LRBB wire: results of failure-case study

B. Lindström, C. Wiesner, D. Wollmann
CERN

Many thanks to: R. Bruce, L. Ceccone, R. Mompo, A. Poyet, A. Rossi, G. Sterbini, J. Uythoven, M. Zerlauth

176th SPS and Machine Protection Panel Meeting - 20190329

BBCW – setup

- 2 parallel, straight, wires at distances +- 5.7 – 13 mm from beam
  - TCTs at nominal positions (7.8 sigma), implying ~11.2 mm hor and ~9.9 mm ver
- Already in: TCTPV.4R1.B2 and TCTPH.4R5.B2
- Also install in either:
  - 1. TCTPV.4L1.B1 and TCTPH.4L5.B1
  - 2. TCTPH.4L1.B1 and TCTPV.4L5.B1
- Wires are hard-wired in series, 1 PC per set of wires
- 1000* mm long, 2.5 mm diameter, current up to 350 A
- Optics: LHC Run II pp 2018 collision 0.25/0.30 cm beta*
  - Run III optics not yet published

*1000 mm long according to ”LRBB – readiness of hardware and installation”, A.Rossi, 23rd HL-LHC TCC meeting, Jan 19 2017
984 mm long according to ”Compensation of the Long-Range Beam-Beam Interaction in the LHC”, A.Poyet, Master thesis 2017

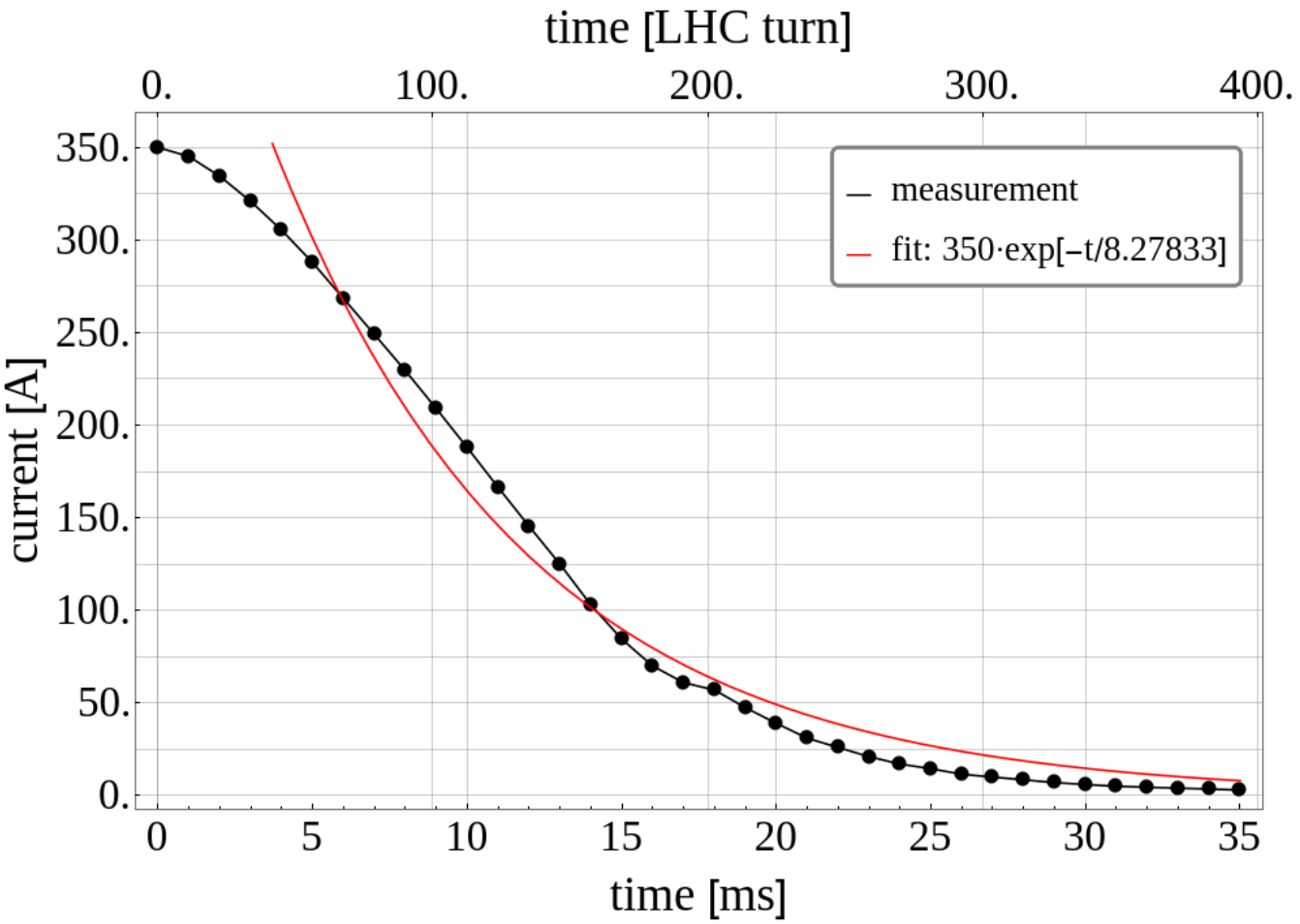
Collimator Beta Functions

Collimator	Beta x [m]	Beta y [m]
TCTPV.4L1.B1	2199.74	1557.71
TCTPH.4L5.B1	2165.16	1466.13
TCTPV.4R1.B2	2182.42	1511.57
TCTPH.4R5.B2	2147.97	1421.38
TCTPH.4L1.B1	2165.16	1466.12
TCTPV.4L5.B1	2199.74	1557.71

- 25 cm optics
- Similar beta functions, no significant difference between the wires in terms of failures, except for collimator margins (phase advance dependence)

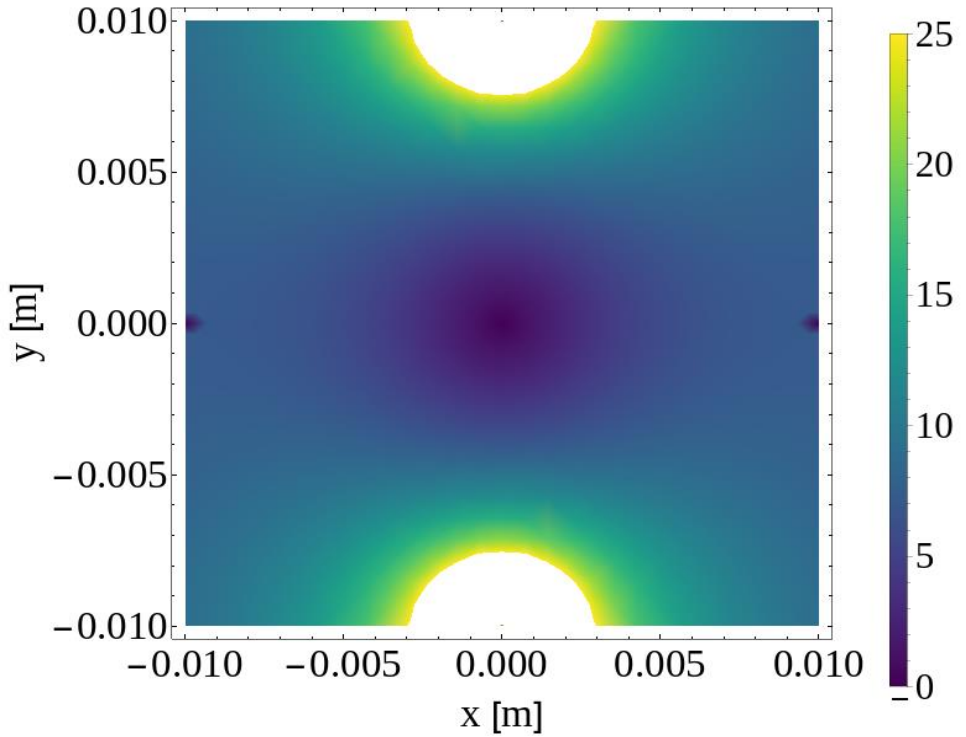
Current decay time constant

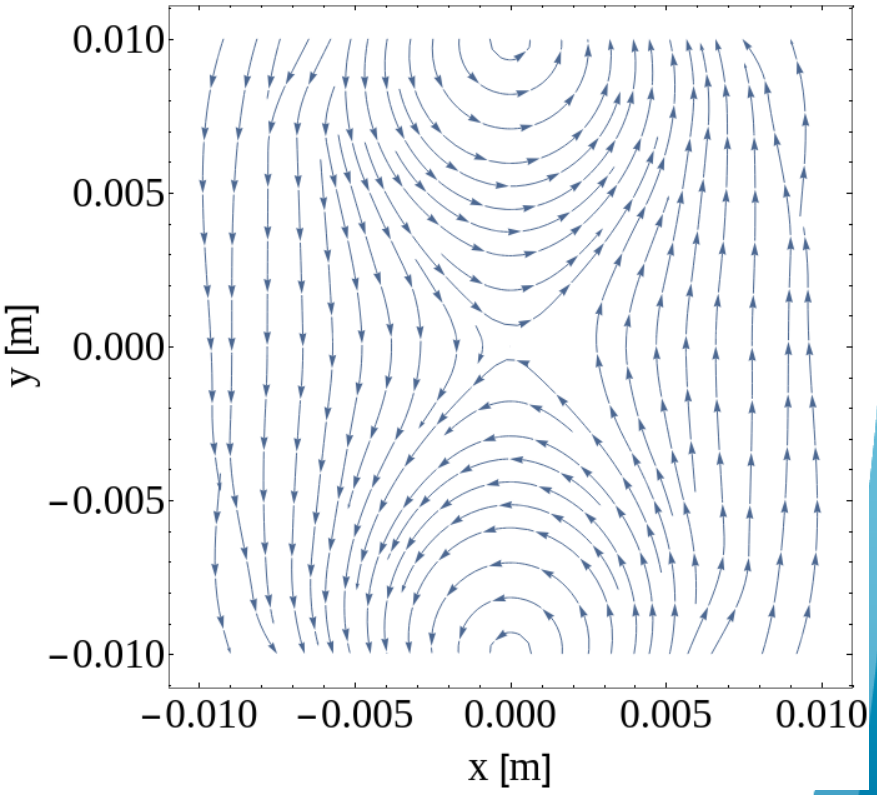
- Fitting an exponential decay to the measured current decay



Nominal magnetic field

- From Biot-Savart, assumed infinitely thin wire and free vacuum
- +- 10 mm, 350 A

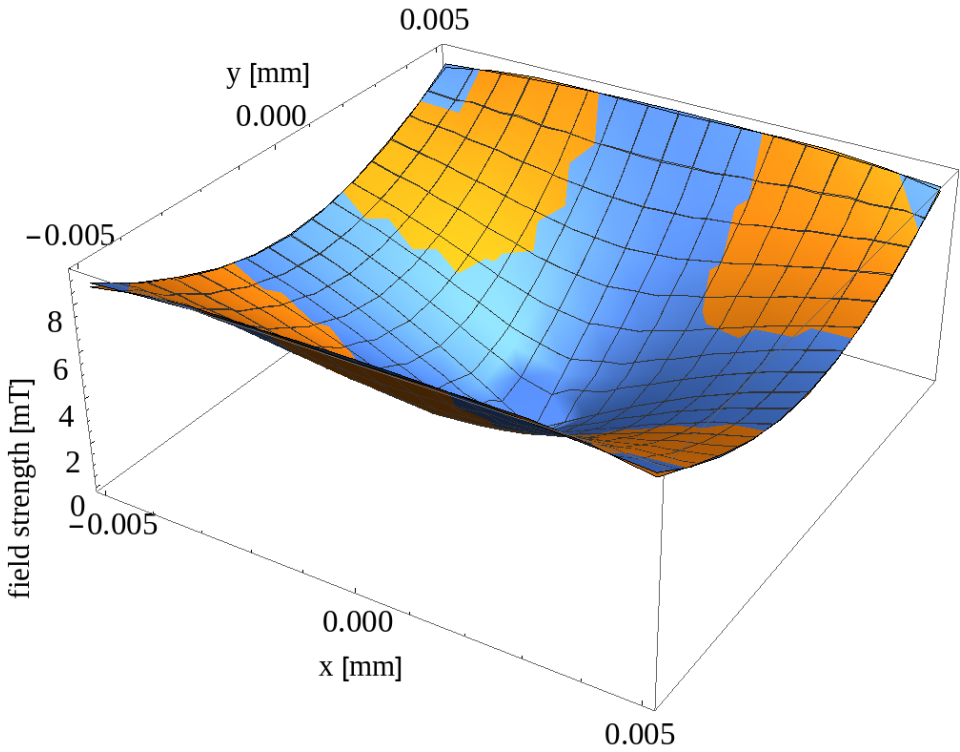




Multipolar decomposition

Order n	Normal [T/m^n]	Skew [T/m^n]
0	0	0
1	**1.4**	0
2	0	0
3	**-14000**	0
4	0	0
5	**1.3e8**	0
6	0	0
7	**-1.2e12**	0

- +- 10 mm, 350 A
- c.f. Q4/Q5 gradient: 160 T/m
- Orange: original field
  Blue: multipoles



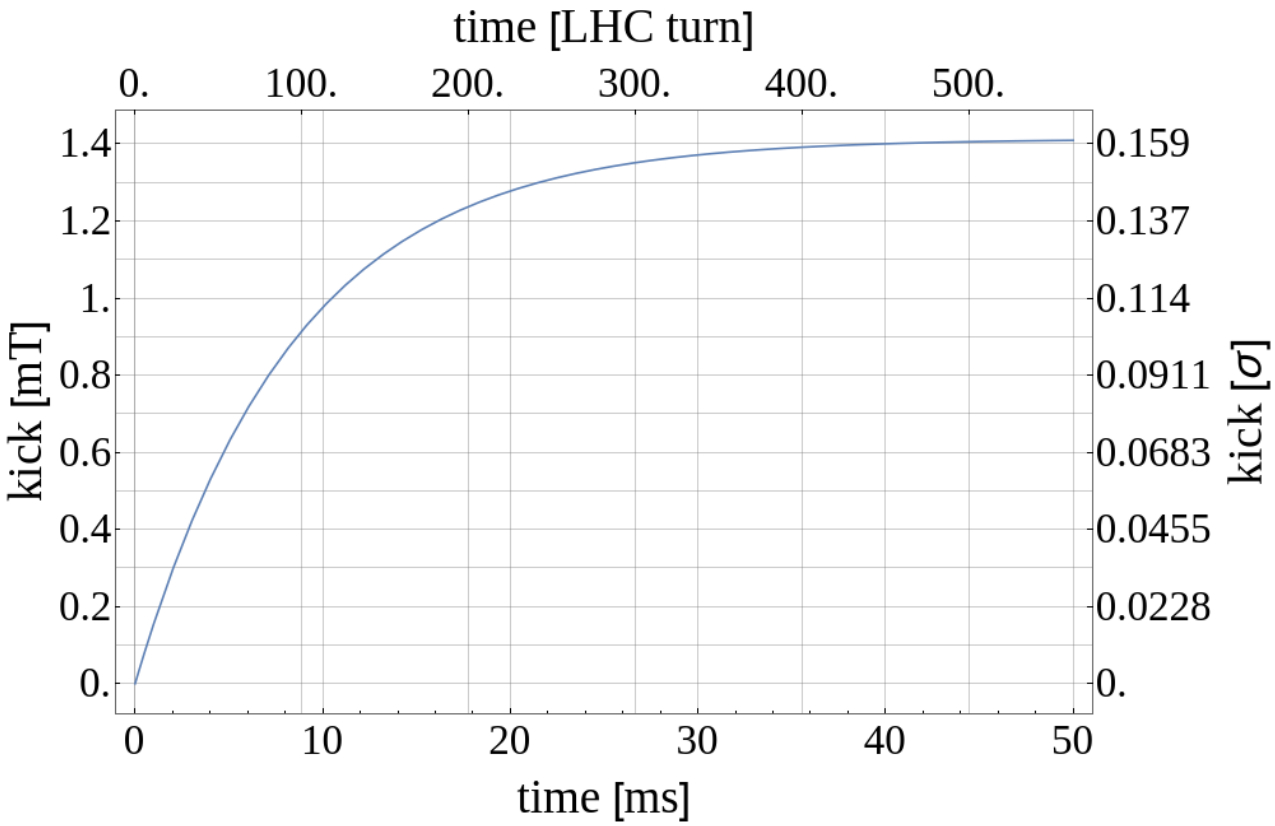
Potential failure scenarios

- PC trip – both wires loose current simultaneously
  - Beta beating
  - Tune shift
  - Orbit distortion if beam not centered in the TCT
- Single wire short, one wire still powered (not likely in RunIII)
  - Dipolar kick
  - Beta beating
  - Tune shift
- Incorrect polarity on one wire
  - Circuit is hardwired, both wires in single cicuit, same PC, this failure should be detected during commissioning and corrected
    - Procedure for commissioning / interventions
  - Strong dipolar kick

- PC current is interlocked at 350 A max, but can potentially deliver up to 600 A

PC Trip – orbit distortion

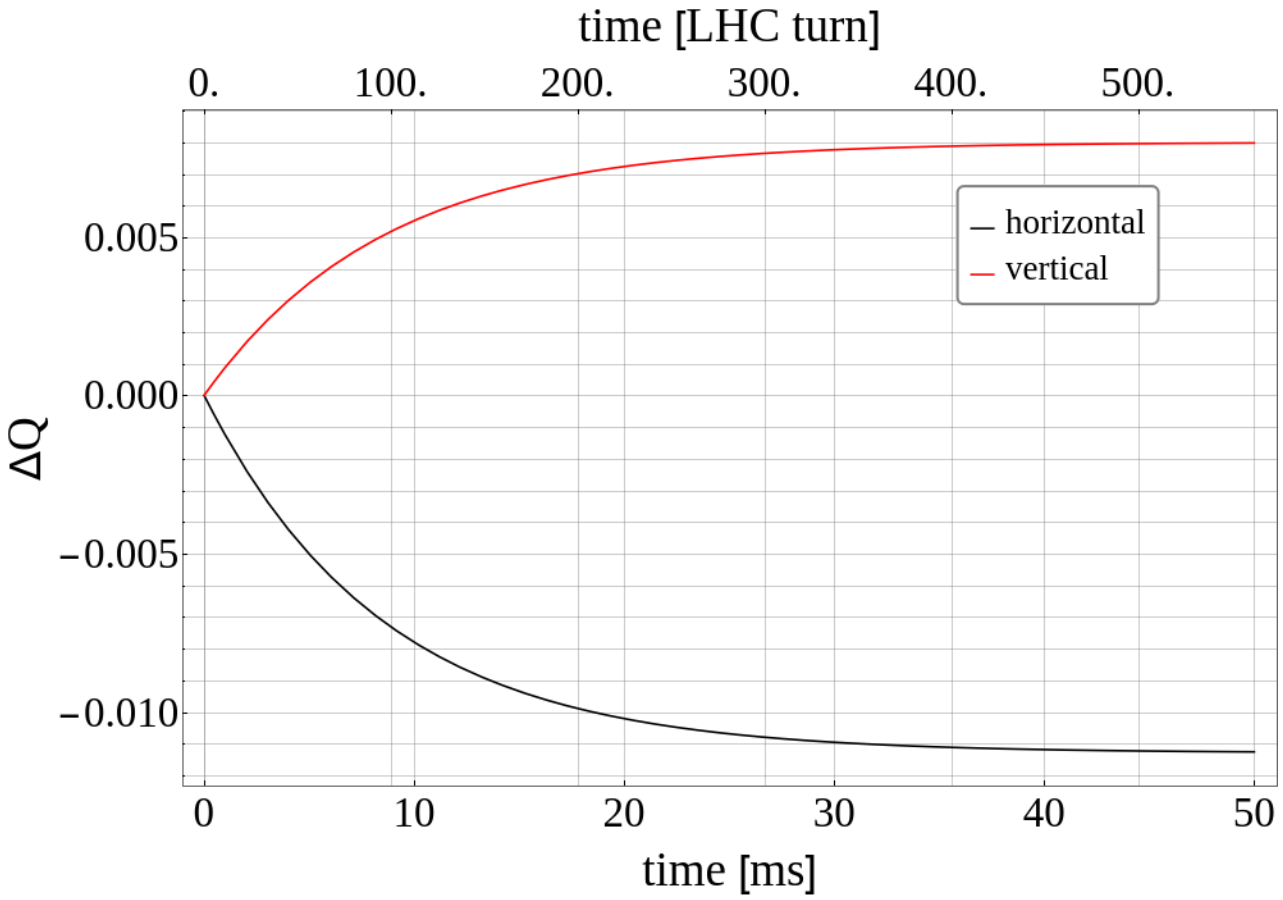
- TCTs are normally centered around the beam orbit, but up to 1 mm offset is allowed
  - Quadrupolar field change gives a kick



*normalized emittance: 2.5 µm.rad

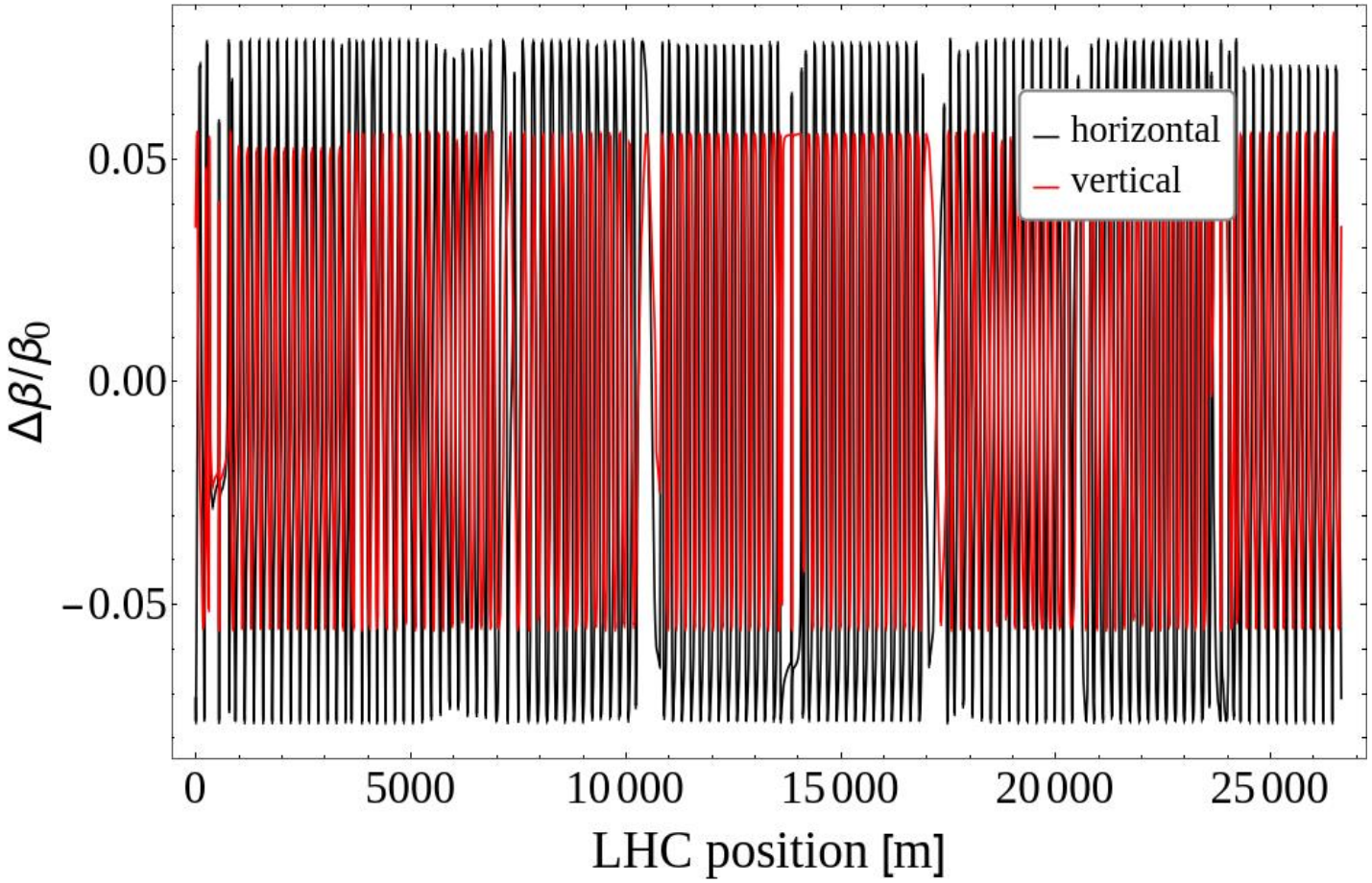
PC Trip – tune shift

- Nominal tunes: Qx 62.31 Qy 60.32
- No risk of third order resonance



PC Trip – beta beating

- After ~50 ms
- General beta beating limit at 10 %

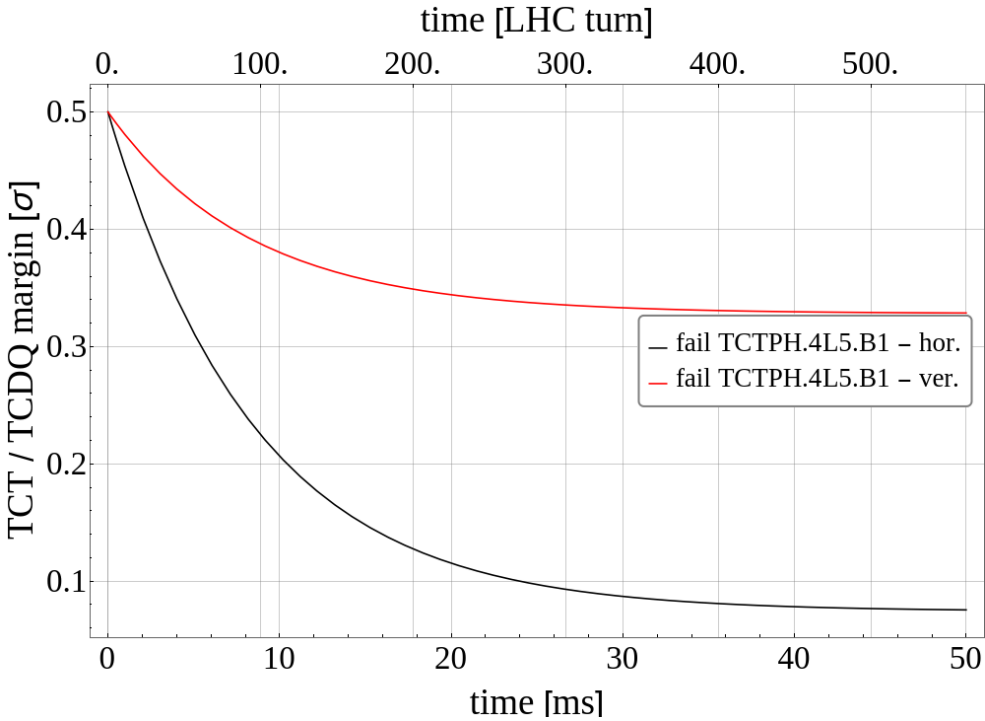


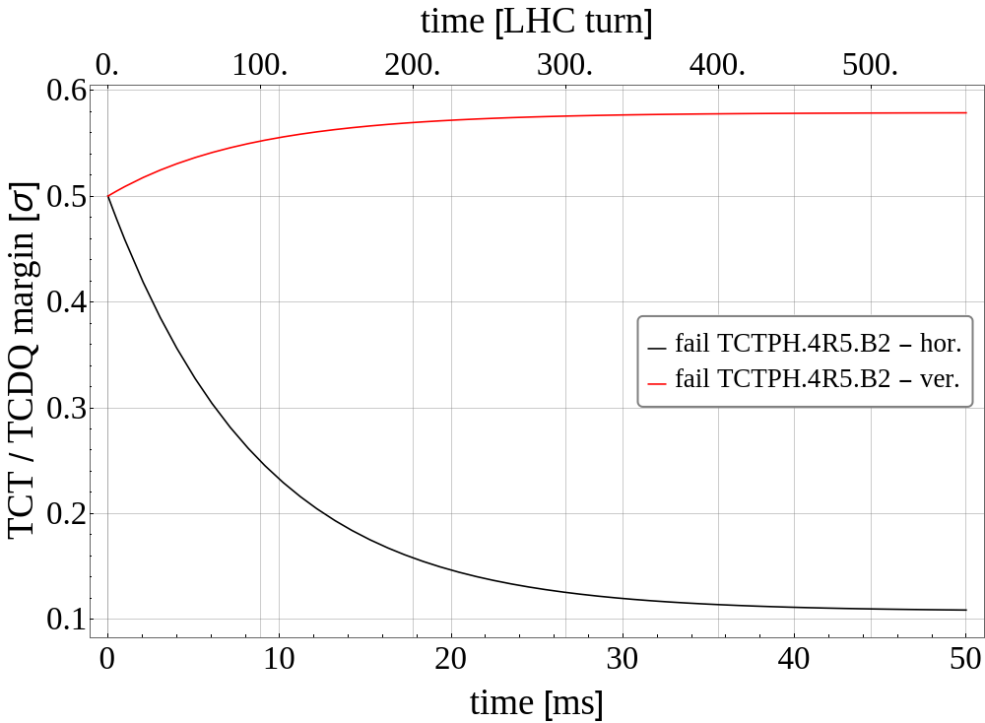
TCT – TCDQ margin

- 2018 nominal parameters:
  - TCT: 7.8 sigma
  - TCDQ: 7.3 sigma

- At 30 cm optics, 0.58-0.76 sigma more margin
- b1 less critical than b2 due to MKD – TCDQ phase advance, which gives an extra ~0.1 sigma margin for b1 (not included in plots)

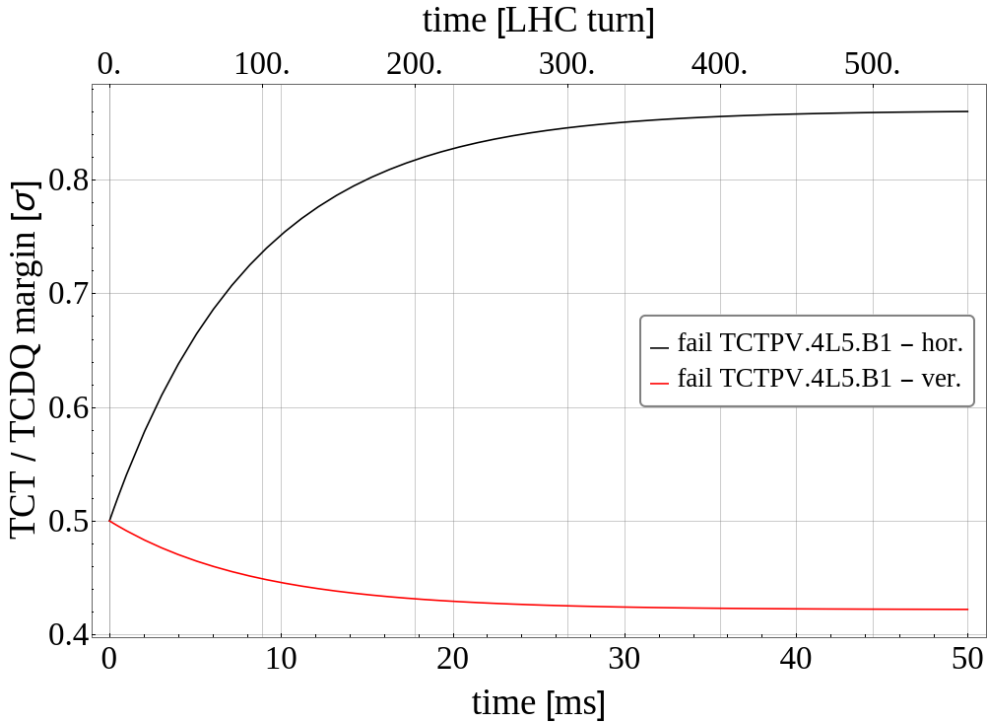
*normalized emittance: 3.5 µm.rad

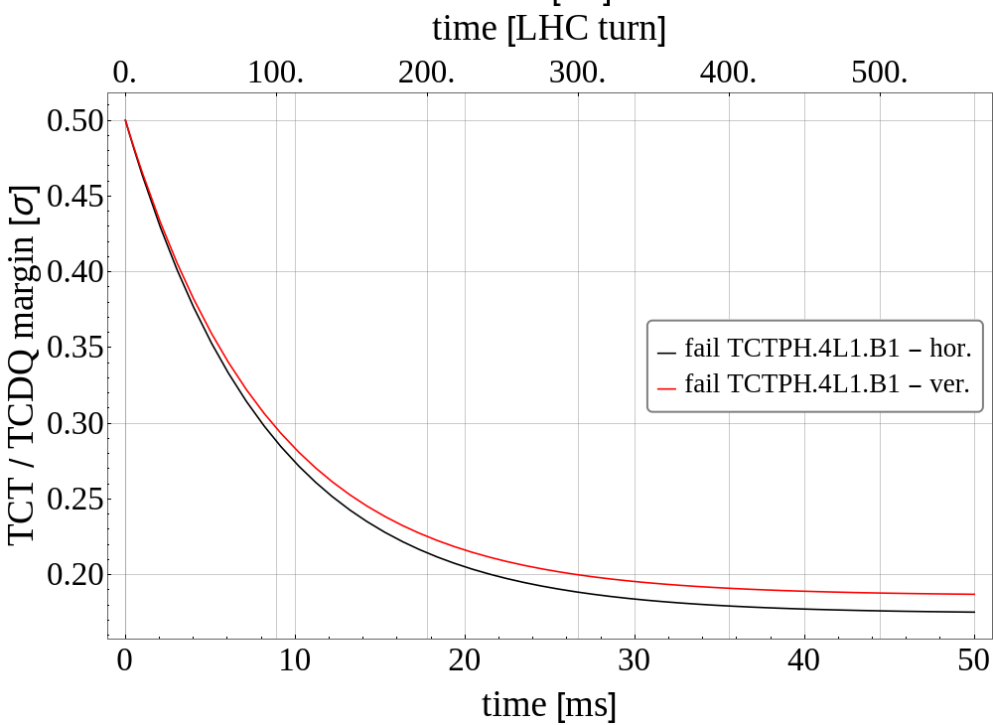




TCT – TCDQ margin

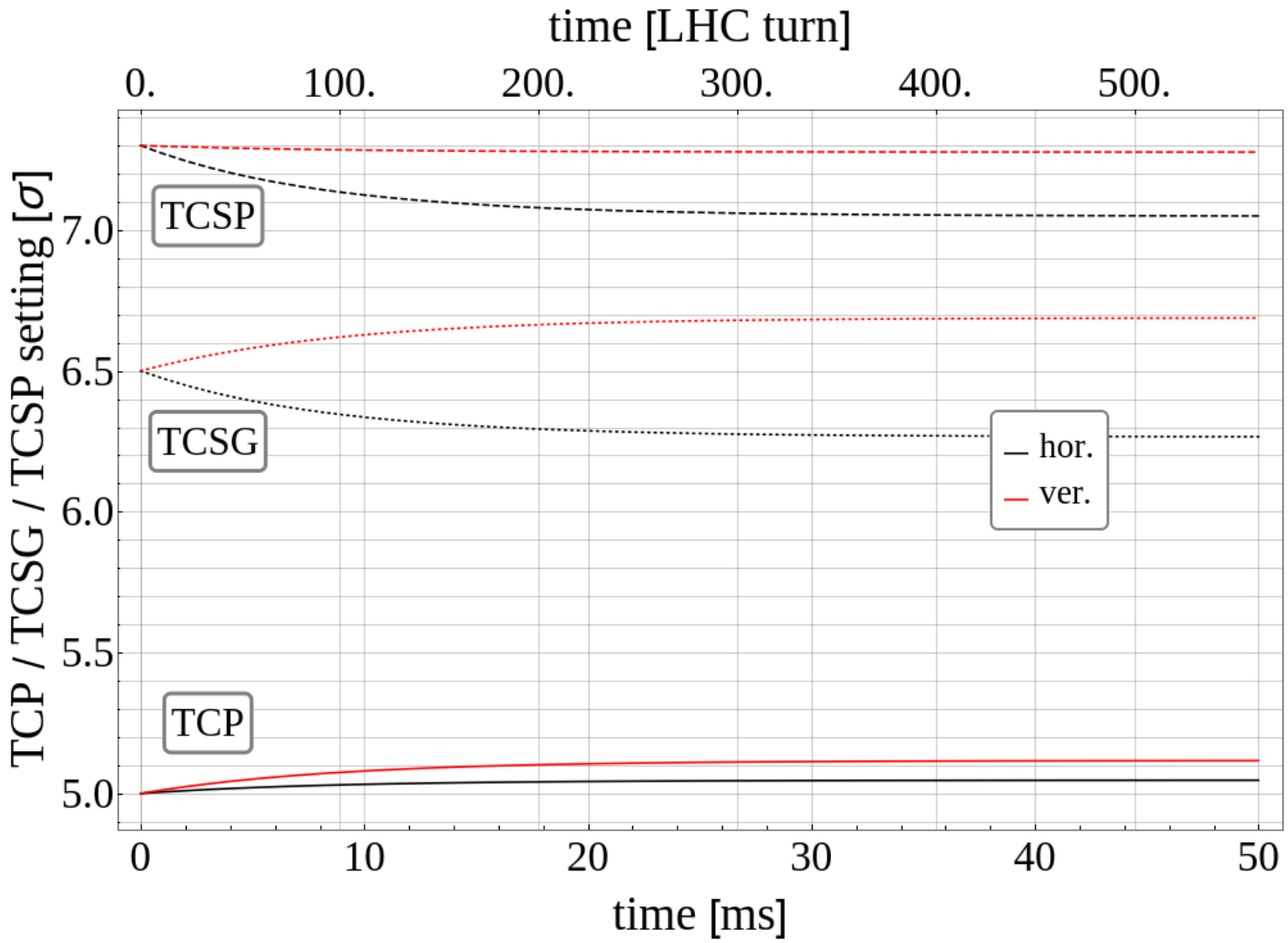
- 2018 nominal parameters:
  - TCT: 7.8 sigma
  - TCDQ: 7.3 sigma
- Optional installation points:





*normalized emittance: 3.5 µm.rad

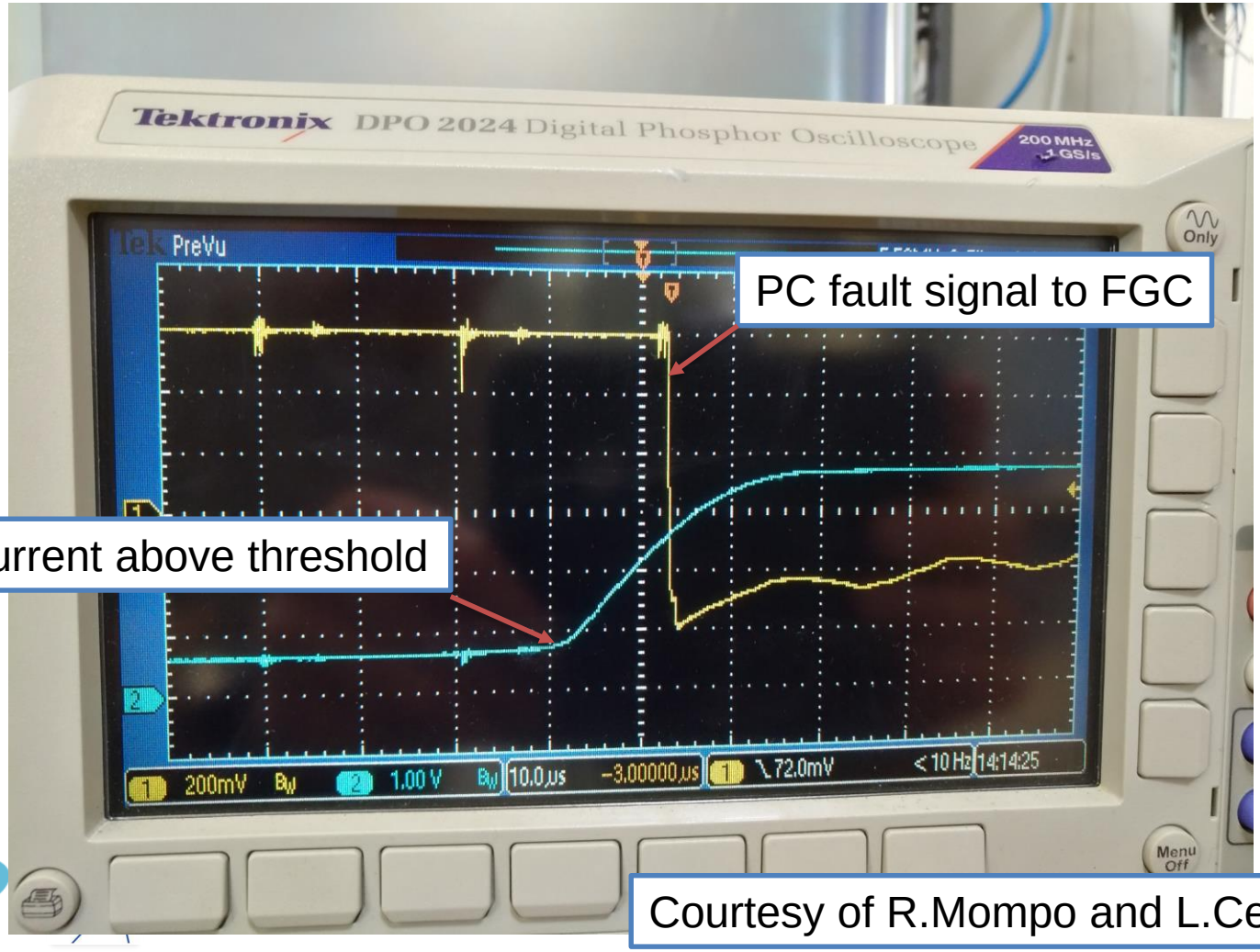
TCP – TCSG – TCSP margins



*normalized emittance: 3.5 µm.rad
Trip in TCTPV.4L5.B1

Interlock delay measurement

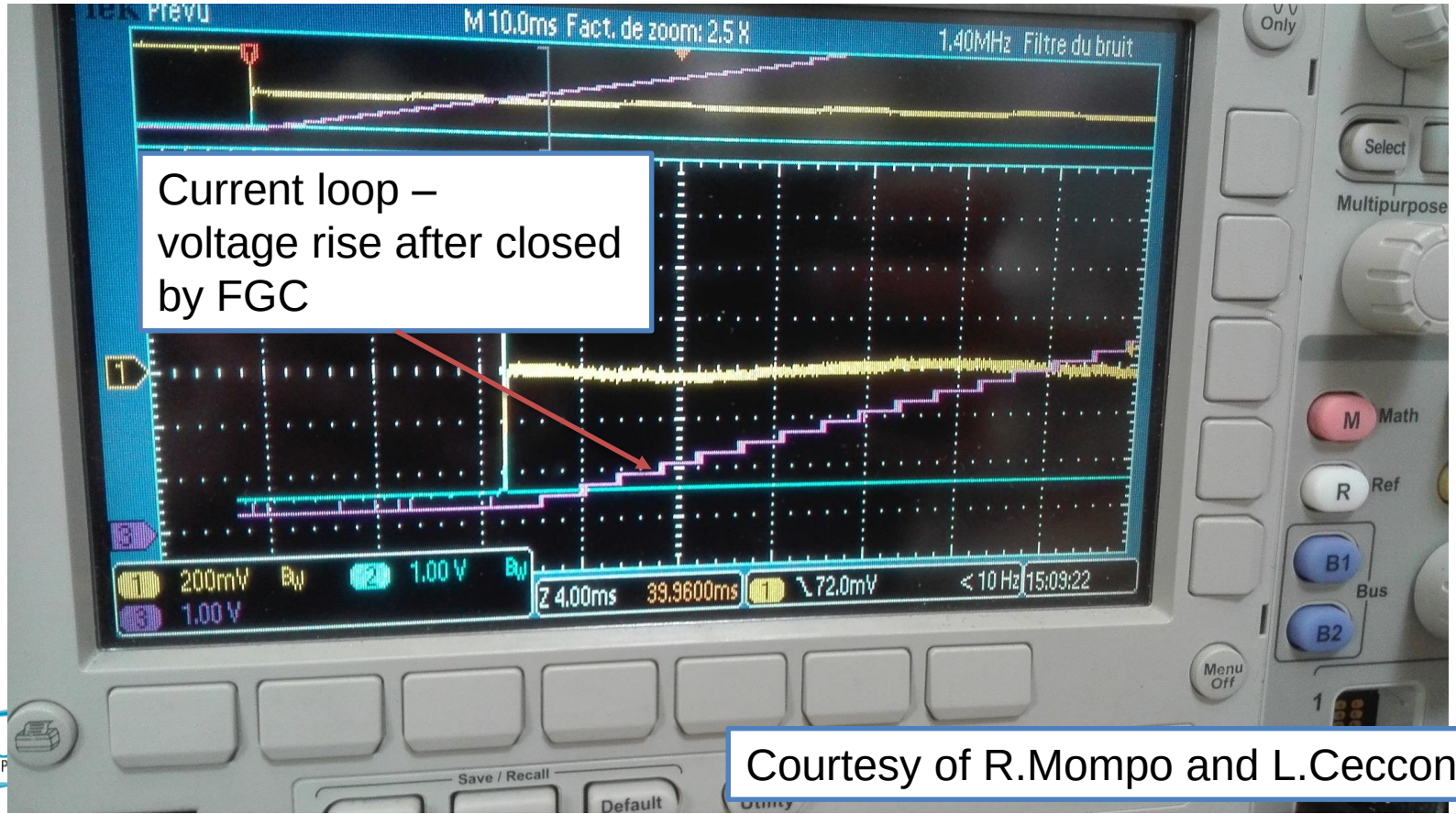
- Interlock chain: PC -> FGC -> PC -> WIC -> BIS
- PC: fault signal to FGC: ~14 µs



Courtesy of R.Mompo and L.Ceccone

Interlock delay measurement

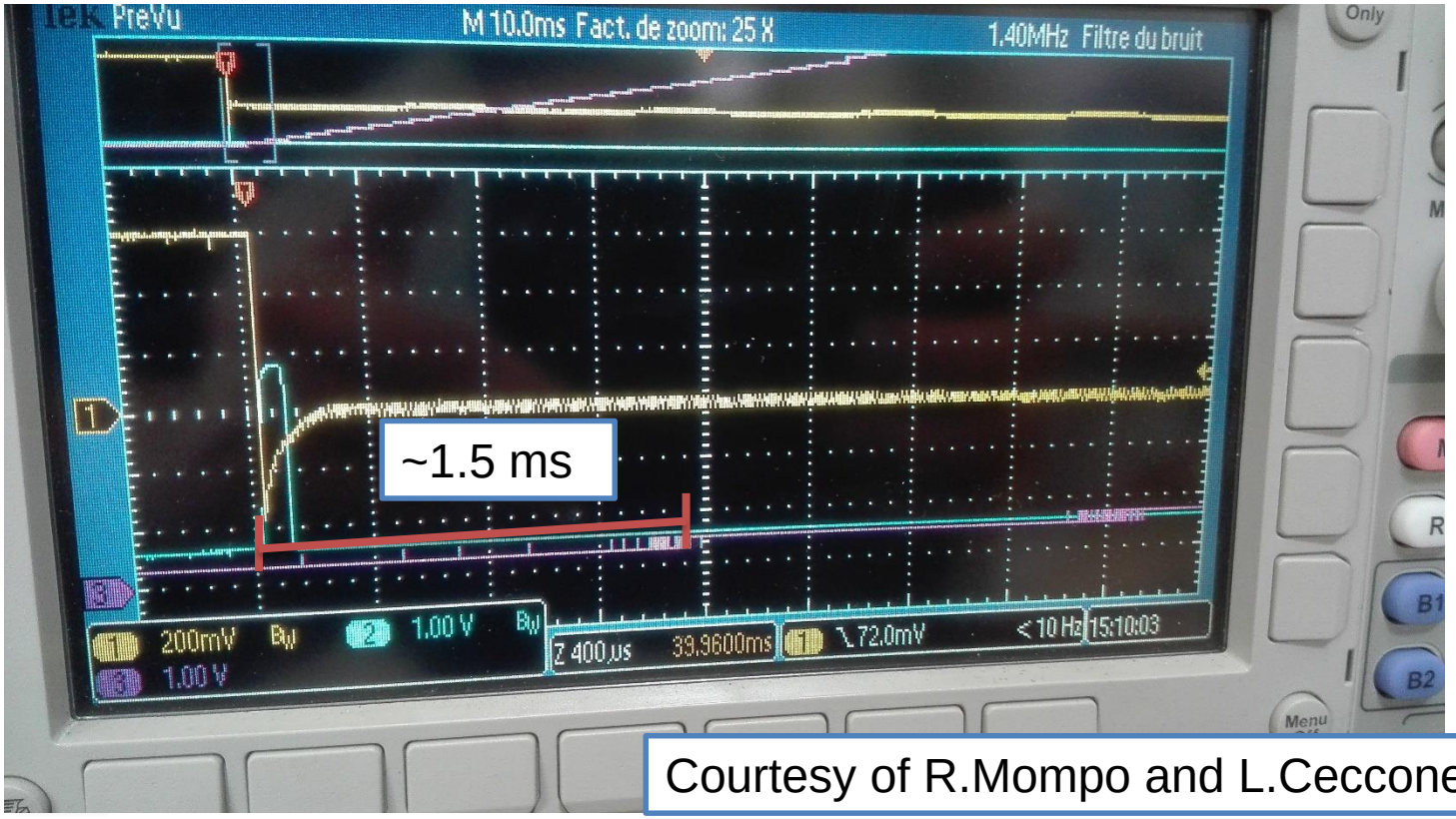
- Interlock chain: PC -> FGC -> PC -> WIC -> BIS
- PC: fault signal to FGC: ~14 µs
- FGC: sees fault signal and closes current loop:



Courtesy of R.Mompo and L.Ceccone

Interlock delay measurement

- Interlock chain: PC -> FGC -> PC -> WIC -> BIS
- PC: fault signal to FGC: ~14 µs
- FGC: sees fault signal and closes current loop: ~1.5 ms (?)
  - **Measurement needs to be repeated with a real WIC**
- WIC detects closed current loop in PC: ~6 µs



Courtesy of R.Mompo and L.Ceccone

Summary

Optics and wire settings:	25 cm beta*		30 cm beta*
	350 A, 5.7 mm	350 A, 11/10 mm	350 A, 11/10 mm
single wire short, dipolar kick	12.1 mT 1.4 sigma	7 mT 0.8 sigma	7 mT 0.7 sigma
PC trip, beam offset by 1 mm	4.4 mT 0.5 sigma	1.4 mT 0.16 sigma	1.4 mT 0.14 sigma
tune shift (deltaQ)	hor: 0.035 ver: .-0.025	hor: 0.011 ver: -0.008	hor: 0.093 ver: -0.006
beta beating	hor: 0.24 ver: 0.17	hor: 0.08 ver: 0.06	hor: 0.07 ver: 0.05
TCT/TCDQ margin (sigma)	b1: -1.1 b2: -0.8	b1: 0.09 b2: 0.11	b1: 0.73 b2: 0.99

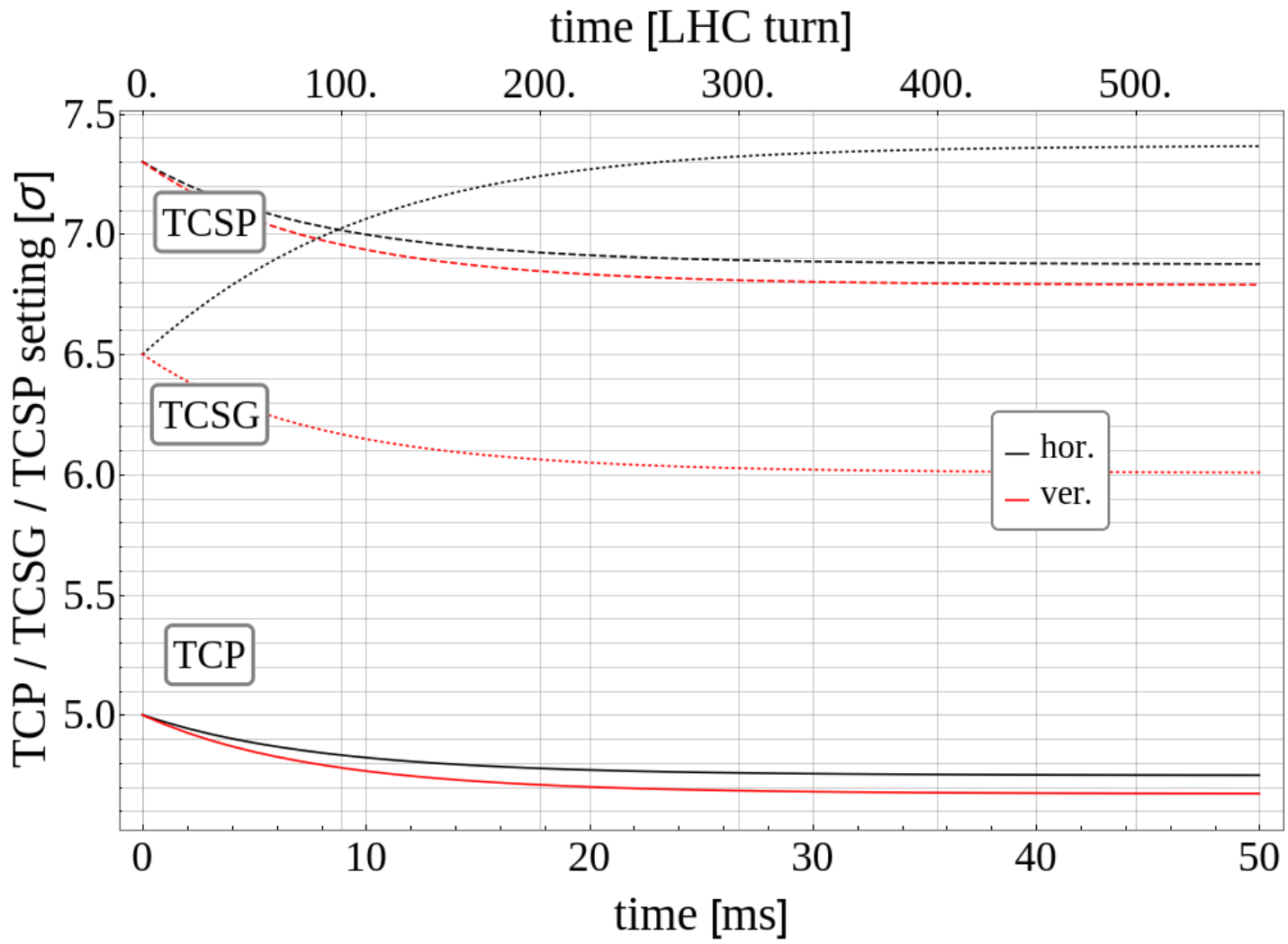
all values, 50 ms after failure start

Conclusions

- If both wires are powered correctly, no strong kicks expected for a PC trip
- TCT to TCDQ margins ~0.1 sigma
- Interlock delay needs further measurement, but likely >1.5ms
  - Sufficient or does it need to be faster?

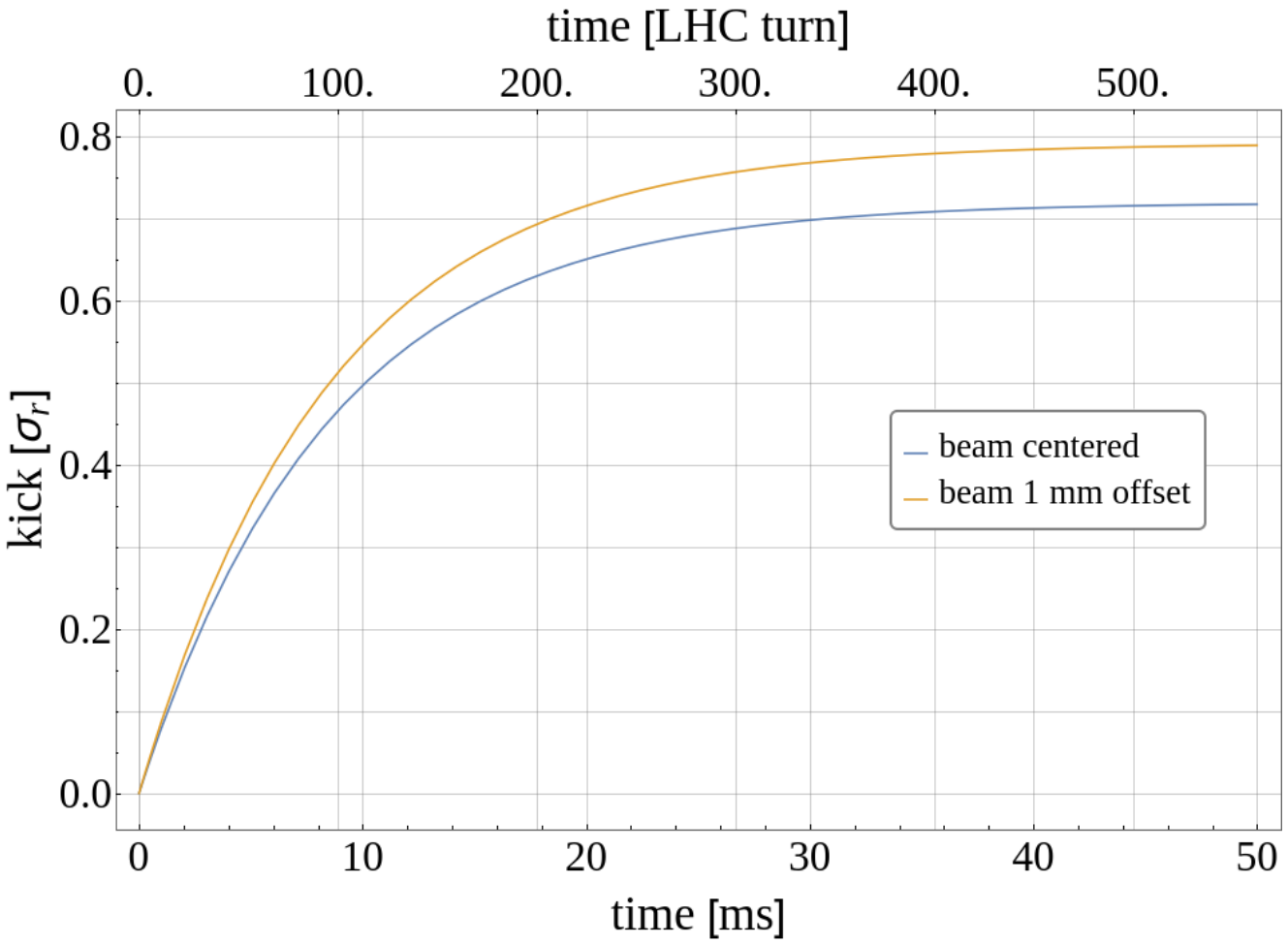
- To ensure correct wire polarities, need a procedure for:
  - Commissioning
  - What to check/validate after any wire intervention
  - e.g. validate with low intensity beam and wire current

5.7 mm – 350 A – TCTPV.4L1.B1



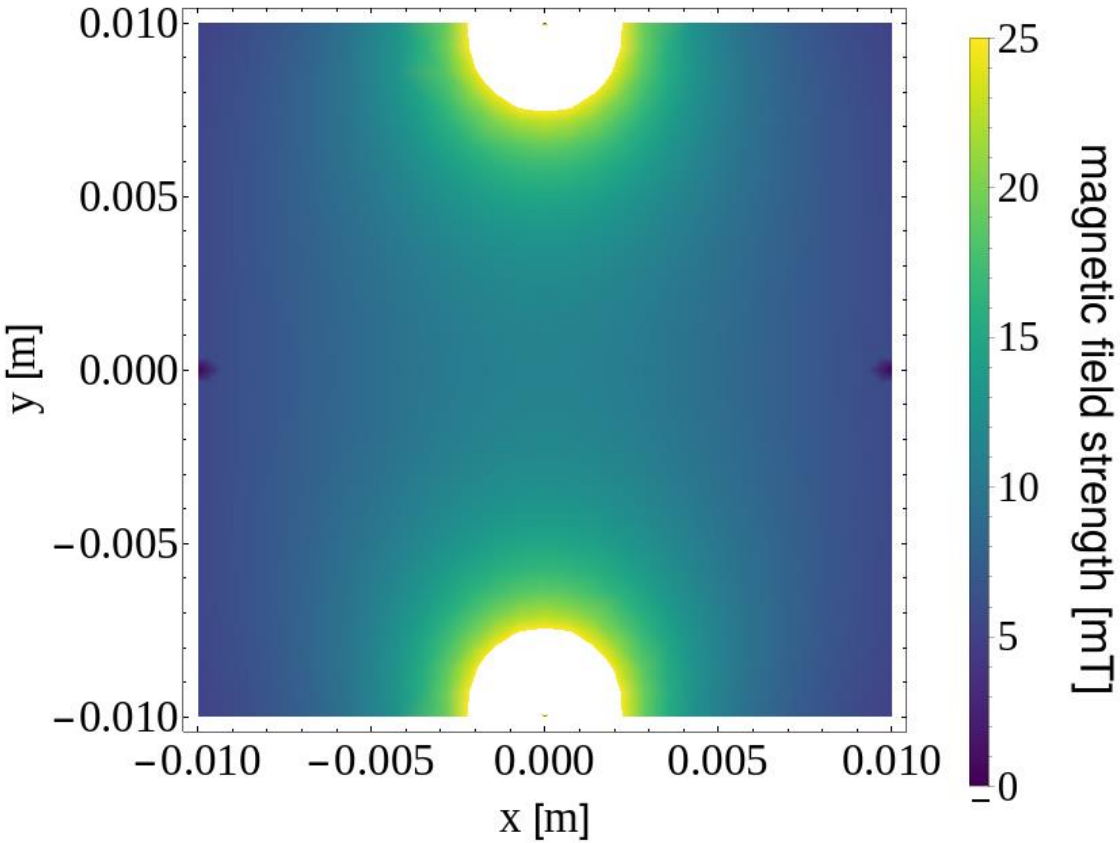
Single wire short – kick

- Dipolar field: 7 mT



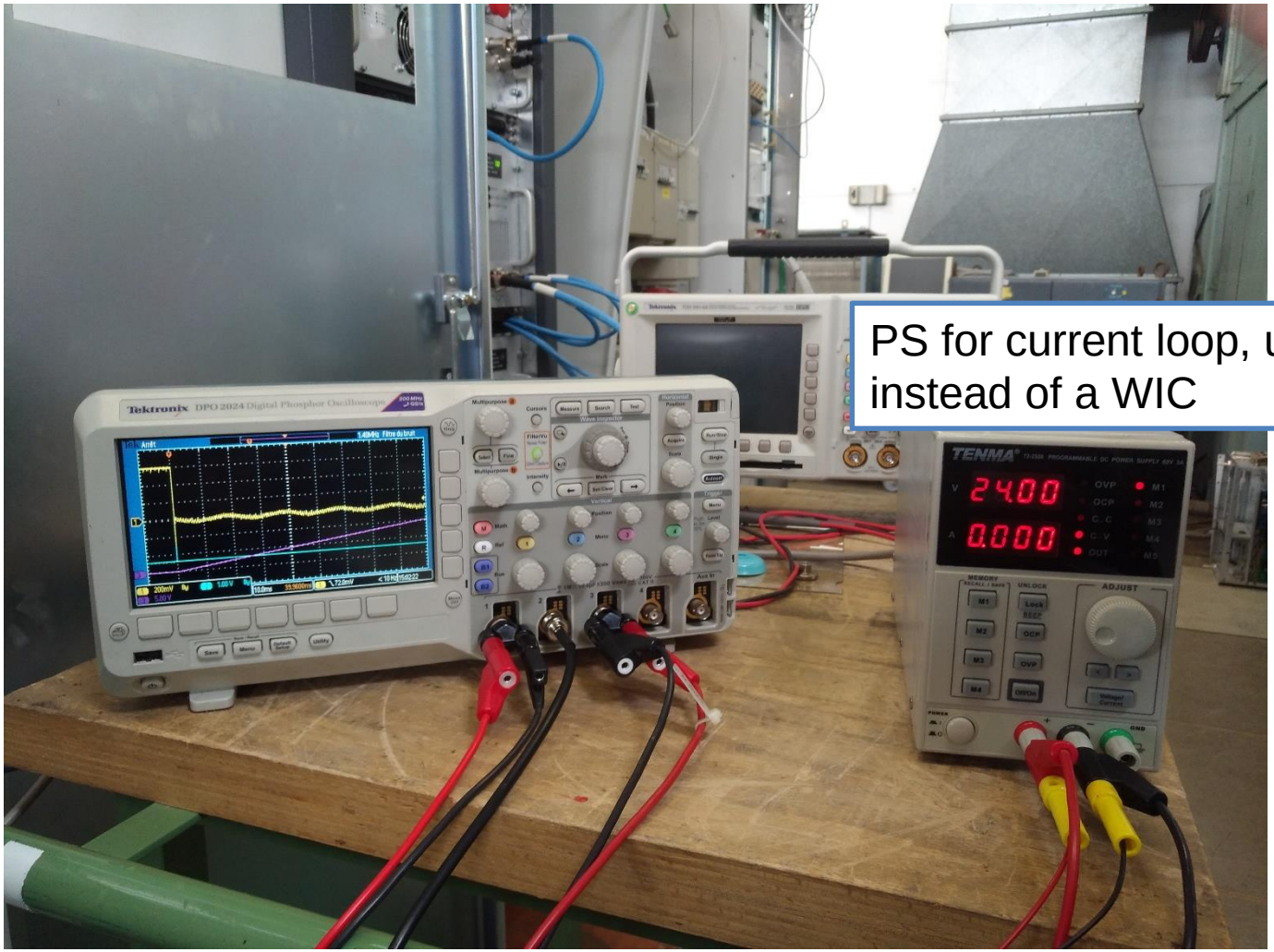
One wire with opposite polarity

- If one wire opposite polarity: 14 mT kick at zero-position



Order n	Normal [T/m^n]	Skew [T/m^n]
0	0	0.014
1	0	0
2	0	-140
3	0	0
4	0	1.2e6
5	0	0
6	0	0
7	0	0

Delay measurement



PS for current loop, used instead of a WIC

Delay measurement