Quench of Triplet quadrupole (RQX.R1, 03.06.2018)

- Observations
  - Beam
  - Triplet circuit
  - Cryogenic system
- Simulations
- Summary

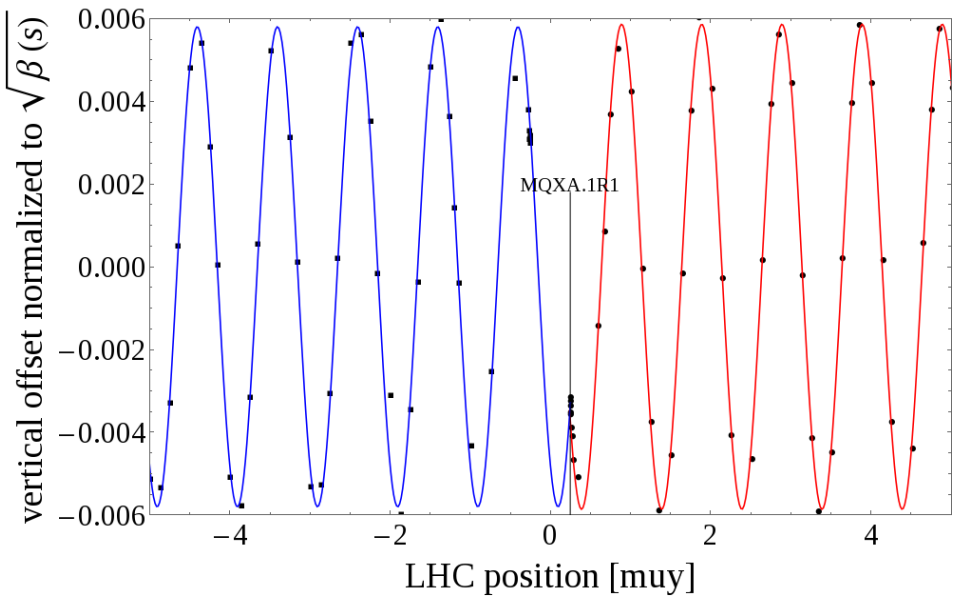
B. Lindstroem, E. Ravaioli, A. Verweij, D. Wollmann

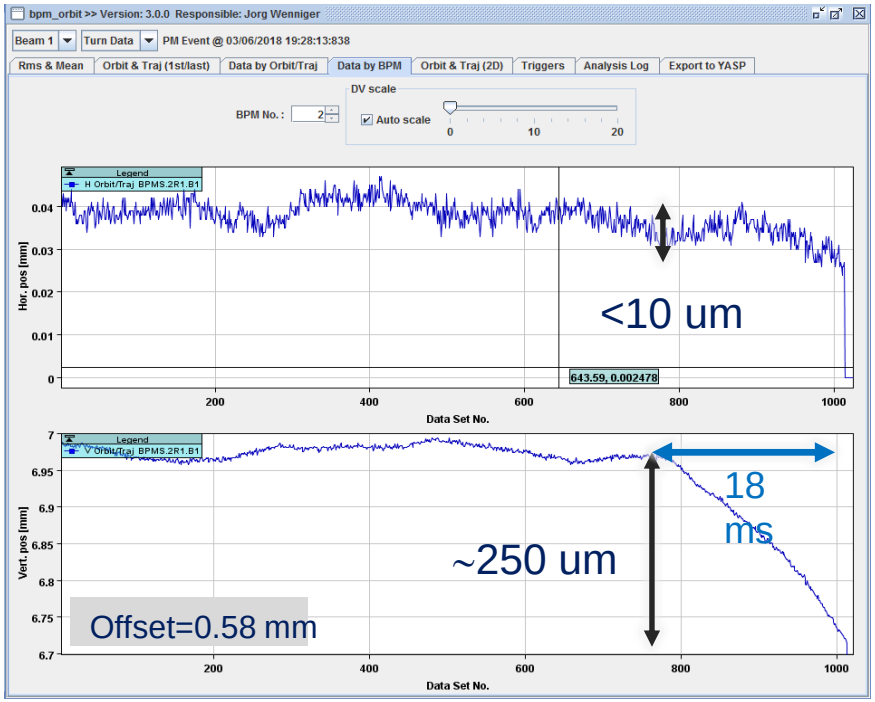
More details:

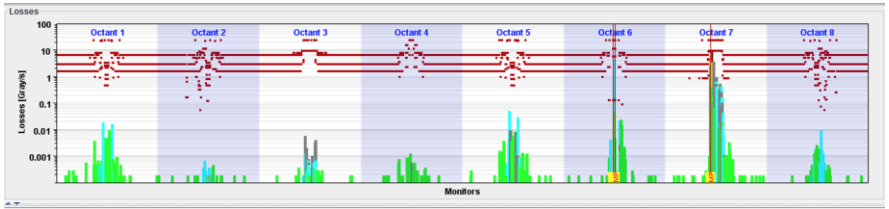
- Analysis of the sequence of events in RQX.R1 circuit on 3 June 2018, Internal note, TE-MPE, EDMS 2025613
- 168th and 169th MPP
- A. Verweij: Analysis of IT quench, 351st LMC, 20.06.2018

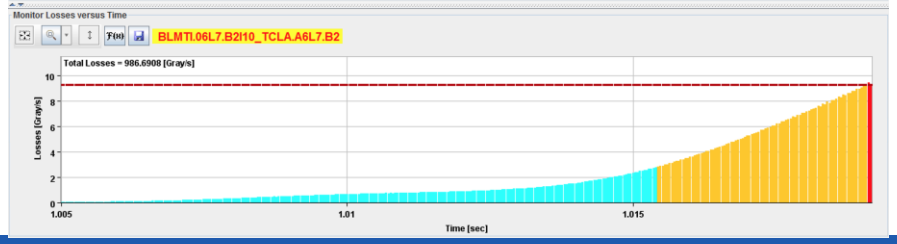
Beam observations during triplet event

- Significant orbit movement in B1
- No orbit change observed in B2
- Beams dumped by losses in collimators
- Max kick before beam dump: 0.2 urad



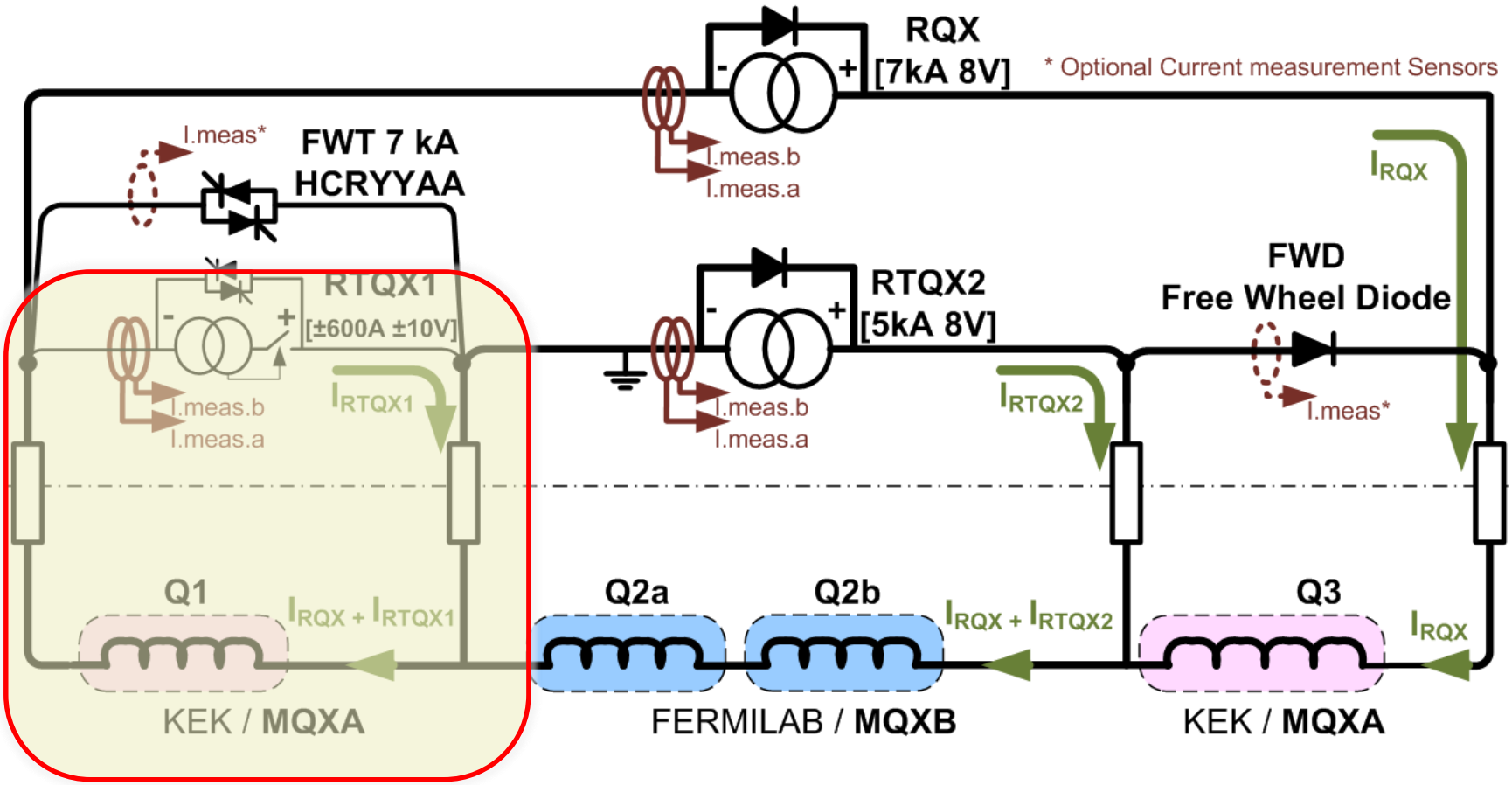






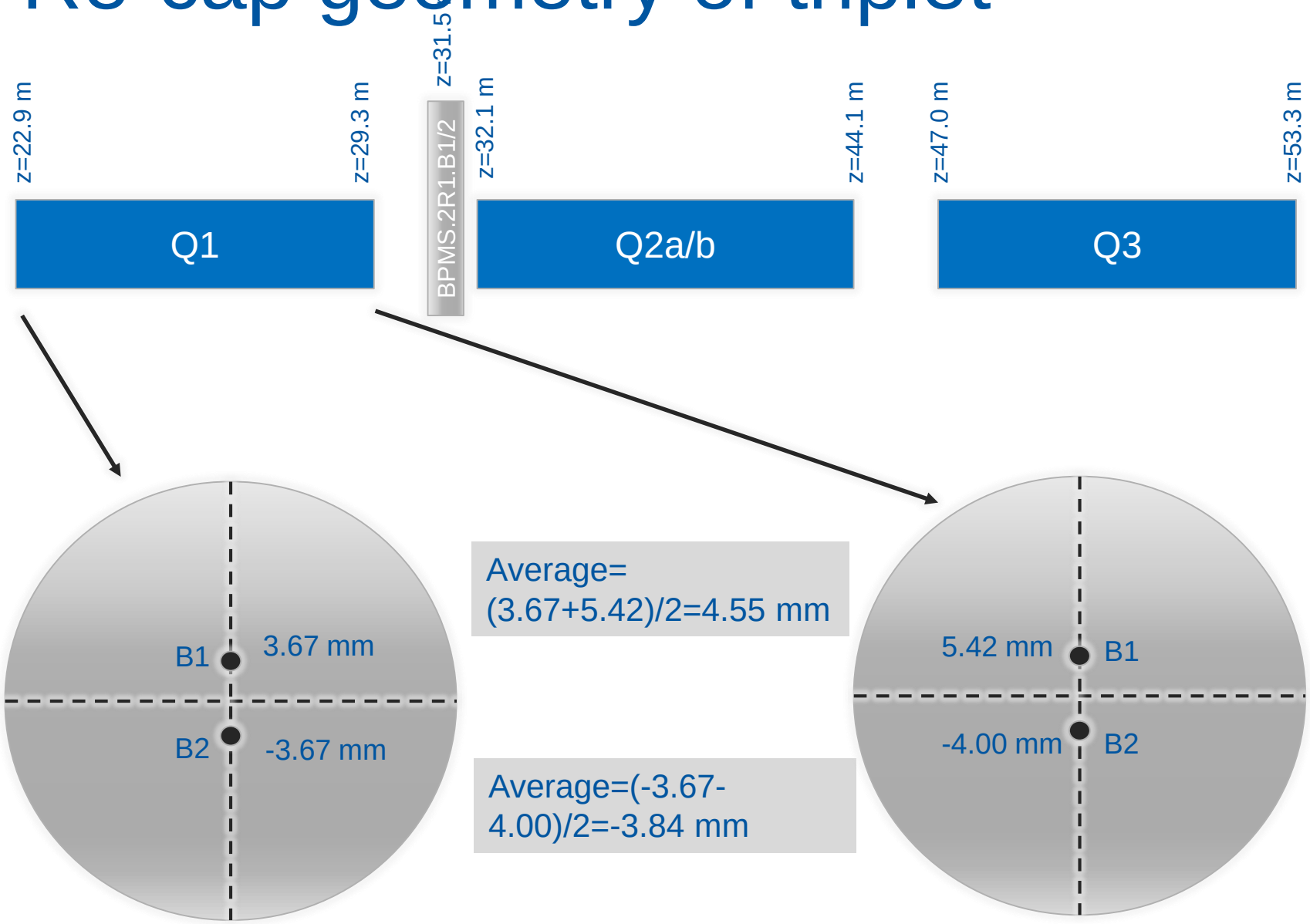
- Plotting two consecutive turns identifies the source of the orbit distortion in the triplet R1

Re-cap nested triplet circuit

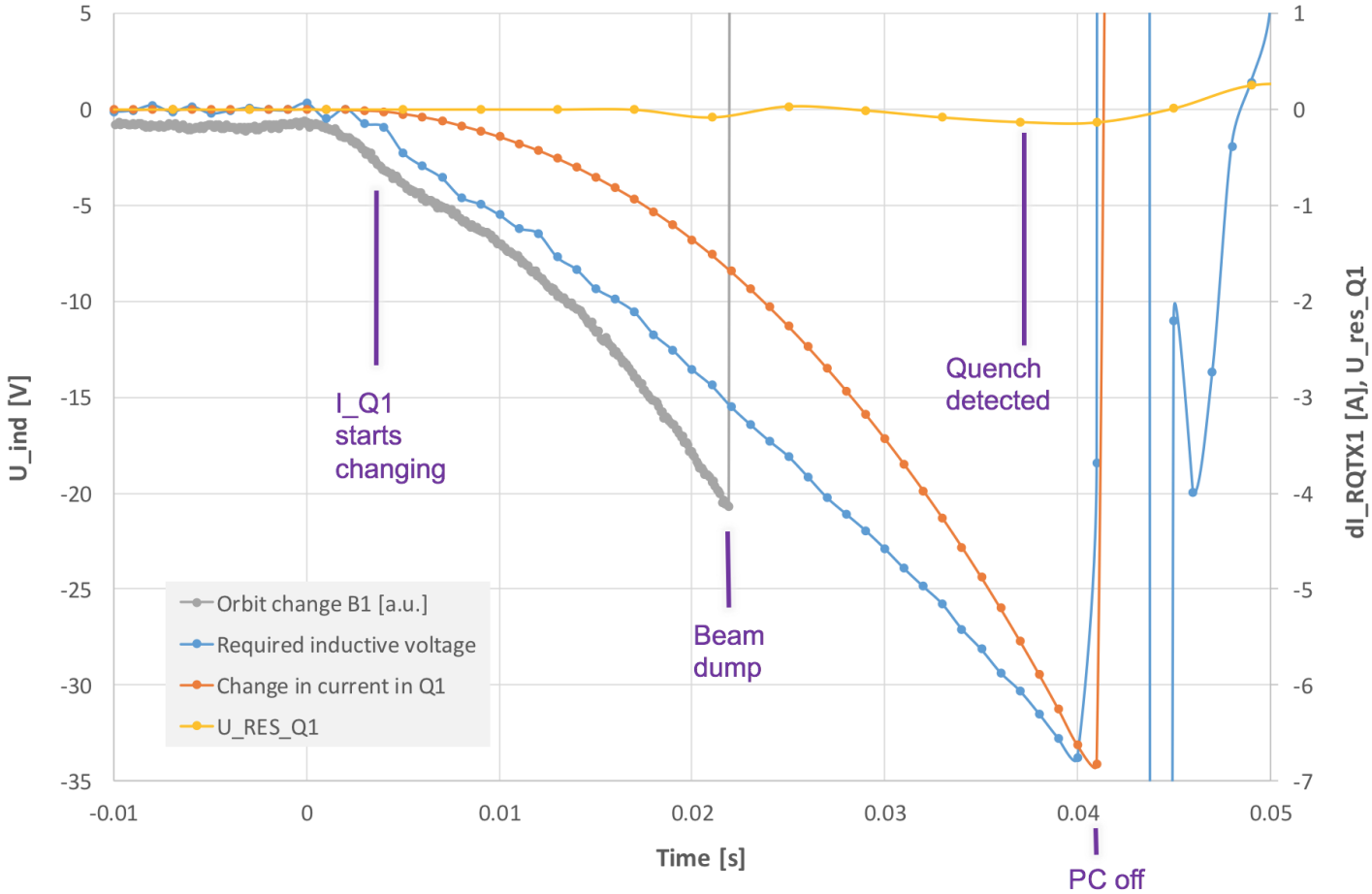


- Nested circuit with two main power converters (RQX and RTQX2) and one trim converter (RTQX1). The event originates in Q1.

Re-cap geometry of triplet

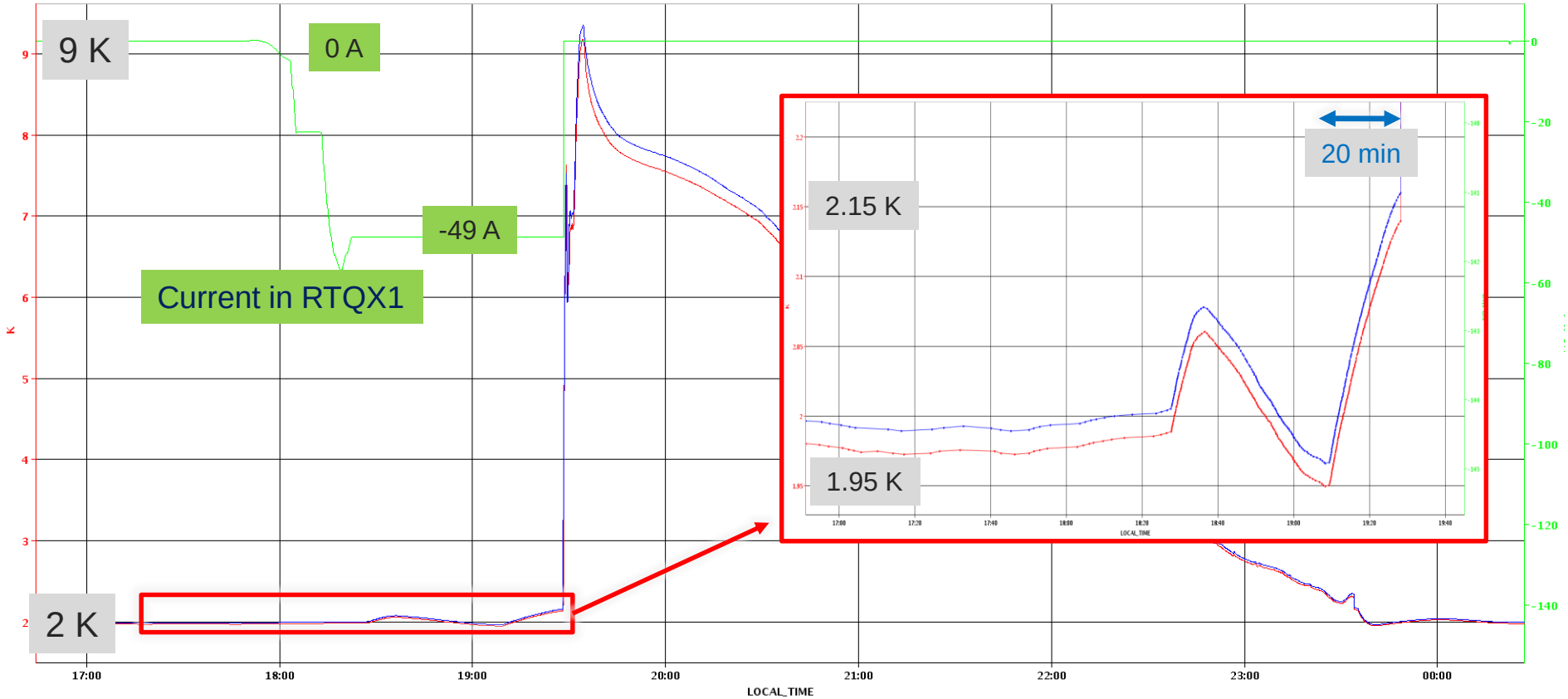


Circuit observations versus beam observations



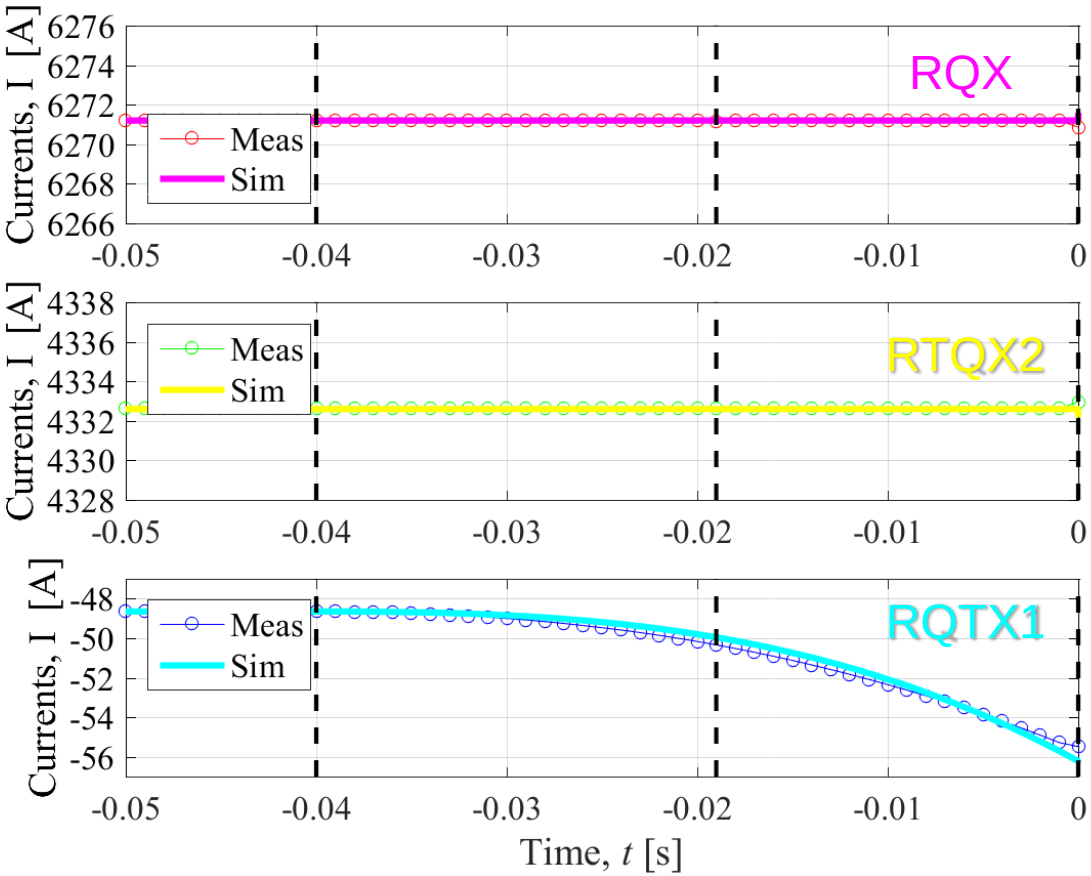
- Current change in RQTX1 at beam dump: - 1.7 A
- Quench detected only 18ms after beam dump
- Total current change in RQTX1 at moment of PC off: - 7 A
- Usually quench: quench detected with U_{res} > 100 mV (current change tens of mA) → very fast developing quench, detected very late, due to missing symmetric quench detection in triplet quads

Observations in cryogenic system



- Temperature oscillations in helium bath before event
- Triplet R1 warms up from ~1.97 K to ~2.16 K
- Helium temperature above lambda point means less cooling for magnet at energy deposition due to debris from IP

Observations in circuit versus simulations



- $I_{Q1} = I_{RQX} + I_{RTQX1}$
- $I_{Q2} = I_{RQX} + I_{RTQX2}$
- $I_{Q3} = I_{RQX}$

- Observed behaviour in circuit well reproduced by simulations
- Very fast current decay was achieved in simulations by defining high normal zone propagation velocity

Expected kick strength & beam offsets from circuit measurements

- Expected kick from measured current change at 6.2 kA (TF = 30.312 T/m/kA, and max ΔI 1.7 A)
  - B1 kick: **6.7e-8 rad**
  - B2 kick: **6.0e-8 rad**
- Expected offset from calculated kick:
  - **82 µm** offset at BPMS.2R1.B1
  - **39 µm** offset at BPMS.2R1.B2
- But, observed B1 offset: **250 µm**, B2 offset: **<10 µm**

→ **Factor 3** discrepancy

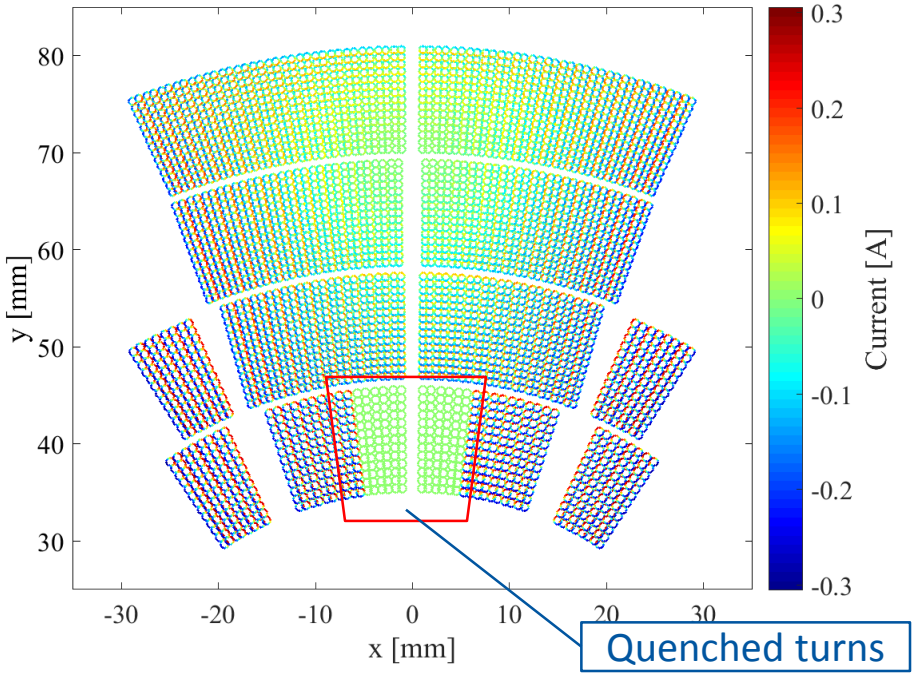
- Correct orbit in triplet confirmed by Q1 k-modulation measurements on 16.06.2018

→ Detailed study of field distortions during quench due to:

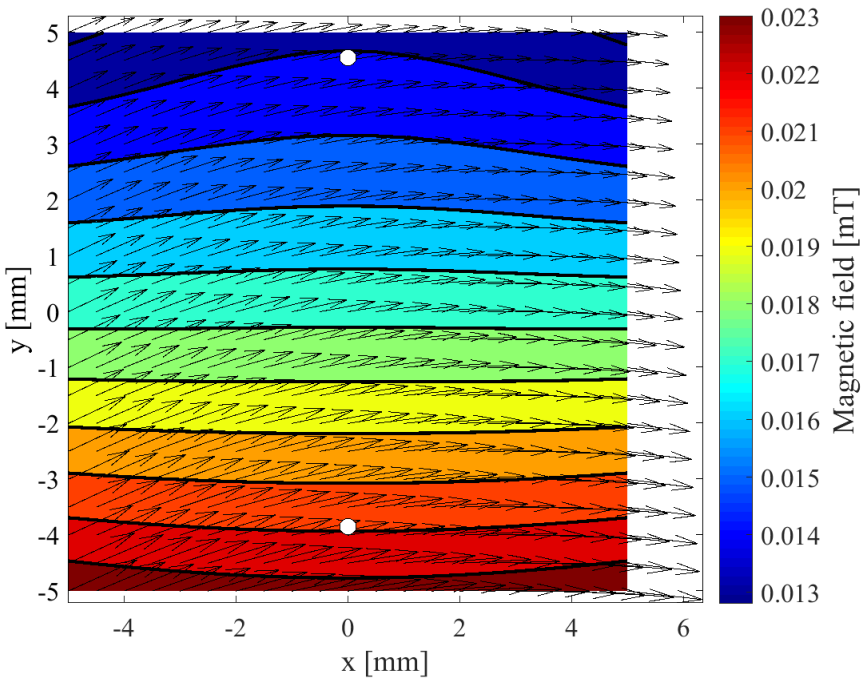
  - Inter-filament Coupling Currents (IFCC)
  - Inter-strand Coupling Currents (ISCC)
  - Current re-distribution in sc. Cables (CRC)

Inter-Filament Coupling Currents (IFCC)

Currents (only 1/4 magnet cross-section shown)



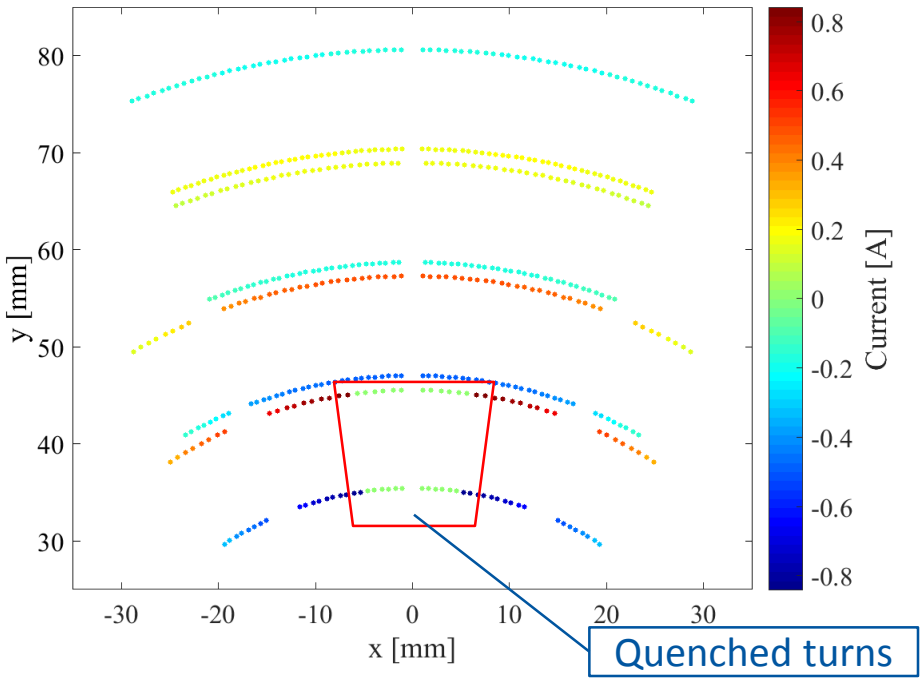
Magnetic field induced in the magnet aperture



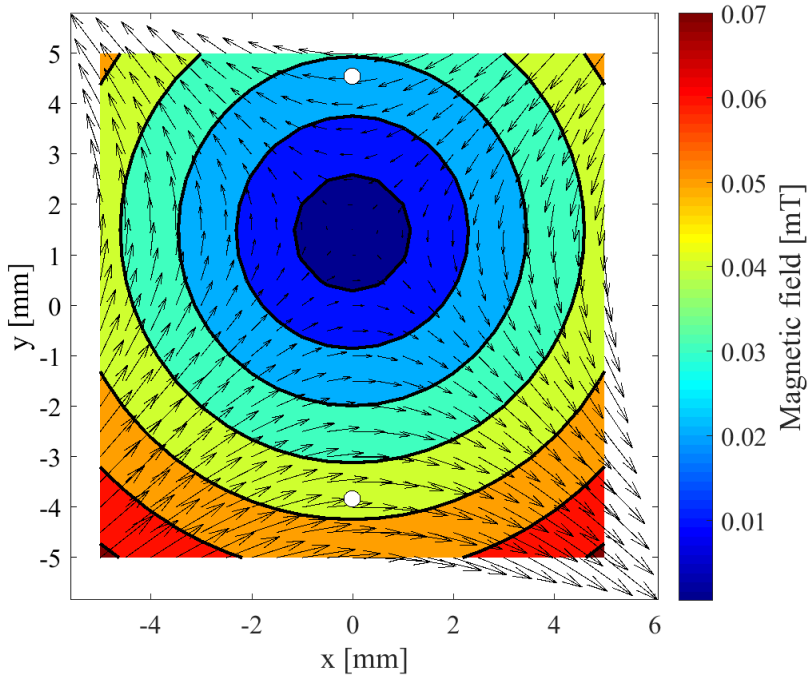
in [mT]	From BPM	From ΔI	IFCC	ISCC	CRC	All
B1, ΔB_X	+0.7	+0.233	+0.014			
B1, ΔB_Y	<0.1	+0.000	+0.002			
B2, ΔB_X	<0.1	–0.197	+0.022			
B2, ΔB_Y	<0.1	+0.000	+0.003			

Inter-Strand Coupling Currents (ISCC)

Currents (only 1/4 magnet cross-section shown)



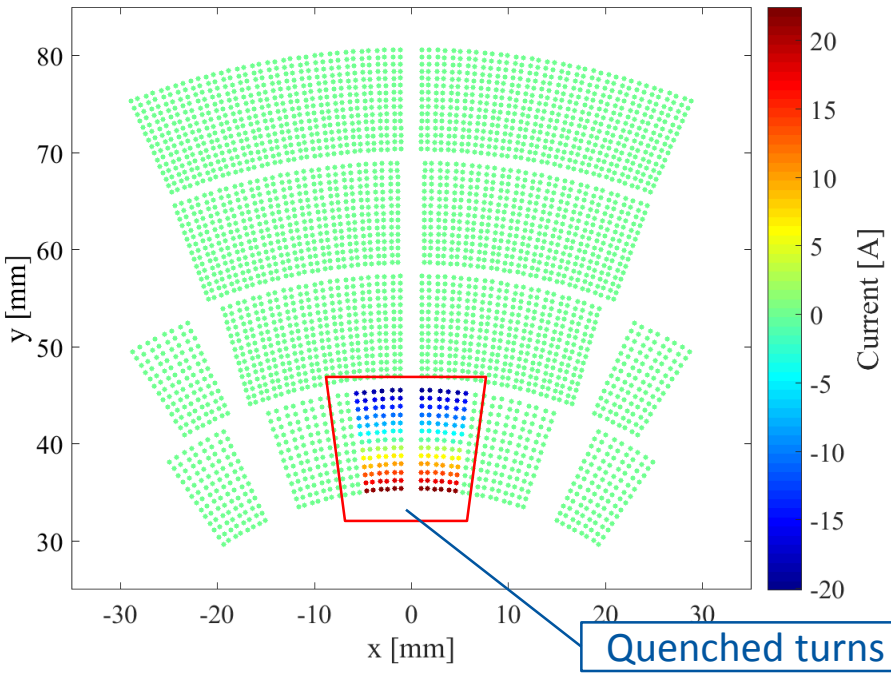
Magnetic field induced in the magnet aperture



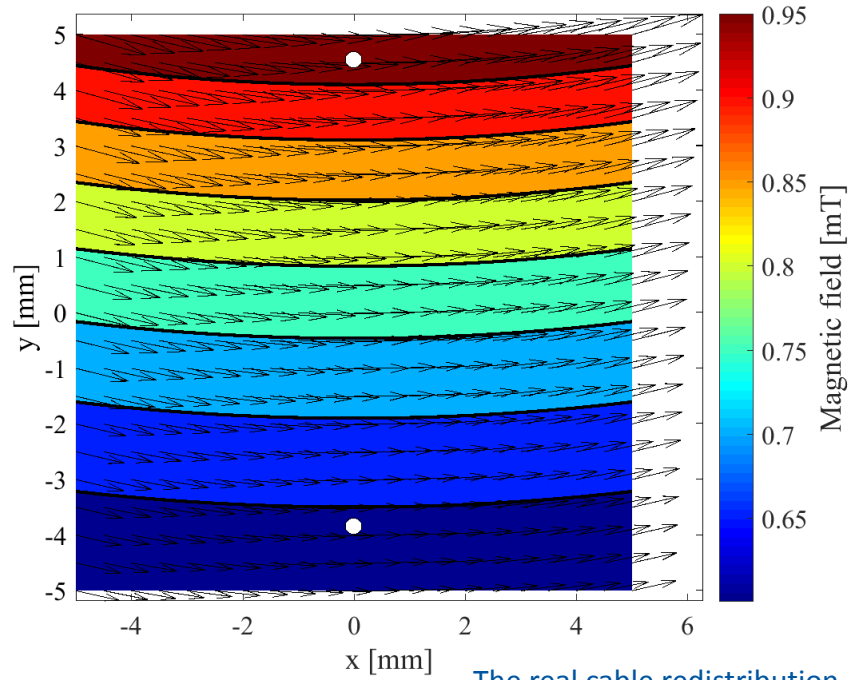
in [mT]	From BPM	From ΔI	IFCC	ISCC	CRC	All
B1, ΔB_X	+0.7	+0.233	+0.014	–0.026		
B1, ΔB_Y	<0.1	+0.000	+0.002	+0.000		
B2, ΔB_X	<0.1	–0.197	+0.022	+0.048		
B2, ΔB_Y	<0.1	+0.000	+0.003	+0.000		

Current Redistribution in the Cable (CRC)

Currents (only 1/4 magnet cross-section shown)



Magnetic field induced in the magnet aperture



in [mT]	From BPM	From ΔI	IFCC	ISCC	CRC
B1, ΔB_X	+0.7	+0.233	+0.014	–0.026	+0 / +0.967
B1, ΔB_Y	<0.1	+0.000	+0.002	+0.000	+0.000
B2, ΔB_X	<0.1	–0.197	+0.022	+0.048	+0 / +0.636
B2, ΔB_Y	<0.1	+0.000	+0.003	+0.000	+0.000

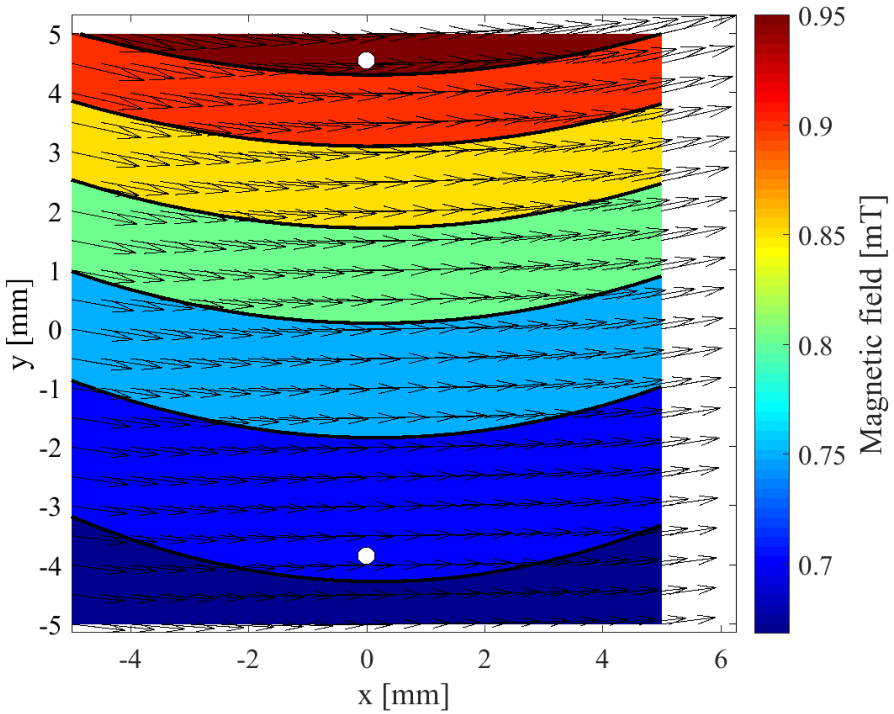
The real cable redistribution currents are between two extreme cases

- Infinite contact resistance between strands: Effect is zero
- Zero contact resistance between strands: Effect is maximum (full redistribution)

Kicks from IFCC, ISCC and CRC

- Dipole kicks observed in beam can be explained by current redistribution in the sc. cables during the quench
- The other effects studied are one order of magnitude too small

- Note, that the exact values of many parameters used in the simulations are unknow: number of quenched turns, initial length normal zone, normal-zone propagation velocity, turn-to-turn quench propagation time, conductor properties, …



in [mT]	From BPM	From ΔI	IFCC	ISCC	CRC	All
B1, ΔB_X	+0.7	+0.233	+0.014	–0.026	+0 / +0.967	+0.221 / +1.188
B1, ΔB_Y	<0.1	+0.000	+0.002	+0.000	+0.000	+0.002
B2, ΔB_X	<0.1	–0.197	+0.022	+0.048	+0 / +0.636	–0.127 / +0.509
B2, ΔB_Y	<0.1	+0.000	+0.003	+0.000	+0.000	+0.003

Summary

- Beam dump observed on 03.06.2018 due to losses in the collimation system has it's origin in the triplet R1 (Q1)
- Very fast (symmetric) quench leading to beam dump after 240 turns → QPS detection only ~40 ms after onset of quench
- Origin of event most likely due to warm up of helium in combination with debris from the IP
- Asymmetric response of B1 and B2 can be explained by current redistribution in sc. cables during the quench

CERN

QPS signal names