HOW TO OBTAIN CLEAN INJECTIONS

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for TE-ABT

with many inputs from T. Bohl, B. Dehning, L. Drosdal, V. Kain, R. Steerenberg, O. Stein, …

Outline

- Injections in 2015
- Transversal losses
- Longitudinal losses
  - Diamond based beam loss monitors
  - Loss mitigations
- Conclusion

144 bpi, 25 ns, 2015

In 2015:
Up to 93 % dump threshold on the TDI was reached.

Injection Beam 1 | Injection Beam 2

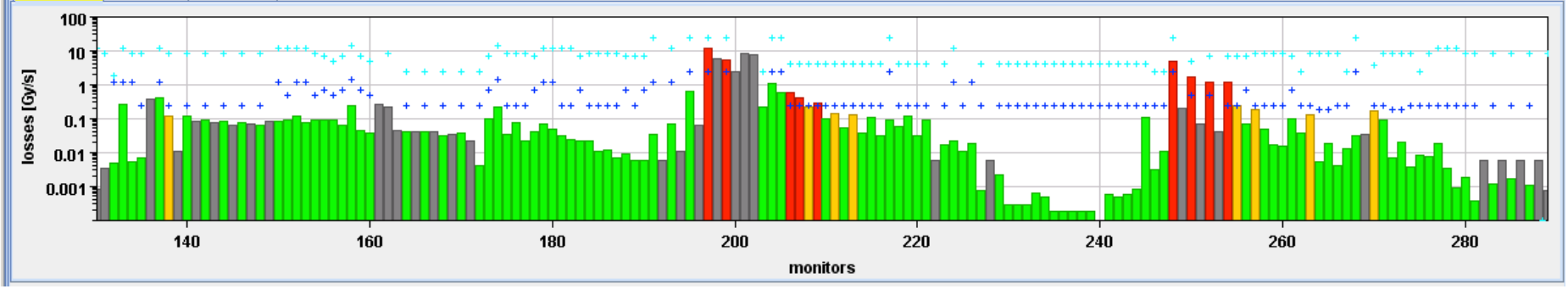
2015-11-08 1:09:58.285: Beam injected! BQMs: Injected 144 bunches(444 bunches circulating). BLM analysis was bad.

BEAM EXTRACTION | INJECTION KICKER | BEAM LOSS | RF BUCKETS | INJ.OSCILLATIONS | TRANSFER LINE | RF PHASE | SCRAPING

2015-11-08 1:09:58.301: Beam losses above thresholds.

Monitor name	Max loss	IQC applied	IQC ref	Dump threshold	Ratio to dump
BLMTI.04L2.B1E10_TDI.4L2.B1	11.0008	2.3000	4.6	23.1680	47.48%
BLMTI.04R2.B2E10_TCTPV.4R2.B2	1.6295	0.4650	0.93	4.6336	35.17%
BLMTI.04L2.B1E20_TDI.4L2.B1	4.9981	2.3150	4.63	23.1680	21.57%
BLMTI.04R2.B1I10_TCLIA.4R2	4.7464	2.3150	4.63	23.1680	20.49%
BLMEI.04R2.B1I10_MBRC	1.1774	0.2300	0.46	6.9504	16.94%
BLMTI.04R2.B2E10_TCTPH.4R2.B2	1.1123	0.4650	0.93	6.9504	16.00%
BLMQI.03L2.B1E10_MQXA	0.5654	0.2300	0.46	3.8459	14.70%
BLMQI.03L2.B2I20_MQXA	0.3777	0.2300	0.46	3.8459	9.82%
BLMEI.04L2.B1E10_MBXA	0.2177	2.3150	4.63	2.3168	9.40%

Max plot | Per slot | Per BLM



144 bpi, 25 ns, **2012**

Injected up to 288 bunches with factor 25 smaller loss level at TDI

RBA: lhcop Beam 1: Beam 2: Last injection: Be

Injection IR2 | Injection IR8

2012-07-10 11:47:43.550: Beam injected! BQMs: Injected 144 bunches(240 bunches circulating).

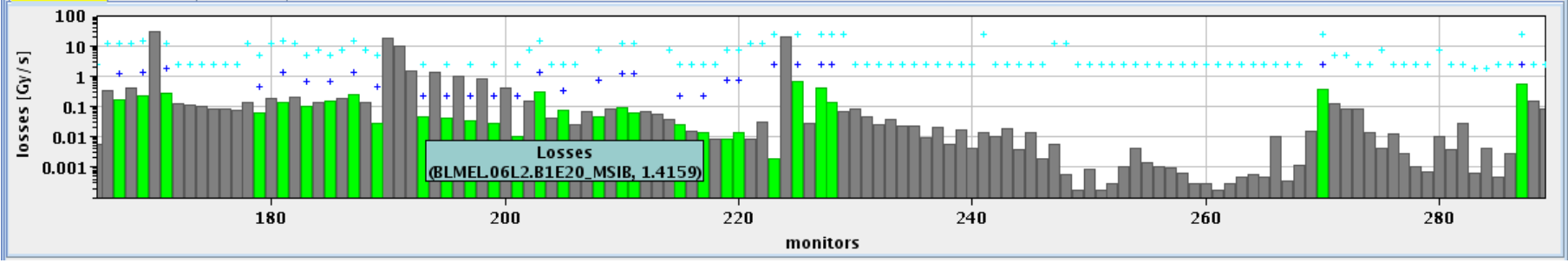
BEAM EXTRACTION | INJECTION KICKER | BEAM LOSS MONITO... | RF BUCKET CHECK | INJECTION OSCILLAT... | TRANSFER LINE | RF PHASE

2012-07-10 11:47:43.566: Beam losses are within thresholds.

Monitor name	Max loss	Applied thre...	IQC ref	Dump thresh...	Filter factor	Ratio to dump
BLMQI.06R2.B2E30_MQML	0.1448	0.0	0.0	2.3168	1.0000	6.25%
BLMEI.08L2.B2I23_MBA	0.1227	0.0	0.0	2.3168	1.0000	5.30%
BLMEI.08L2.B2I22_MBA	0.1135	0.0	0.0	2.3168	1.0000	4.90%
BLMEI.08L2.B2I21_MBA	0.0980	0.0	0.0	2.3168	1.0000	4.23%
BLMEI.08L2.B2I22_MBB	0.0853	0.0	0.0	2.3168	1.0000	3.68%
BLMQI.06R2.B1I10_MQML	0.0836	0.0	0.0	2.3168	1.0000	3.61%
BLMQI.03L2.B1E10_MQXA	0.0834	0.0	0.0	2.3168	1.0000	3.60%
			0.0	2.3168	1.0000	3.56%
			0.0	11.5840	1.0000	3.53%

Losses dominated from TL shower

Max plot | Per slot | Per BLM



Reminder - Transversal losses

- During Run 1 operation, **TLs orbit drifts** have been observed, together with large **shot-to-shot trajectory variations**.
- The main source of shot-to-shot orbit variation in the SPS-to-LHC TLs was identified and also mitigated. Investigations with Model Independent Analysis (MIA) revealed the **SPS extraction septa** as the main source for both lines. At the end of 2011 work was started to improve the power converter of the MSE.6 (TI2) which lead to **improved stability**. Work continued on the MSE.4 during LS1.
- The main source of trajectory drift was considered to be the **SPS orbit variation**.

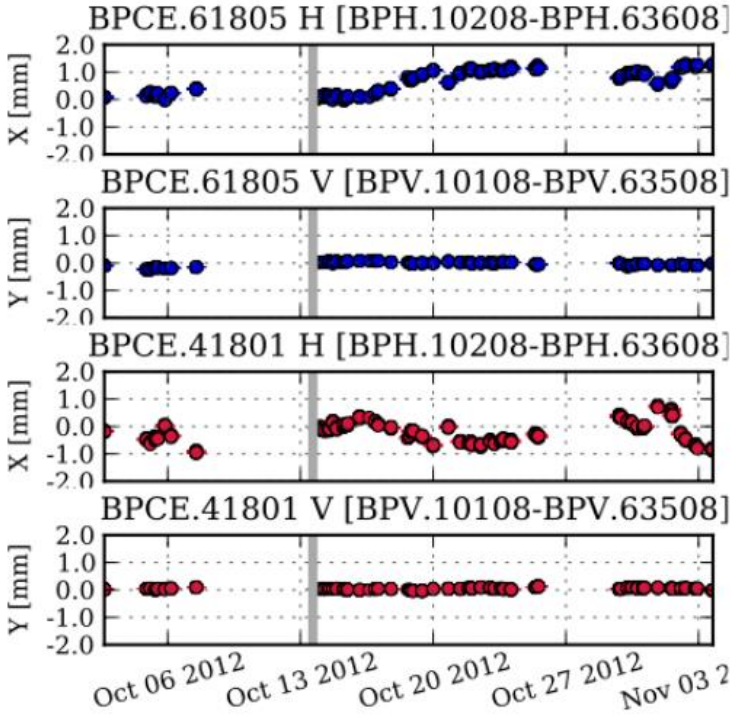
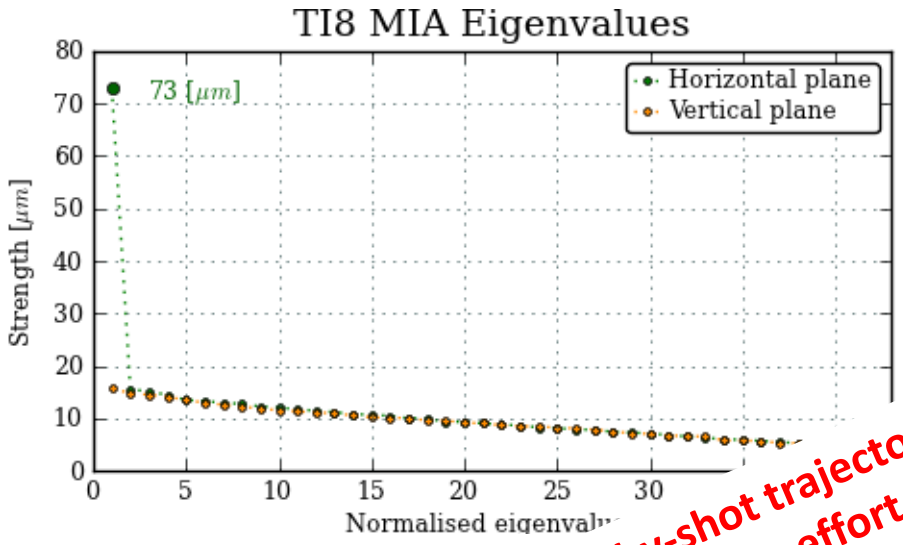


Figure 1: The orbit variation calculated at BPCE.61805 (TI 2) and BPCE.41801 (TI 8) shows a significant drift in the horizontal plane with respect to the reference orbit (grey line).

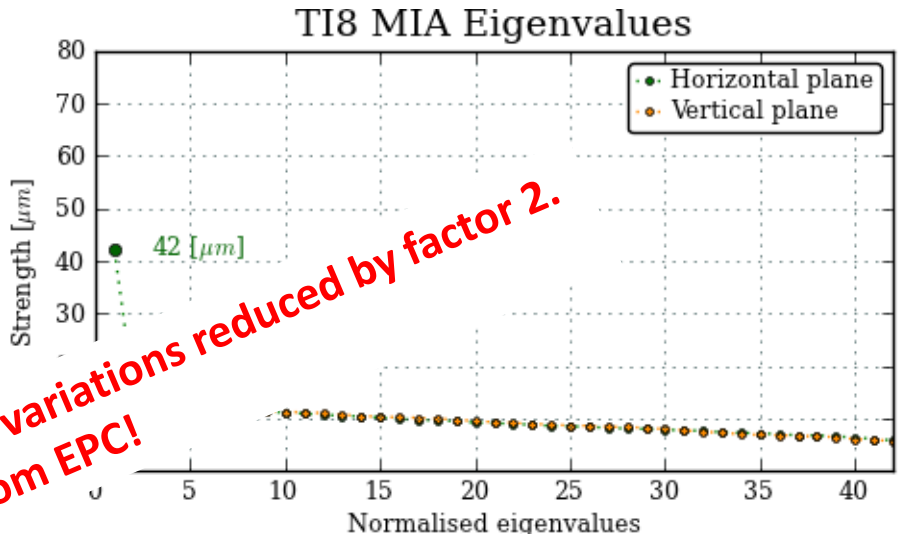
L. Drosdal et al., "Analysis of LHC Transfer Line Trajectory Drifts", IPAC'13
L. Drosdal et al., "Sources and Solutions fot LHC Transfer Line Stability Issues", IPAC'12

Results MIA for TI2 and TI8

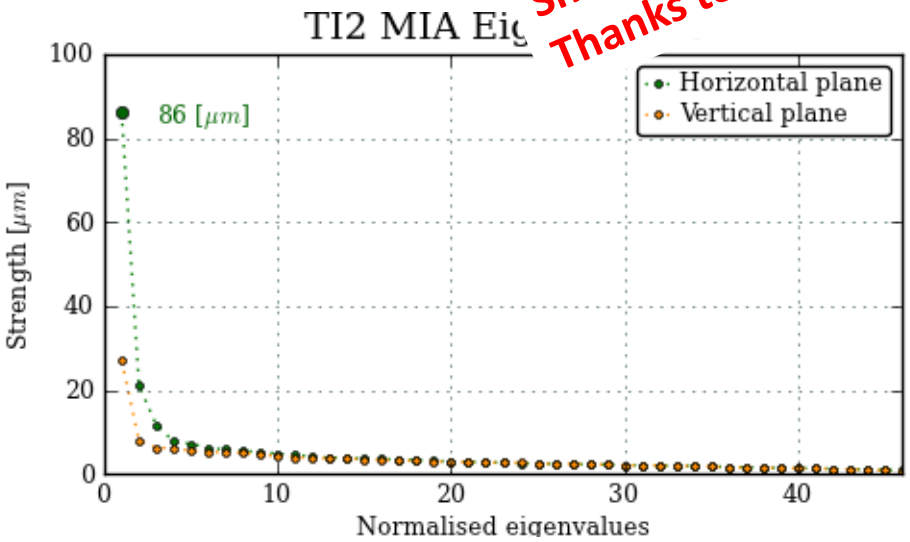
APRIL 2012

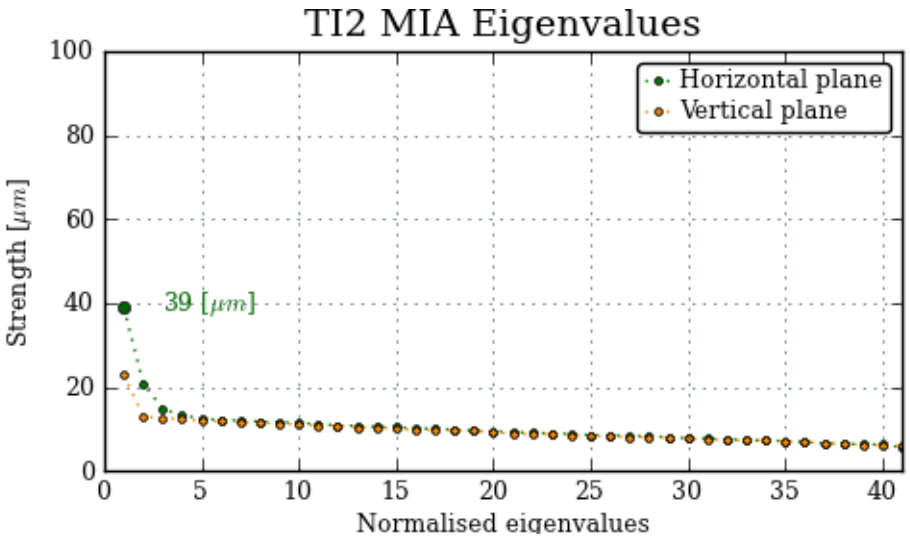


NOVEMBER 2014

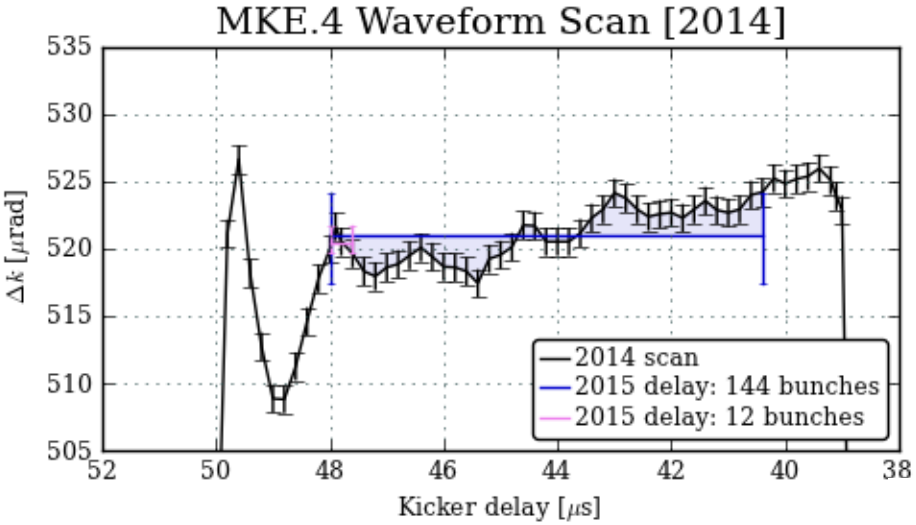


Shot-by-shot trajectory variations reduced by factor 2.
Thanks to big effort from EPC!

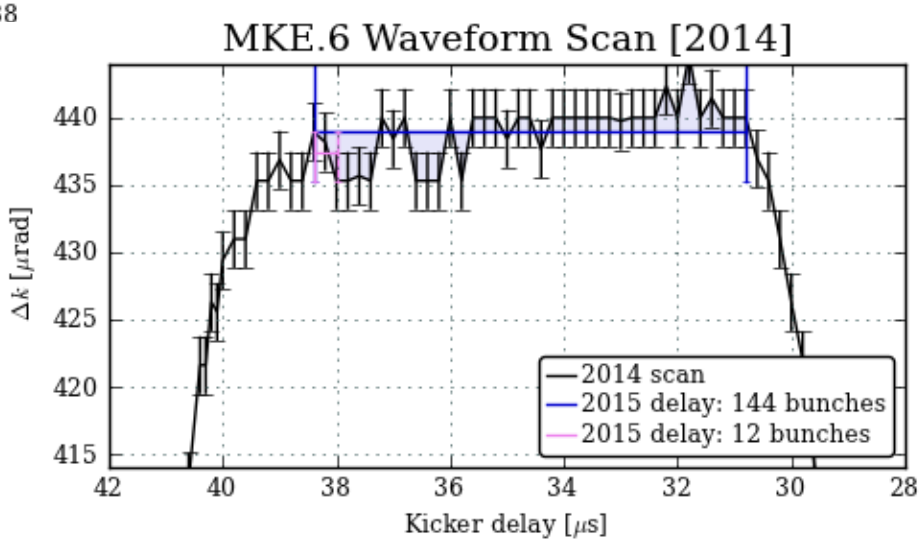




MKE waveform scans



- MKE.4 waveform improved, but not as much as expected
  - Optimised delay: **48.1 μs**



- MKE.6 waveform is flat (no change)
  - Optimised delay: **38.5 μs**

Note: MKE4 generators will be modified during YETS!

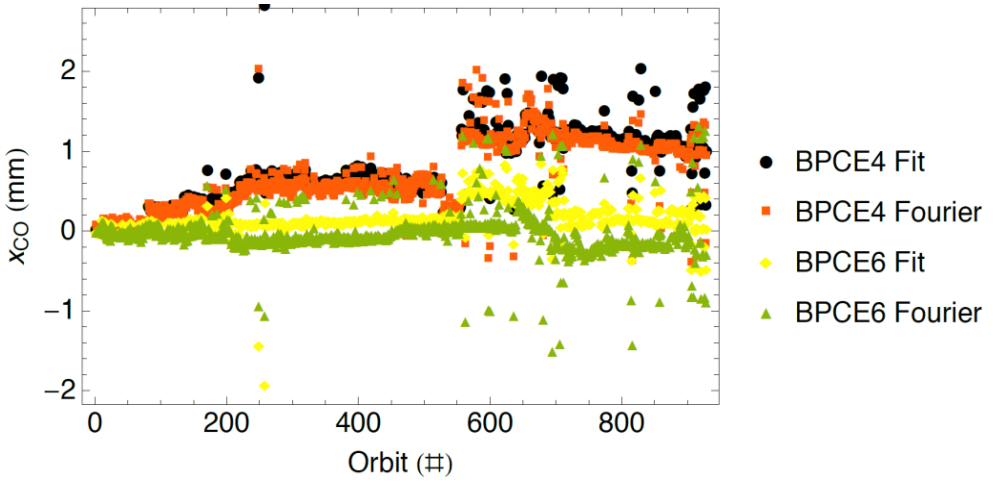
Transversal losses – orbit drifts

SPS orbit stability analysis ongoing.

- Almost 1000 orbits have been saved at extraction.
- An orbit drift, mainly at the BPCE4, can be observed.
- The source of error is assumed to be a single element => single dipole error
- Main bend field variation in the area of **MBA.11190 in LSS1** might lead to the observed **orbit change – more measurements needed**.
- Correlation between temperature and orbit drift to be analysed in detail.

TL collimator settings:

- **TCDIs at 5 σ** (with nom. emittance).
- Initial setting at 4.5 σ.
- Was increased in 2011.



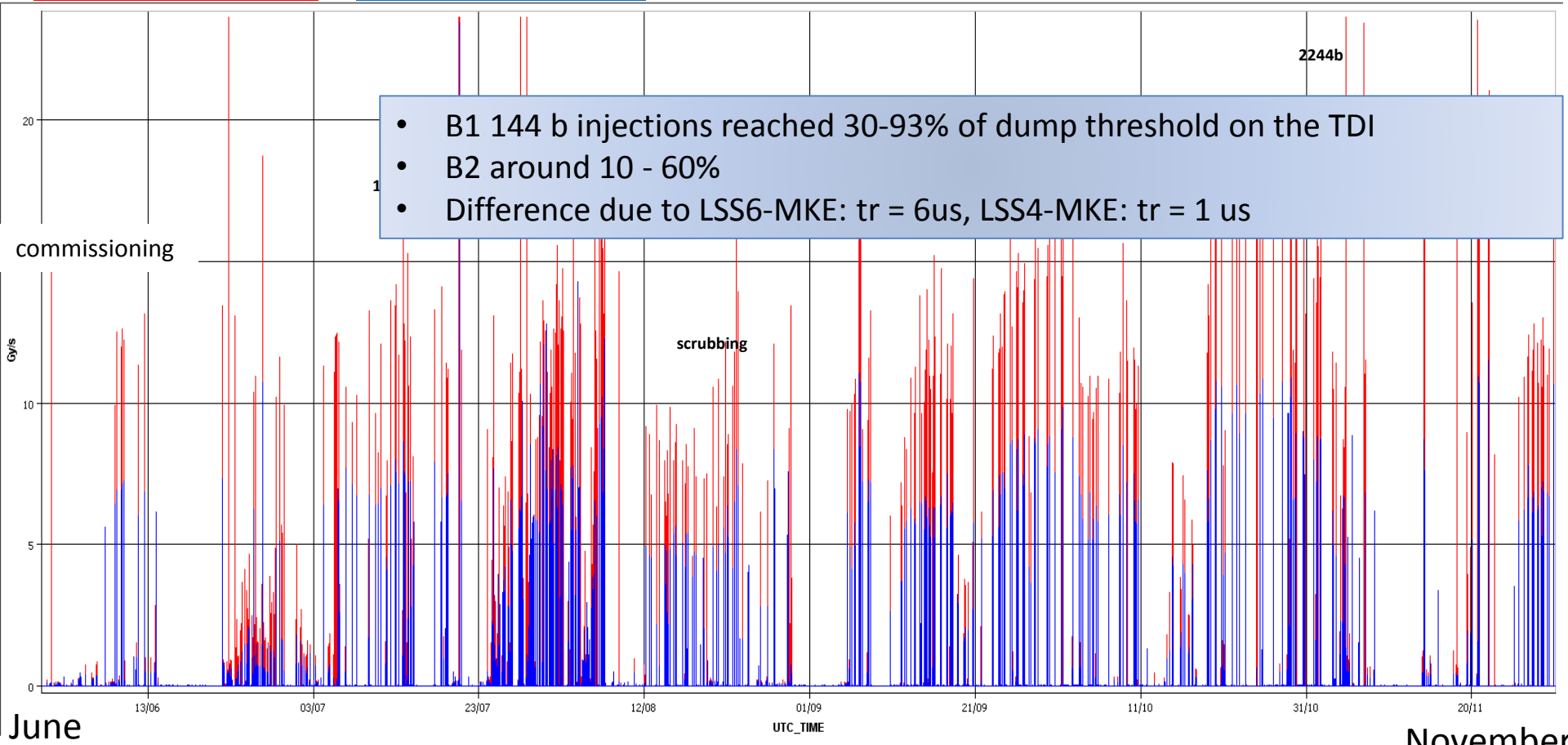
Comparison to run 1

- Less MSE ripple
- No bump in LHC → smooth steering.
- Optimized delay for first bunch on MKE f.t..
- But higher losses on the TDI!

→ **Longitudinal losses …**

Losses at the TDI 2015

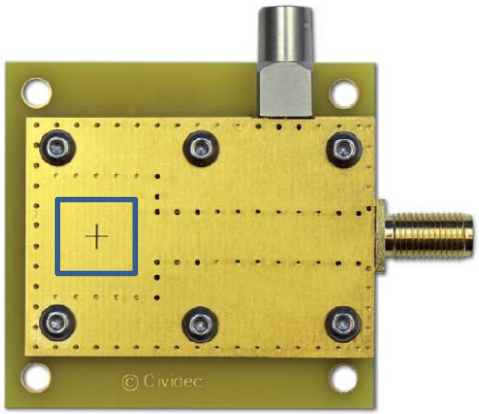
BLM TDI.4L2.B1 BLM TDI.4R8.B2



- B1 144 b injections reached 30-93% of dump threshold on the TDI
- B2 around 10 - 60%
- Difference due to LSS6-MKE: tr = 6us, LSS4-MKE: tr = 1 us

June November

Diamond detectors



- pCVD diamond based beam loss monitors, CIVIDEC.
- Active area: 1 cm^2.
- Thickness: 500 µm.
- E field strength: 1 V / µm.
- Nanosecond time resolution.
- Radiation hard.
- Characterized between 1 – 1E8 MIPs.
- Can be installed at cryogenic temperatures.
- Vacuum compatibility.
- RF shielded.

Aim:

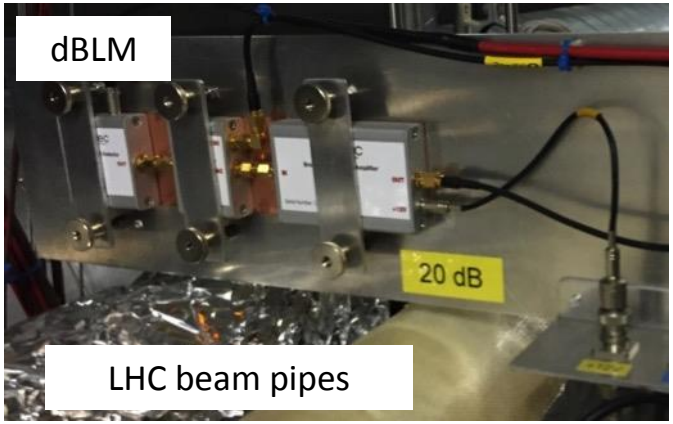
- Bunch-by-bunch loss data.
- Detect ghost bunches and RF – recapture at injection.
- Study UFOs.
- Can be used for beam based alignment.
- etc.

dBLMs around LHC

In total: 8 dBLMs.

- **Extraction losses at the PS** – position: installed close to **septum MU16**.
- **Extraction losses at the SPS** – position: installed close to **TPSG TI2** and close to the **septum TI8**.
- **Injection losses at LHC** – position: IR2 and IR8, downstream of **TDI**.
- **Global losses** and post-mortem event recordings **in left and right IR7**, downstream TCPs.
- **Extraction losses at LHC** – position: IR6, downstream of **TCDQ**.
- **Transfer line losses** – position close to **TCDI** in TI2 and TI8 – to be discussed.
- **Global losses in the SPS** – position: close to **TIDP**, tbd – to be discussed.

Close collaboration with BE-BI-BL, (Bernd Dehning et al.)



3 DAQs installed.

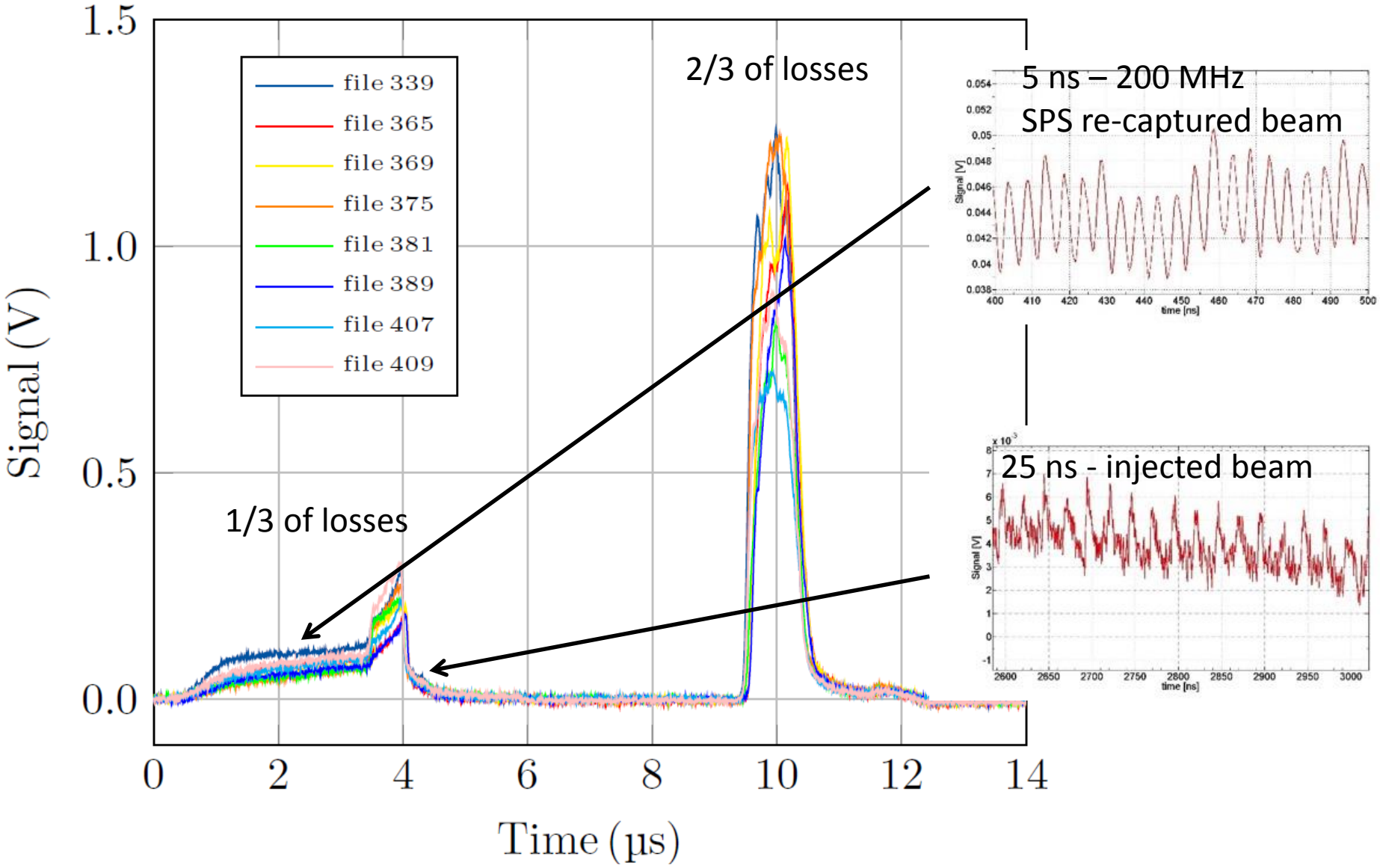
OASIS scope (PS)

Oscilloscope (IP2, IP6, IP7, IP8, SPS)

ROSY CIVIDEC, Scope and Histogram unit (IP7)

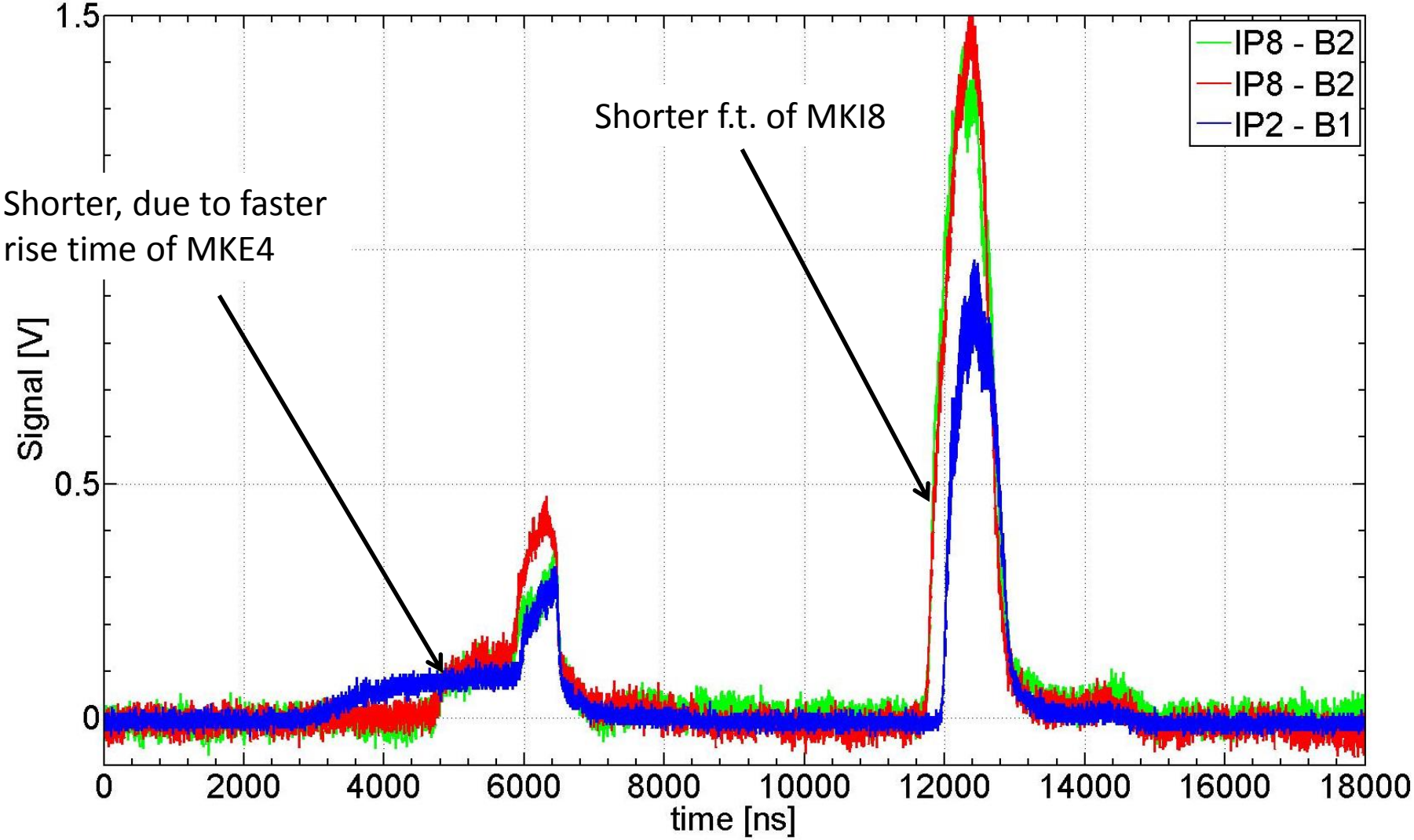
New DAQ card will be developed by BI.

Losses @ TDI for 144b B1

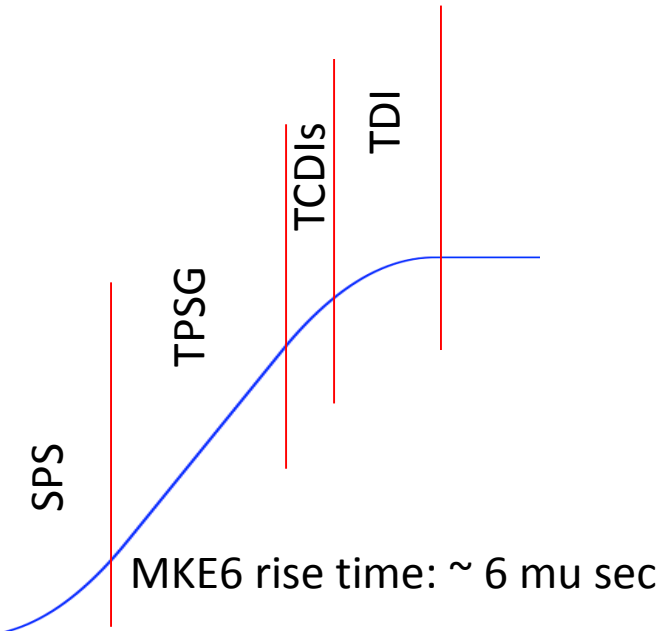


Losses @ TDI for 144b B2

- Signal amplitudes not directly comparable as dBLMs not installed symmetrically at the TDIs.



Loss distribution



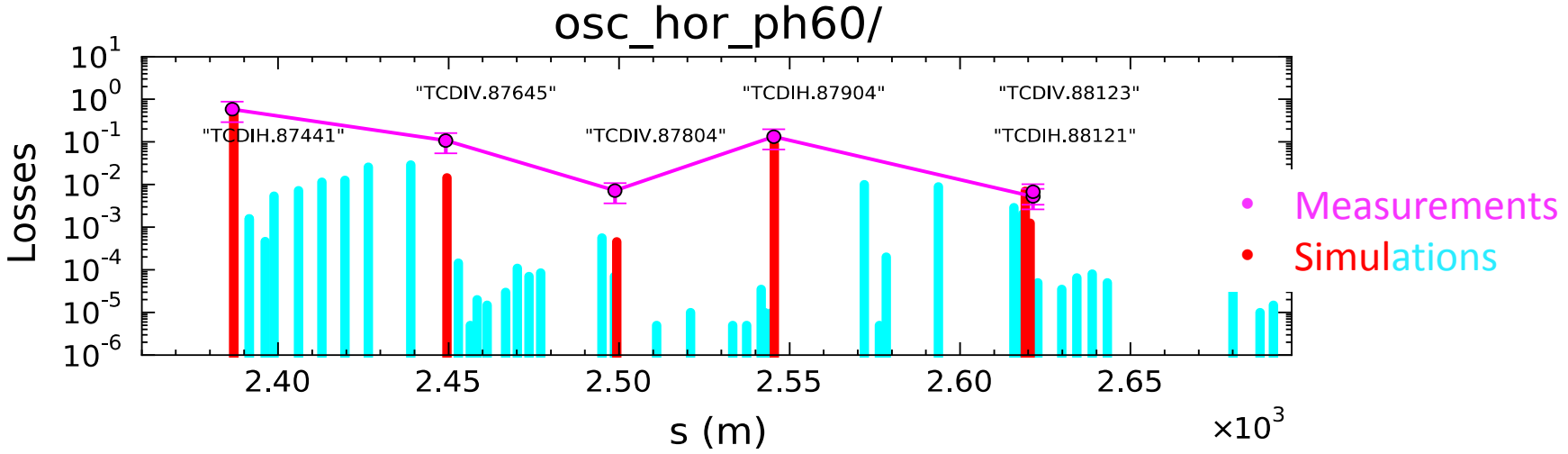
TCDIh activation in TI2 high (11 µSv/h), no value available for TI8.

Losses at injection are now better understood.

- **dBLMs at the TCDIs** would help to understand the longitudinal losses in the LHC as well as the location and intensity of the re-captured beam in the SPS.
- dBLM **data available in IQC** would help to check injection losses faster.
- **Operational specs** for dBLMs and data implementation will be discussed beginning of 2016.

Injection Quality Check Tool

- **OP tool** with input from other groups (ABT, BI, RF)
- Aim: help to identify cause of “dirty” injections.
- Detailed studies during TCDI setup validation with TL loss maps showed that source of TL losses can be identified.



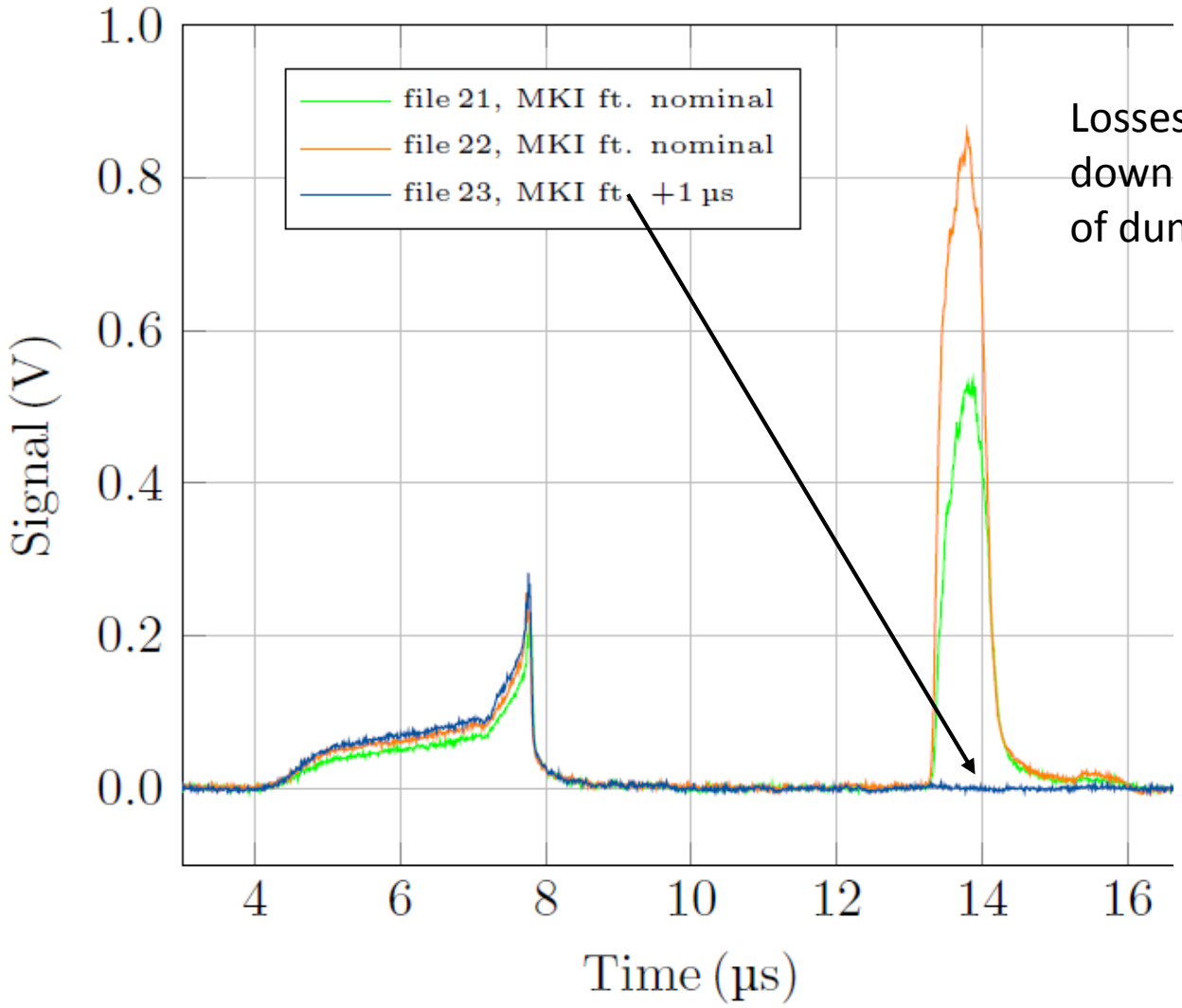
- Suggestions with run 2 experience:
  - to **review the thresholds** for the color code / warning levels.
  - to highlight **TL collimator name causing losses** to allow for better steering.

Loss mitigation

- **Losses from LHC un-bunched beam**
  - Injection gap cleaning in LHC
  - Reduces losses on TDI from a few percent to below a percent - marginal gain compared to satellite loss level.

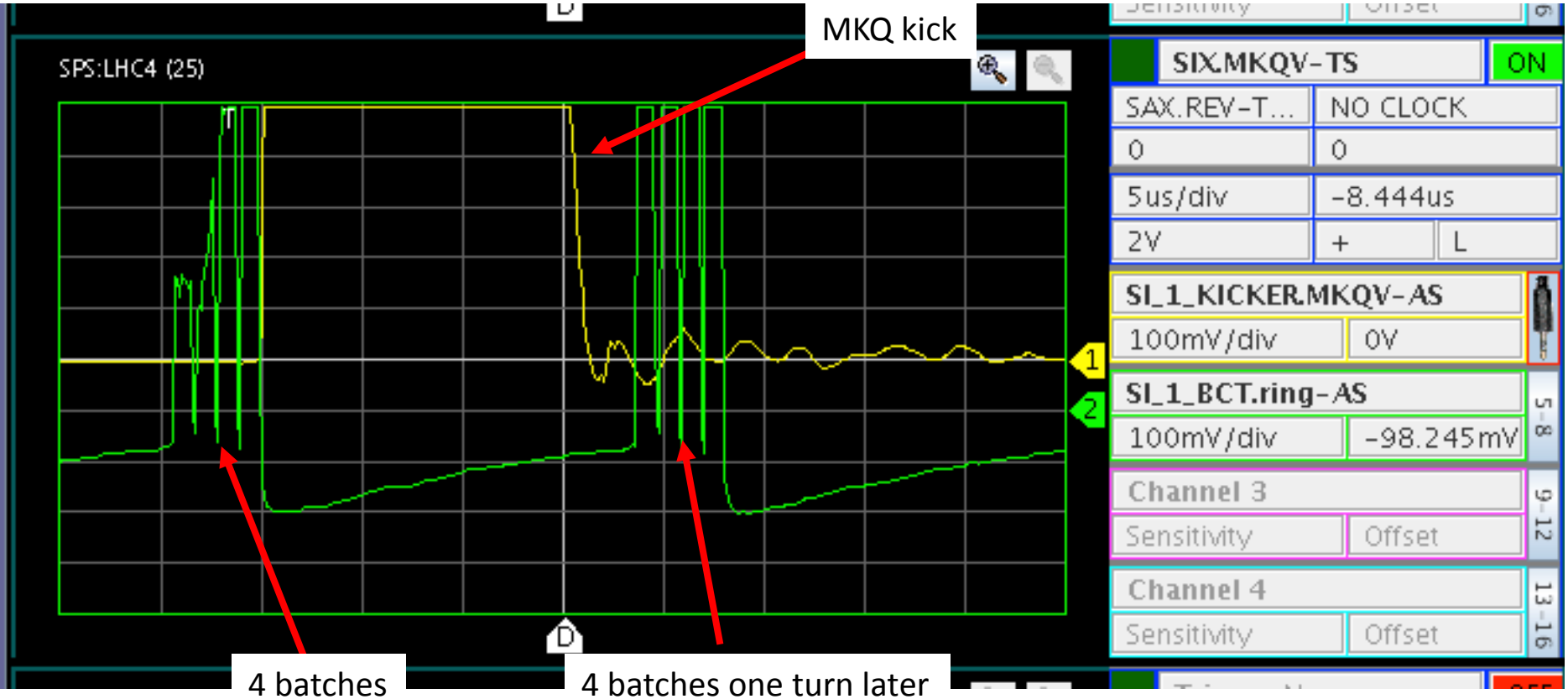
- **Losses from satellites injected into LHC**
  - **LHC**
    - **Increase MKI pulse length**
      - Can be done immediately within TDI limits.
      - Inject satellites close to the batch in a clean way into LHC.
      - Possibility to clean them before next injection with injection gap cleaning.
      - Should make the losses on ALICE/LHCb BCMs cleaner.
    - Blind out dump trigger during injection.
      - Hides the problem.
      - Does not improve for ALICE/LHCb.
  - **SPS**
    - B2 losses will be similar to B1 after SPS MKE4 modifications in the coming YETS.
    - Ramp program optimisation – can be done immediately, but not a huge gain expected.
    - **MKQ kick** to clean the machine around the batch – to be optimized.
  - **PS**
    - Optimisation of bunch length and extraction kicker flattop at extraction – already fairly optimised.

MD results – MKI f.t. increase

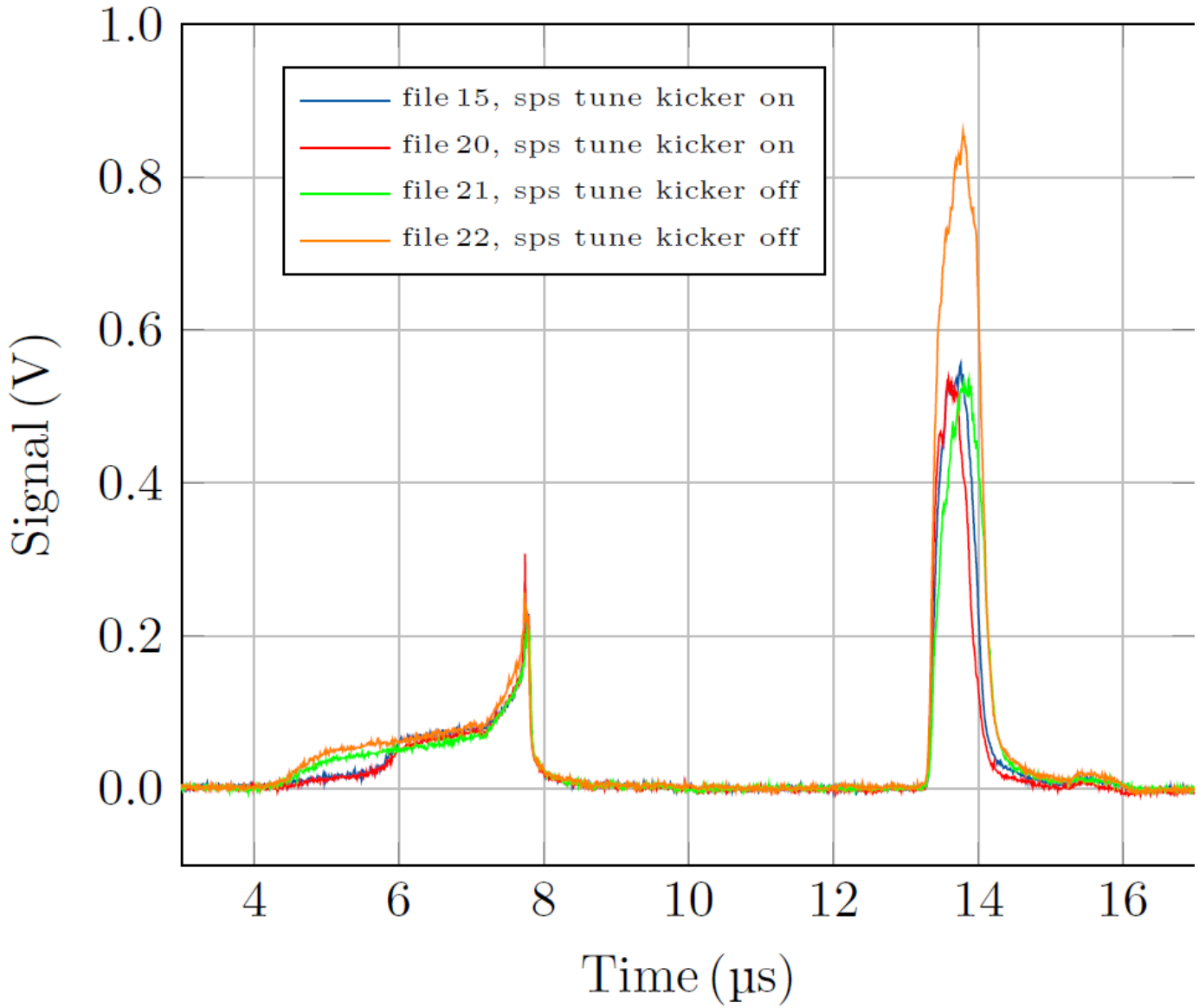


Losses at the TDI went down to 18 % (from ~ 50%) of dump threshold

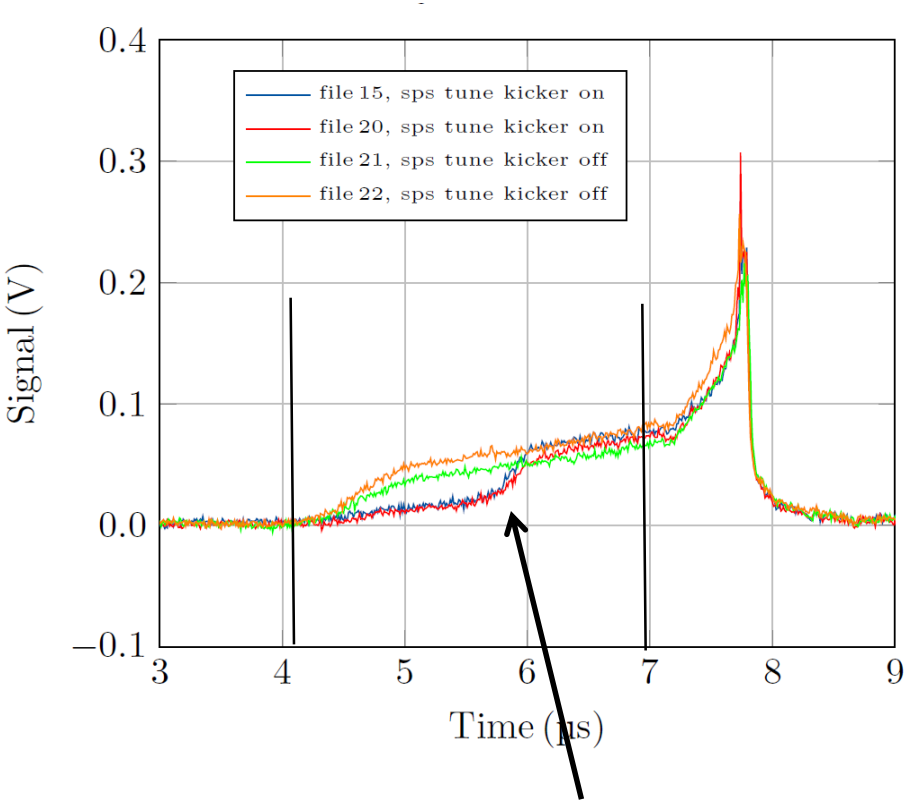
MKQ kick in the SPS – tested during MD

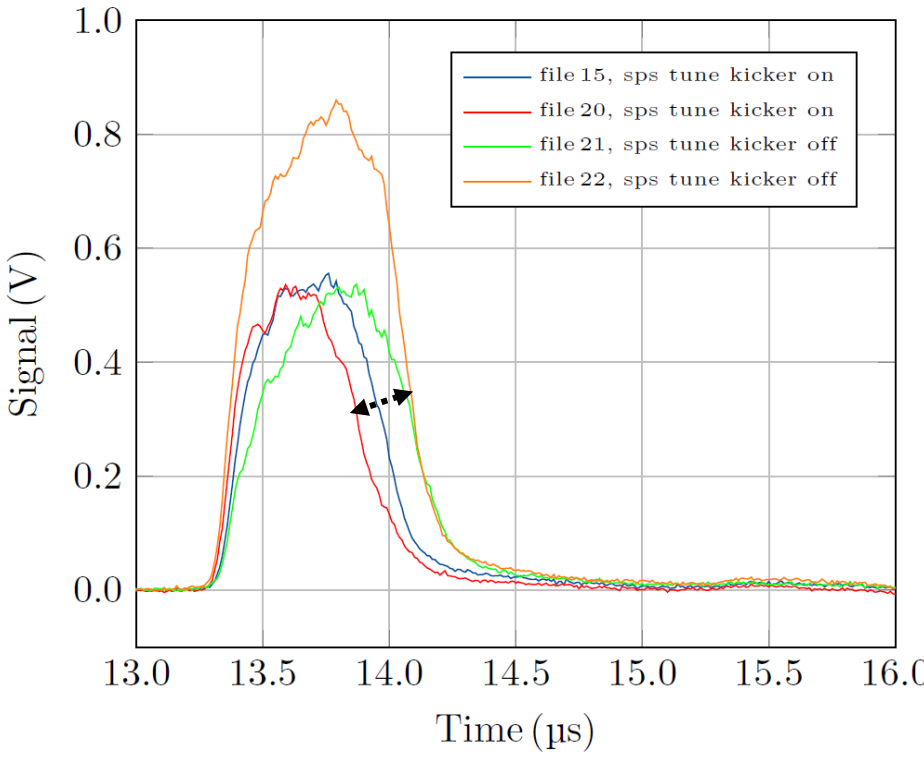


MD results - SPS MKQ on/off



Zoom





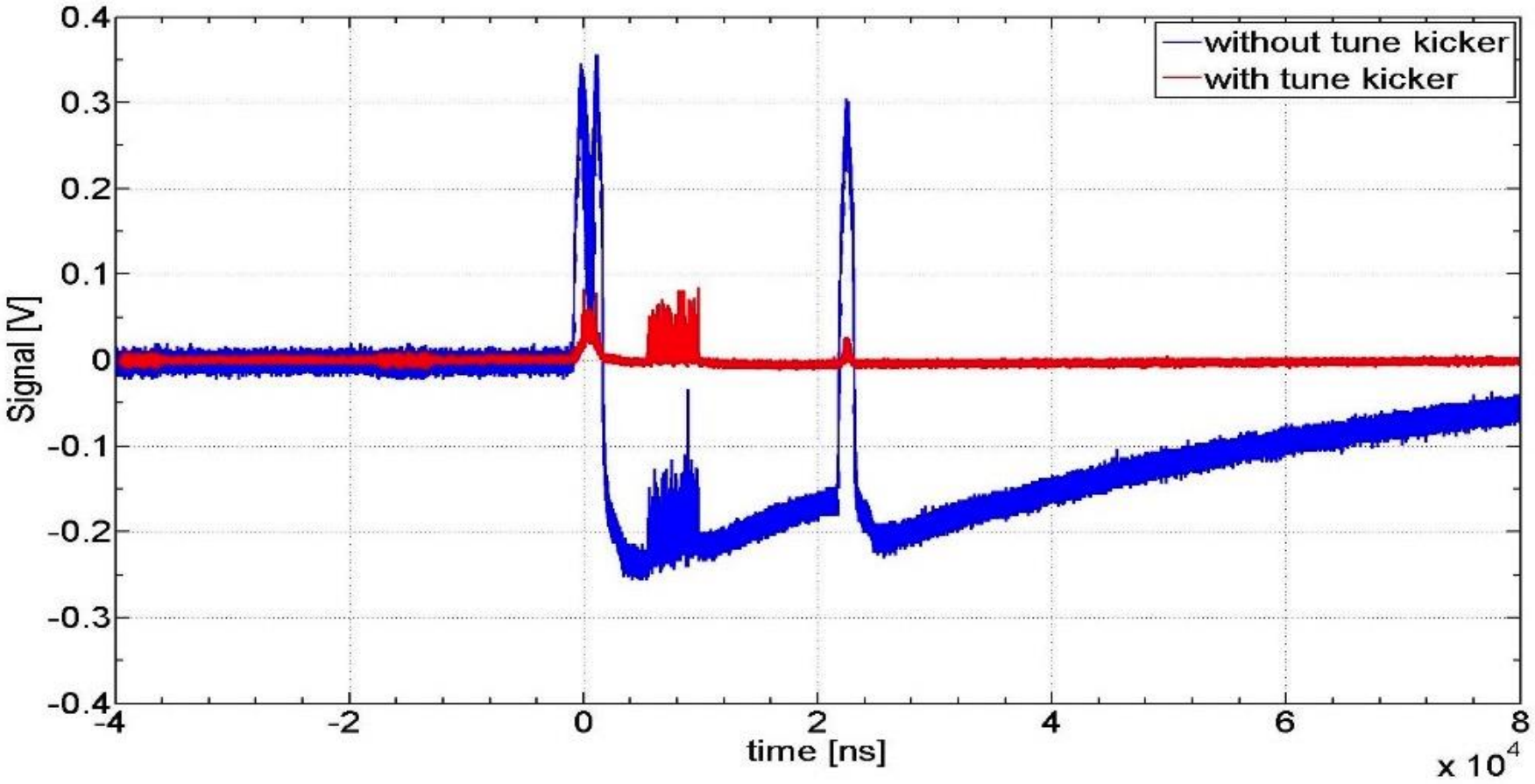
With MKQ off: 25% loss reduction in the first part

Particles lost on TDI with full impact parameter: ~4E9p (average: 6.2E6 p / 5ns).

Detailed analysis ongoing for different impact parameters.

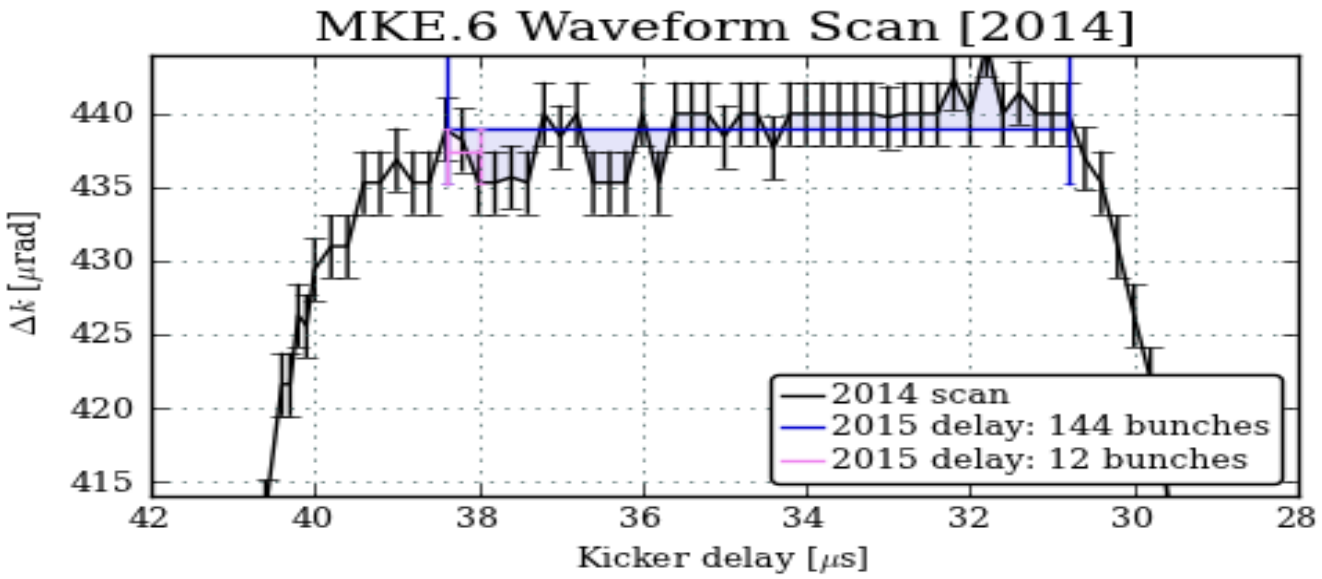
Losses at the TDI went down to 30 % (from ~ 50%) of dump threshold.

Losses at the TPSG in LSS6



Outlook

- 288 b injections: MKI f.t. length 7.8 mu sec
- Re-captured beam behind the 288 bunches train might overlap with the fall time of the MKE → losses at the TPSG / TCDIs. See second slide concerning injections in 2012.
- Otherwise, the MKQ kick can be optimized.



Conclusion

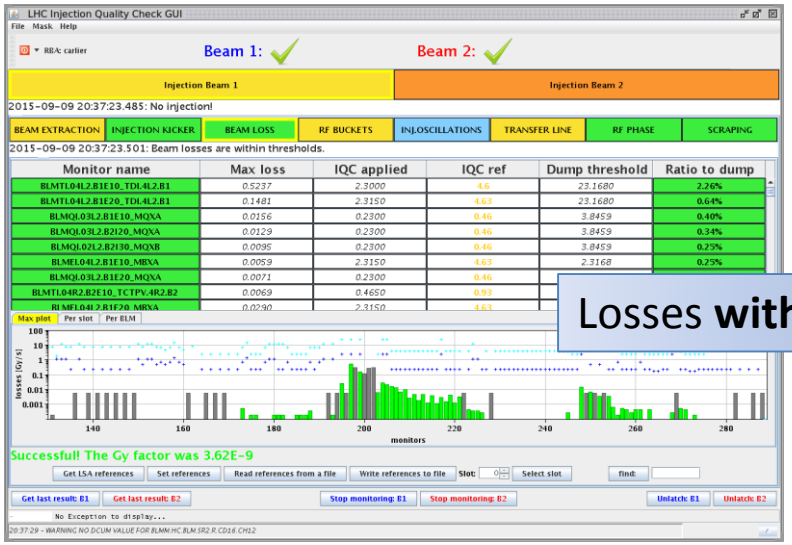
- Losses during injections reached up to **93 % dump threshold** on TDI.
- Transversal losses well understood and under control, further studies ongoing.
- Longitudinal losses due to **re-captured beam** / ghost bunches coming from SPS.
- Measured with **dBLMs** installed close to the TDIs in IP2 and IP8.
  - Specs for operational and expert tool to be defined.
- On request of OP, ABT can provide input to revise IQC thresholds.
- Possible **loss mitigations**:
  - MKI f.t. length increase (**within limits**) – ghosts properly injected into LHC.
  - SPS tune kicker to clean around batches.
- **To be followed-up during injection setup.**

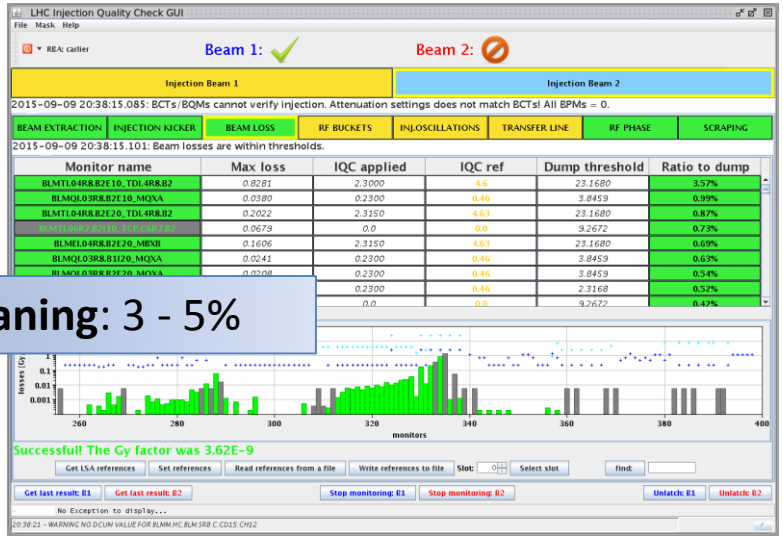
Thank you for your attention!

LHC Injection gap cleaning

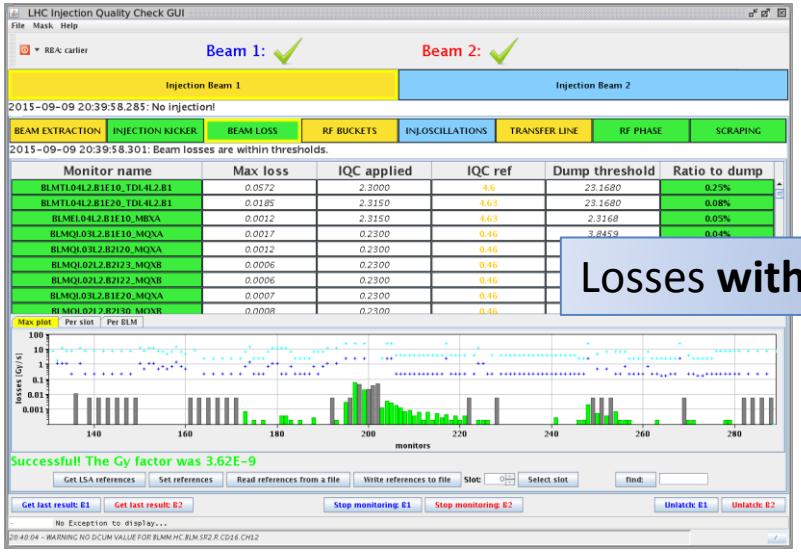
B1

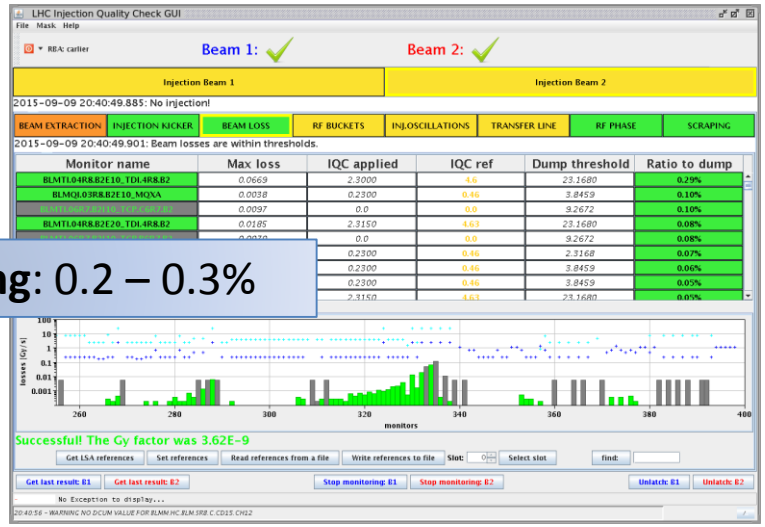
B2





Losses **without cleaning**: 3 - 5%



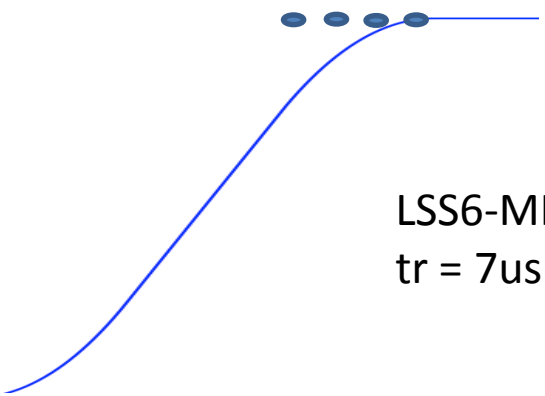


Losses **with cleaning**: 0.2 – 0.3%

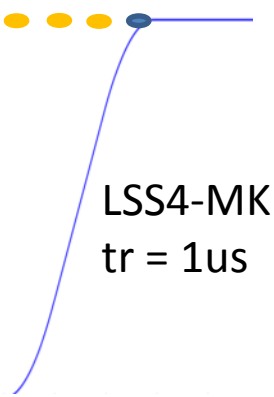
B1 – B2 difference

Dumped in SPS?
14% higher dump intensity
for B2 extraction

No losses at extraction
for both

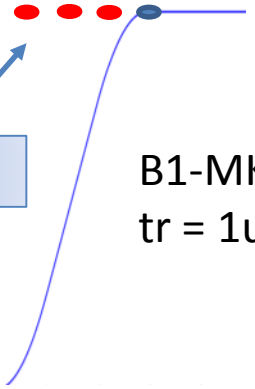


LSS6-MKE:
tr = 7us

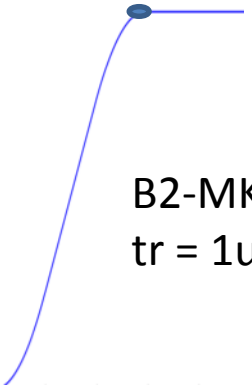


LSS4-MKE:
tr = 1us

Dumped on TDI



B1-MKI:
tr = 1us



B2-MKI:
tr = 1us

LBOC, 23rd June 2015