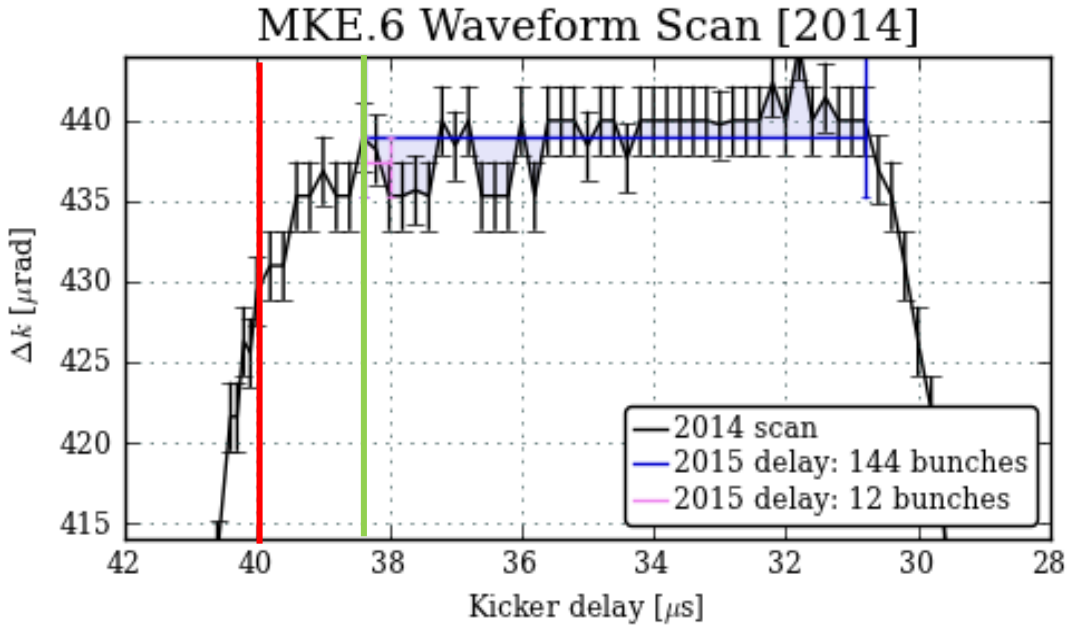
Before LS1

After LS1

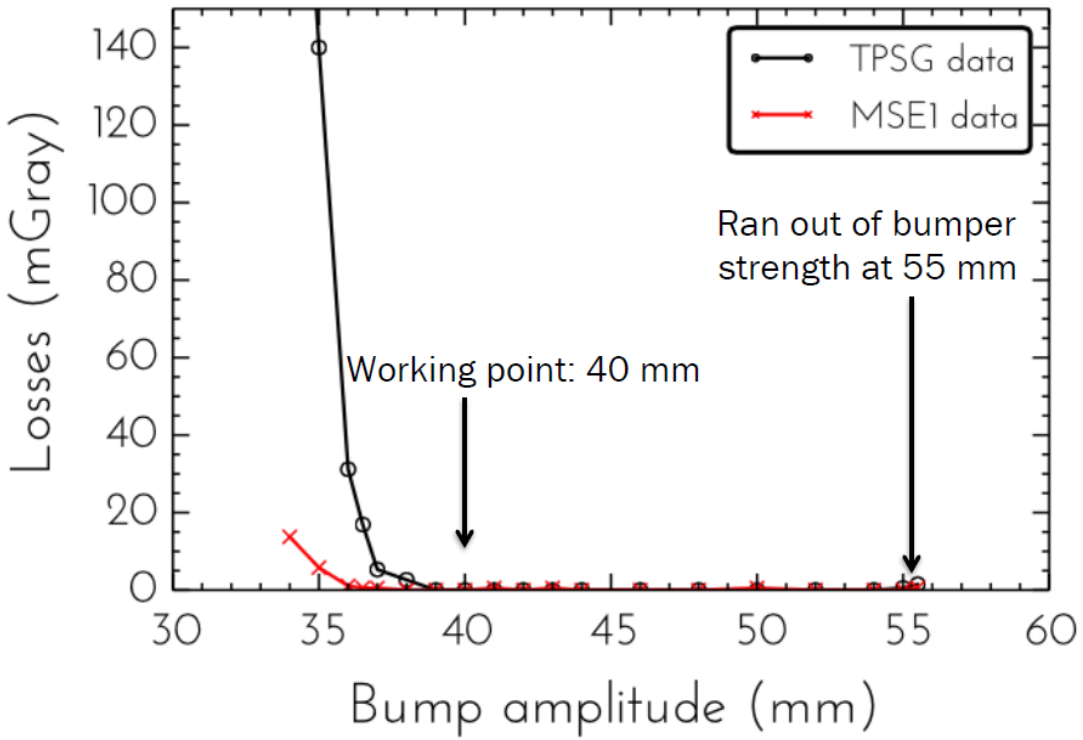
BLMQI.A9L2	BLMQI.08L2.B2I30_MQML	UJ22	HCBLM_I001-05003083	IC	HCBLM_I001-05003083	BJBAP.C8L2_1	BJBAP.C8L2	U	1	Not Installed				3022.6704	BLMQI.08L2.B2I30_MQML	no	1	IC+SF	BJBAP.C8L2
BLMQI.F8L2	BLMQI.08L2.B1E10_MQML	UJ22	HCBLM_I001-05003060	IC	HCBLM_I001-05003060	BJBAP.C8L2_2	BJBAP.C8L2	U	1	Installed	small	2200	150	3025.7604	BLMQI.08L2.B1E10_MQML	blind	1	IC+SF	BJSAP.B8L2, rename
BLMQI.E8L2	BLMQI.08L2.B2I20_MQML	UJ22	HCBLM_I001-05003956	IC	HCBLM_I001-05003956	BJBAP.C8L2_3	BJBAP.C8L2	U	1	Not Installed				3027.0434	BLMQI.08L2.B2I20_MQML	no	1	IC+SF	BJBAP.C8L2
BLMQI.D8L2	BLMQI.08L2.B1E20_MQML	UJ22	HCBLM_I001-05003006	IC	HCBLM_I001-05003006	BJBAP.C8L2_4	BJBAP.C8L2	U	1	Installed	small	2200	150	3028.2434	BLMQI.08L2.B1E20_MQML	blind	1	IC+SF	BJSAP.B8L2, rename
BLMQL.A8L2	BLMQL.08L2.B2I10_MQML	UJ22		0.4 LIC		BJBAP.C8L2_5	BJBAP.C8L2	U	1	Not Installed				3030.4154	BLMQL.08L2.B2I10_MQML	no	1	LIC	BJBAP.C8L2
BLMQI.B8L2	BLMQI.08L2.B1E30_MQML	UJ22	HCBLM_I001-05003333	IC	HCBLM_I001-05003333	BJBAP.C8L2_6	BJBAP.C8L2	U	1	Installed	small	2200	150	3032.9154	BLMQI.08L2.B1E30_MQML	blind	1	IC+SF	BJSAP.B8L2, rename
BLMEI.F8L2	BLMEI.08L2.B2I23_MBA	UJ22	HCBLM_I001-05003936	IC	HCBLM_I001-05003936	BJBAP.A8L2_1	BJBAP.A8L2	U	1	Not Installed				3035.0854	BLMEI.08L2.B2I23_MBA	no	1	IC	BJBAP.A8L2
BLMES.F8L2	BLMES.08L2.B2I23_MBA	UJ22	HCBLM_S001-05000337	SEM	HCBLM_S001-05000337	BJSAP.B8L2_1	BJSAP.B8L2	M	0	Not Installed				3035.0854	BLMEL.08L2.B2I23_MBA	no	0	LIC+BF	BJBAP.A8L2
BLMEI.E8L2	BLMEI.08L2.B2I22_MBA	UJ22	HCBLM_I001-05003094	IC	HCBLM_I001-05003094	BJBAP.A8L2_2	BJBAP.A8L2	U	1	Not Installed				3038.7354	BLMEI.08L2.B2I22_MBA	no	1	IC	BJBAP.A8L2
BLMES.E8L2	BLMES.08L2.B2I22_MBA	UJ22	HCBLM_S001-05000232	SEM	HCBLM_S001-05000232	BJSAP.B8L2_2	BJSAP.B8L2	M	0	Not Installed				3038.7354	BLMEL.08L2.B2I22_MBA	blind	0	LIC+BF	BJSAP.B8L2, rename
BLMEI.D8L2	BLMEI.08L2.B2I21_MBA	UJ22	HCBLM_I001-05003948	IC	HCBLM_I001-05003948	BJBAP.A8L2_3	BJBAP.A8L2	U	1	Not Installed				3042.1754	BLMEI.08L2.B2I21_MBA	no	1	IC	BJBAP.A8L2
BLMES.D8L2	BLMES.08L2.B2I21_MBA	UJ22	HCBLM_S001-05000327	SEM	HCBLM_S001-05000327	BJSAP.B8L2_3	BJSAP.B8L2	M	0	Not Installed				3042.1754	BLMEL.08L2.B2I21_MBA	blind	0	LIC+BF	BJSAP.B8L2, rename
BLMEI.C8L2	BLMEI.08L2.B2I30_MBB	UJ22	HCBLM_I001-05003082	IC	HCBLM_I001-05003082	BJBAP.A8L2_4	BJBAP.A8L2	U	1	Not Installed				3046.0354	BLMEI.08L2.B2I30_MBB	no	1	IC	BJBAP.A8L2
BLMES.C8L2	BLMES.08L2.B2I30_MBB	UJ22	HCBLM_S001-05000235	SEM	HCBLM_S001-05000235	BJSAP.B8L2_4	BJSAP.B8L2	M	0	Not Installed				3046.0354	BLMEL.08L2.B2I30_MBB	blind	0	LIC+BF	BJSAP.B8L2, rename
BLMEI.B8L2	BLMEI.08L2.B2I22_MBB	UJ23	HCBLM_I001-05003931	IC	HCBLM_I001-05003931	BJBAP.A8L2_5	BJBAP.A8L2	U	1	Not Installed				3051.4954	BLMEI.08L2.B2I22_MBB	no	1	IC	BJBAP.A8L2
BLMES.B8L2	BLMES.08L2.B2I22_MBB	UJ23	HCBLM_S001-05000354	SEM	HCBLM_S001-05000354	BJSAP.B8L2_5	BJSAP.B8L2	M	0	Not Installed				3051.4954	BLMEL.08L2.B2I22_MBB	blind	0	LIC+BF	BJSAP.B8L2, rename
BLMEI.A8L2	BLMEI.08L2.B2I21_MBB	UJ23	HCBLM_I001-05003426	IC	HCBLM_I001-05003426	BJBAP.A8L2_6	BJBAP.A8L2	U	1	Not Installed				3056.6954	BLMEI.08L2.B2I21_MBB	no	1	IC	BJBAP.A8L2
BLMES.A8L2	BLMES.08L2.B2I21_MBB	UJ23	HCBLM_S001-05000303	SEM	HCBLM_S001-05000303	BJSAP.B8L2_6	BJSAP.B8L2	M	0	Not Installed				3056.6954	BLMEL.08L2.B2I21_MBB	blind	0	LIC+BF	BJSAP.B8L2, rename
BLMQI.A8L2	BLMQI.07L2.B2I30_MQM	UJ23	HCBLM_I001-05003986	IC	HCBLM_I001-05003986	BJBAP.A7L2_1	BJBAP.A7L2	M	1	Not Installed				3061.6954	BLMQI.07L2.B2I30_MQM	no	1	IC	BJBAP.A7L2
BLMQI.F7L2	BLMQI.07L2.B1E10_MQM	RH23	HCBLM_I001-05003057	IC	HCBLM_I001-05003057	BJBAP.A7L2_2	BJBAP.A7L2	M	1	Installed	small	2200	150	3064.8254	BLMQI.07L2.B1E10_MQM	no	1	IC+SF	BJBAP.A7L2
BLMQI.E7L2	BLMQI.07L2.B2I20_MQM	RH23	HCBLM_I001-05003942	IC	HCBLM_I001-05003942	BJBAP.A7L2_3	BJBAP.A7L2	M	1	Not Installed				3067.2489	BLMQI.07L2.B2I20_MQM	no	1	IC	BJBAP.A7L2
BLMQI.D7L2	BLMQI.07L2.B1E20_MQM	RH23	HCBLM_I001-05003034	IC	HCBLM_I001-05003034	BJBAP.A7L2_4	BJBAP.A7L2	M	1	Installed	small	2200	150	3068.4489	move to MB interconnect cell 8	no	1	IC+SF	BJBAP.A7L2
BLMQI.C7L2	BLMQI.07L2.B2I10_MQM	RH23	HCBLM_I001-05003363	IC	HCBLM_I001-05003363	BJBAP.A7L2_5	BJBAP.A7L2	M	1	Not Installed				3071.8154	BLMQI.07L2.B2I10_MQM	no	1	IC	BJBAP.A7L2
BLMQI.B7L2	BLMQI.07L2.B1E30_MQM	RH23	HCBLM_I001-05003038	IC	HCBLM_I001-05003038	BJBAP.A7L2_6	BJBAP.A7L2	M	1	Installed	small	2200	150	3075.3654	BLMQI.07L2.B1E30_MQM	blind	1	IC+SF	BJBAP.A6L2

Extraction Issues in LSS6

- High losses when extracting HiRadMat beam (12 bunches)
- Found out:
  - **Not optimum delay** between Beam and MKE pulse (40 instead of 38.5 μs) ➔ corrected
  - **Drift of the orbit** at the extraction point by 2.5 mm ➔ corrected and extraction bump from 40 mm to 42 mm



Proposed delay 38.5 μs



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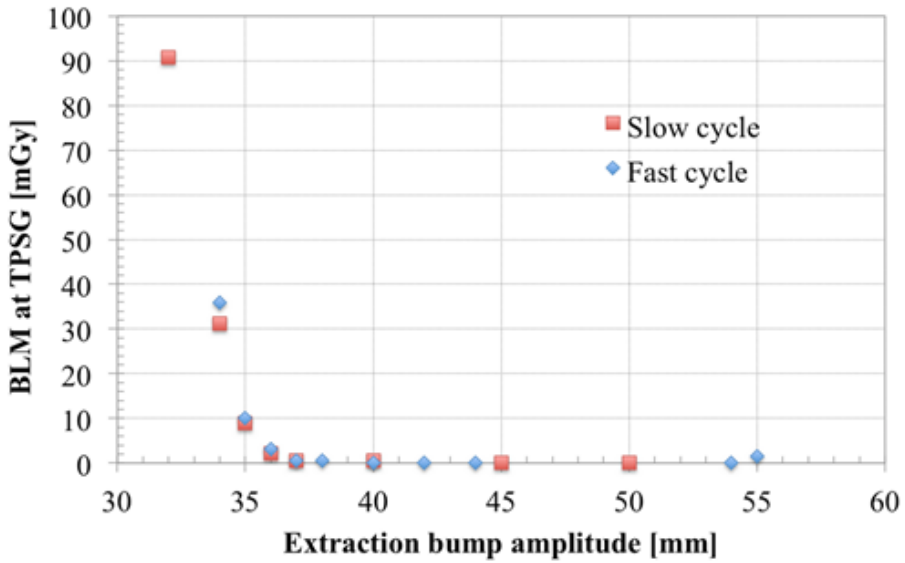
- This did not solve the extraction problem and we realised that losses were only present for nominal bunch on LHC25ns cycle but not on PILOT cycle
  - Measure extraction aperture for both cycles ➔ no difference
  - Measured MKE delay for both cycles ➔ no difference



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  - Measure extraction aperture for both cycles ➔ no difference
  - Measured MKE delay for both cycles ➔ no difference
- Found out that main problems:
  - LHC25ns was not fully set up: uncaptured beam kicked out by longer rise time of MKE6 wrt MKE4➔ corrected
  - The MKP generators not properly adjusted and 250 ns rise time not yet possible ➔ not possible to extract 4 batches on the LSS6 flattop waveform (too short: 8 us) ➔ possible to increase MKE6 flattop during Xmas stop (also in view of 80 bunches and BCMS)
  - HiRadMat beam-MKE synchronization ➔ corrected

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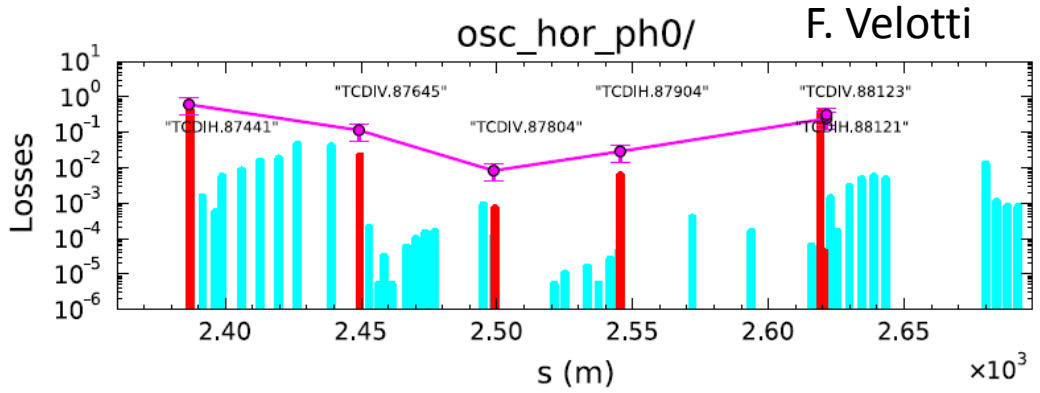
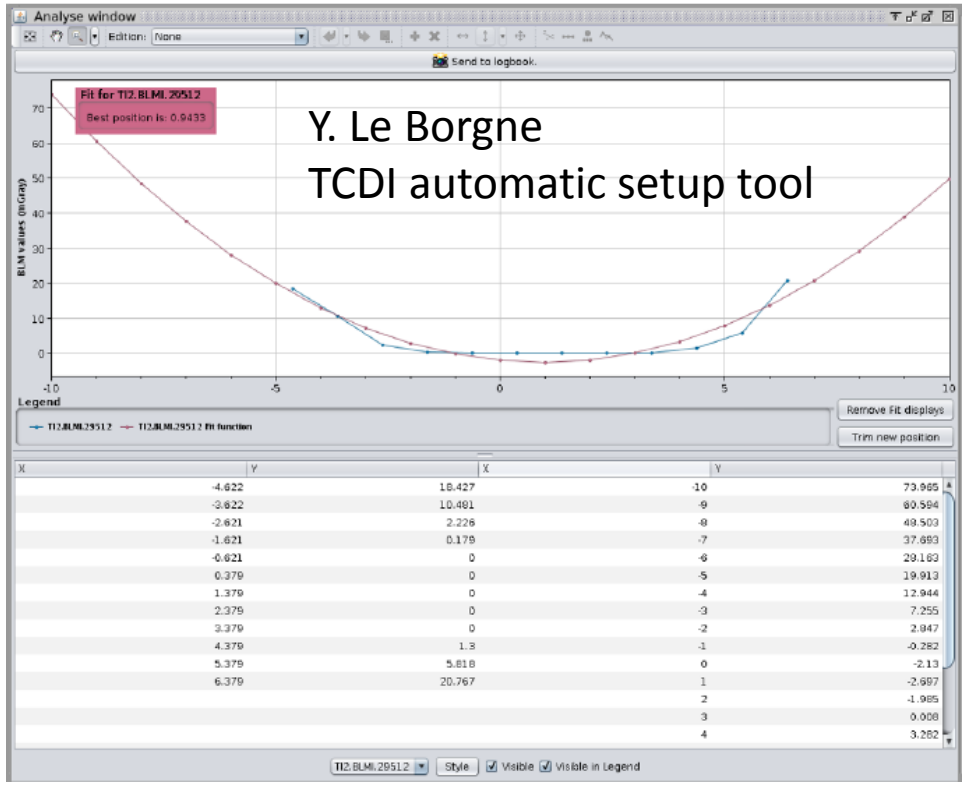
  - HiRadMat beam-MKE synchronization ➔ corrected

- Orbit drifts at extraction point are still a non fully understood issue ➔ strong impact on TL stability (BPCE resolution not enough for fine interlock)
- Possible solution: beam position at BPCE extrapolated from SPS orbit in IQC ➔ monitor orbit drift and improve TL and injection diagnostics in case of problems

Injection Protection Collimators

- TDI, TCLIA/B and TCDI are **set up** and **fully validated**
- Now **straightforward procedures** for setup and validation
- Effective time (**PROVIDED BEAM AVAILABILITY**) reduced from 1 shift per TL down to 3 hours
- "Position" and "Energy" **dump thresholds set up** to:
  - TDI and TCLIA/B: position±0.25σ, gap+1σ
  - TCDI: position±0.5σ, gap+1σ
- TDI **BETS interlock** thresholds set to gap±1.5σ

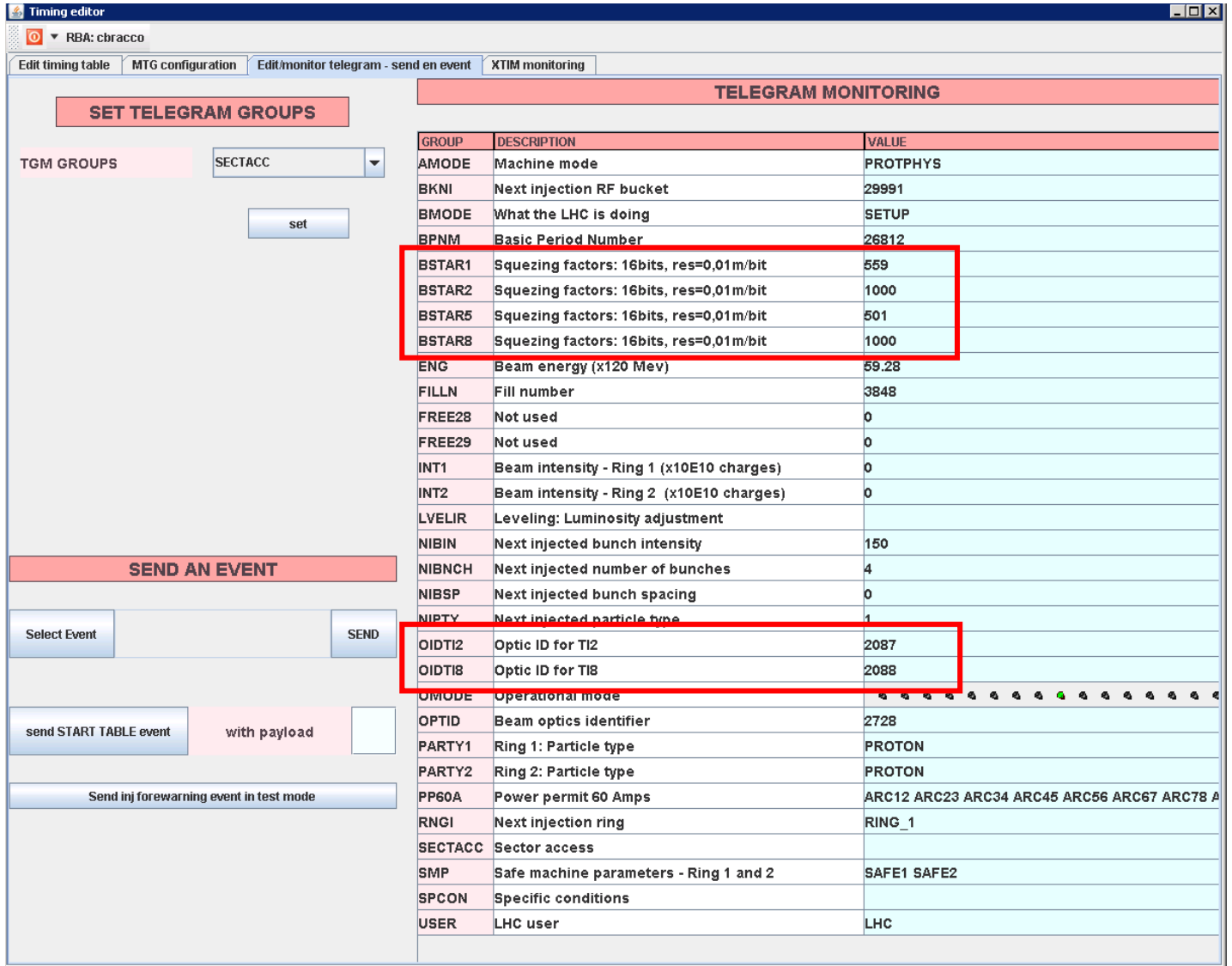




Optics ID for TCDI

- Aim: check the **TL optics** and verify that **TCDI settings** are correct for that optics
- Proposed to adapt β* interlock used for the ring collimators:
  - All/some **TL quad currents** defined as **critical settings** in LSA **V**
  - Associate a **unique ID** **V**
  - Distribute it through timing system **V**
  - Define TCDI thresholds and specifications **X**
  - Control implementation **X**

The FESA class has to be modified: a new "Active_IP" has to be added which checks the OIDTI2/8 telegram instead of the BSTAR1/2/5/8 telegram ➔ impact on ring collimators ➔ repeat MP checks also for them!
Not ready to be implemented in TS1



Missing Optics ID Critical for High Intensity?

- TCDI settings (aperture) depend on the TL optics
- In the past when changing from Q26 to Q20 optics it was not caught that the optics change was affecting the region were TL collimators are ➔ one TCDI with gap larger than 5 σ ➔ poorer protection
- Now **system setup, validated and reference defined ➔ protection for injection of high intensity beam is granted** (other checks are performed and prevent extraction if magnet currents are wrong).
- Still important to implement this interlock in view of **future possible optics changes**. When? TS or Xmas stop? It has to be defined **which MP checks** have to **be repeated**: all? Only β^*? For **all ring collimators or a sample**?

TDI Limits

- TDI hBN block cannot withstand temperatures higher than 450 ◦C (B_2O_3 reactant melting temperature) ➔ limit the maximum number of bunches which can hit the TDI (maximum allowed temperature = 400 ◦C)

Beam type	Bunch/Doublet intensity	Emittance (um rad)	Bunch/Doublet spacing (nsec)	Bunches/Doublets per batch	1 batch	2 batches	3 batches	4 batches
Standard 25 nsec	1.20E+11	2.6	25	72	*72 (1.8 usec)* 206 deg C	*144 (3.8 usec)* 352 deg C	*216 (5.8 usec)* 483 deg C	*288 (7.8 usec)* 606 deg C
BCMS	1.30E+11	1.3	25	48	*48 (1.2 usec)* 239 deg C	*96 (2.6 usec)* 408 deg C	*144 (4.0 usec)* 560 deg C	
50 nsec	1.20E+11	1.5	50	36	*36 (1.8 usec)* 160 deg C	*72 (3.8 usec)* 277 deg C	*108 (5.8 usec)* 378 deg C	*144 (7.8 usec)* 473 deg C
Doublet(*)	1.60E+11	4	25	72	*72 (1.8 usec)* 212 deg C	*144 (3.8 usec)* 363 deg C		

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- Consequences:
  - **Limit** number of **injected bunches**
  - **Increase number of injection**
  - **Limit maximum number of circulating bunches** (maximum reachable with 25 ns beam: 2448 instead of 2736, B. Gorini LMC 13/05/2015)

- How to insure that no more than 144 bunches hit the TDI when operating with 25 ns beam?
  - **Reduce length** of **injection kicker** to 3.8 μs (erratic on circulating beam)
  - **Reduce length** of the **SPS flat-bottom of LHC cycle**

- A new TDI with graphite instead of hBN will be installed during the next Xmas stop.

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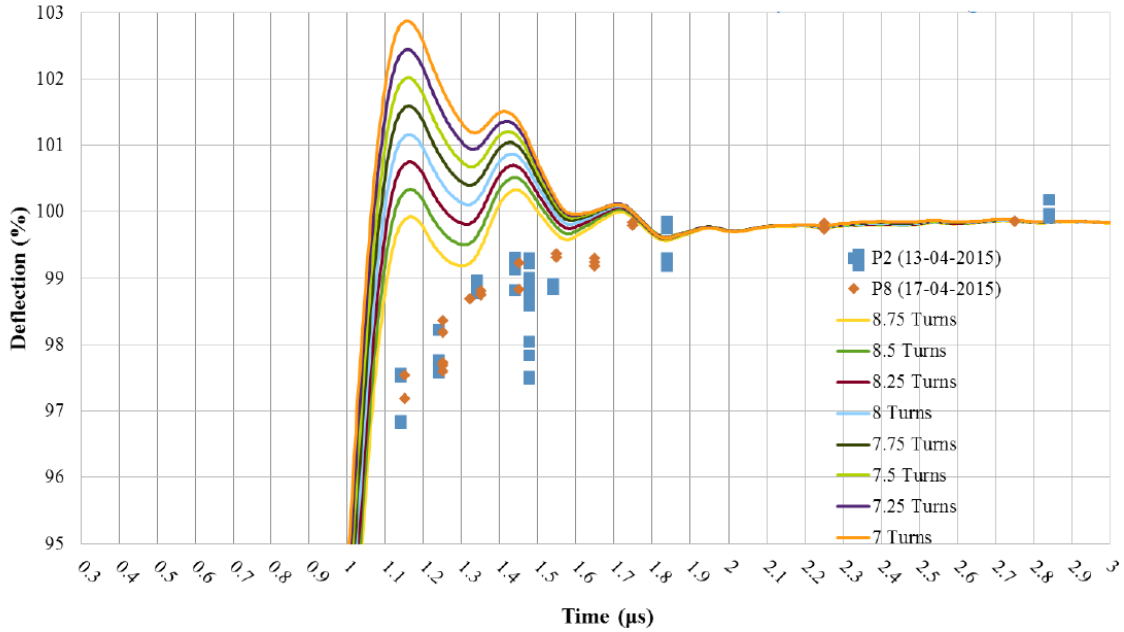
Critical topic: flip between 25 ns and 50 ns configuration!

MKI Waveform

- Measured an **MKI rise time**, both in IR2 and IR8, **longer than nominal** (1.2 μs instead of 0.9μs) and thus a shorter flattop (possible to adjust)
- The **number** of the **MS end turns** were **increased** in April 2010 from 8.25 to 8.75 to **reduce the overshoot**
- Wrt to LS1 the **TMR resistance is reduced** and the **number of screen conductors increased** ➔ undershoot
- New calculations were done taking into account all these effects and the **optimum number of MS end turns calculated** (7.25)
- This change will be implemented during TS1
- A new waveform scan will have to be performed



Summary

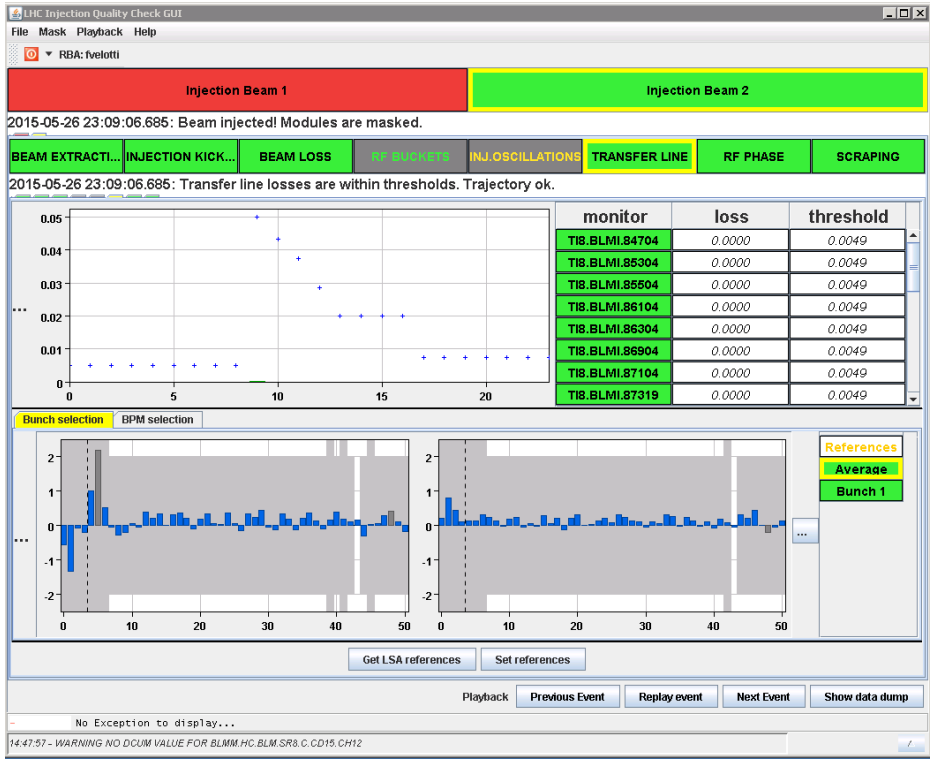
- Large difference between PILOT and INDIV/25ns ➔ **bad trajectories** and **injection oscillations** for **PILOT** (used to set up the LHC): **Not critical for MP** but **not ideal for operation**. Proposal: put **PILOT** on **SLOW cycle**
- **Injection losses** of the **same order of Run 1** (only 6 bunches injected!). Still too low intensity to draw conclusions about LIC and need of BLM blinding.
- **Large trajectory drift in H plane** after fixing a DAQ problem for **TI 8 bends**. **Not critical for MP**, no increase in injection losses (but losses appearing in IR7) and possible to steer on injection oscillations. **Not reassuring for operation**: GOLDEN reference could be no more valid if this happens again!
- **Orbit drifts** of few mm affect the **SPS extraction** point and have a big **impact on TL stability**. **Not critical for MP** but **frequent steering** is expected to be needed. Proposal: monitor losses and orbit drifts in IQC to improve diagnostics (possible future interlock on next extraction)
- All injection **protection collimators set up and validated**. **Optics_ID** for TCDI **not yet in place** (need to modify FESA class and revalidation also for ring collimators). **Not critical for MP** since needed only in case of optics change.
- **TDI hBN block** fragility **limits the number of injected** (and circulating) **bunches**. **Critical for MP** since an adequate **strategy** has to be put in place **to insure the correct flip between 25 ns and 50 ns settings** (MKI pulse and SPS flat-bottom length)
- **MKI rise time** will be restored to its **nominal value after TS1**, to be checked with measurements.

Ready to start with high intensity beams with some care!

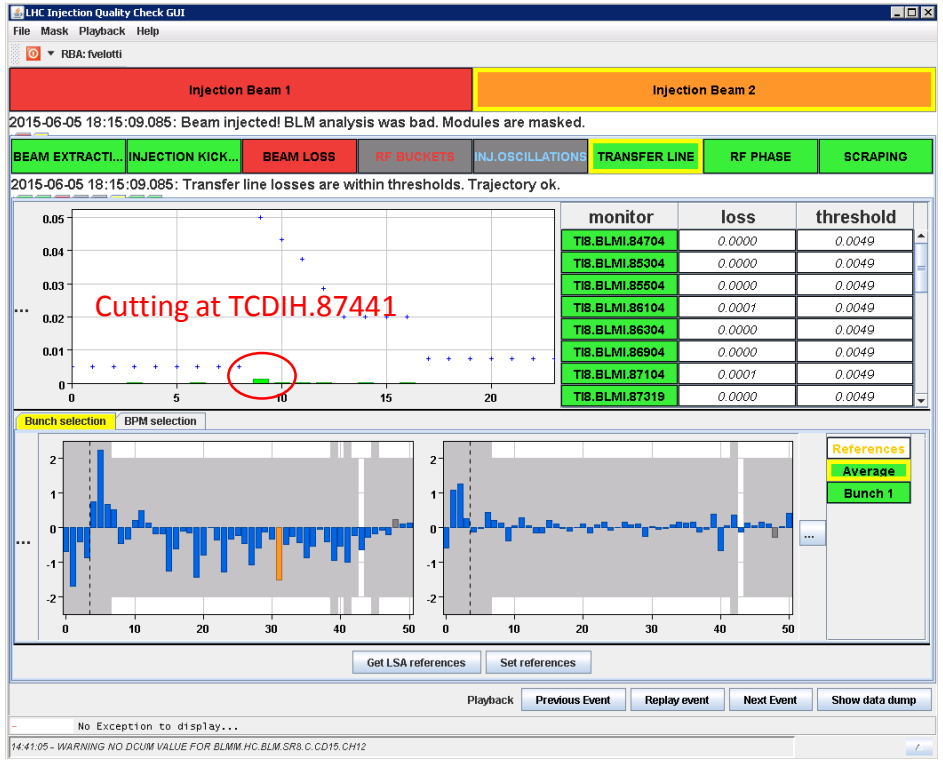
Thanks a lot for your attention!

TL Comparison

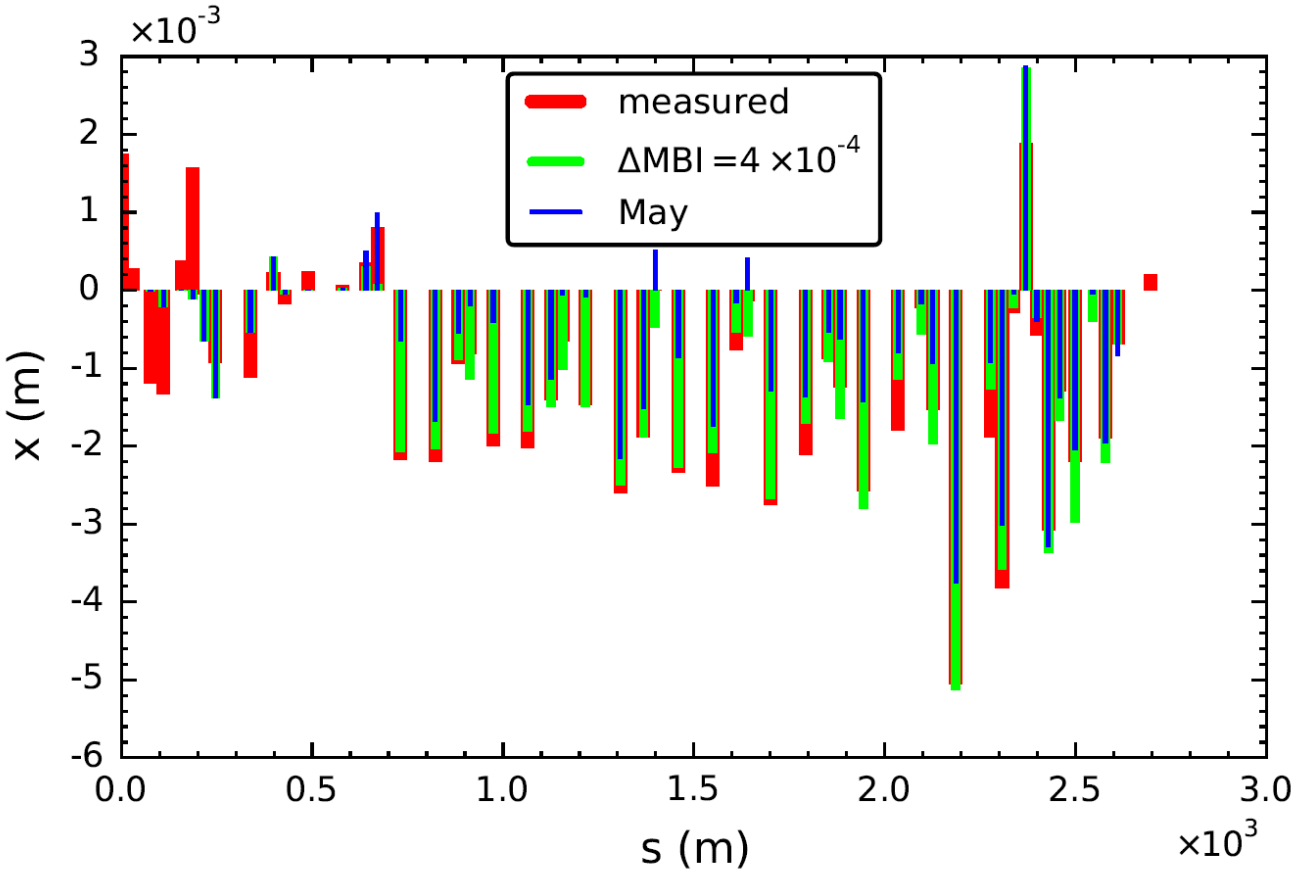
Before RBI change



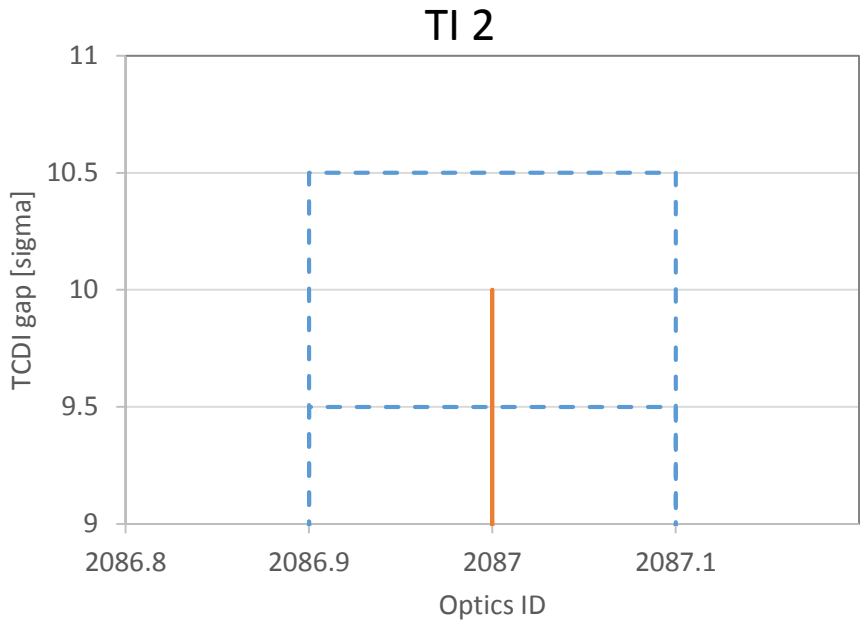
After RBI change

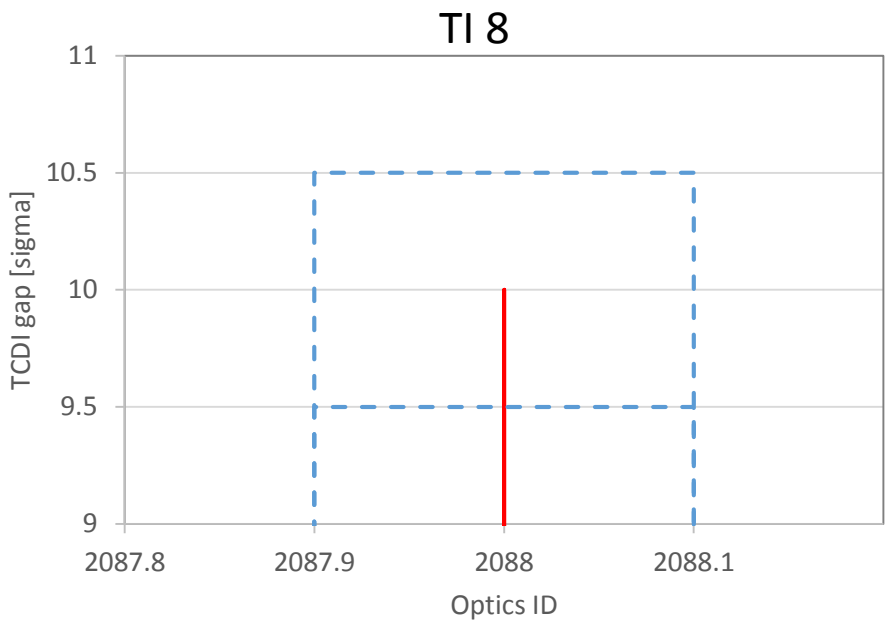


Real 4 A Current Change?



Proposal for TCDI Threshold Tables





Optics_ID	GU_IN [mm]	GD_IN [mm]	GU_OUT [mm]	GD_OUT [mm]
2086.9	9.5	9.5	10.5	10.5
2087	9.5	9.5	10.5	10.5
2087.1	9.5	9.5	10.5	10.5

Optics_ID	GU_IN [mm]	GD_IN [mm]	GU_OUT [mm]	GD_OUT [mm]
2087.9	9.5	9.5	10.5	10.5
2088	9.5	9.5	10.5	10.5
2088.1	9.5	9.5	10.5	10.5

For simplicity it is assumed 1 σ = 1 mm (thresholds = gap +/-0.5 σ)