TT40 accident on 25/10/04

Analysis

Input from

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Introduction

During high intensity extraction on 25/10/04 an incident occurred and the vacuum chamber in the TT40 magnet QTR4002 was damaged. The magnet coil also appears to be damaged. No other vacuum leaks were seen in the line.

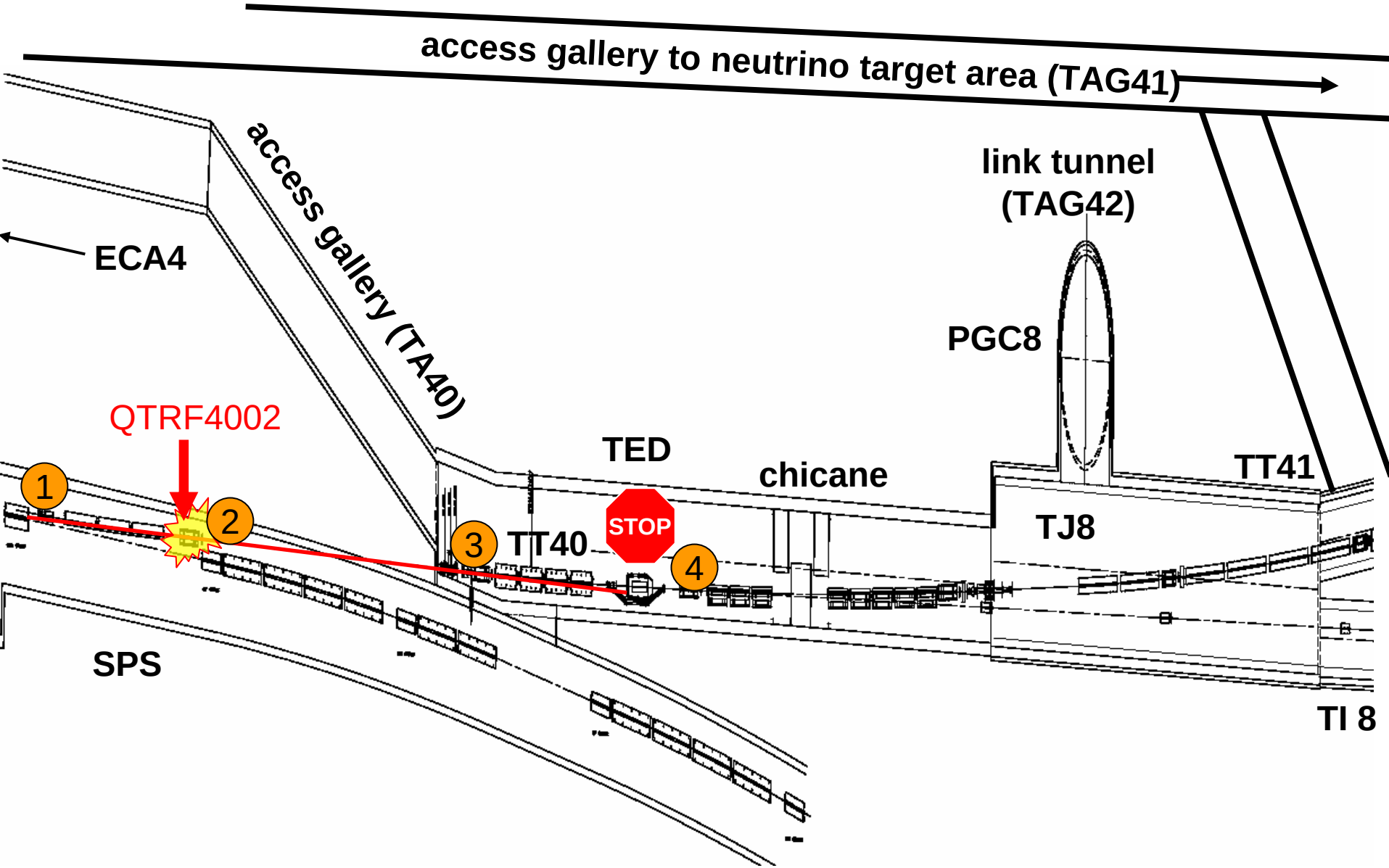
The beam was a full LHC batch of 3.4 10^{13} p+ in 288 bunches at 450 GeV

Problems had occurred during the setting-up with the MSE septum interlock tripping the power convertor, and also with the BPCE bumped beam position interlock.

Clearly there were deficiencies in the interlock system and the procedures for the high-intensity tests.

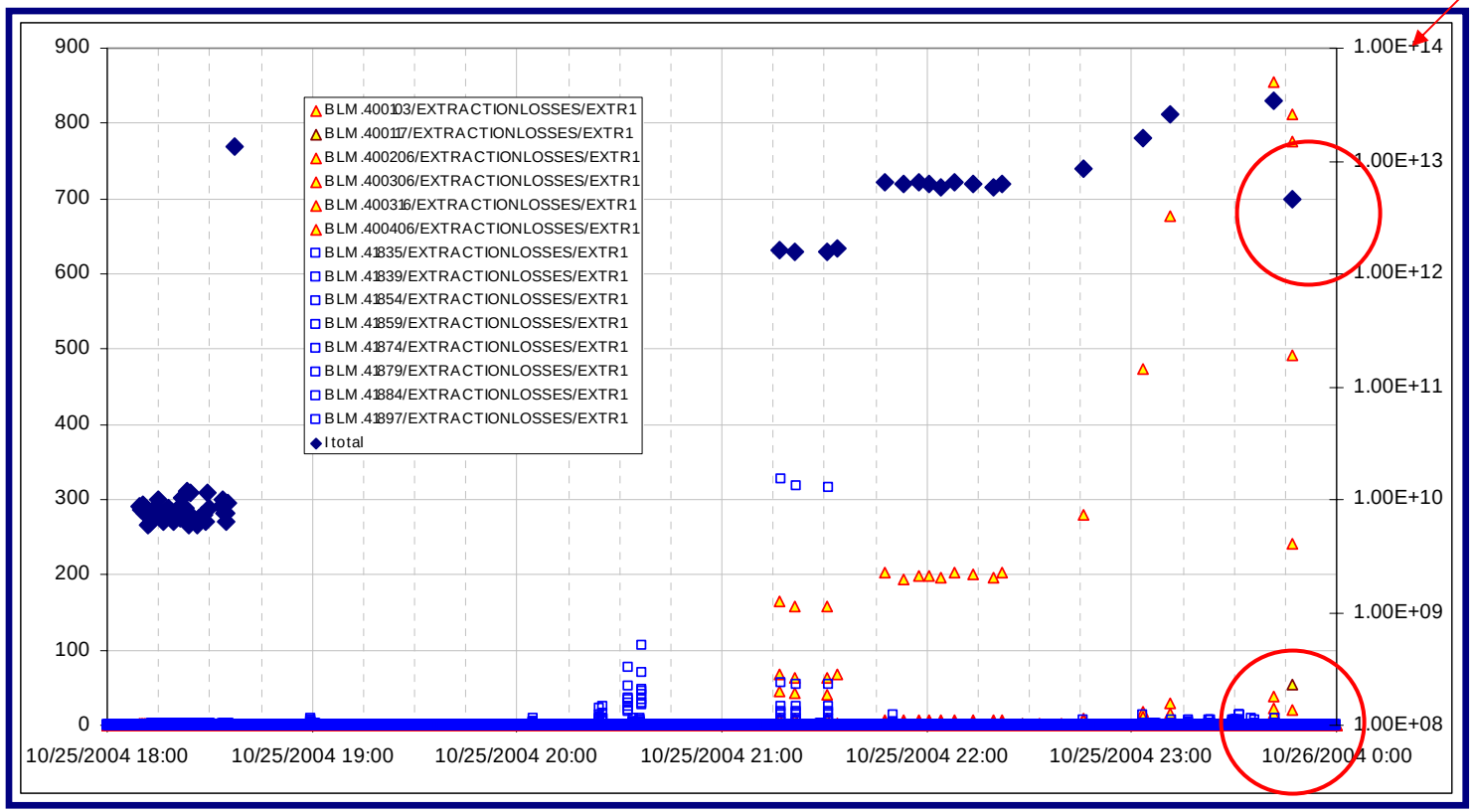
In the following the accident cause is identified and the remedial measures which have already been taken are explained.

During the second test on 8/11, several improvements were made and everything went smoothly….


access gallery to neutrino target area (TAG41)
access gallery (TA40)
link tunnel
(TAG42)
ECA4
PGC8
QTRF4002
TED
chicane
TT41
1
2
3
TT40
STOP
4
TJ8
SPS
TI 8

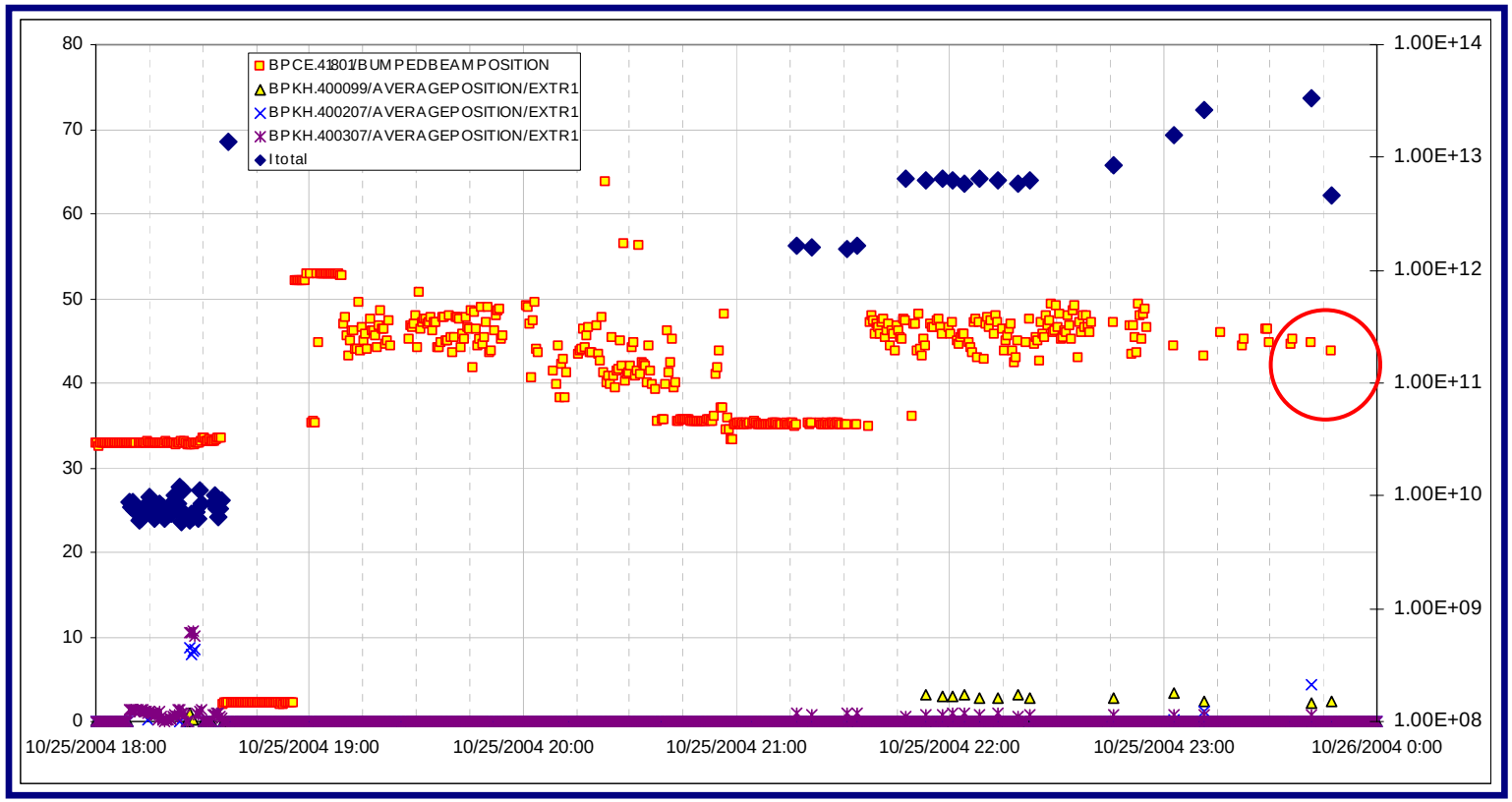
History: losses and extracted intensity

Log scale !



Conclusion : No losses on the septum for the bad extraction. Kicker OK.

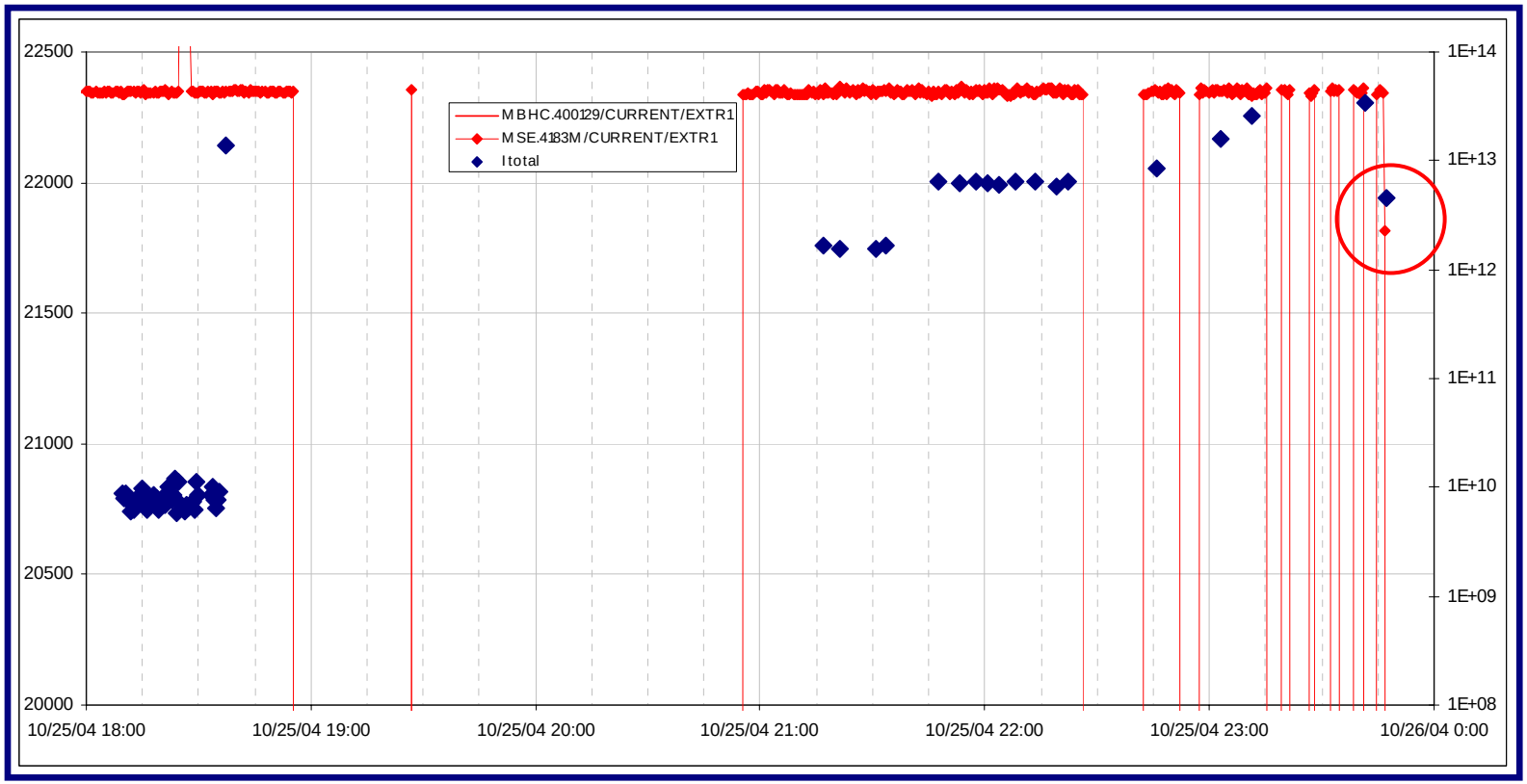
History – bumped beam position



Conclusion : Bumped beam was in the correct position

(Note: high BPCE noise, pick-ups were saturated)

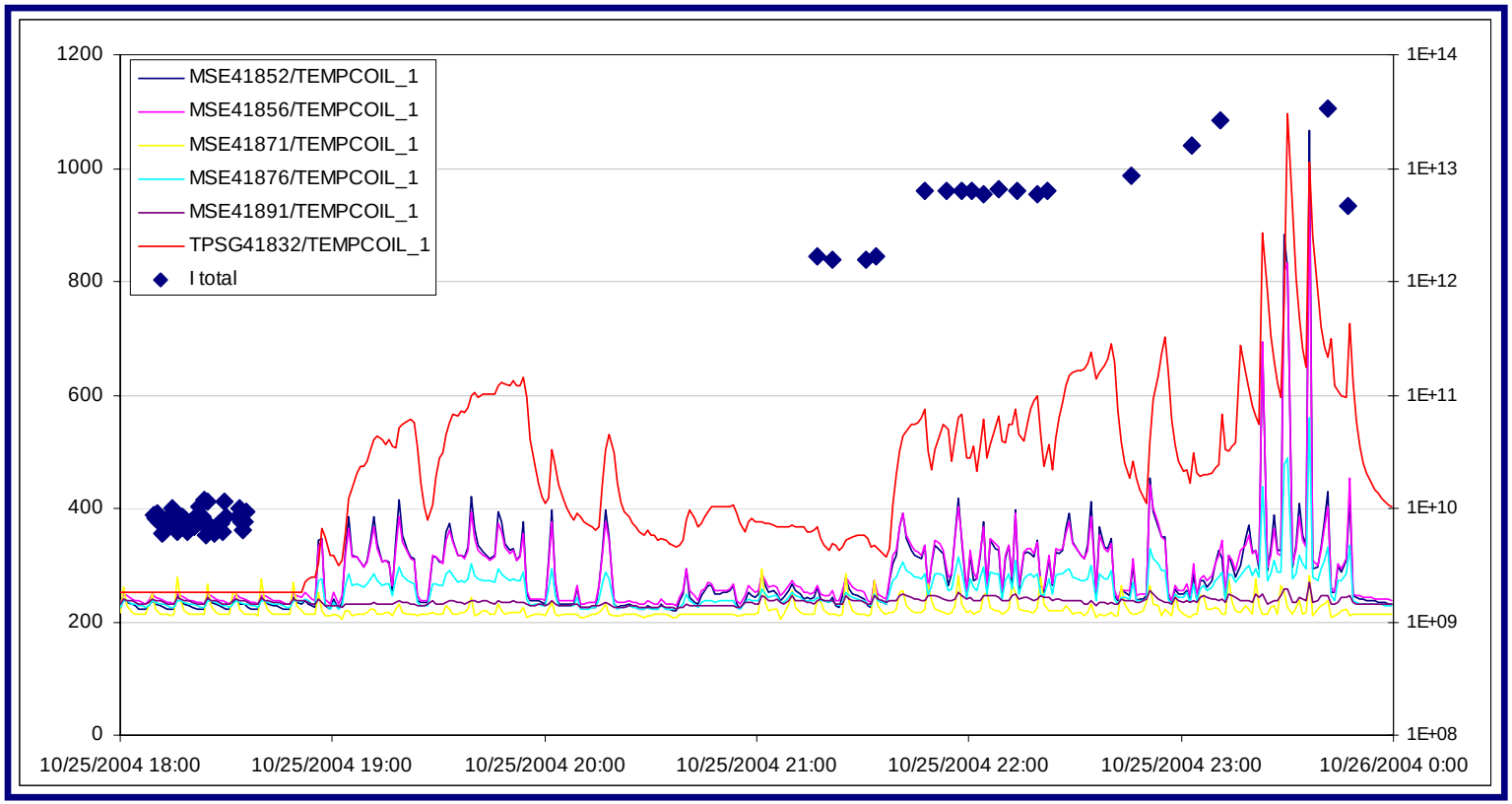
History – MSE current



Conclusion : MSE current appears to be ~2.5% low at extraction

(Note: ~8 MSE trips previous to the accident)

History – MSE temperature

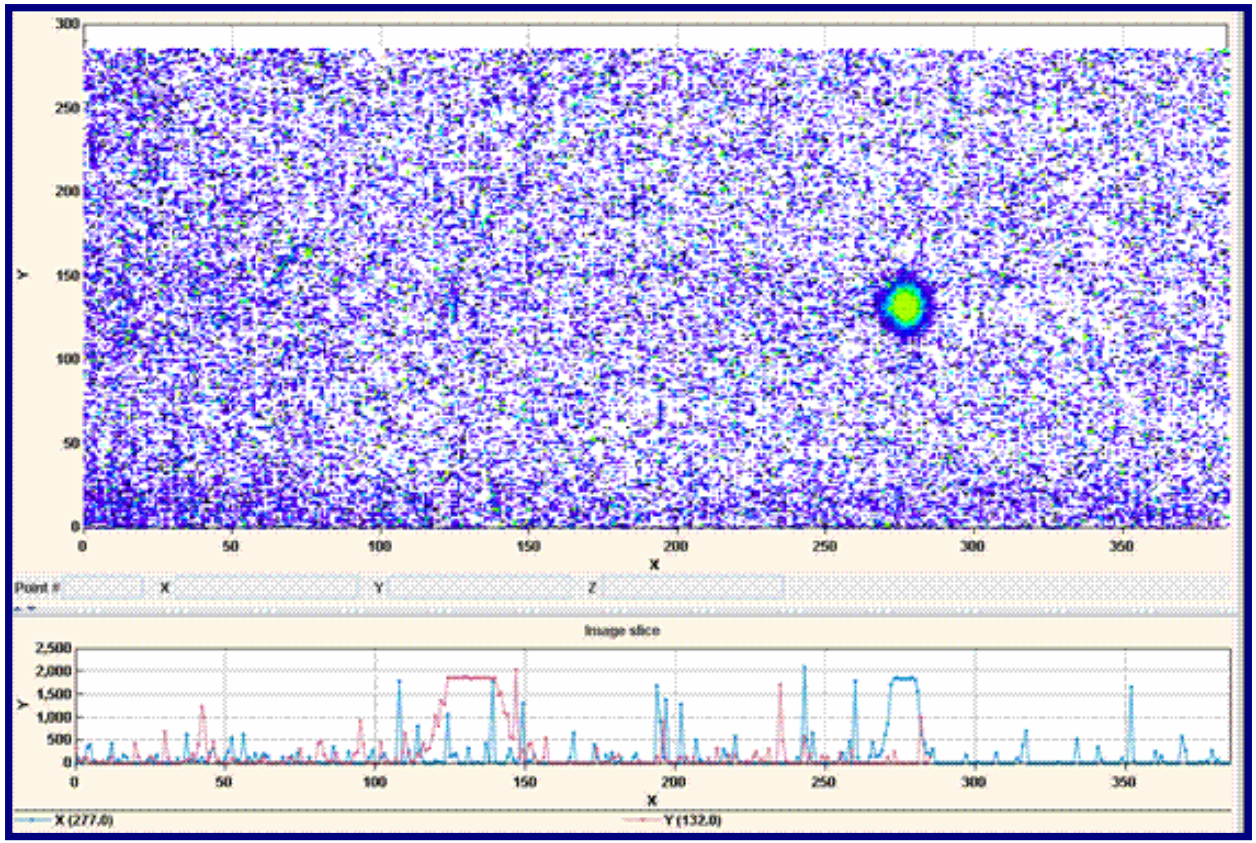


Conclusion : MSE temperature probes pick up beam signals with high intensity beam. Equipment expert disabled the temperature interlocks on the PLC side and extraction continued

Damage analysis

- Signs of beam impact for ~1.2m on right-hand mid-plane of vacuum chamber.
- Molten material ejected onto the other side of the chamber over ~1m.
- Chamber wall is cut through for ~20cm – traces of molten material on the outside.
- No signs of heating from any impact on the large exit flange of the magnet (i.e. no significant primaries penetrated through the chamber).

Event reconstruction -screens

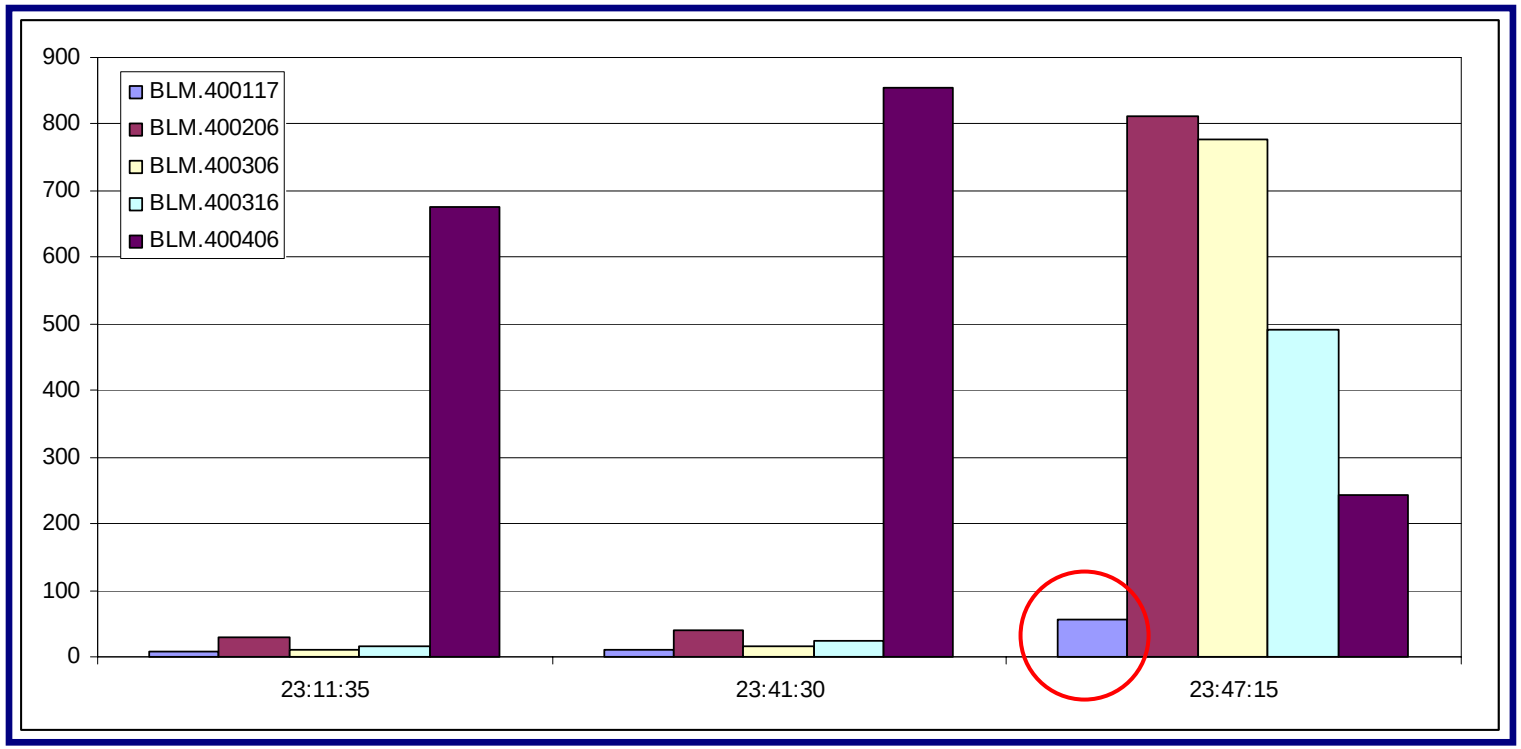


- BTVI 4001 screenshot at 23:47:36 captured the beam
- The beam passed 10.8 mm horizontally to the inside of the position for the previous shots

Event reconstruction - BPMs

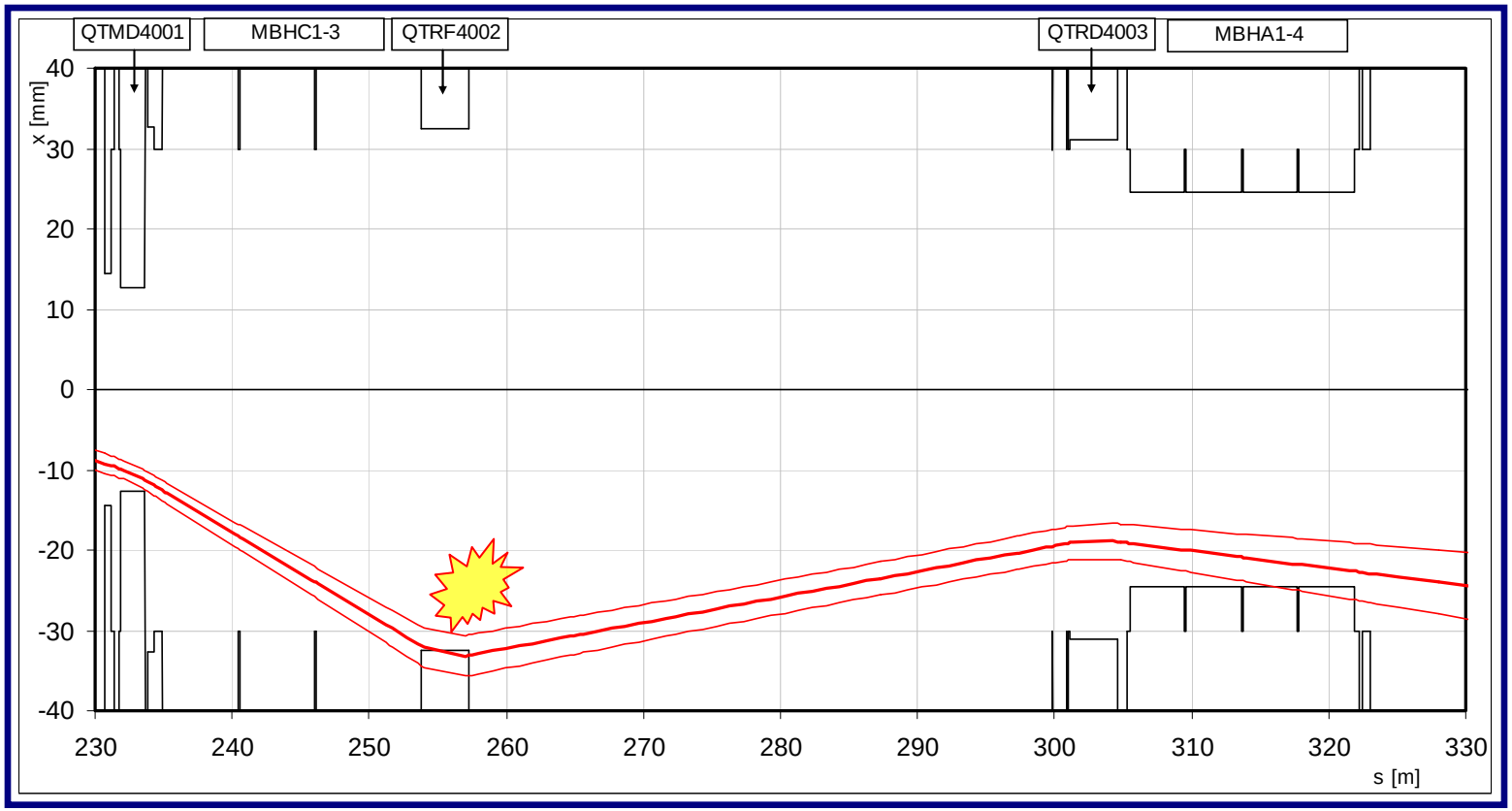
BPK400099 indicates a trajectory about 4.3mm inside the previous ones

Event reconstruction - BLMs



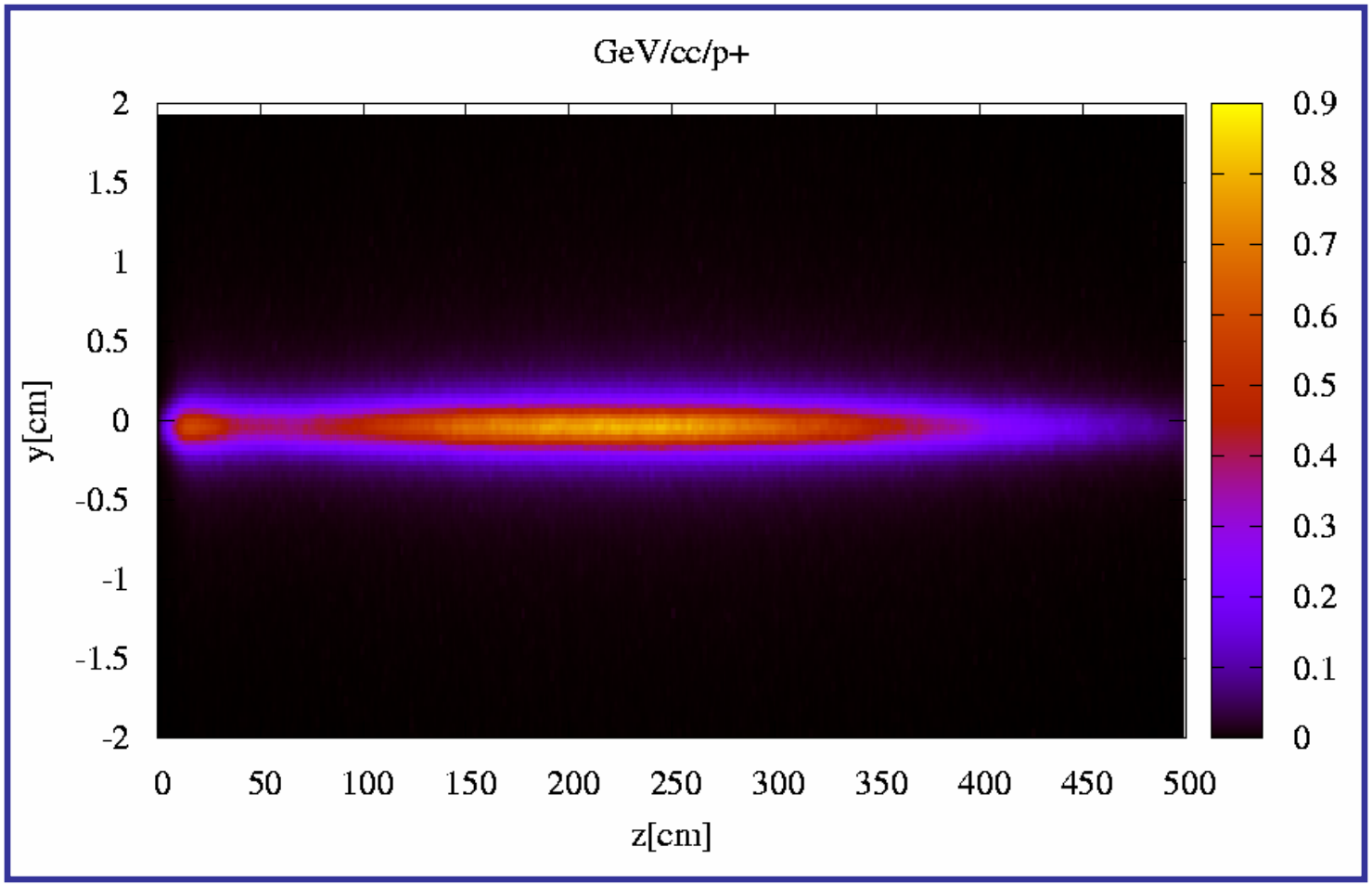
- BLM 4002, 4003 record the accident on the magnet
- BLM 4001 reads higher – backscattered radiation OR losses on QTMD4001?

Event reconstruction - trajectory



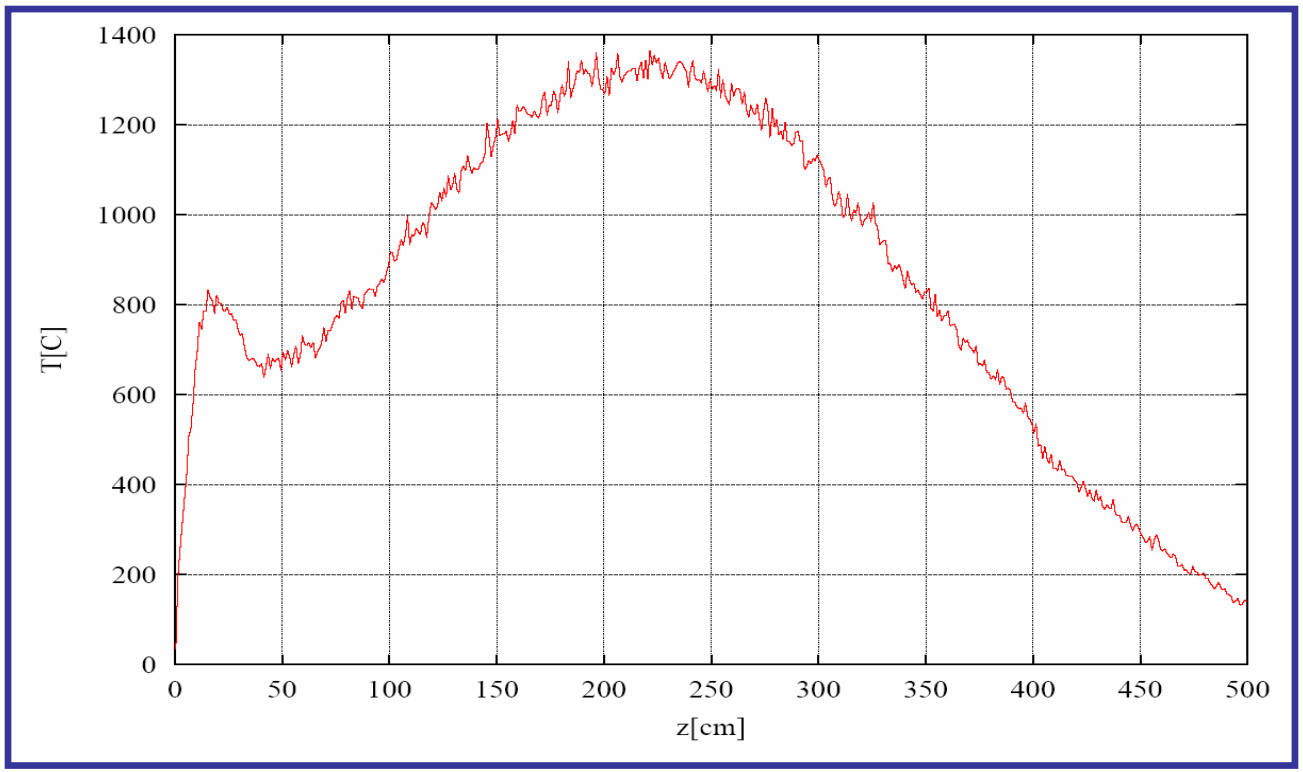
- A trajectory ~consistent with the observed BTV and BPM readings, and the damage location in the QTRD, requires an MSE $\Delta I/I_{nom}$ of -5.1%.
- The impact angle at the chamber is calculated at 0.59 mrad.
- The beam size (1 σ) is 0.7 mm in both planes.

First FLUKA simulation results



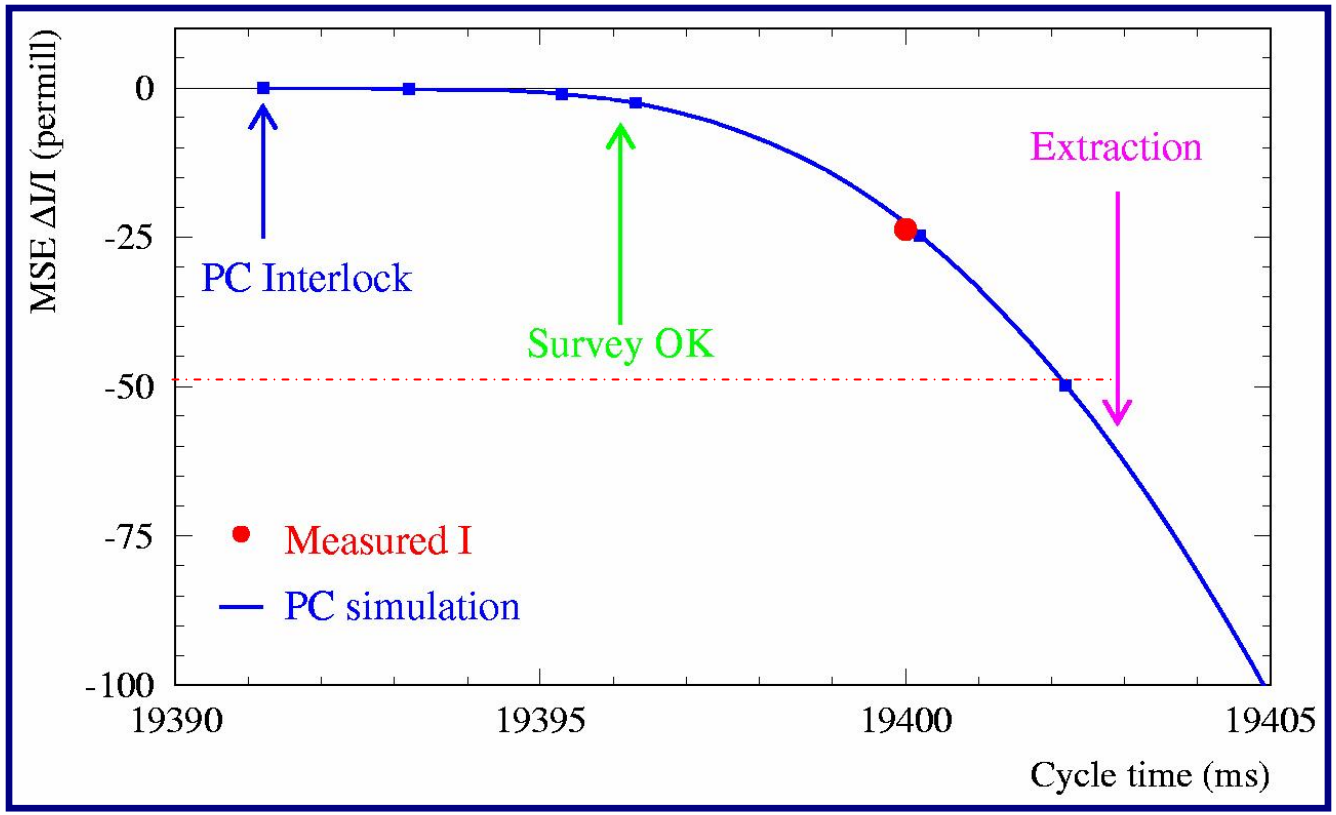
- A FLUKA model of the impact was made with the 1mm steel chamber and the calculated parameters (x' = 0.59mrad, sx = sy = 0.7mm, 3.4 1013 p+).

First FLUKA simulation results



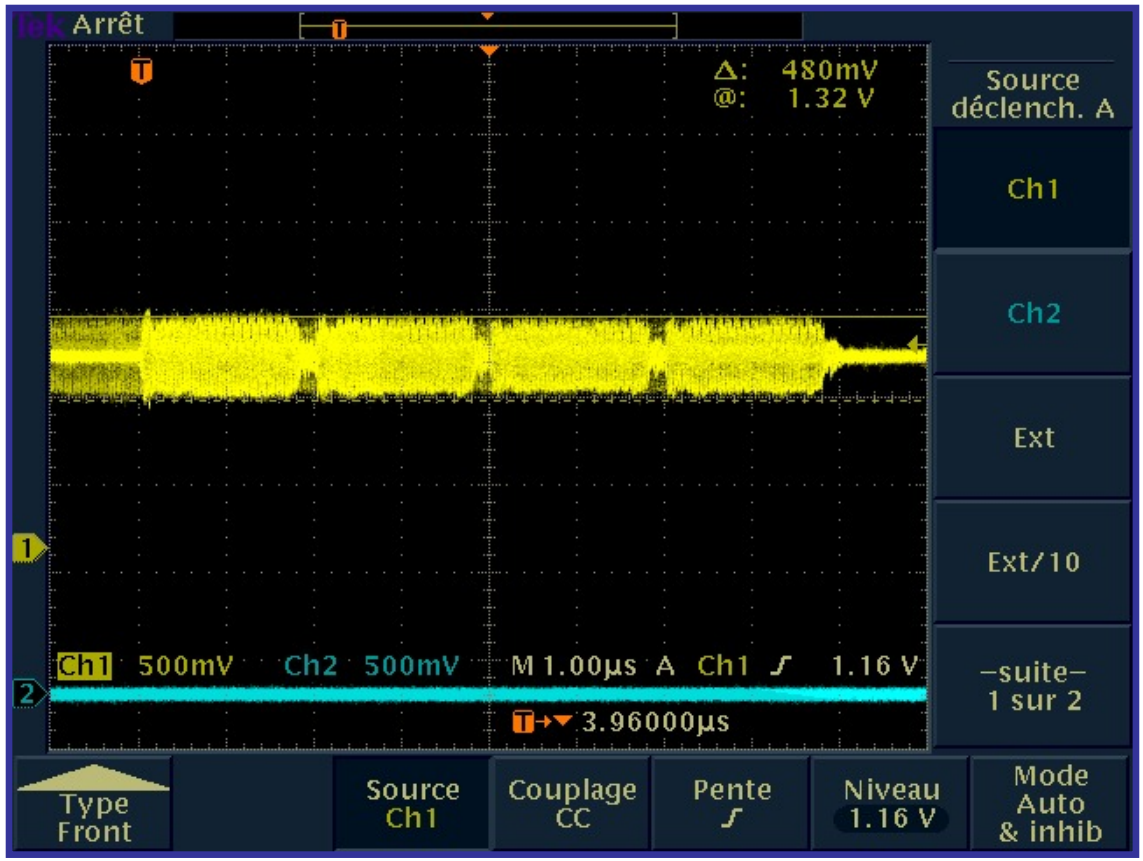
- Melting point (304L) is about 1400 C, so this first simulation seems to underestimate the energy deposition
- Probably indicates that the beam impacted more upstream….

Event reconstruction - interlock



- The I_{MSE} surveillance window only works to about 7ms before extraction
- The current measurement happens at the nominal extraction time - about 3ms before real extraction (kicker prepulse delays)
- The MSE time constant is short (L/R = 23ms)…. $\Delta I/I$ is about -5% in the 11ms
- At the time of the surveillance $\Delta I/I$ was about -0.5 % - still inside tolerance window

Noise on MSE PLC



- Crosstalk over cables and within PLC into other channels, increasing with beam intensity, number of connections (reduces as tanks get disconnected)
- MSE tripped also with noisy Pt100 interlocks disabled in the interlock matrix

Summary of what went wrong…

- The intense LHC beam caused noise on the sensor cables of the MSE septum, which was transmitted to the PLC (~6V).
- The PLC generated interlock signals on the noise, also with interlocks logically disabled, and these signals tripped out the MSE power supply.
- At the fatal extraction, the supply was tripped by a fake “water flow” interlock coming from the MSE PLC, about 11ms before the extraction event.
- The MSE current started to decay – but at the moment of surveillance 7ms before extraction, was still in tolerance.
- At the moment of extraction, the current had decayed by 5.1%.
- This field error caused the beam to hit the QTRF4002 chamber.

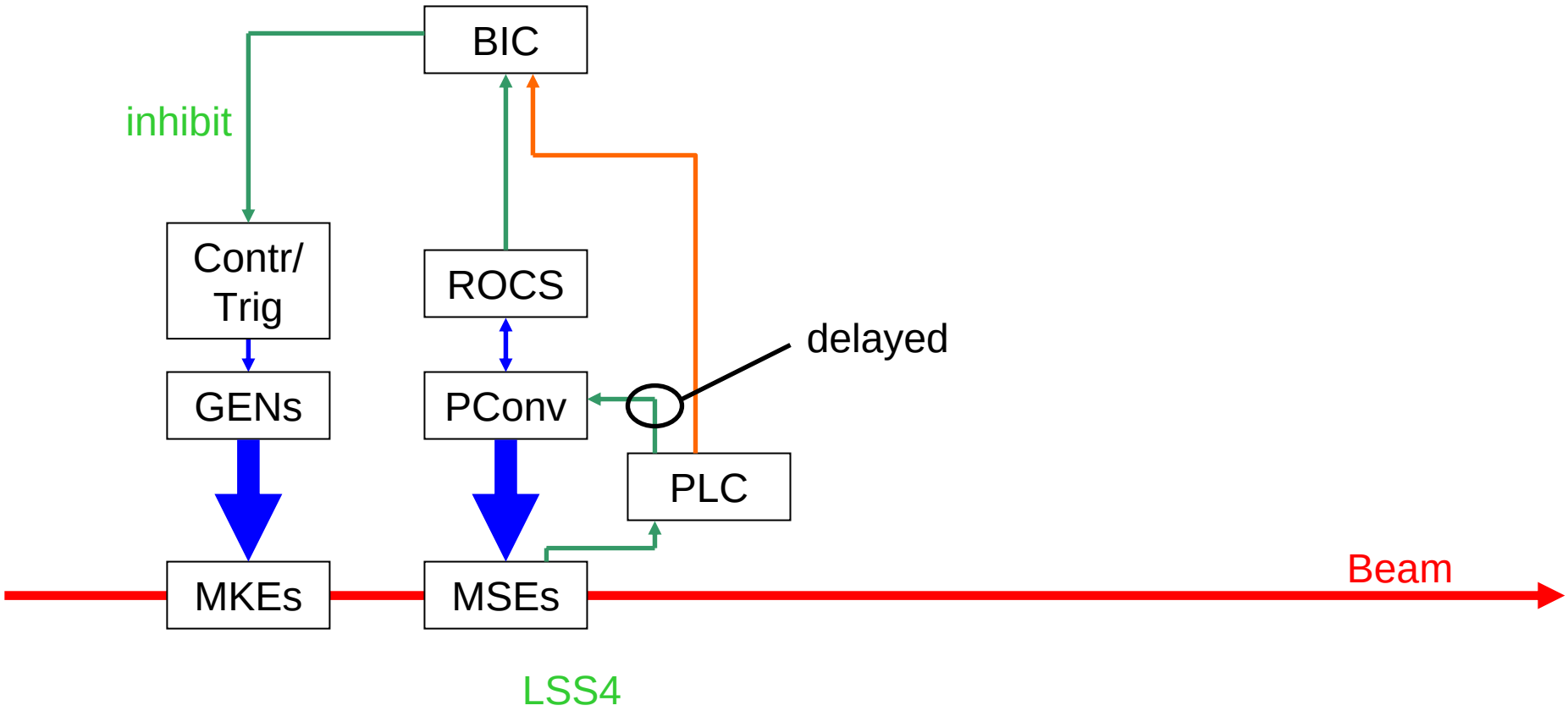
And why it went wrong….

- The Interlock controller BIC did not have any direct input from the MSE PLC – just from the MSE supply current surveillance.
  - This was changed for the test on 8/11/04, with a signal first sent to the BIC, and then to the convertor after a ~10ms delay
- The MSE noise problem should have been solved with a high intensity bumped beam without extracting.
  - This was done on 6/11/04 during the TI 8 test, with the disconnecting of the MSE temperature gauges, and further tested before any extraction on 8/11/04.

Improvements for the high-intensity MD on 8./9.11

Direct signal from the MSE interlock controller (PLC) to the BIC.

Delay of 10 ms in the PLC before sending interlocks to the PConv.



And other improvements made before the test on 8/11/04….

- Proper procedures for the setting-up of the high intensity extraction, which was separated as far as possible from the TT40 materials test.
- The directive that problems have to be completely solved, *especially with machine safety interlock systems,* before commissioning high intensity beams can continue.
- The ROCS current surveillance window was shortened from 10 ms to 1ms and shifted as close as possible to the effective extraction, single measurement instead of averaging.
- The ROCS current surveillance was tested in this new configuration and a serious bug found (2 cycles old data). This bug was fixed.
- The BPCE bumped beam position was very noisy, which meant this was not fully operational during the first test. Attenuators were added before 6/11/04 to solve this.
- MSE girder position and ‘independent’ kicker PFN voltage interlocks are still missing (BET like system)

And some lessons…

- Proper procedures for commissioning with high intensity beams are essential.
- Clear responsibility should be established.
- Problems encountered have to be completely solved before commissioning can continue.
- Full, formal testing of all safety interlock related equipment *and software* is essential (can we rely on compiled software in multi tasking environment?)
- Fast current surveillance for these systems in the extraction, transfer and injection regions must be implemented.
- Passive protection devices should be used wherever possible.
- Magnet trips will be correlated with injection / extraction