

CERN

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TRANSFER LINE STABILITY

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M. Medahi, J. Wenninger**



Transfer line stability

Transfer line stability issues

1. Drifts

2. Shot-by-shot variations

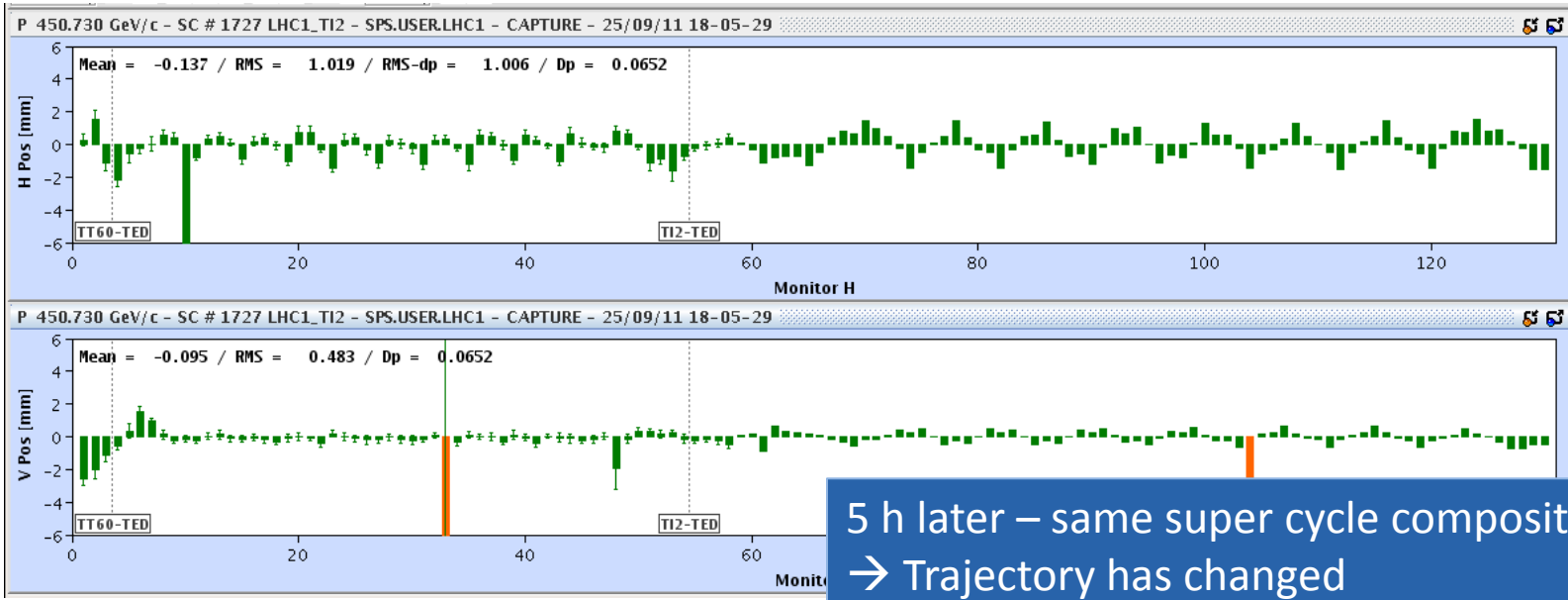
- Dedicated stability studies
- Sources of instabilities

3. Bunch-by-bunch variations

- MKE waveform scan

Impact on operations

Observation



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

→ Necessary to re-steer the line

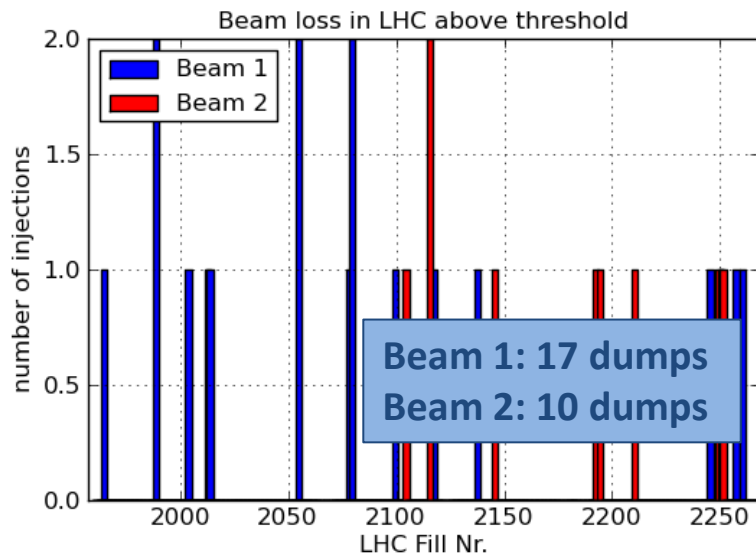
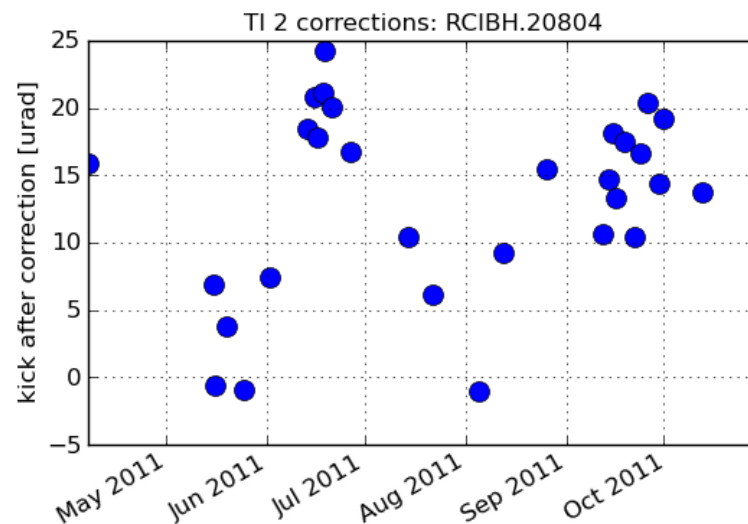
- Tight transfer line collimators – high losses if trajectory not centered
- Injection oscillations have to be below 1.5 mm to respect available aperture in the LHC



Transfer lines are drifting

Frequent steering required:

- Beginning of run: ~ twice a week
- End of run: every second day
- Steering mainly triggered by losses on transfer line collimators
- Also sometimes beams dumped



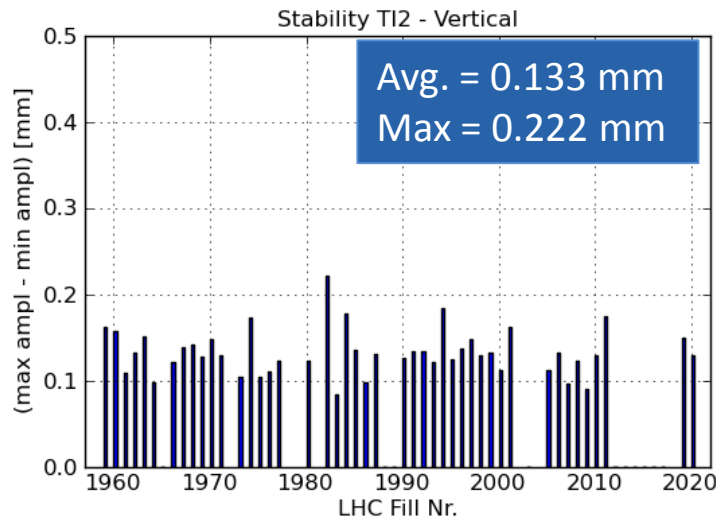
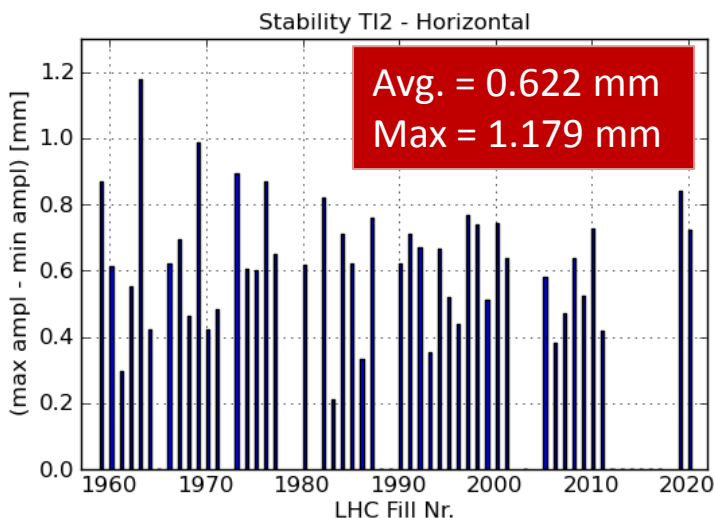
- Frequently the same corrector proposed
- TI 2: RCIBH.20804 – in phase with MSE/MST
- Offsets drifting back and forth
- Dependence on SPS supercycle?



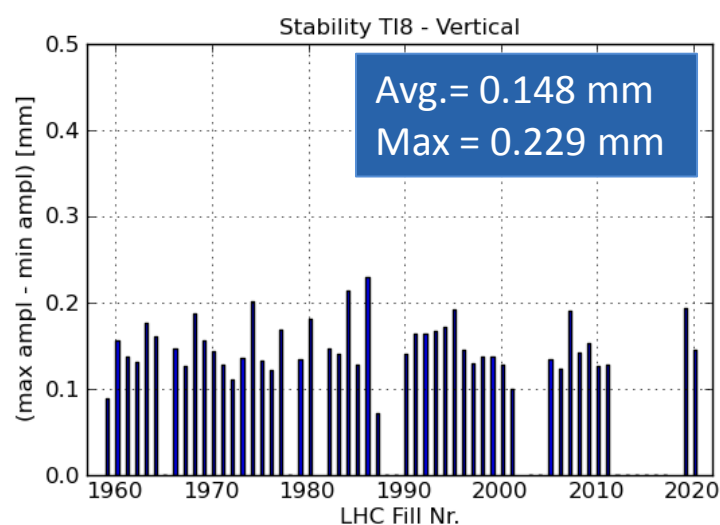
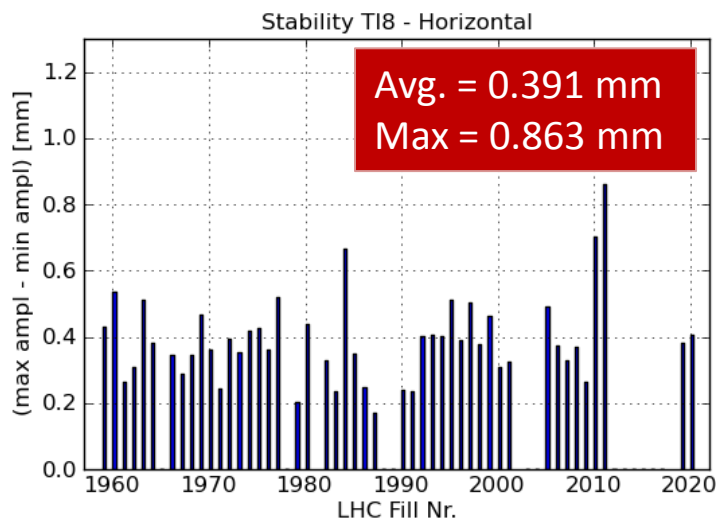
Large shot-by-shot variations

Analyzed ~ 60 fills from mid July to mid August:

TI 2



TI 8



Shot-by-shot stability studies

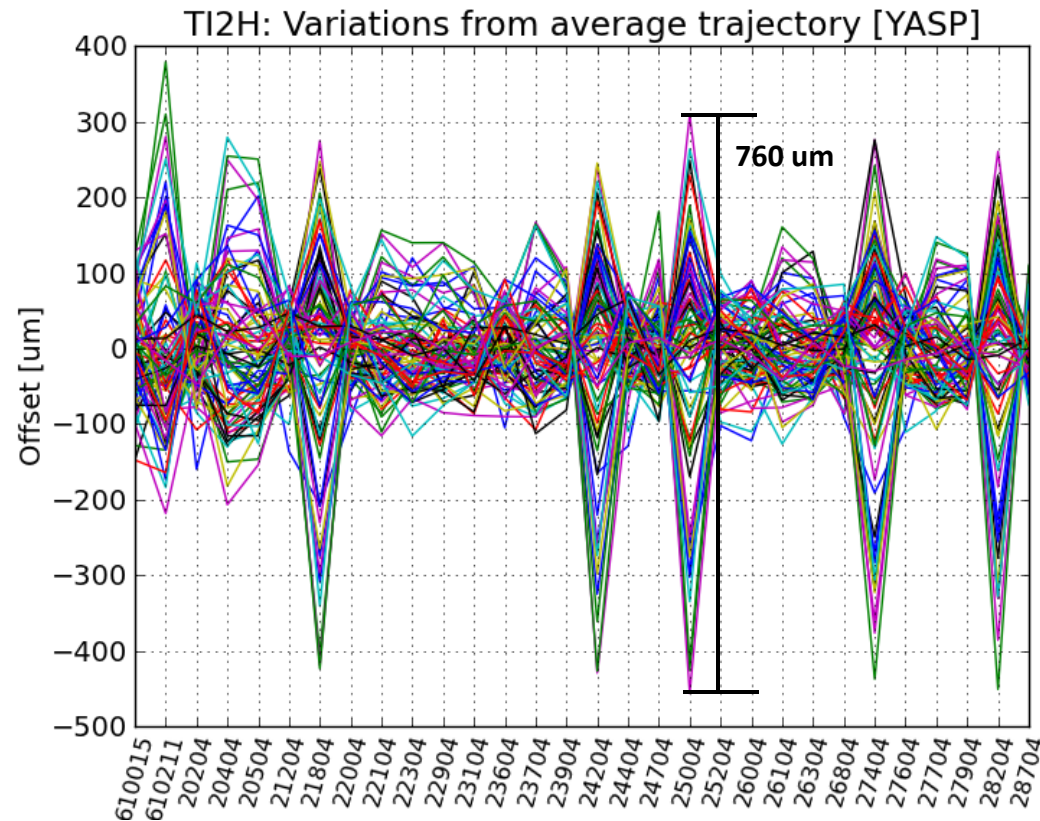
Dedicated periods of repeated extractions on downstream TEDs with 12 bunches for study of shot-by-shot variations

TI 2: 82 Shots, 19 June

- Horizontal plane: max 760 μm
- Vertical plane: max 260 μm

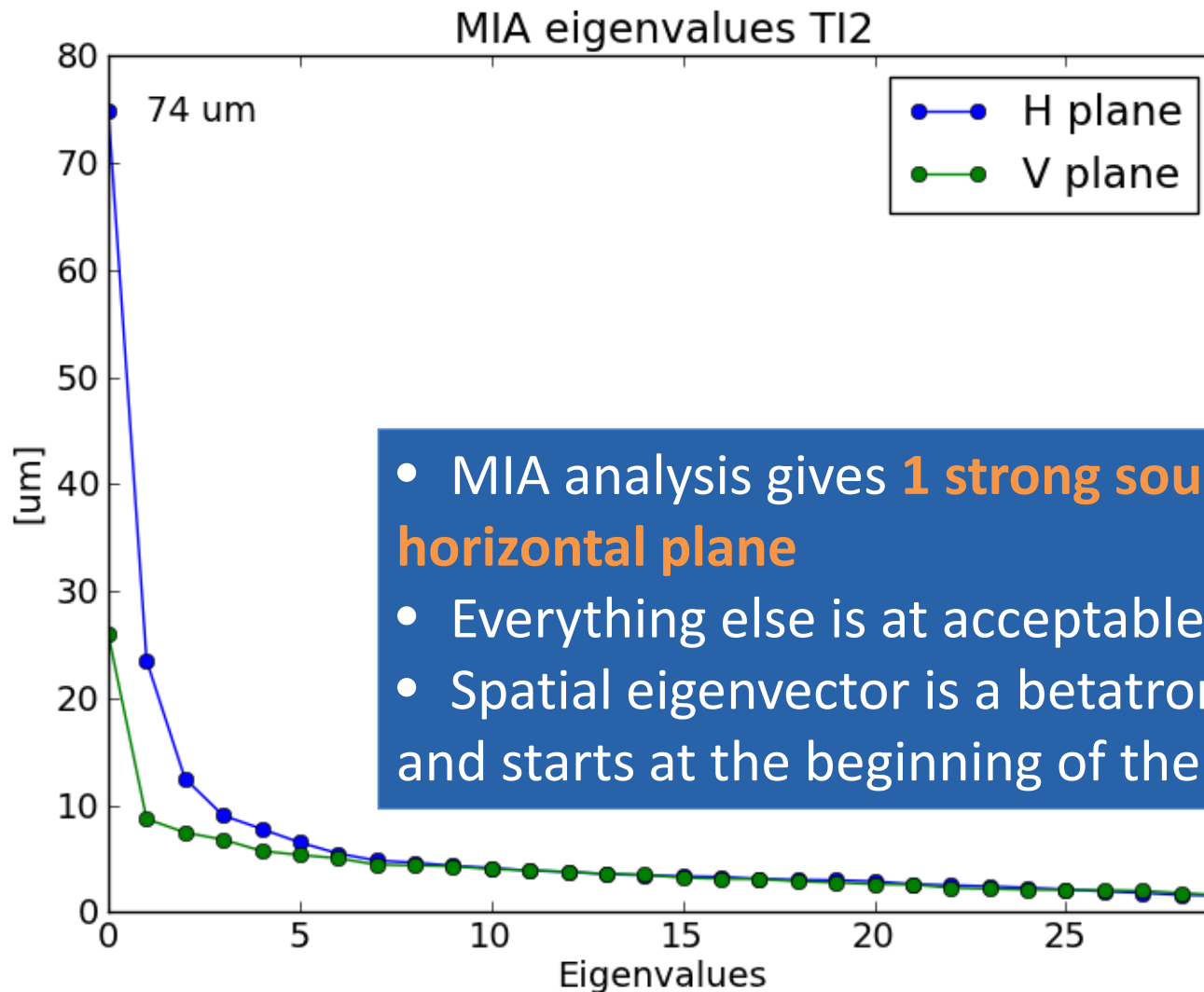
TI 8: 117 Shots, 2 November

- Horizontal plane: max 770 μm
- Vertical plane: max 260 μm



→ used data in **M**odel **I**ndependent **A**nalysis to find strongest eigenmodes of oscillations

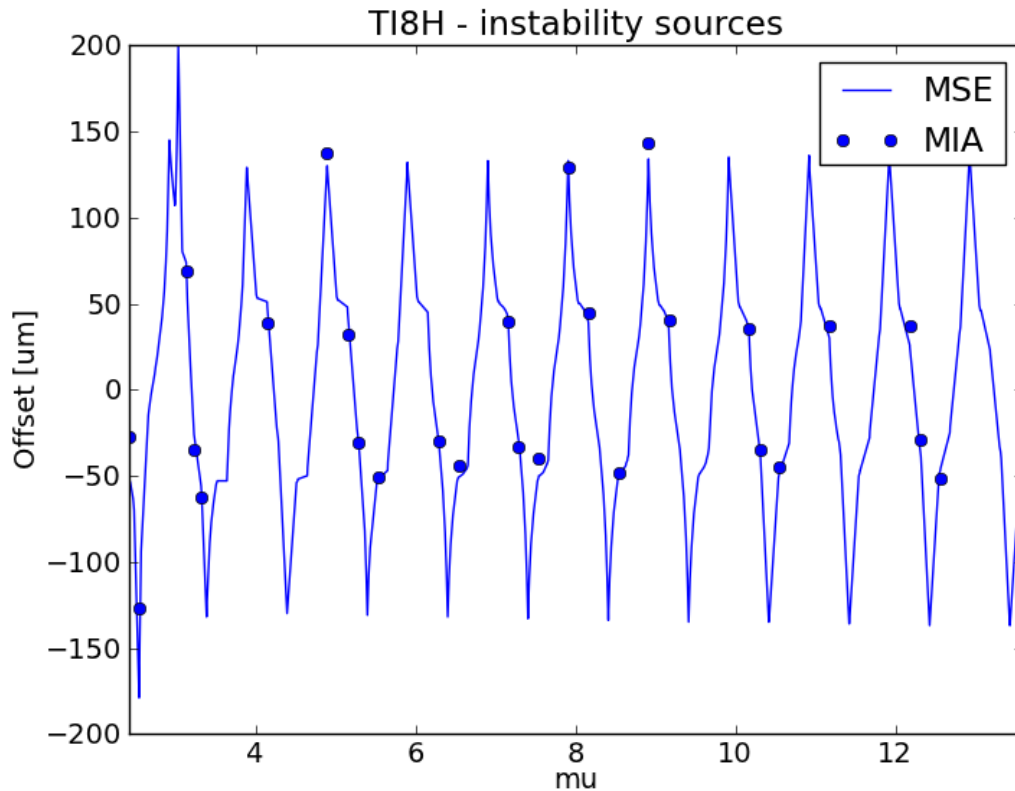
TI 2 MIA result



- MIA analysis gives **1 strong source** in the **horizontal plane**
- Everything else is at acceptable levels
- Spatial eigenvector is a betatron oscillation and starts at the beginning of the line

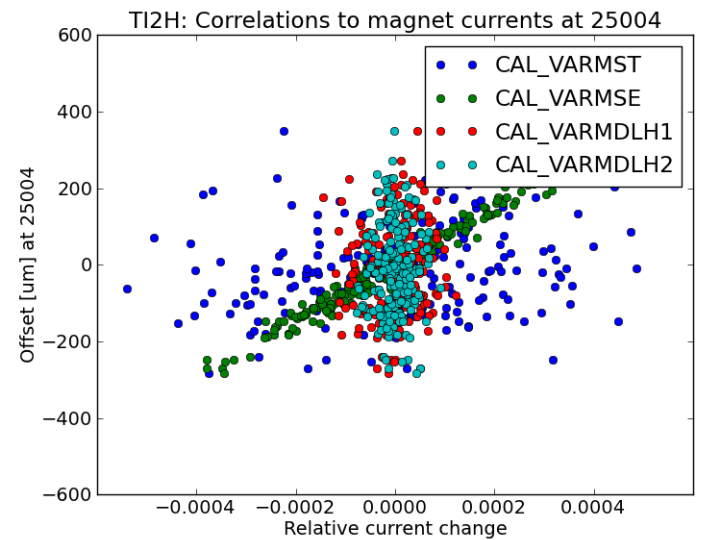
TI 2 source: MSE

- Simulation of an MSE error matches with the strongest eigenmode of the MIA analysis:

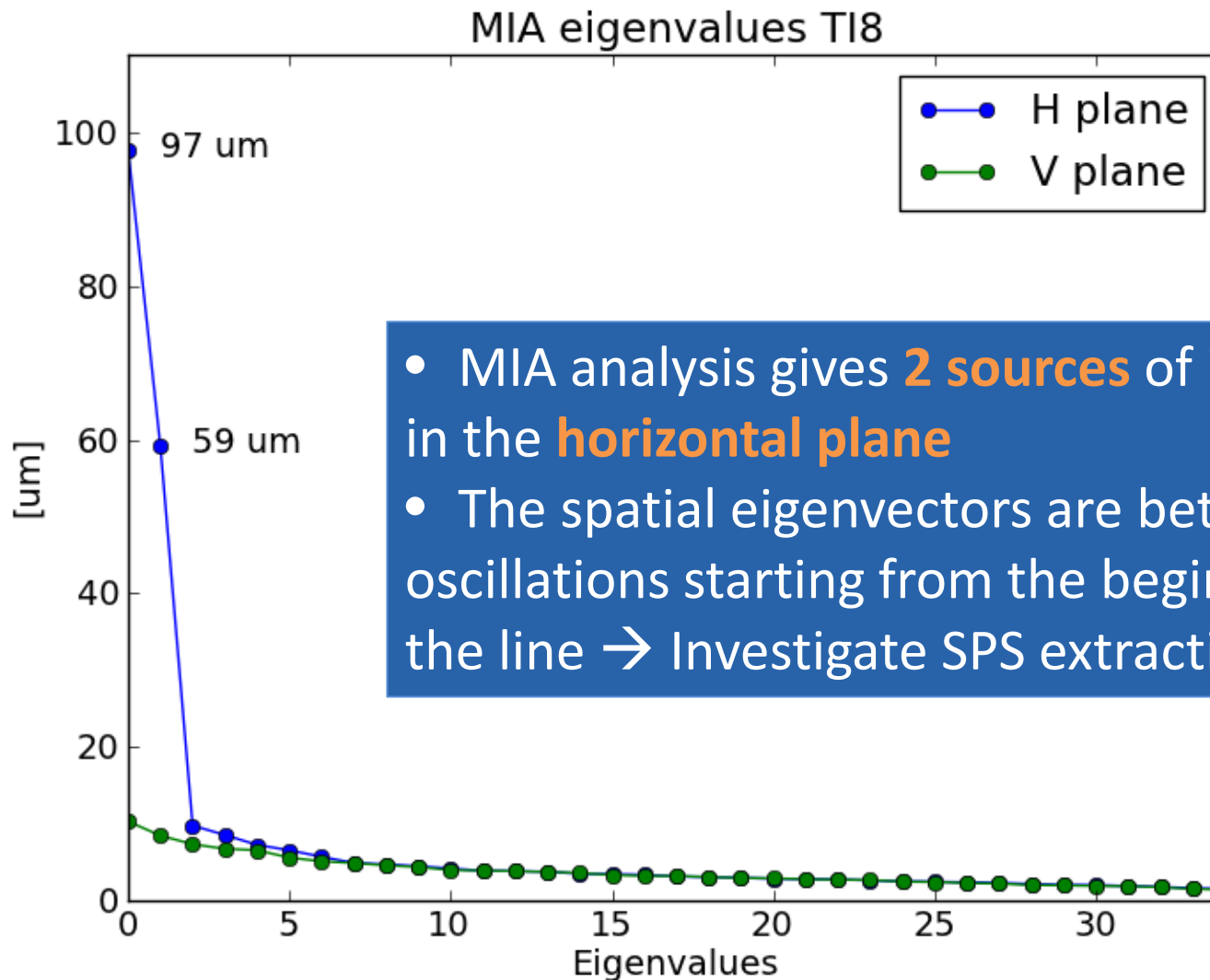


Observed variations in the magnet currents:

- Observed MSE variations are large enough to produce this oscillation
- MST is not strong enough



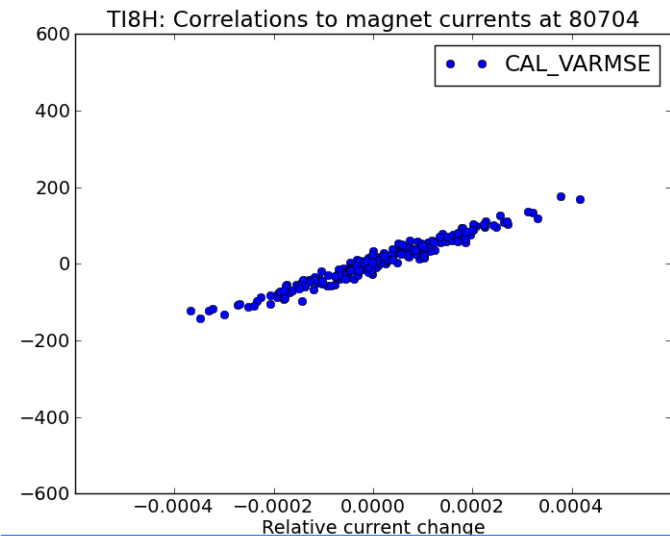
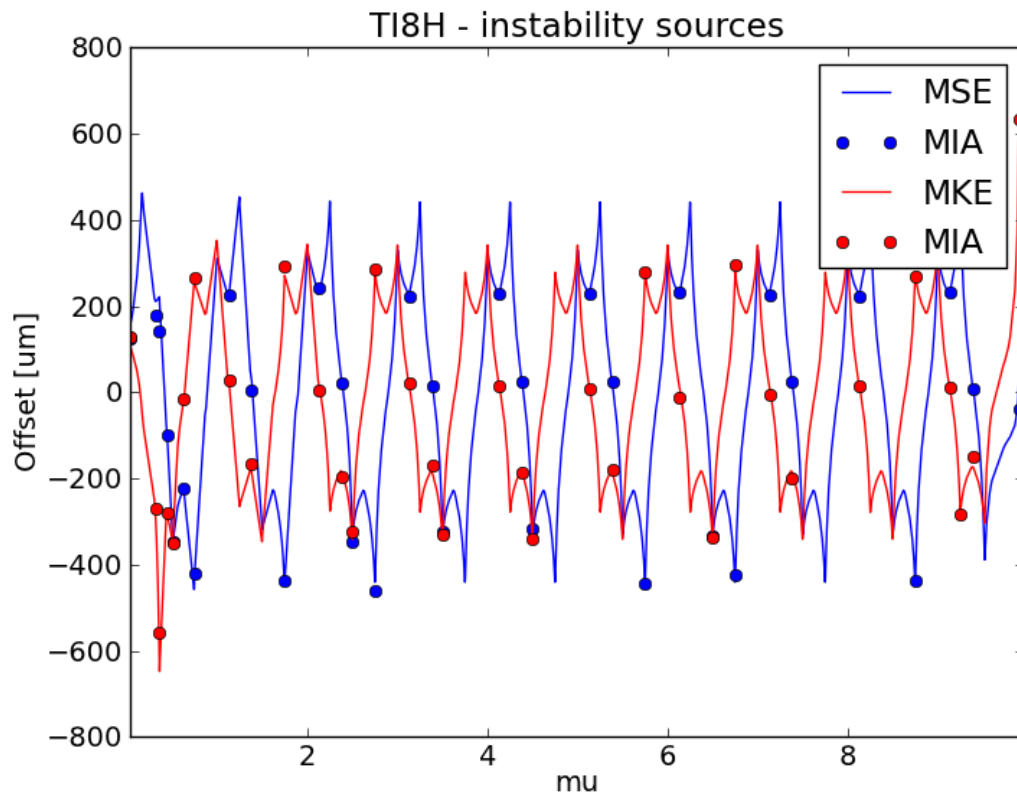
TI 8 MIA result



- MIA analysis gives **2 sources** of instabilities in the **horizontal plane**
- The spatial eigenvectors are betatron oscillations starting from the beginning of the line → Investigate SPS extraction

T18 error sources

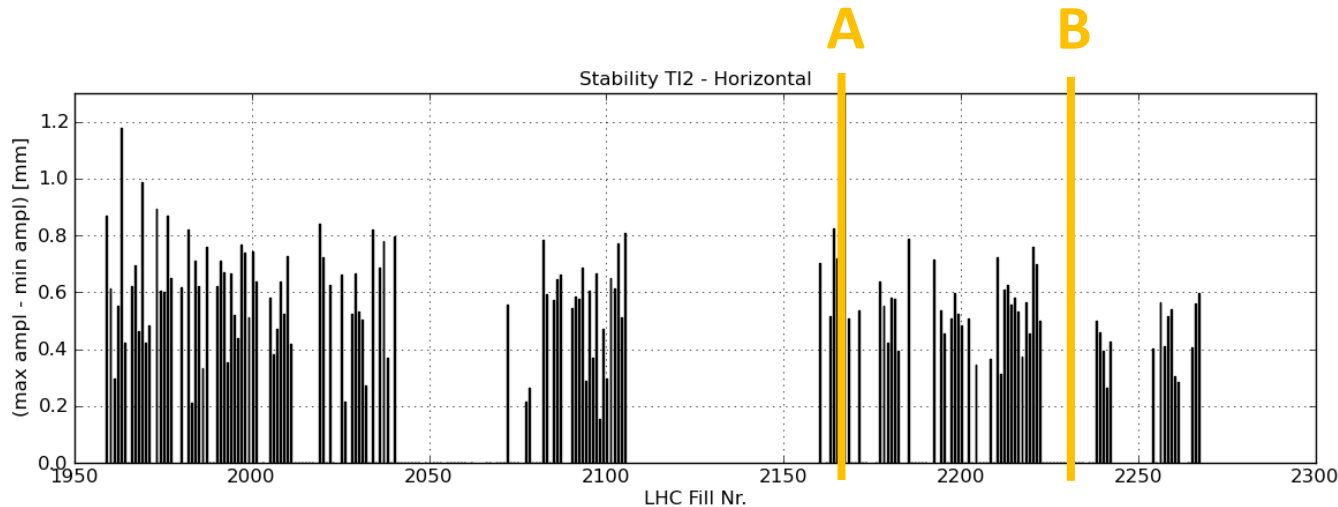
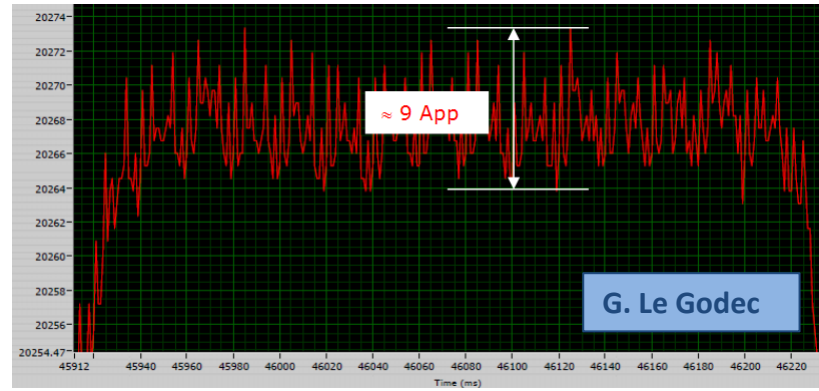
- The trajectory from the sources can be found as a linear combination of the largest eigenvectors
- Trajectories match simulated errors on **MSE and MKE**



- Logged MSE current variations large enough to explain oscillations
- MKE variations still to be investigated

T12 – MSE improvement

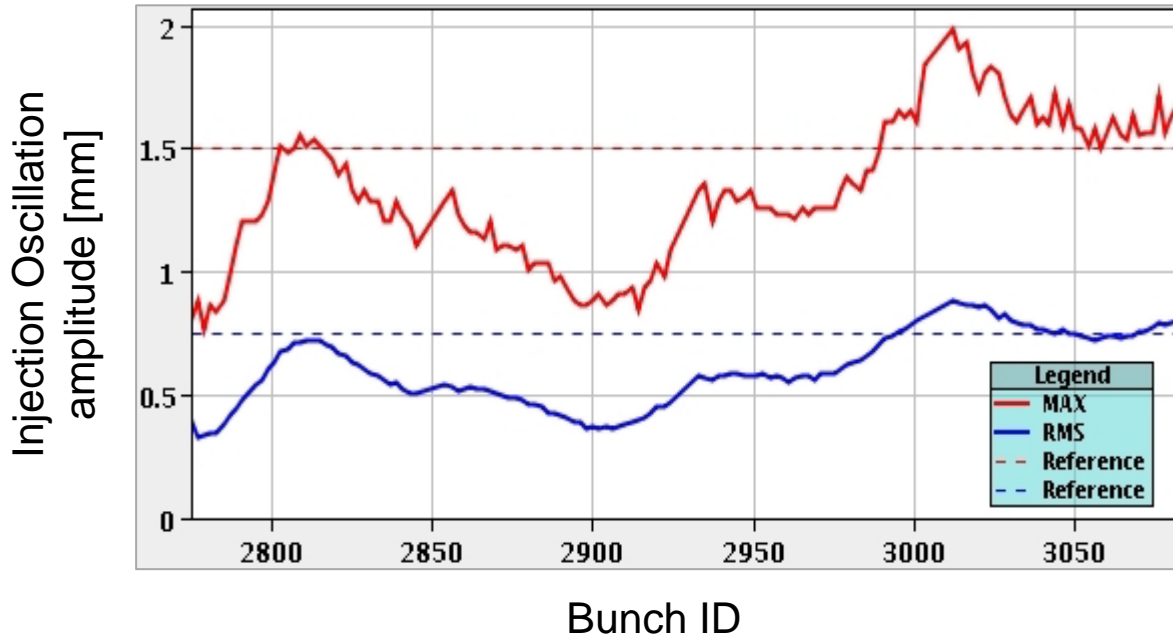
- MSE: low inductance 20 kA circuit:
- Work started Sept. **(A)**
- Power converter ripple was reduced from **18A → 9A** towards the end of the proton run **(B)**



- Improvement by factor 2 in H still necessary for both lines – work will continue during shutdown to get to the same level as in V

Bunch-by-bunch variations

- Large bunch-by-bunch trajectory variations observed for **TI 8 H** – seen on the bunch-by-bunch injection oscillation amplitudes



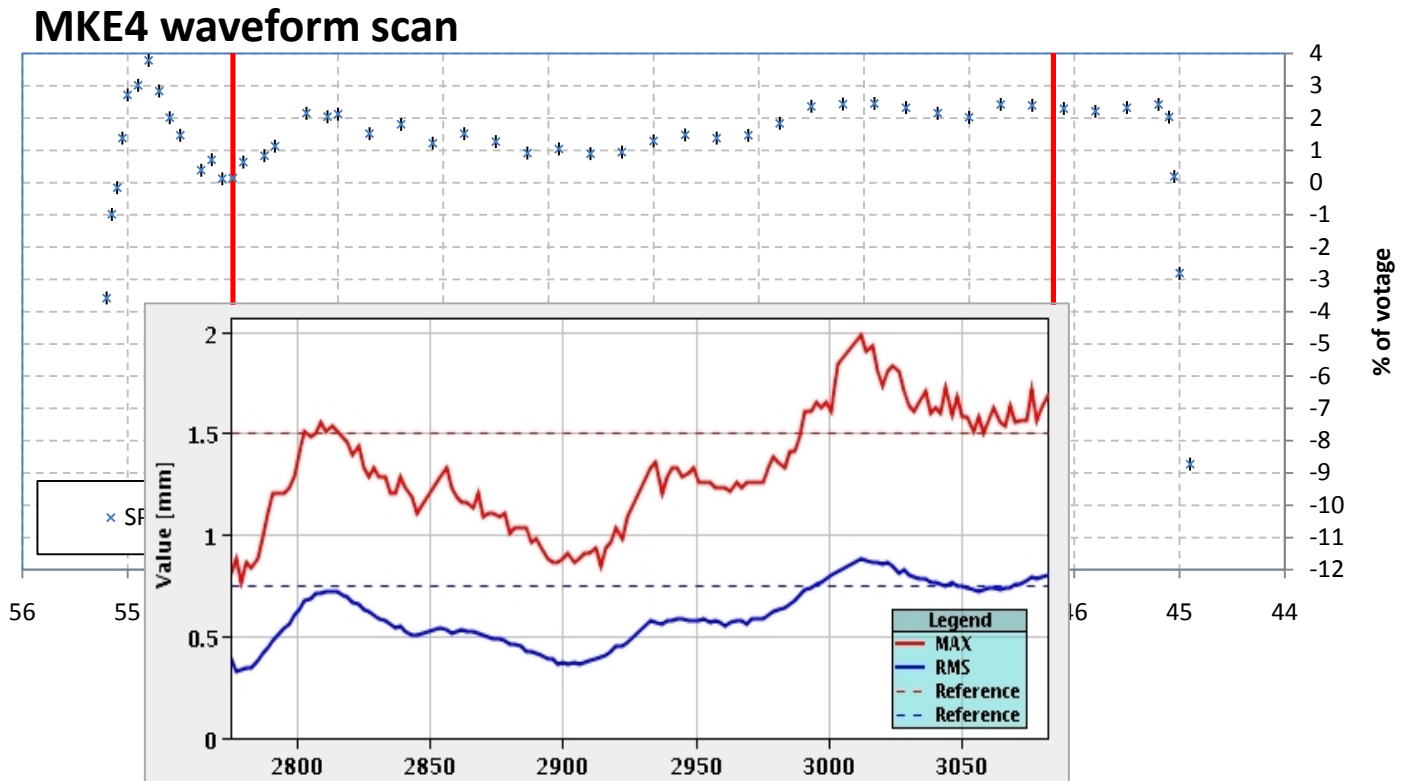
Plot from the IQC B2, 144 bunches Horizontal plane

Variation > 1mm (max)

- Suspected too large ripple of the horizontal extraction kicker (MKE) waveform

MKE4 waveform scan

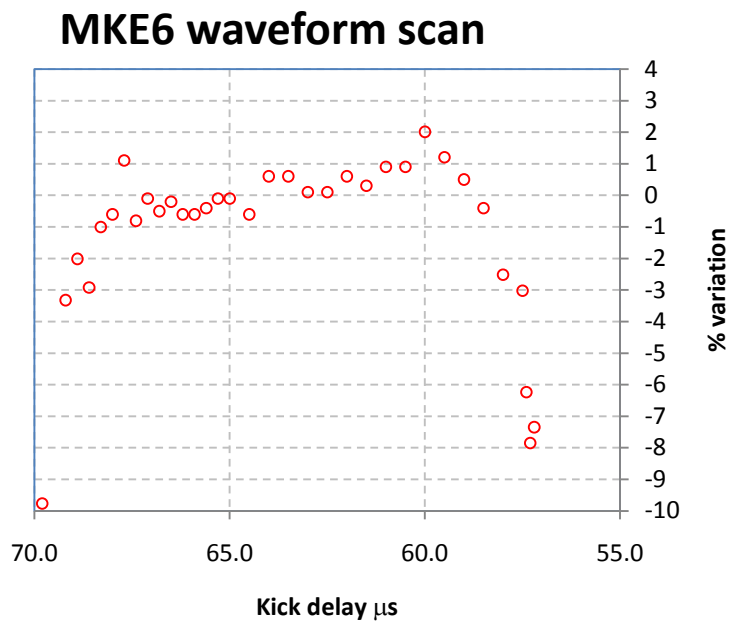
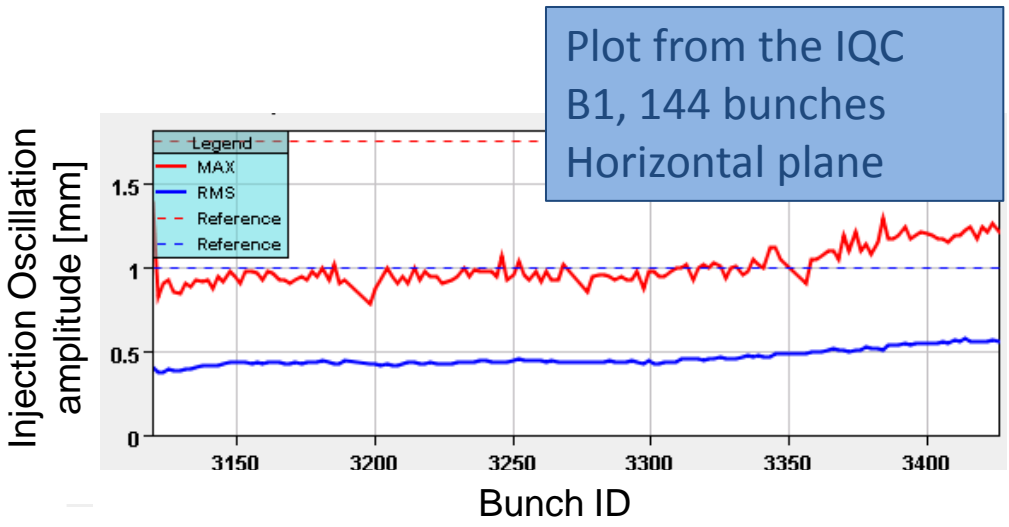
The MKE4 waveform shows a ripple varying up to 4% of voltage -
specification: 1 % flattop ripple!



Shape of ripple is similar to observed bunch-by-bunch variations!

Outlook for improvements

- The MKE4 flat-top ripple is out of specifications → needs to be improved – **not possible for 2012 shutdown**
- Immediate action: change the delay to move the beam to a flatter part of the waveform
- For beam 1 the waveform is ok:

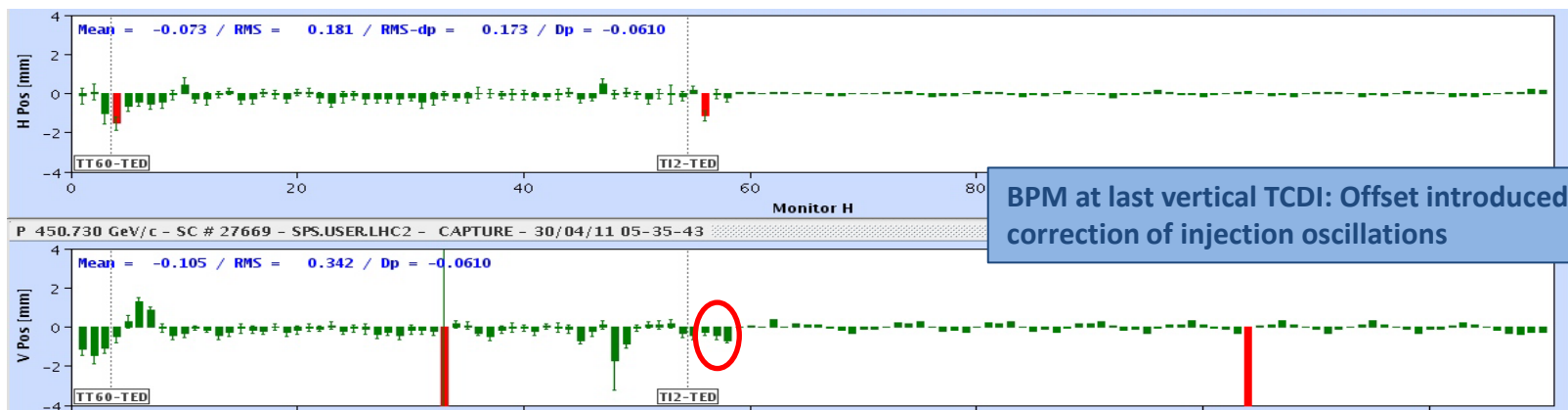




Impact on operations

Steering is complicated due to several effects:

Shot-by-shot variations	Need to average over several shots to correct trajectory	TI2 H TI8 H
Bunch-by-bunch variations	When steering on 12 bunches (intermediate intensity) we only sample a small part of the waveform – not representative for 144 bunches!	TI8 H
LHC orbit and transfer line trajectory drifting apart	Difficult to optimize injection oscillations and trajectory at TCDIs at the same time	TI2 H TI8 H



→ In 2011: ~ 30 min – 2 h to steer (excluding some big outliers)

Summary

- During the 2011 operations much time was spent on steering of the transfer lines – **steering was complicated due to several effects**
- Studies have been done to understand the causes:
 - Large **shot-by-shot** variations are observed for both lines in the **horizontal plane** – sources identified as the **MSE** and possibly **MKE4**
 - **Bunch-by-bunch** variations on **beam 2 in horizontal plane** - caused by a ripple on **MKE4**
 - MSE stability under improvement
 - MKE4 needs further investigation
- **Drifts** still to be investigated

Estimate 2012 if stability is not improved:

1h steering x 0.5/days x 120 days = 60h!