Electrical measurements and diagnostics

XMAS 2010/2011 shutdown

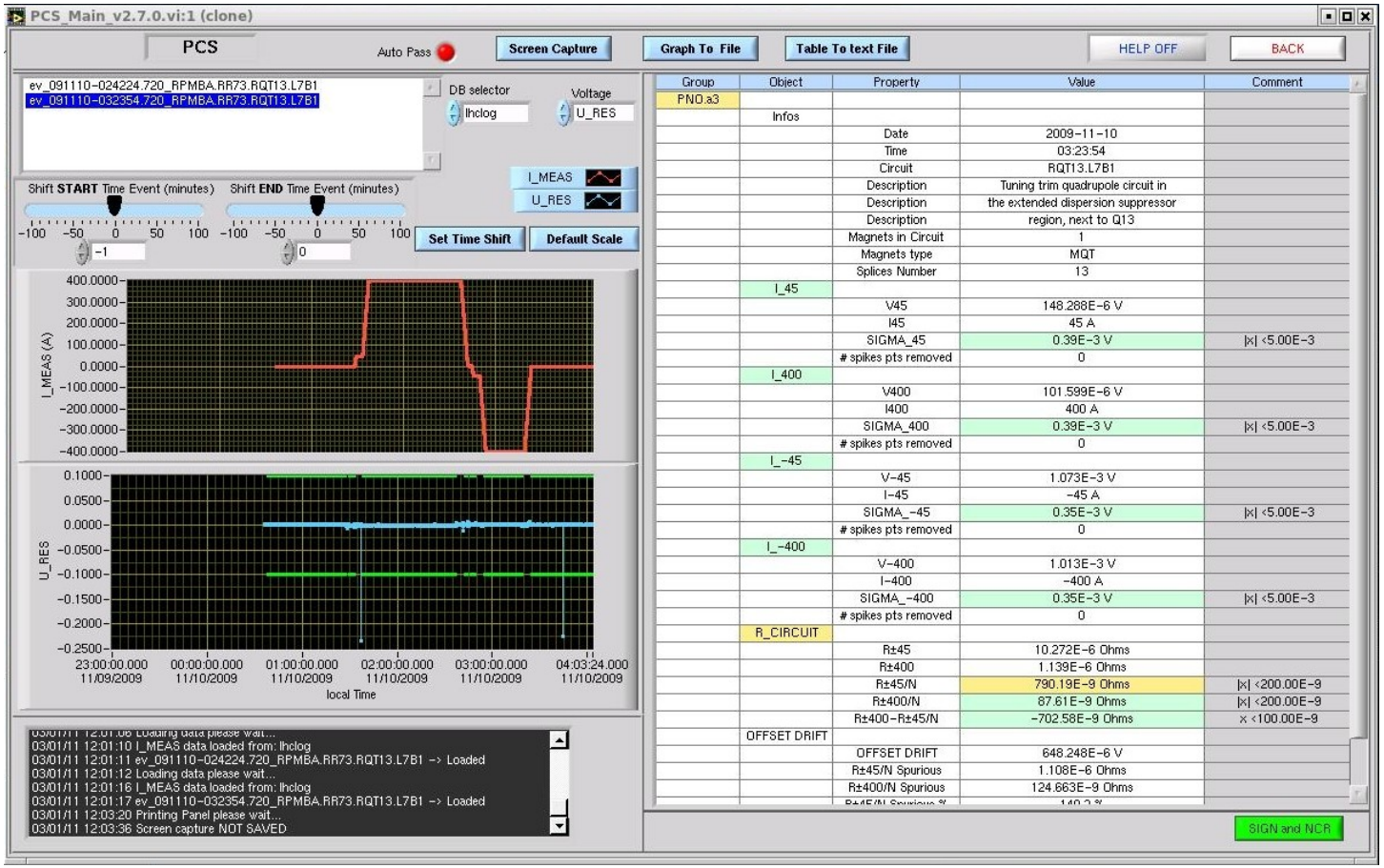
Outline

- RQT13.L7B1 – circuit too resistive
  - PNO.a3 strange results – exceeding the thresholds
  - Circuit configuration
  - Measurement details
  - Current cycle
  - Results
  - Conclusions and ‘TO DO’ list
- Resistance measurements in corrector circuits: type test on RCS.A45B1
  - Type test configuration
  - Acquisition system details
  - Linear fit
  - Results summary
  - Conclusions
- Upcoming tests – Quench propagation measurement

Hardware commisioning tests

-**PNO.a3 Bipolar Cycle 600A I_PNO**

(PNO.A3: BIPOLAR CYCLE This test is to verify the correct functionality of magnet and Current Leads at nominal current level as well as the high-current integrity of the splices)

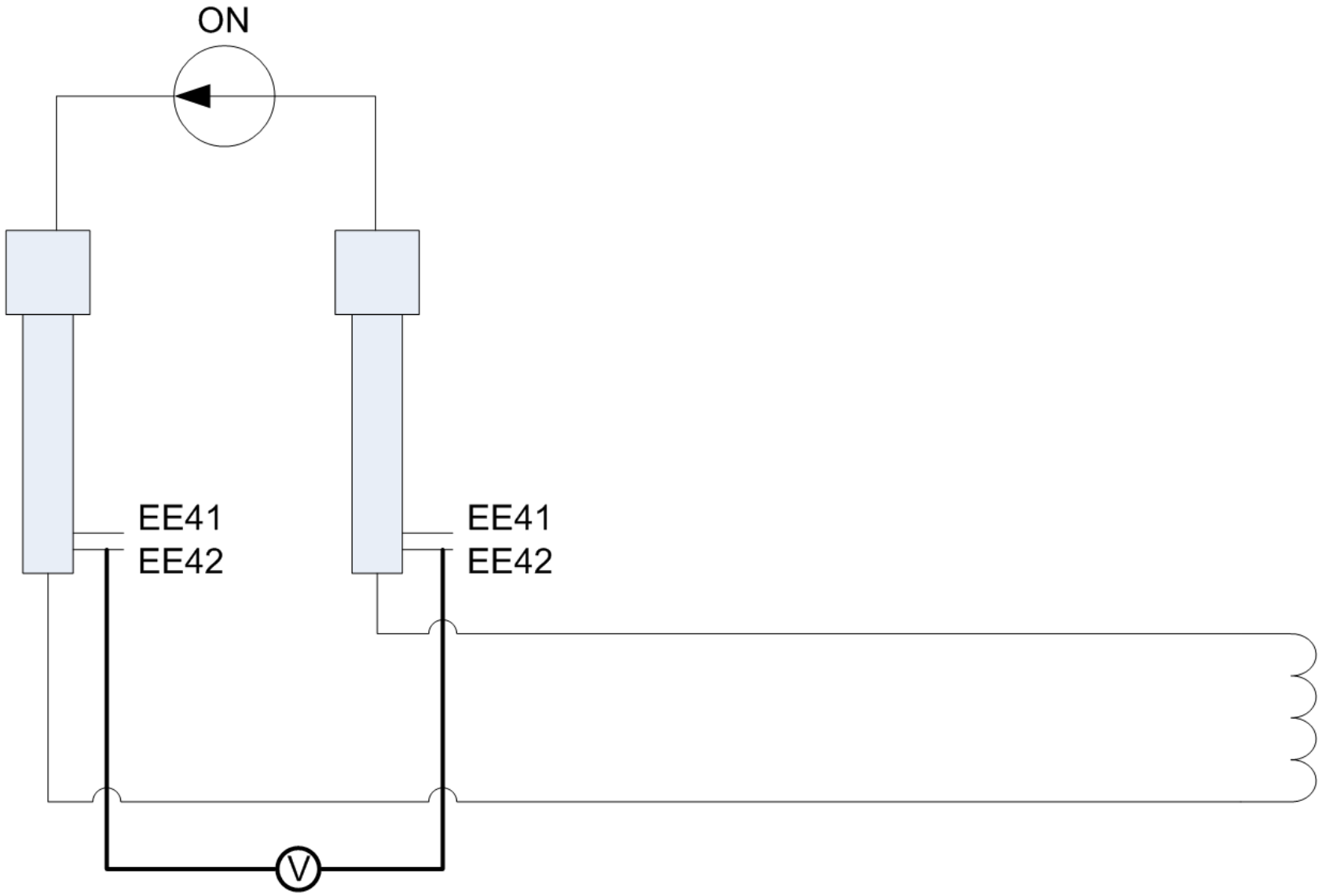


Group	Object	Property	Value	Comment
PNO.a3				
	Infos			
		Date	2009-11-10	
		Time	03:23:54	
		Circuit	RQT13.L7B1	
		Description	Tuning trim quadrupole circuit in	
		Description	the extended dispersion suppressor	
		Description	region, next to Q13	
		Magnets in Circuit	1	
		Magnets type	MQT	
		Splices Number	13	
	I_45			
		V45	148.288E-6 V	
		I45	45 A	
		SIGMA_45	0.39E-3 V	|x| <5.00E-3
		# spikes pts removed	0	
	I_400			
		V400	101.599E-6 V	
		I400	400 A	
		SIGMA_400	0.39E-3 V	|x| <5.00E-3
		# spikes pts removed	0	
	I_-45			
		V-45	1.073E-3 V	
		I-45	-45 A	
		SIGMA_-45	0.35E-3 V	|x| <5.00E-3
		# spikes pts removed	0	
	I_-400			
		V-400	1.013E-3 V	
		I-400	-400 A	
		SIGMA_-400	0.35E-3 V	|x| <5.00E-3
		# spikes pts removed	0	
	R_CIRCUIT			
		R±45	10.272E-6 Ohms	
		R±400	1.139E-6 Ohms	
		R±45/N	790.19E-9 Ohms	|x| <200.00E-9
		R±400/N	87.61E-9 Ohms	|x| <200.00E-9
		R±400-R±45/N	-702.58E-9 Ohms	x <100.00E-9
	OFFSET DRIFT			
		OFFSET DRIFT	648.248E-6 V	
		R±45/N Spurious	1.108E-6 Ohms	
		R±400/N Spurious	124.663E-9 Ohms	

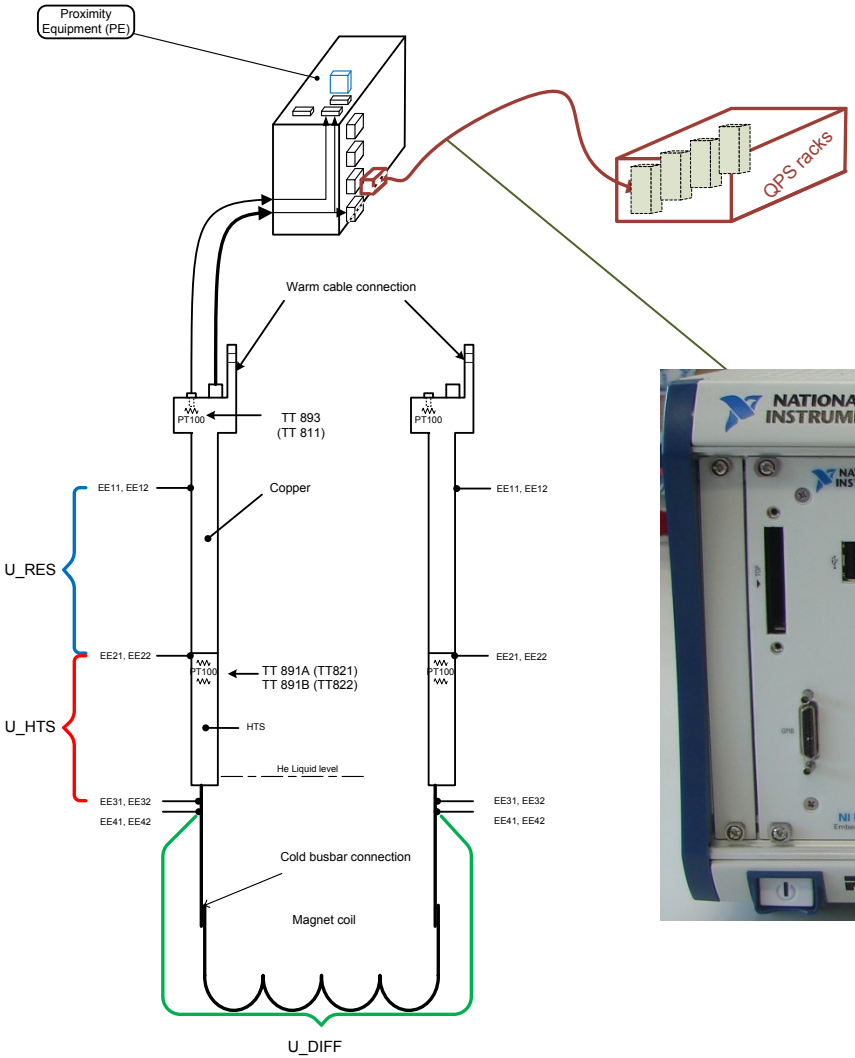
RQT13.L7B1 resistance checks

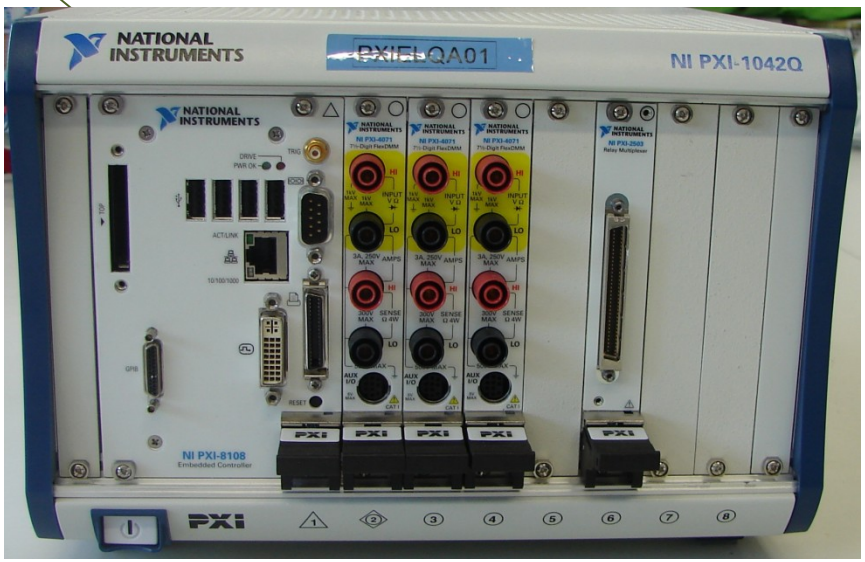
- HCC 2008
  - 2008-07-23 16:22:45 RPNO **0.718E-06 ohm**
- HCC 2009
  - 2009-11-06 17:58:48 RPNO **0.967E-06 ohm**
  - 2009-11-10 01:27:06 RPNO **1.139E-06 ohm**
- HCC 2011
  - 2011-01-30 14:30:26 RPNO **0.999E-06 ohm**
  - 2011-02-16 17:43:46 RPNO **4.725E-06 ohm**
  - 2011-02-16 20:24:21 RPNO **4.398E-06 ohm**
  - 2011-02-17 02:04:09 RPNO **4.536E-06 ohm**
  - 2011-02-18 18:31:47 RPNO **3.191E-06 ohm**

RQT13.L7B1 set-up



RQT13.L7B1 set-up

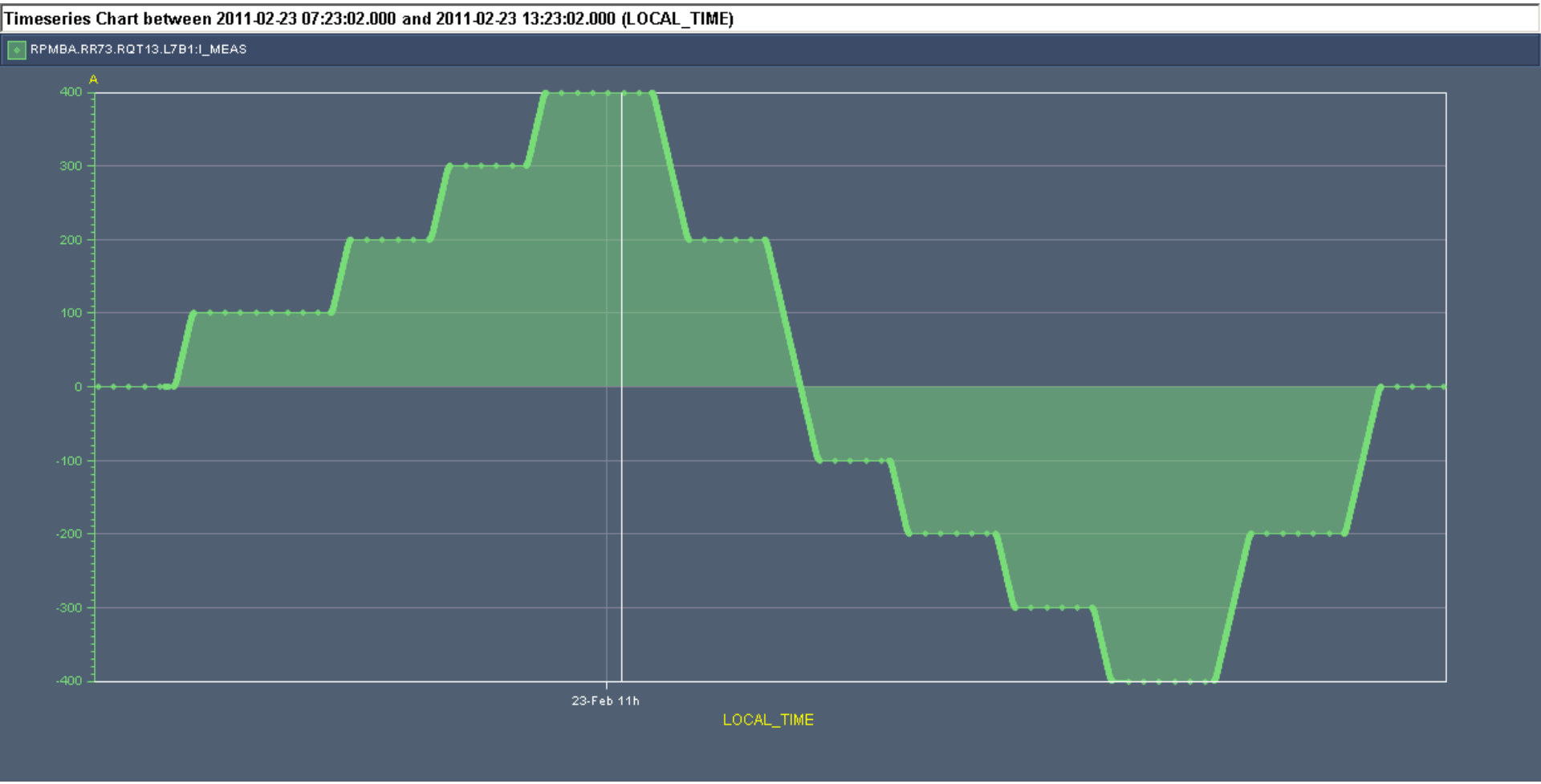




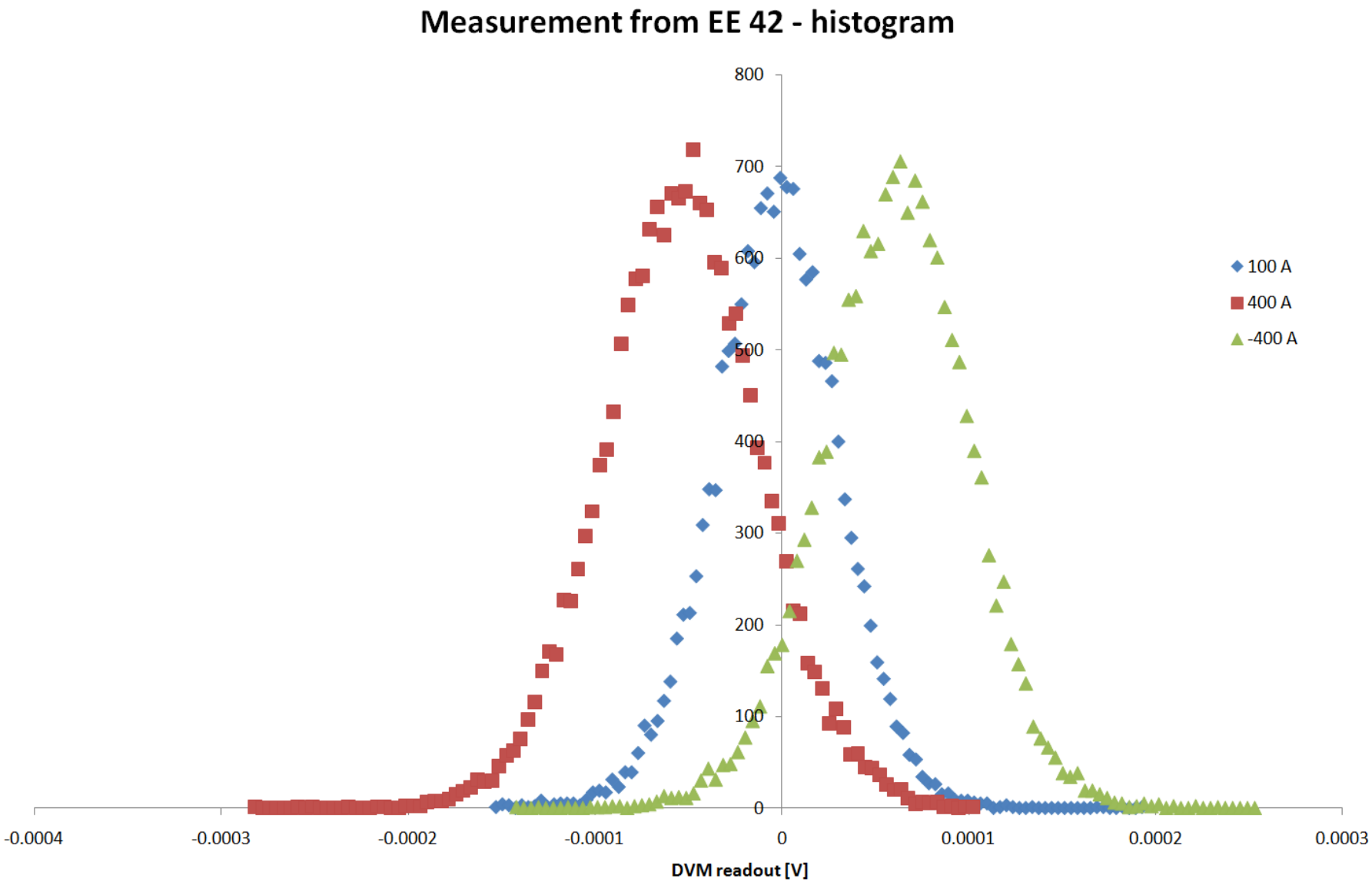
Measurement details

- The purpose of this measurement was to use an independent voltmeter with a high resolution to get a precise value of resistance of the cold part of the circuit.
- The measurement was done in parallel on both pairs of cold V-taps:
  - EE41 lead 1 – EE41 lead 2
  - EE42 lead 1 – EE42 lead 2
- The aperture time of the DVM (we used a PXI device) was set to 1 PLC (power line cycle) in order to filter 50Hz noise.
- Given a fairly high noise (only when powering) we have acquired data for at least 2-3 minutes at each current plateau.
- We have acquired several plateaus in order to be able to apply a reasonable linear fit: 100 A, 200 A, 300 A, 400 A, 200 A, -100 A, -200 A, -300 A, -400 A, -200 A.

RQT13.L7B1


Timeseries Chart between 2011-02-23 07:23:02.000 and 2011-02-23 13:23:02.000 (LOCAL_TIME)
RPMBA.RR73.RQT13.L7B1:I_MEAS
A
400
300
200
100
0
-100
-200
-300
-400
23-Feb 11h
LOCAL_TIME

RQT13.L7B1 - histogram



RQT13.L7B1 results

- Between V-taps EE41
  - ✓ **R = 136 nΩ**
- Between V-taps EE42
  - ✓ **R = 134 nΩ**
- Precision estimated from the linear fit is about **0.5 nΩ**
- Resistance per splice is **4.4 nΩ**
- Voltage readout at each current plateau has a Gaussian distribution
- Time spent on the measurement was certainly long enough to precisely calculate the circuit resistance

RQT13.L7B1 - conclusions

- **RQT13.L7B1 – is a healthy circuit**
- There are 31 splices in this circuit (in the PCS application the value is 13)
- Precision achieved with the PXI system is good
- The circuit resistance is much lower than what was measured during the powering tests, probably because it is much below the resolution of DVMs used for this purpose (but not meant for it by design)
  - Resolution of U_diff=5mV
  - Low resolution is ‘hidden’ in a compensated U_res signal
  - With the noise of 100-200 µV the long averaging time doesn’t help (no dither)
- We can’t compare this value to the other circuits as this is the only one we have measured

Total number of splices per circuit

Sector	DFB	Circuit	Type	Splices
67	DFBAL.5R6	RQS.R6B2	MQS	65
	DFBAL.5R6	RQT12.R6B1	MQT	23
	DFBAL.5R6	RQT12.R6B2	MQT	23
	DFBAL.5R6	RQT13.R6B1	MQT	25
	DFBAL.5R6	RQT13.R6B2	MQT	25
	DFBAL.5R6	RQTD.A67B1	MQT	189
	DFBAL.5R6	RQTD.A67B2	MQT	191
	DFBAL.5R6	RQTF.A67B1	MQT	191
	DFBAL.5R6	RQTF.A67B2	MQT	189
	DFBAL.5R6	RQTL11.R6B1	MQTLI	21
	DFBAL.5R6	RQTL11.R6B2	MQTLI	21
	DFBAM.7L7	RQS.A67B1	MQS	131
	DFBAM.7L7	RQS.L7B2	MQS	71
	DFBAM.7L7	RQT12.L7B1	MQT	29
	DFBAM.7L7	RQT12.L7B2	MQT	29
	DFBAM.7L7	RQT13.L7B1	MQT	31
	DFBAM.7L7	RQT13.L7B2	MQT	31
	DFBAM.7L7	RQTL10.L7B1	MQTLI	25
	DFBAM.7L7	RQTL10.L7B2	MQTLI	25
	DFBAM.7L7	RQTL11.L7B1	MQTLI	27
	DFBAM.7L7	RQTL11.L7B2	MQTLI	27
	DFBAM.7L7	RQTL7.L7B1	MQTLI	19
	DFBAM.7L7	RQTL7.L7B2	MQTLI	19
	DFBAM.7L7	RQTL8.L7B1	MQTLI	21
	DFBAM.7L7	RQTL8.L7B2	MQTLI	21
	DFBAM.7L7	RQTL9.L7B1	MQTLI	35
	DFBAM.7L7	RQTL9.L7B2	MQTLI	35
	DFBMH.7L7	RQ6.L7B1	MQTLH	77
	DFBMH.7L7	RQ6.L7B2	MQTLH	77

TO DO list

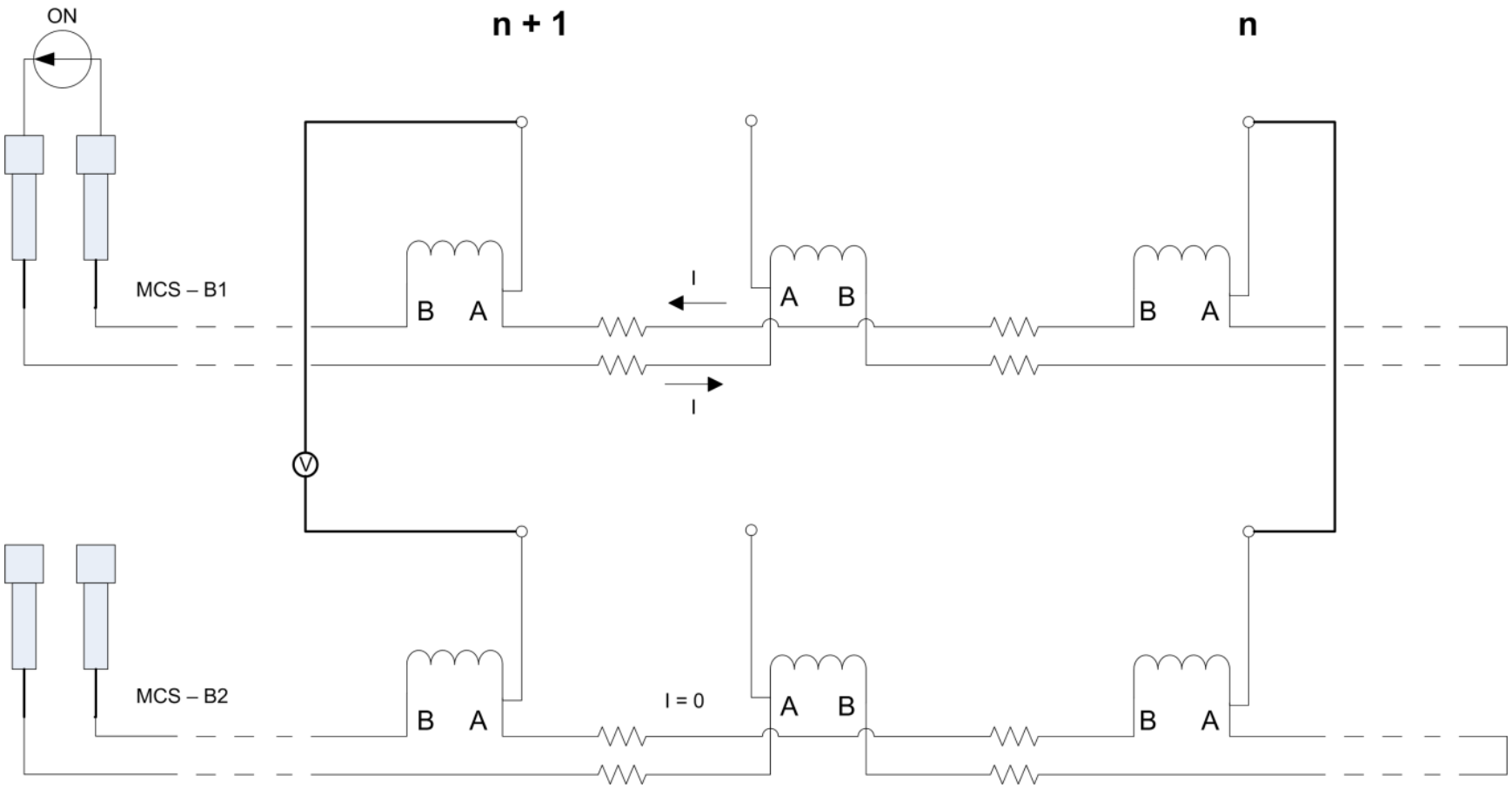
- Count splices in each circuit, include types of splices:
  - Soft soldered joints current lead – bus-bar,
  - Interconnection splices (done in the tunnel)
  - Internal coil splices (done on the surface by the contractor)
- Should we measure more circuits to get an idea about the mean value and the spread of the resistance values we have in the tunnel?
- Should we measure all the circuits before the long shut-down???

Resistance measurements in corrector circuits: *RCS.A45B1*

Type test

RCS.A45B1

Details described in the EDMS document: LHC-MPP-HCP-96-0-10

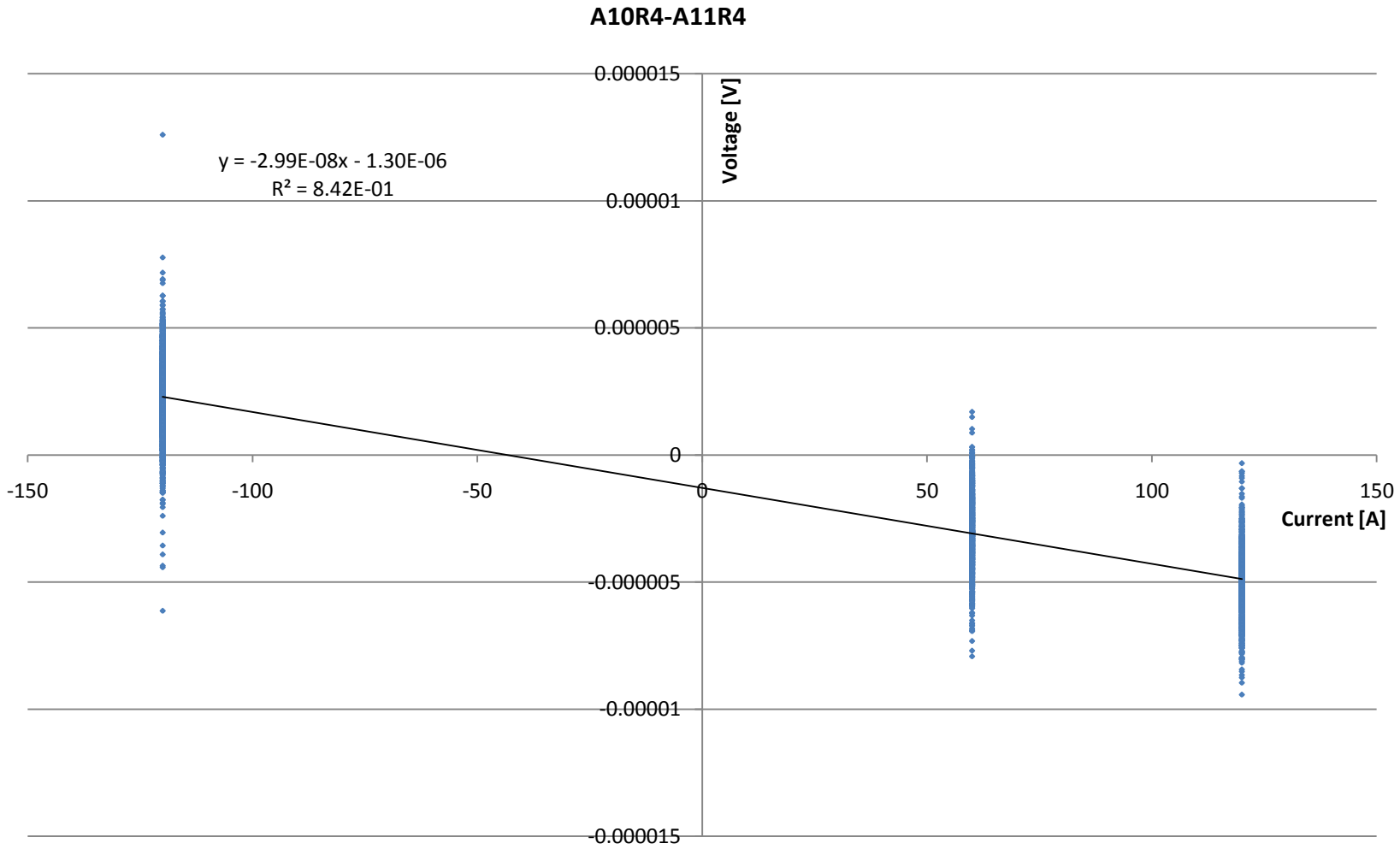


The usage of the other circuit as an “extension cable” helped to limit the measurement noise and simplified the cabling used.

Acquisition

- Keithley 2750 was used
- The DVM was set to a manual range 0.1 V as the signal – even when ramping the current (1.5 A/s) – never exceeded 2 mV
- Aperture of 5 NPLC (Number of Power Line Cycles) – 100 ms – was used in order to filter out the 50 Hz (and multiples) noise
- The DVM was set in a “burst” mode so that samples cover the full period of acquisition and there is no “dead time” in between them. Each recorded 100 s means 1000 samples acquired

Linear fit



Linear fits were calculated and coefficient errors were estimated for each segment. Slope typically was about 30 nΩ with an error of 0.2 -0.6 nΩ depending on a number of points and location.

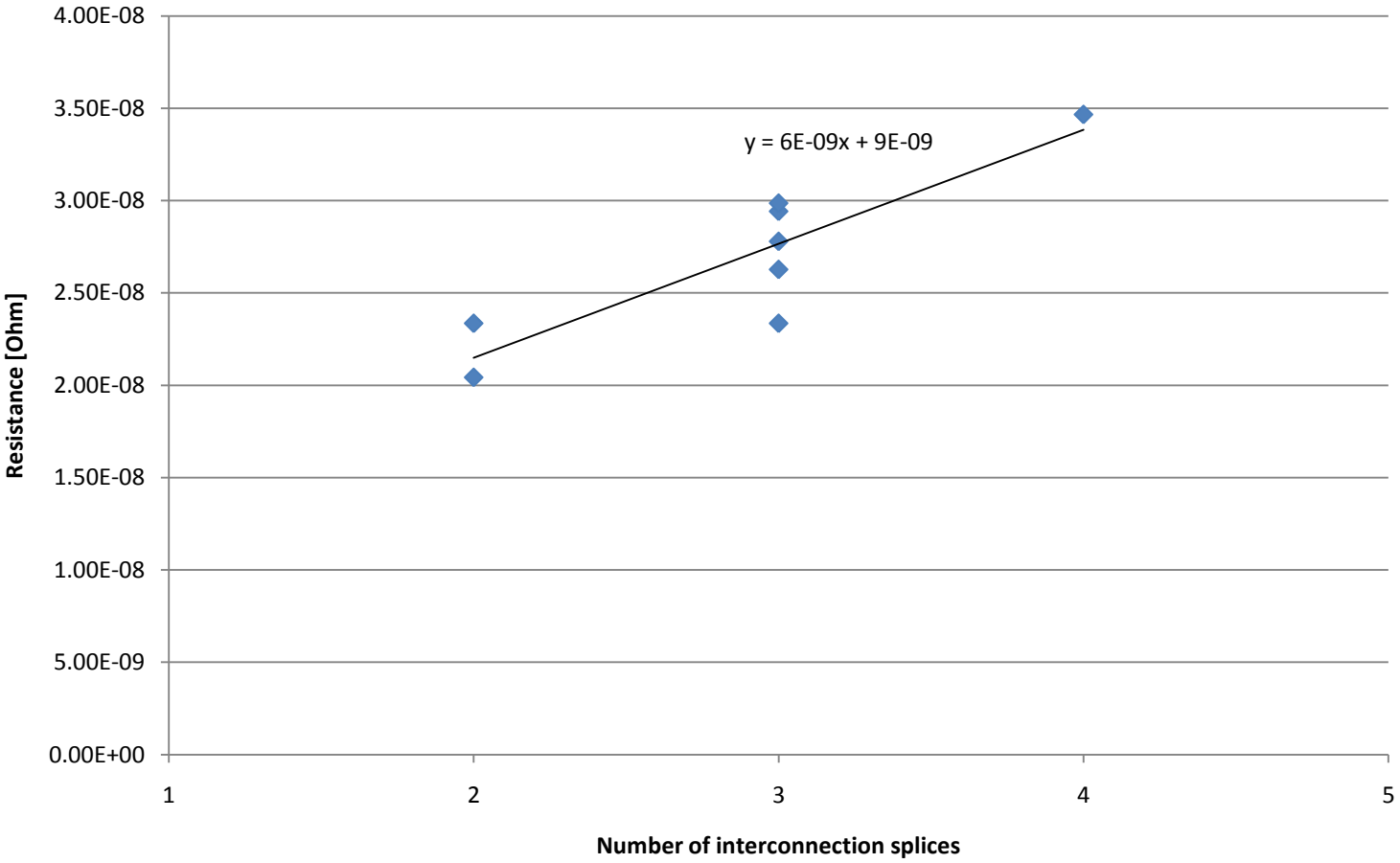
Summary of the measurements

Segment	Measured points	Coil internal splices	Inter-connection splices	Number of splices	Segment resistance [Ω]	Error [Ω]	DVM/setup offset [V]	Error [V]
A8R4-A9R4	7000	7	3	10	2.94E-08	2.0E-10	2.34E-06	1.7E-08
A9R4-A10R4	6000	7	3	10	2.78E-08	2.0E-10	1.76E-06	2.2E-08
A10R4-A11R4	4000	7	3	10	2.99E-08	2.0E-10	-1.30E-06	2.2E-08
A11R4-A12R4	3000	7	4	11	3.47E-08	2.4E-10	3.69E-06	2.5E-08
A12R4-C12R4	5000	7	2	9	2.04E-08	1.7E-10	4.91E-06	1.9E-08
C12R4-B13R4	7000	7	3	10	2.34E-08	1.7E-10	3.15E-06	1.7E-08
B13R4-A14R4	5000	7	3	10	2.63E-08	6.4E-10	-4.39E-06	6.4E-08
A14R4-C14R4	5000	7	2	9	2.34E-08	1.7E-10	3.15E-06	1.7E-08

Each bus-bar segment was measured together with one coil as there is just one V-tap per magnet. It introduced some additional noise as well as additional resistance of 7 internal splices. Three configurations were met:

- 2 interconnections (2 segments),
- 3 interconnections (5 segments),
- 4 interconnections (1 segment).

Interconnection splices resistance



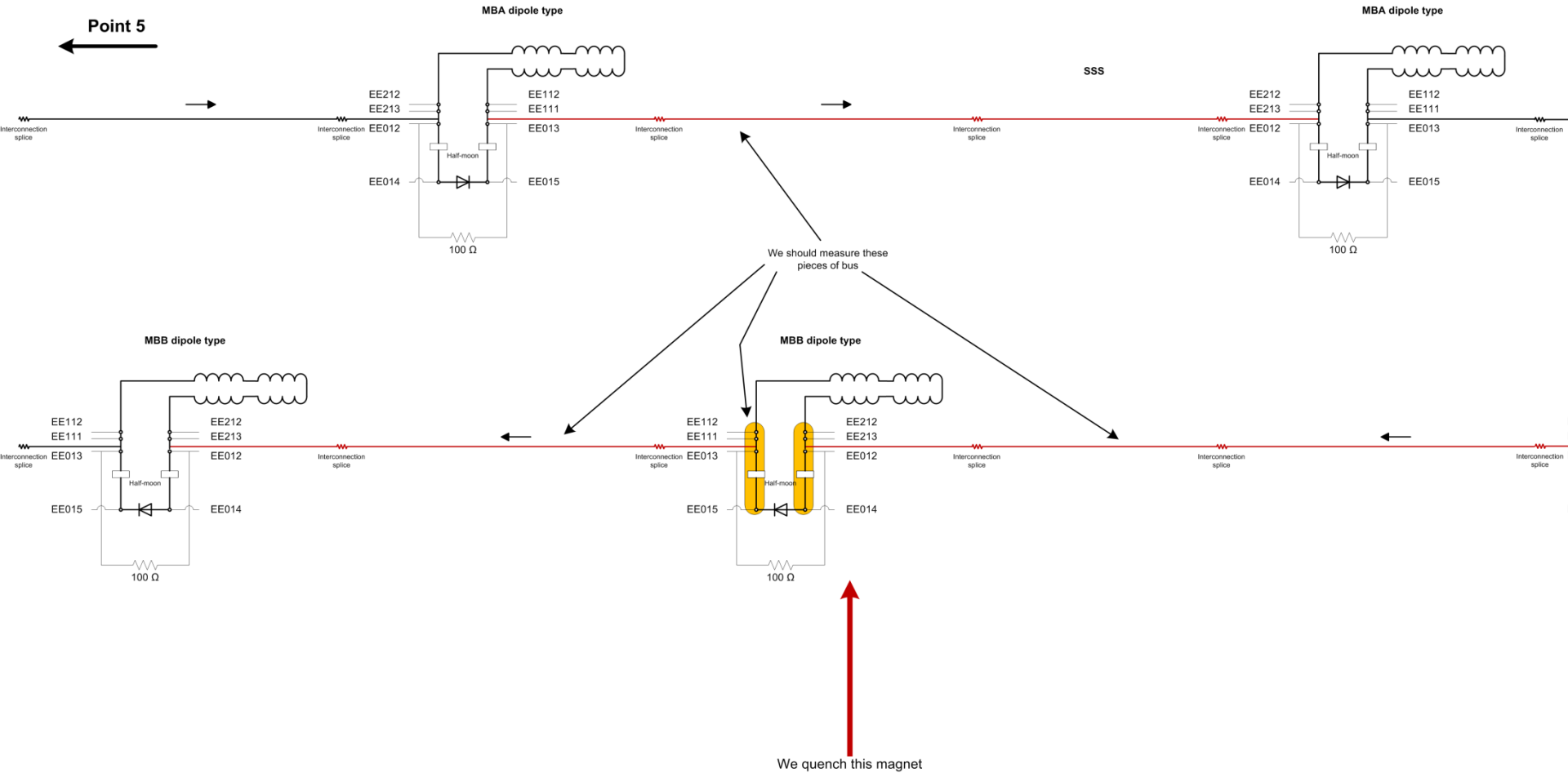
From the collected data it could be deduced that the interconnection splice's resistance is by average about **6 nΩ**. In that case for the 7 internal joints remain 9 nΩ. It would mean that the average value of the internal splice is **1.3 nΩ**.

Conclusions

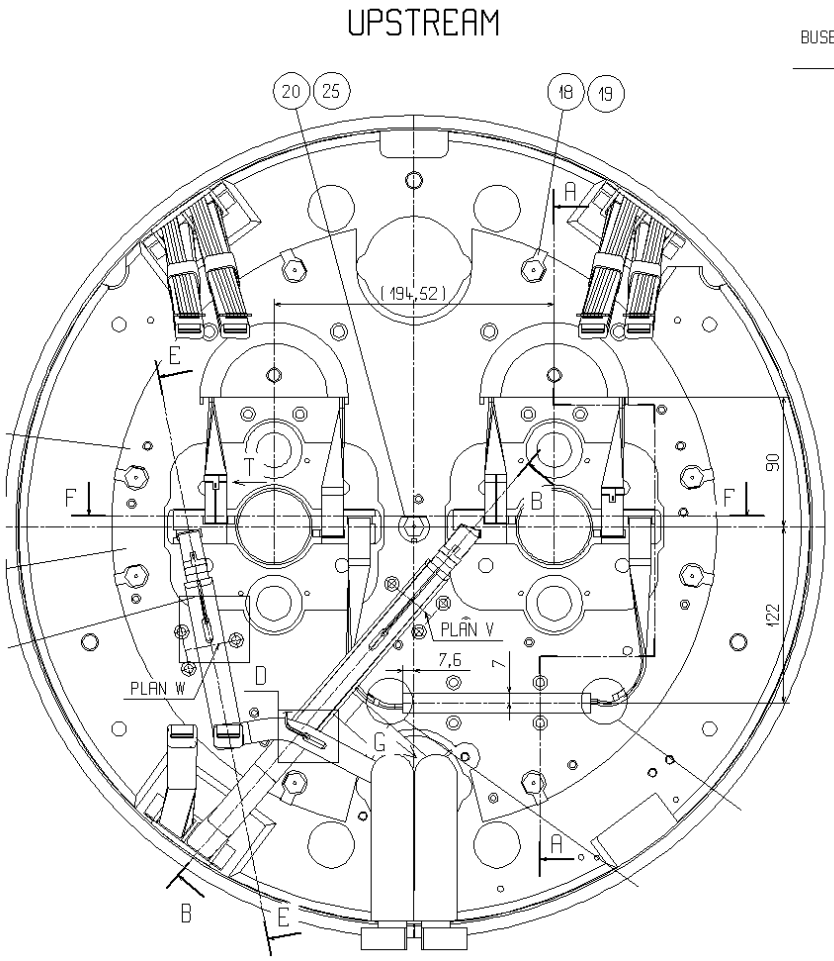
- It was confirmed that with the presented method it is possible to measure the corrector's splice's resistance with a good precision.
- It would be interesting to measure more segments in order to understand better the resistances present in the machine.
  - Getting a better population of measurements should allow to precisely estimate average values of interconnection and internal joints.
  - Long return lines of MCO and MCD circuits that contain only the interconnection splices should be measured as well.
- Similar measurement could be very interesting for the line N.
- The main disadvantage of this measurement is its impact on the time schedule of the machine commissioning.
- HV qualification of MB circuit after the spools measurement is required(?). Similarly in case of the Line N measurements MQD and MQF circuits HV test would be most likely needed.

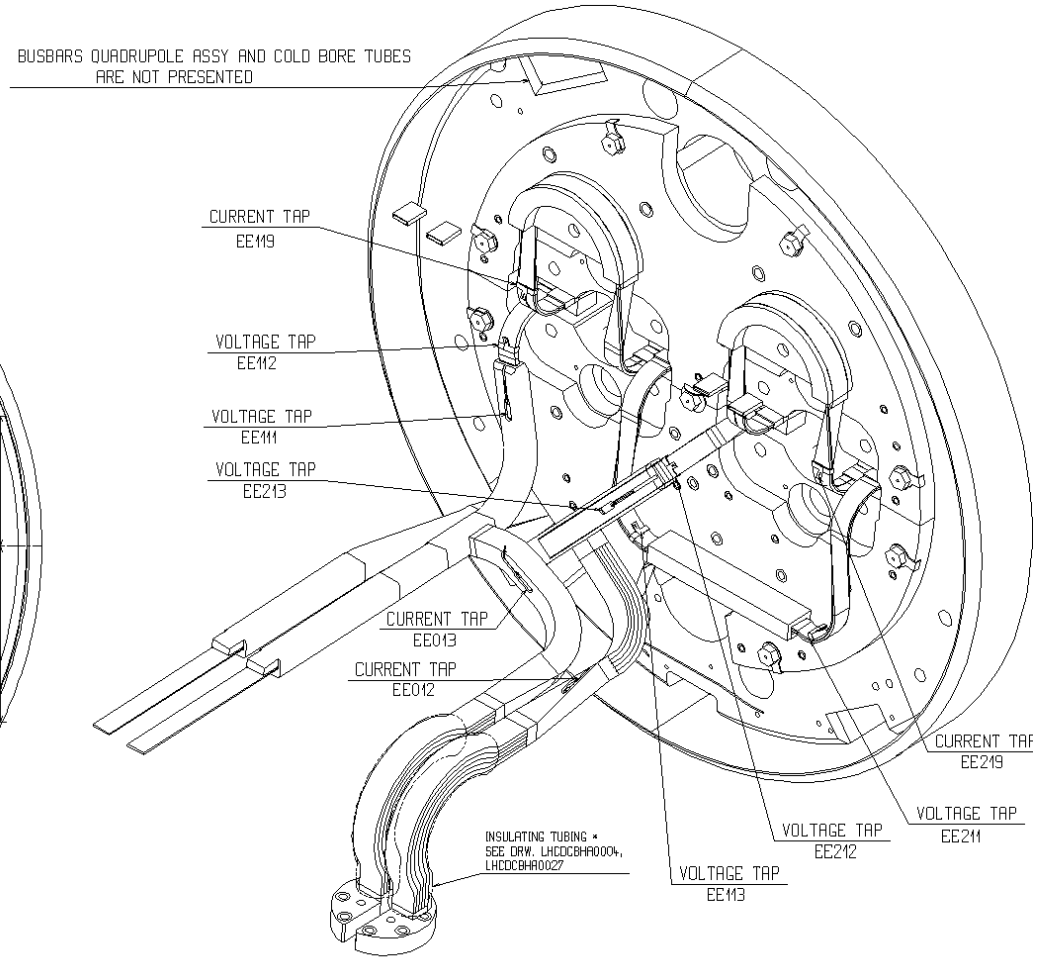
For the future…

- Quench propagation measurement should spot some light on:
  - Time from the magnet quench to the interconnection quench – does it really happen?
  - Half-moon connector resistances



MBB magnet


UPSTREAM
20
25
18
19
A
(194,52)
E
T
F
B
F
90
122
PLAN V
7,6
7
PLAN W
D
G
A
B
E


BUSBARS QUADRUPOLE ASSY AND COLD BORE TUBES ARE NOT PRESENTED
CURRENT TAP EE119
VOLTAGE TAP EE112
VOLTAGE TAP EE111
VOLTAGE TAP EE213
CURRENT TAP EE013
CURRENT TAP EE012
INSULATING TUBING * SEE DRW. LHCDCBHA0004, LHCDCBHA0027
VOLTAGE TAP EE113
VOLTAGE TAP EE212
VOLTAGE TAP EE211
CURRENT TAP EE219

Quench propagation test

- The test will be done in sector 5-6
- There will be 3 magnets instrumented with high precision volt-meters
- 2 magnets will be quenched
- Magnets will be quenched at 2 or 3 different currents:
  - 2 kA
  - 4 kA
  - 6 kA
- The technical specification will come soon and will contain all the details

Quench propagation test

- The test is prepared together by

  Mike Koratzinos,

  Arjan Verweij,

  Mateusz Bednarek

- There will be a similar test in SM18 with a magnet equipped with thermometers and V-taps in the interconnection and half-moons region.

Thank you!

Any questions?