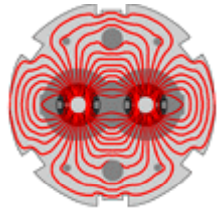
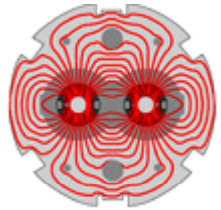


The Sector 3-4 incident

Ph. Lebrun *on behalf of the*
Task Force on the Analysis of the 19 September 2008 Incident

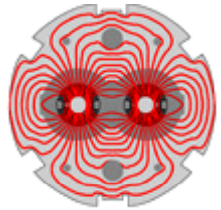
LHC Performance Workshop 2009
Chamonix, 2-6 February 2009

Contents



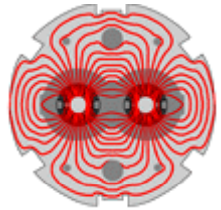
- The Task Force on Analysis of the 19 September Incident
- Sector 3-4 before the incident
- The incident: facts and findings
- Recommendations

Mandate of the Task Force



- Establish the sequence of facts, based on experimental measurements before incident, observations after incident and timing
- Analyse and explain the development of events, in relation with design assumptions, manufacturing & test data and risk analyses performed
- Recommend preventive and corrective actions for Sector 3-4 and others

Contributors to the Task Force



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Serge CLAUDET
Paul CRUIKSHANK
Knud DAHLERUP-PETERSEN
Gijs DE RIJK
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Rob VAN WEELDEREN
Raymond VENESS
Arjan VERWEIJ
Louis WALCKIERS
Rob WOLF

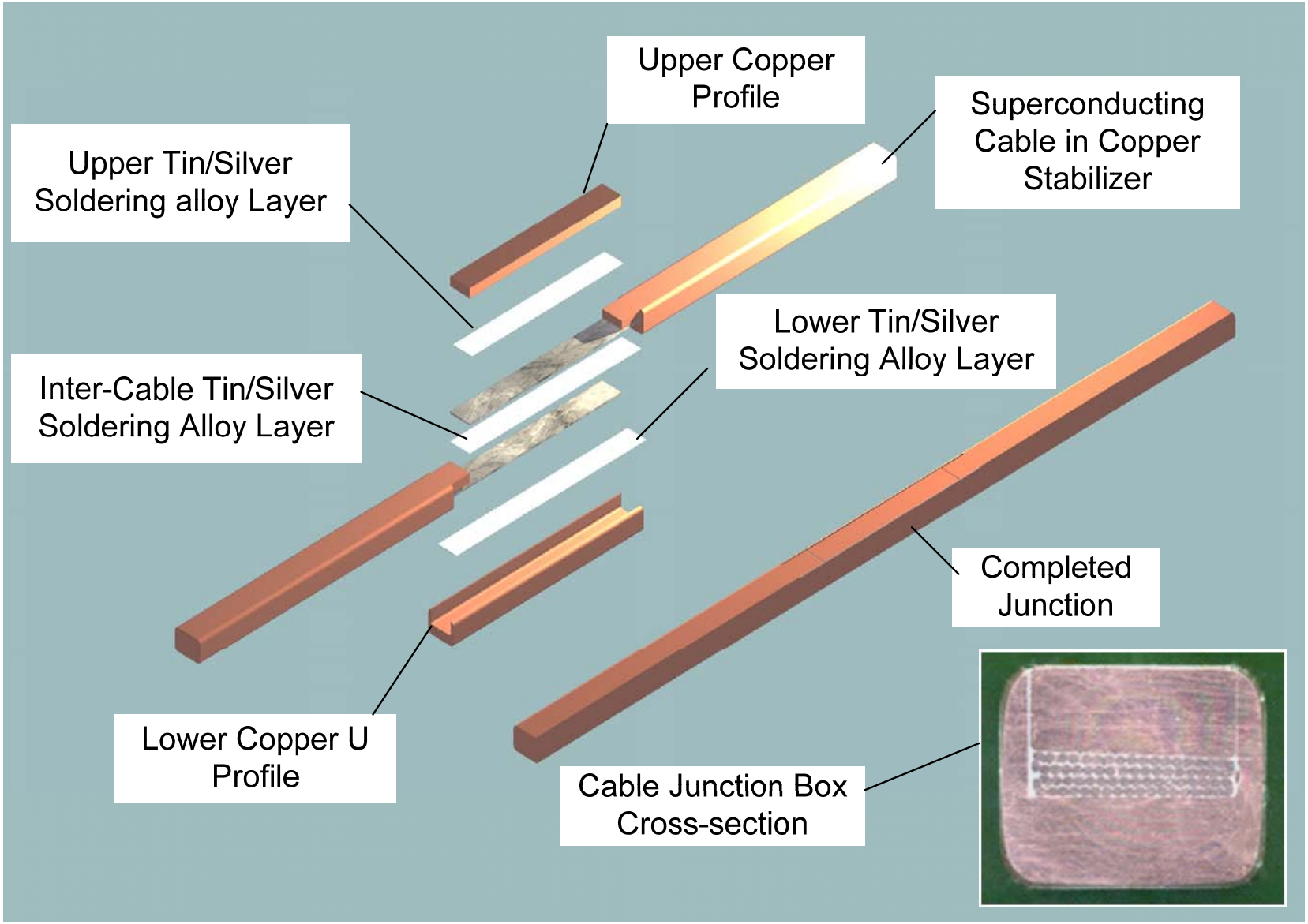
Electrical joints on 12 kA bus bars

History of interconnections in sector 3-4 (Oct 2006-July 2007) shows no particular cause of defect, but worst working conditions of all machine:

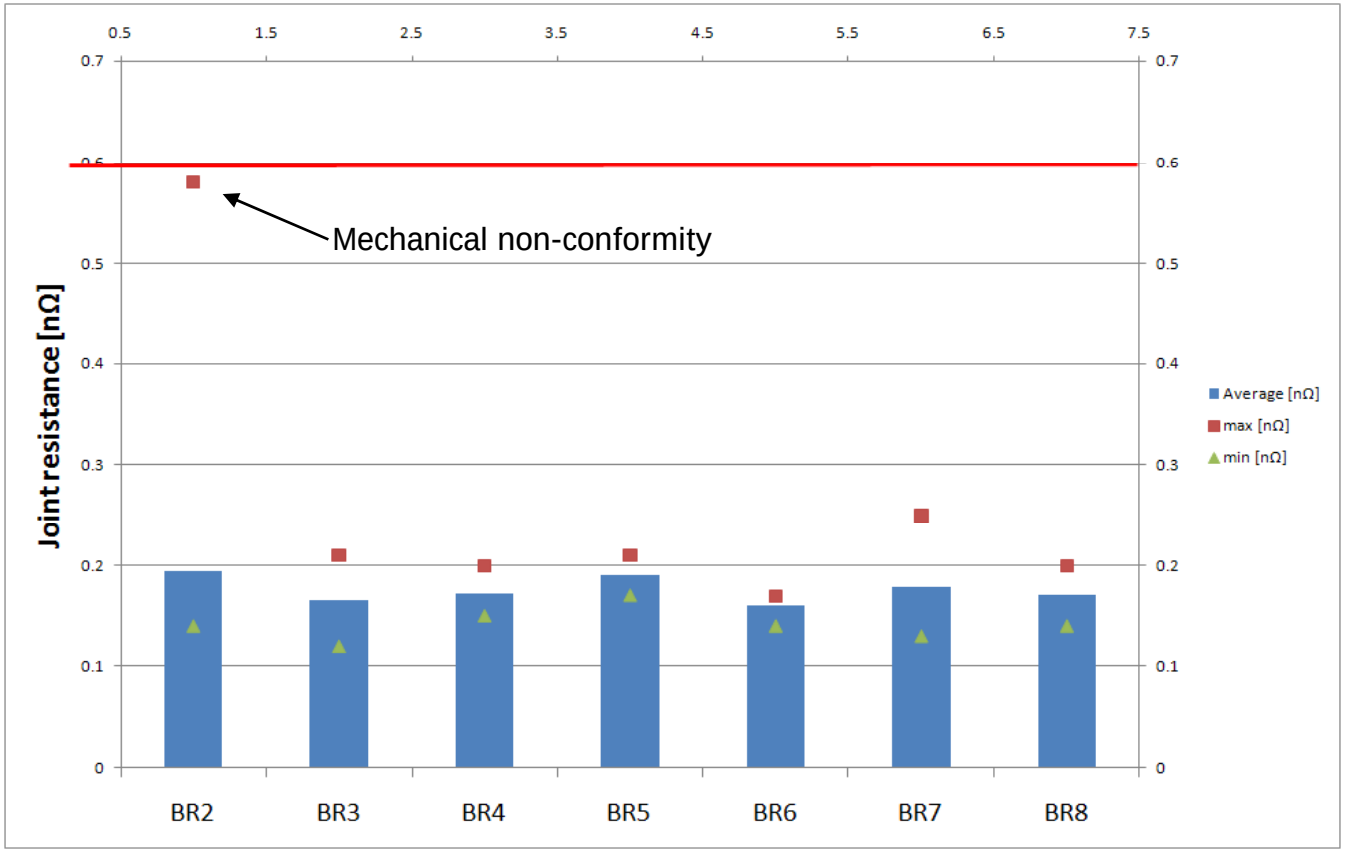
- low temperature and humidity in tunnel
- low productivity of industrial staff (Jan 2007) following contract policy of company

P. Fessia

Electrical joint in 12 kA bus bar

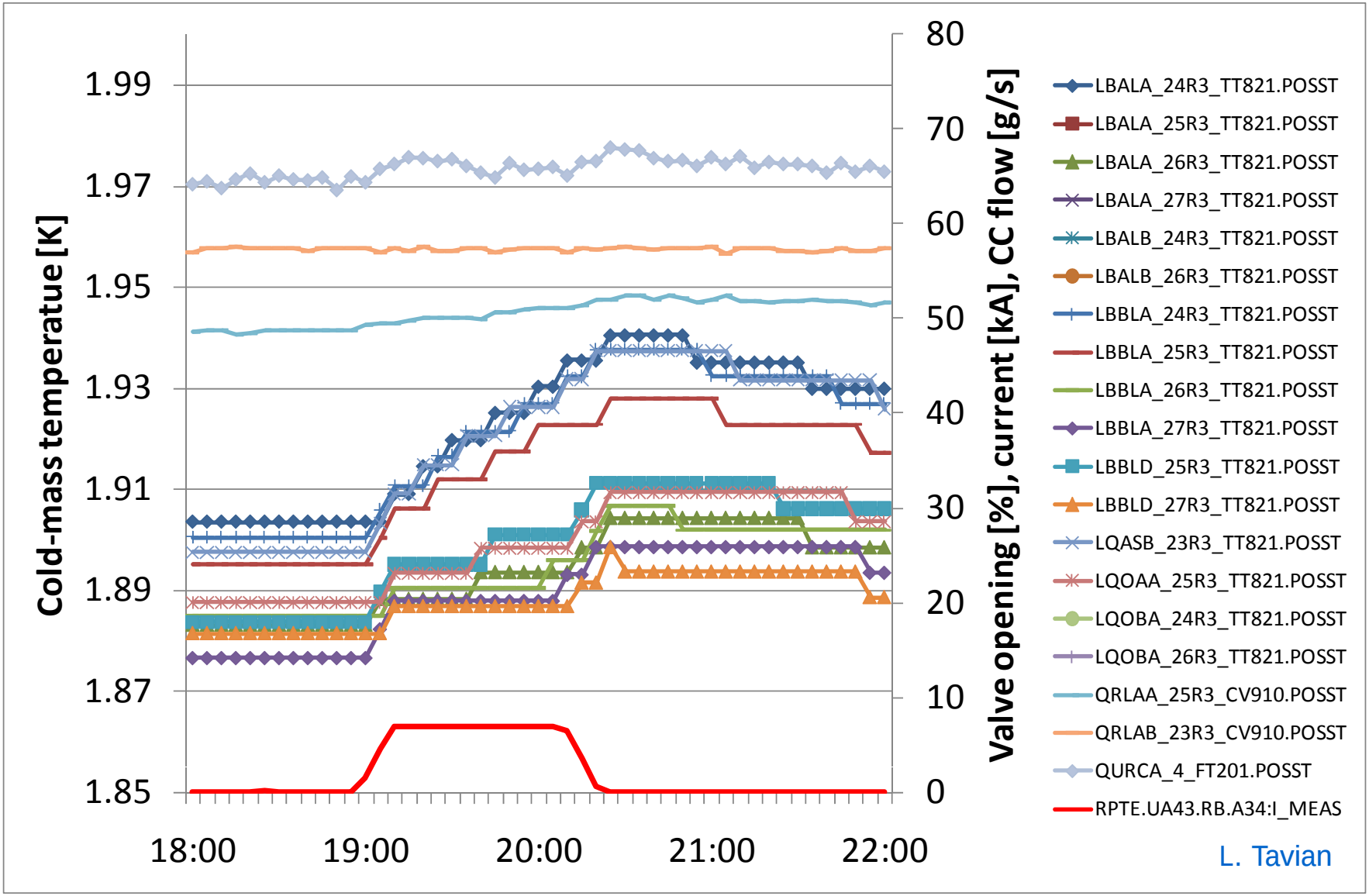


QA of electrical joints: witness samples

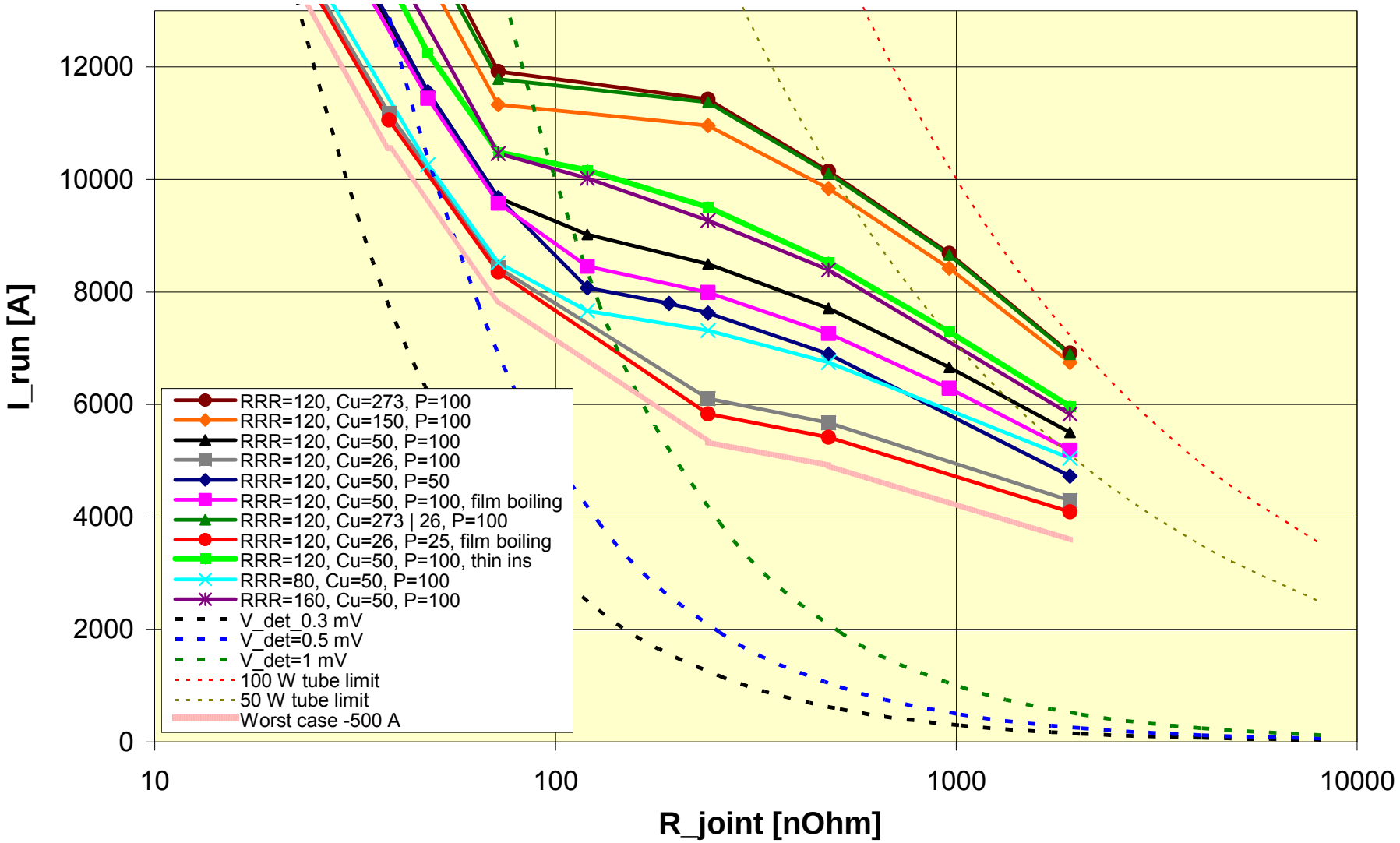


P. Fessia

Temperature drift during 7 kA current flat top (15 Sep 2008)

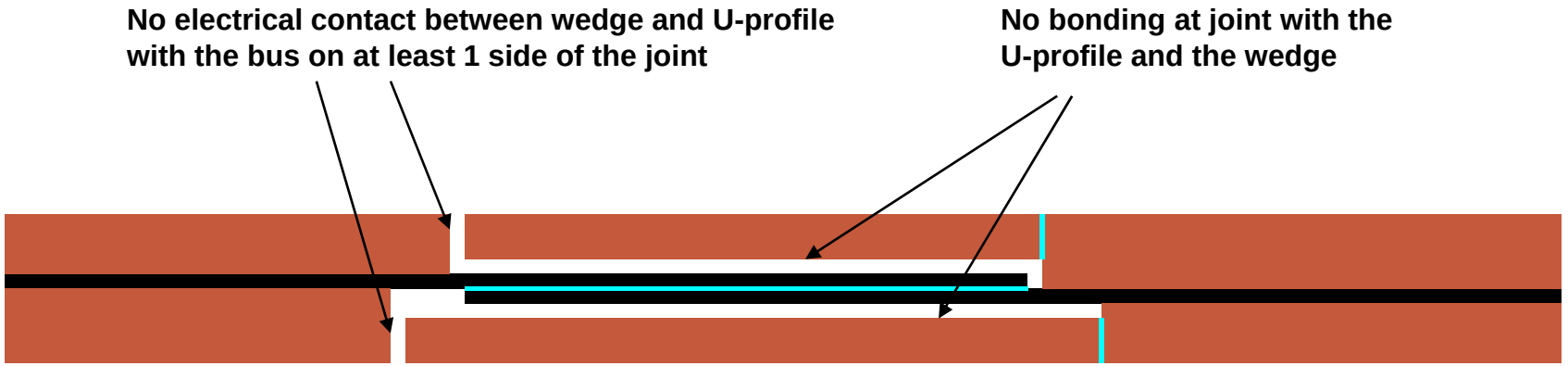


Simulated thermal runaway threshold of electrical interconnect

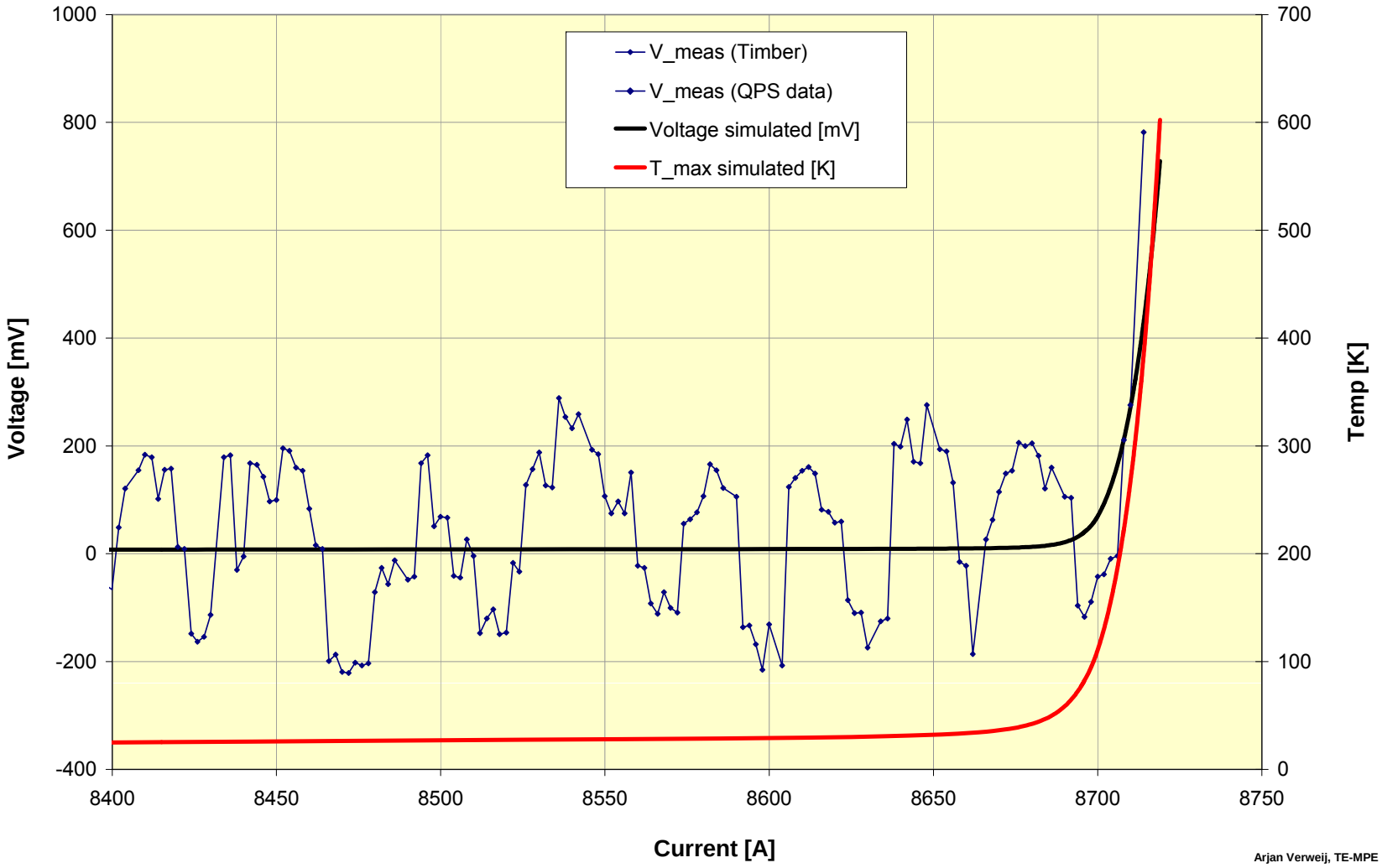


A. Verweij

A resistive joint of about 220 nΩ with bad electrical and thermal contacts with the stabilizer

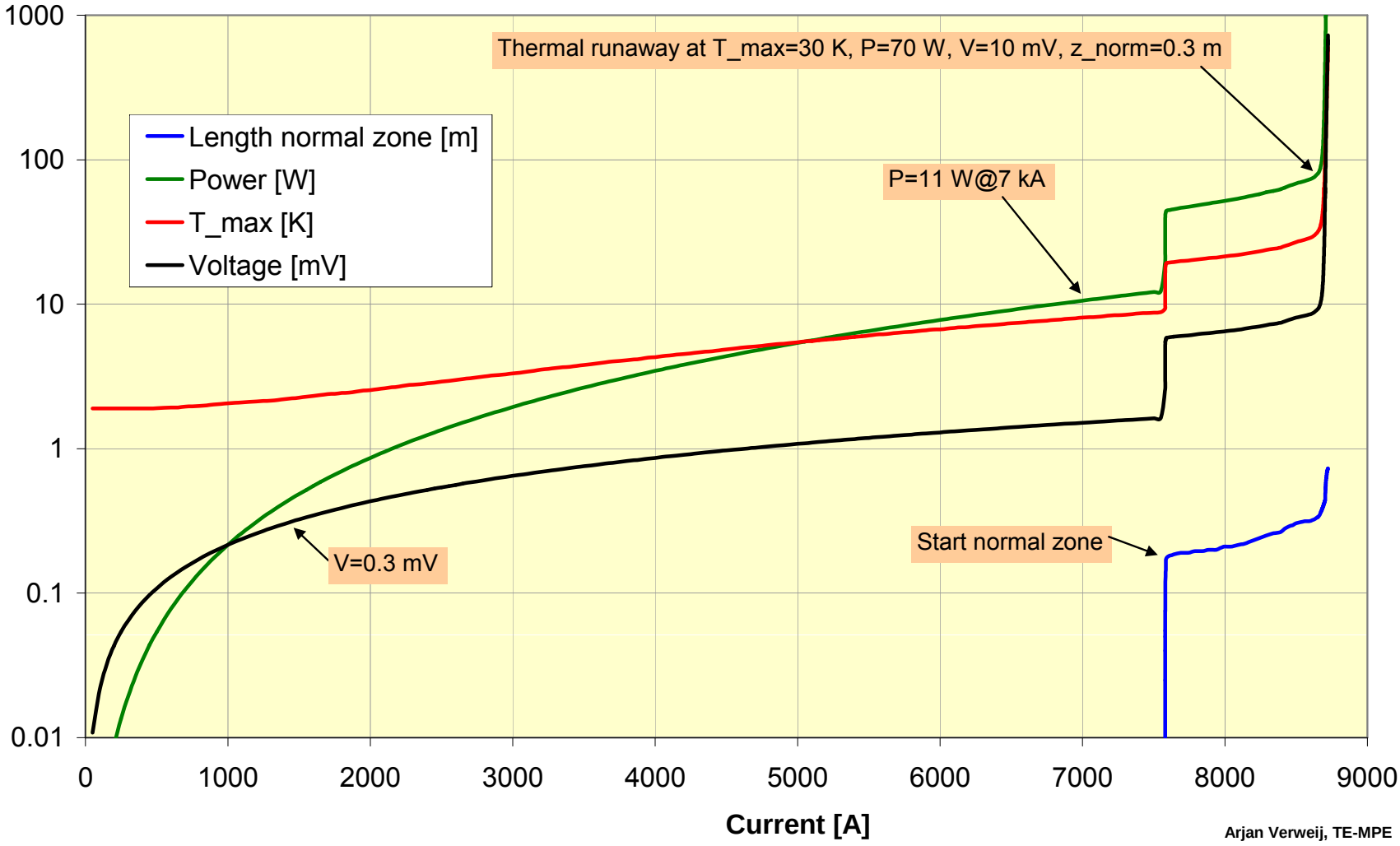


Measured vs simulated incident with 220 nΩ joint and bad contact with U-profile and wedge

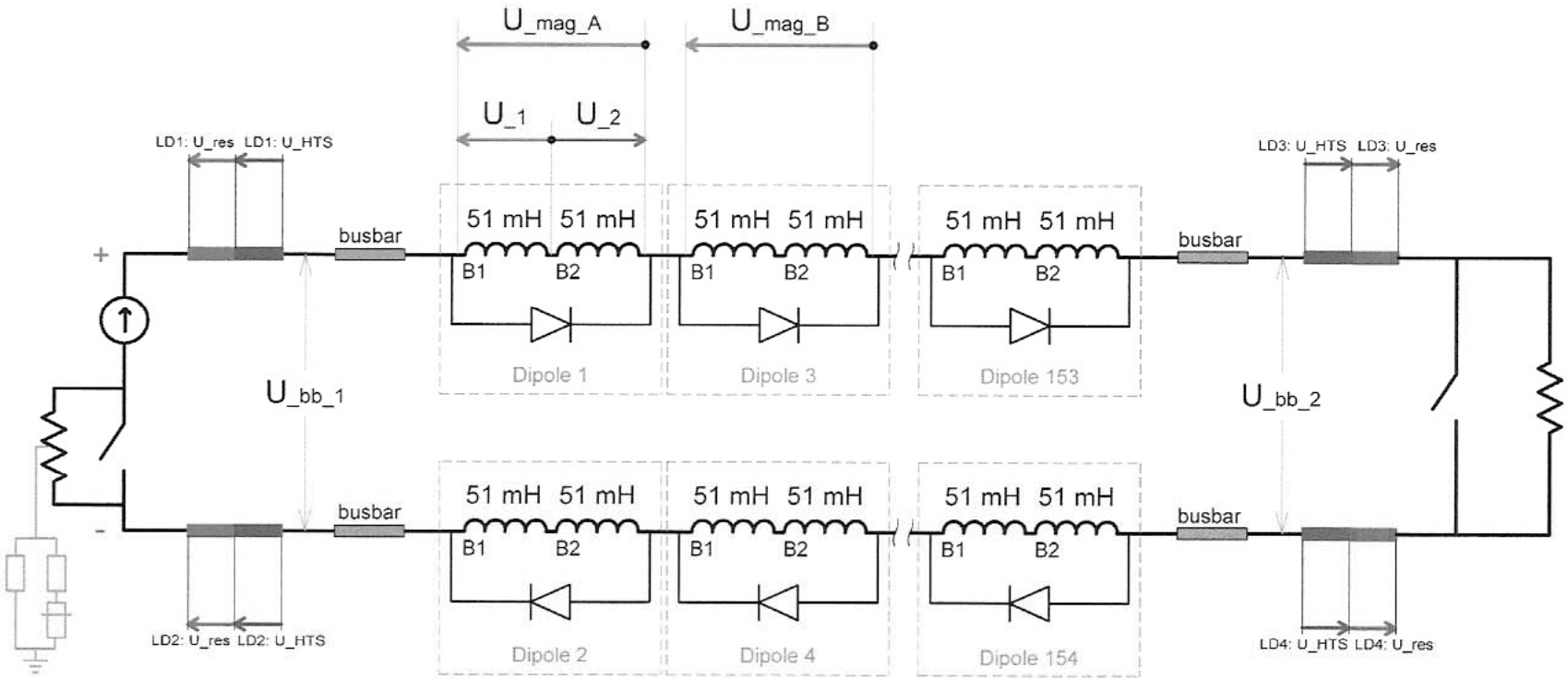


A. Verweij

Simulation of incident with 220 nΩ joint and bad contact with U-profile and wedge

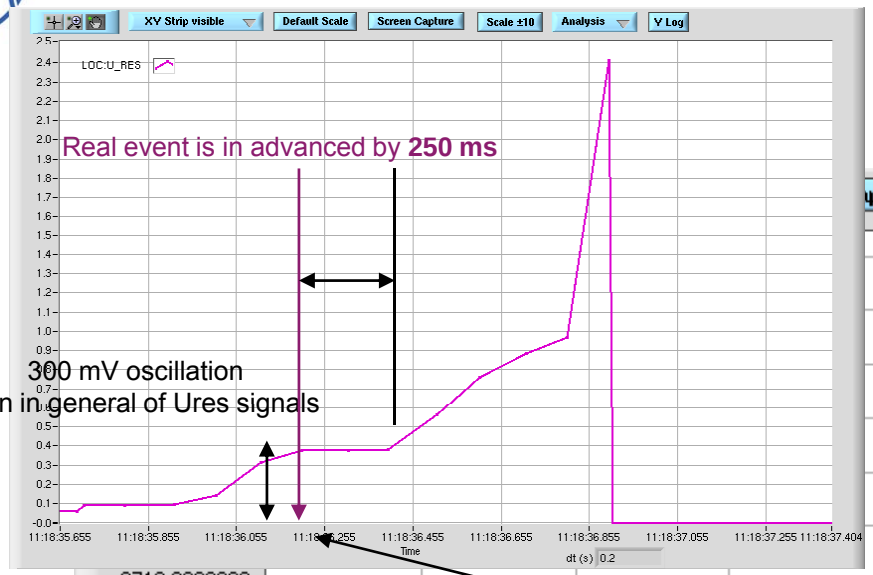


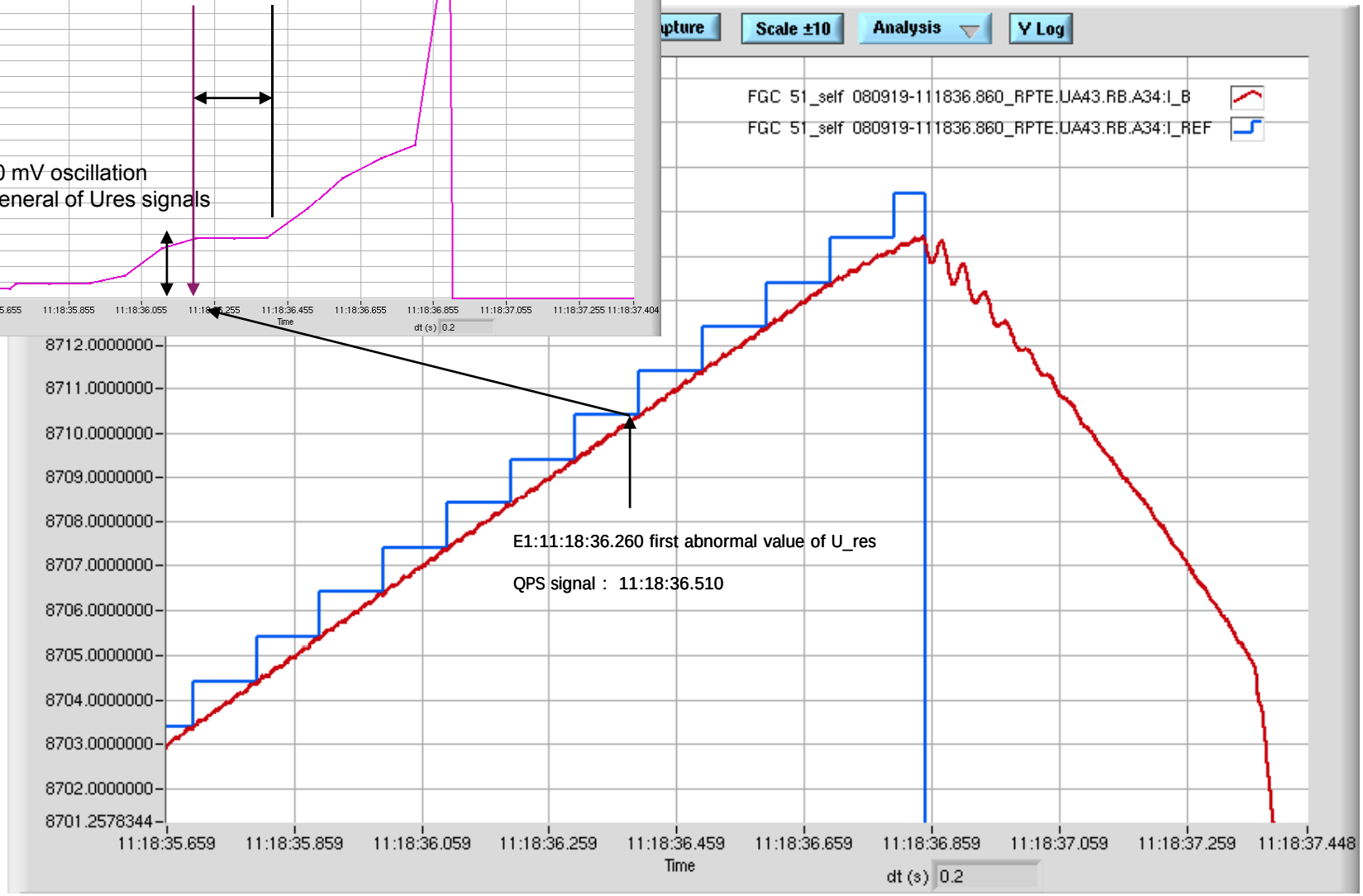
Schematic of dipole circuit in sector



A. Siemko

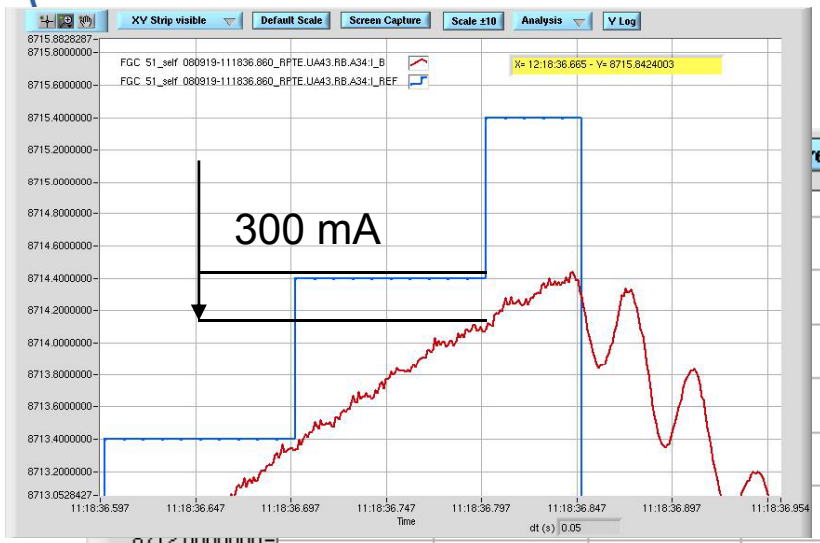
Event Nr. 1 @ 11:18:36.260
Abnormal value of U_res of bus bar detector

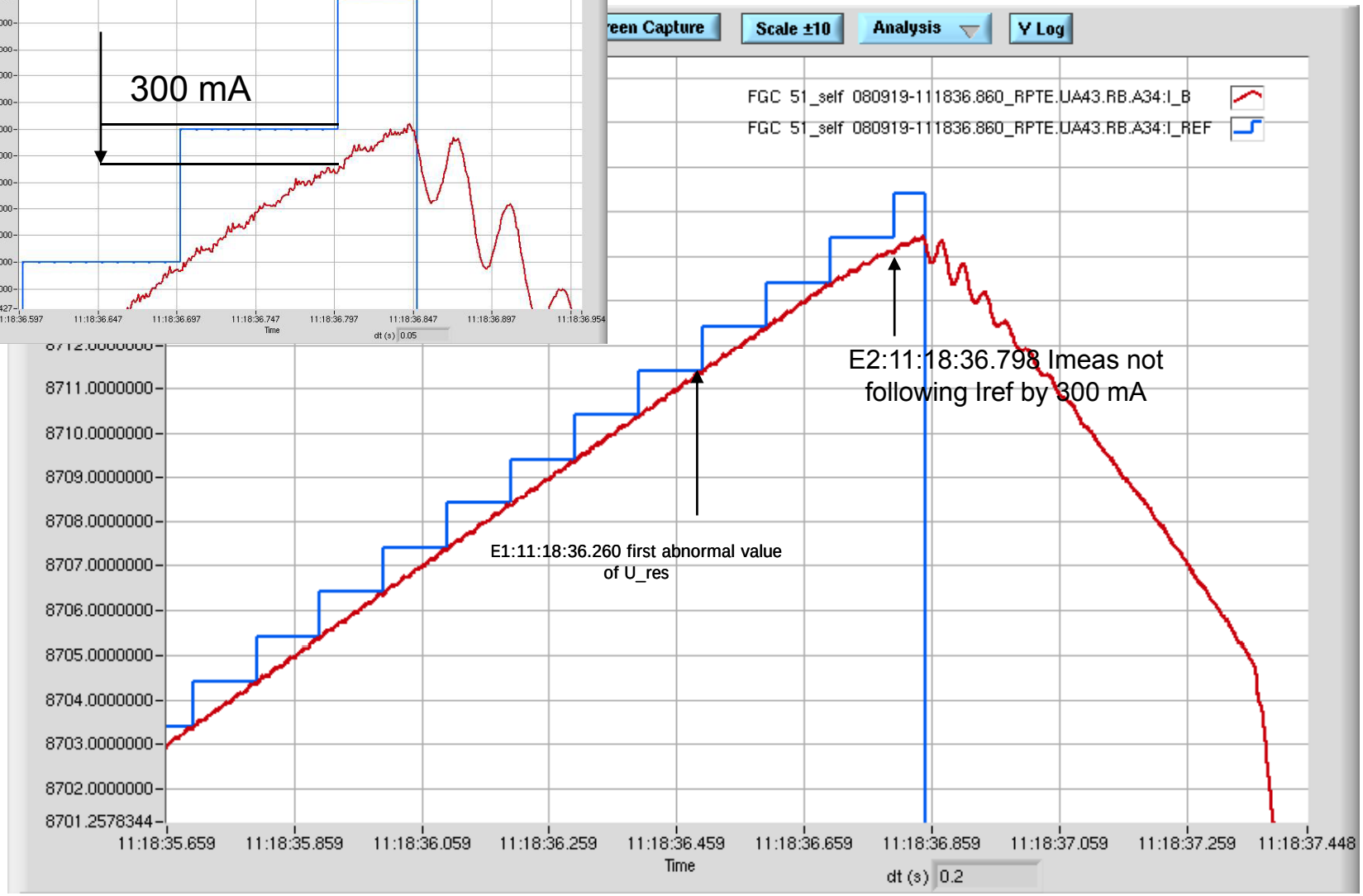




M. Bajko, N. Catalan, G. de Rijk, G. Kirby, S. Le Naour

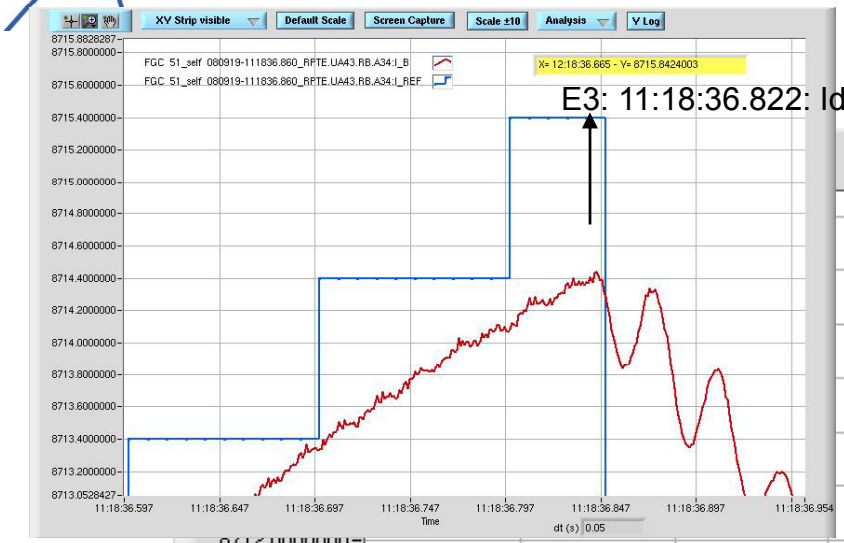
Event Nr. 2 @ 11:18:36.798
Imeas not following Iref by 300 mA

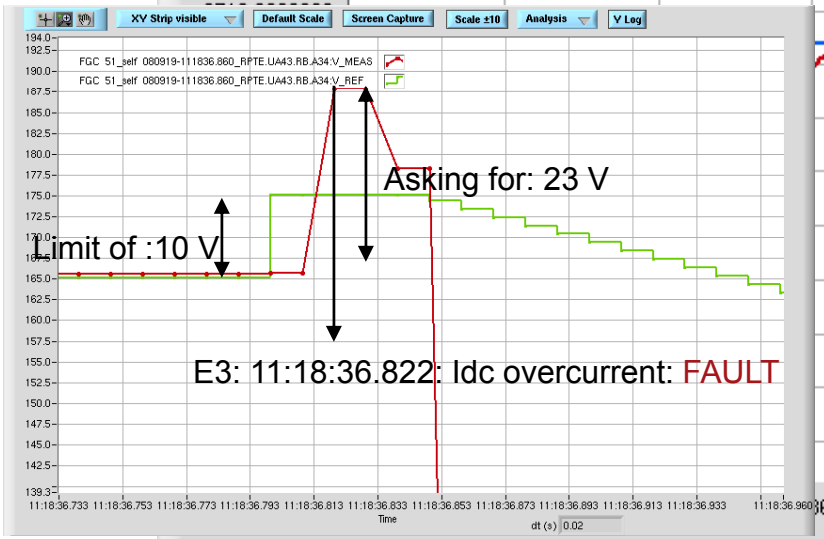


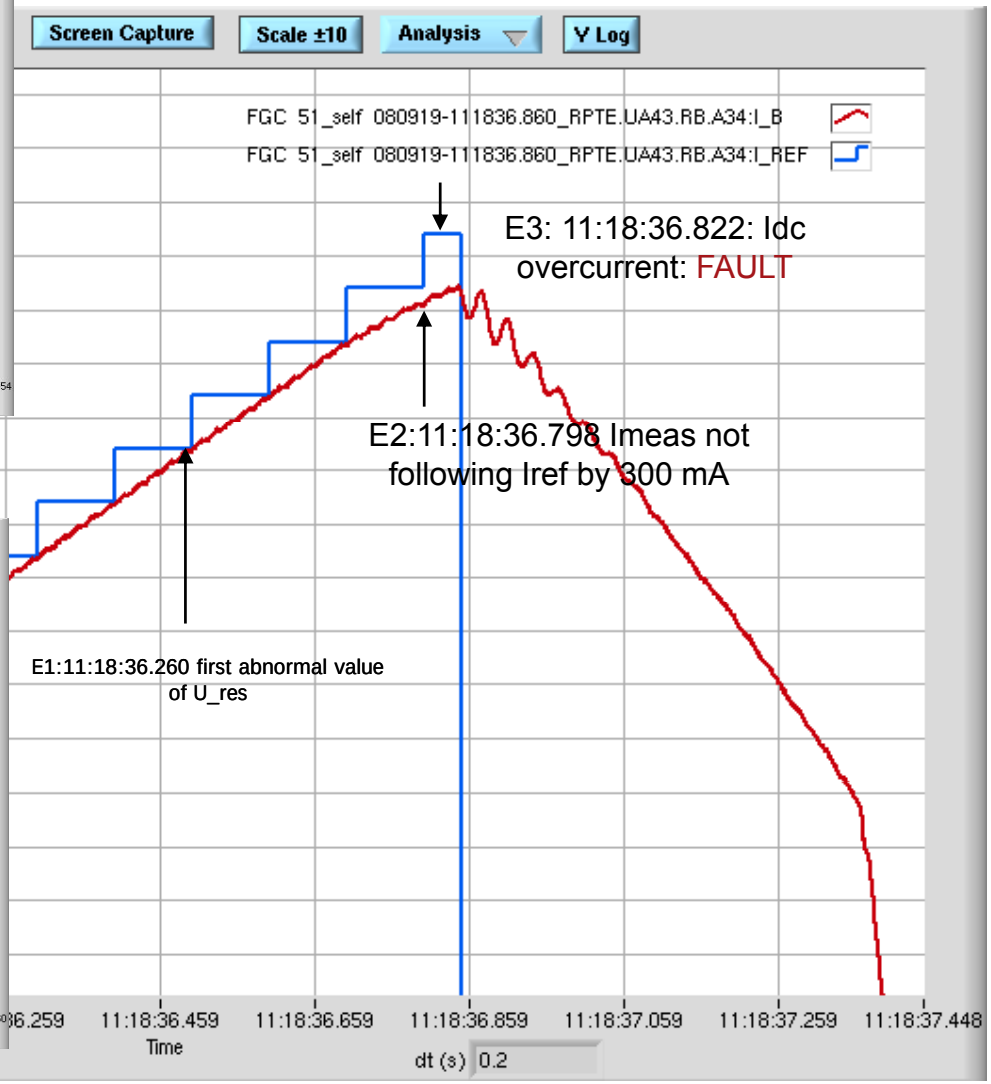


M. Bajko, N. Catalan, G. de Rijk, G. Kirby, S. Le Naour

Event Nr. 3 @ 11:18:36.822
Idc Current overflow: FAULT



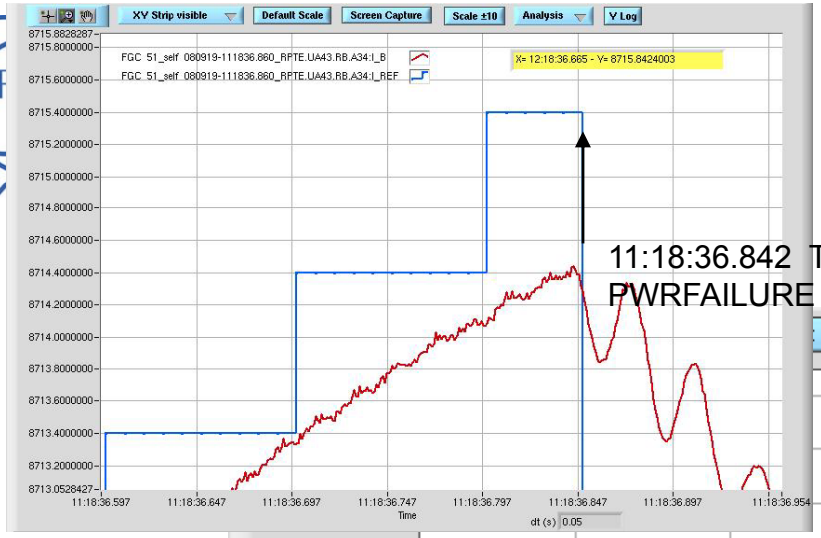


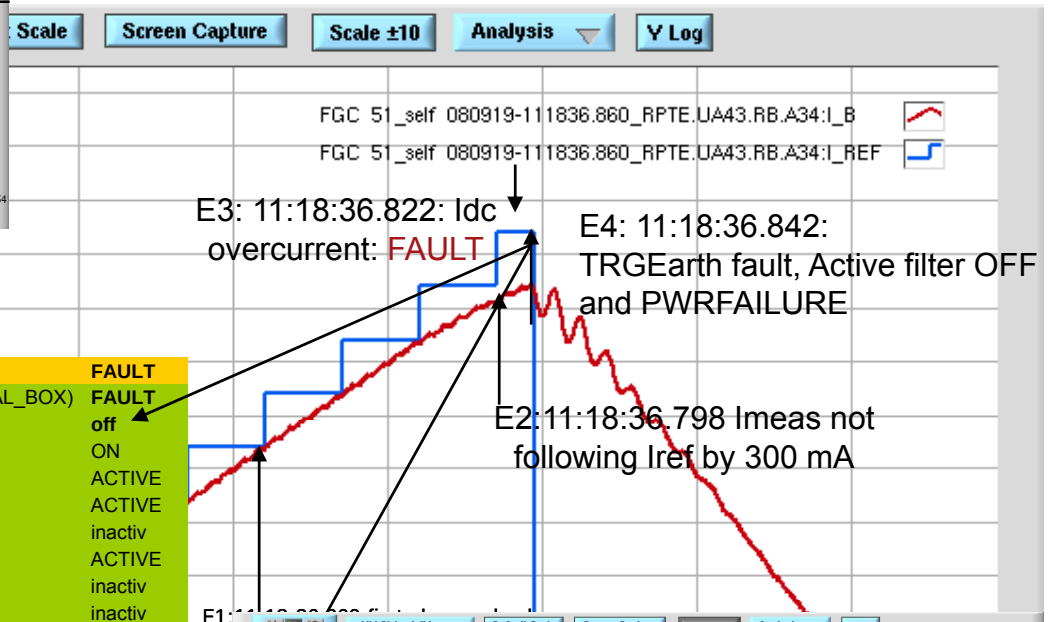


M. Bajko, N. Catalan, G. de Rijk, G. Kirby, S. Le Naour

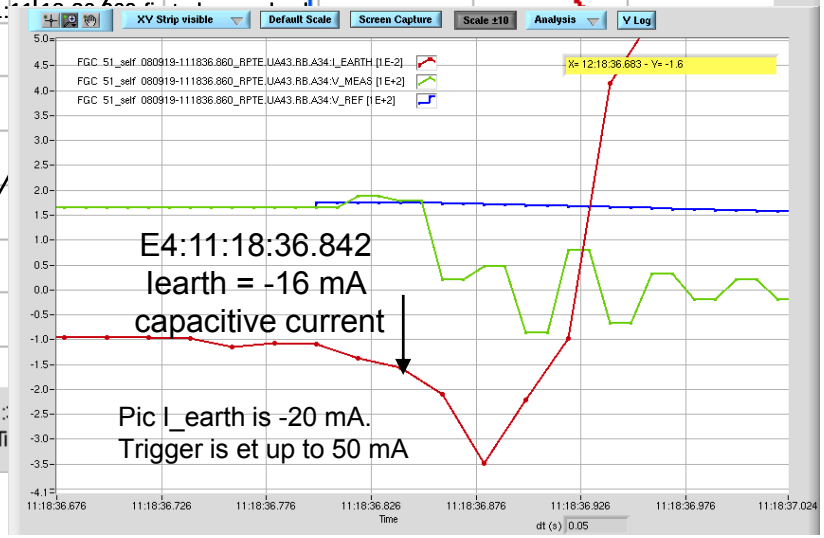
Events Nr. 4-6 @ 11:18:36.842

TRGEARTH-Fault, Active filter off, PWRFAILURE

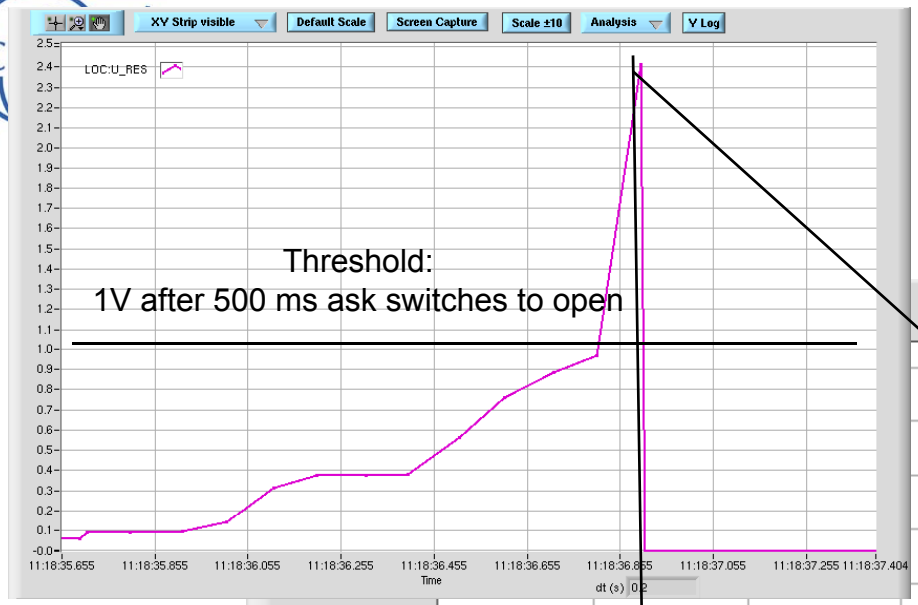


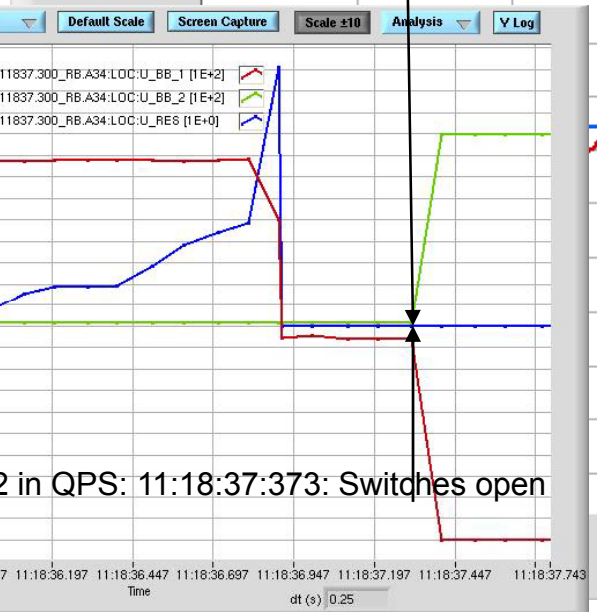


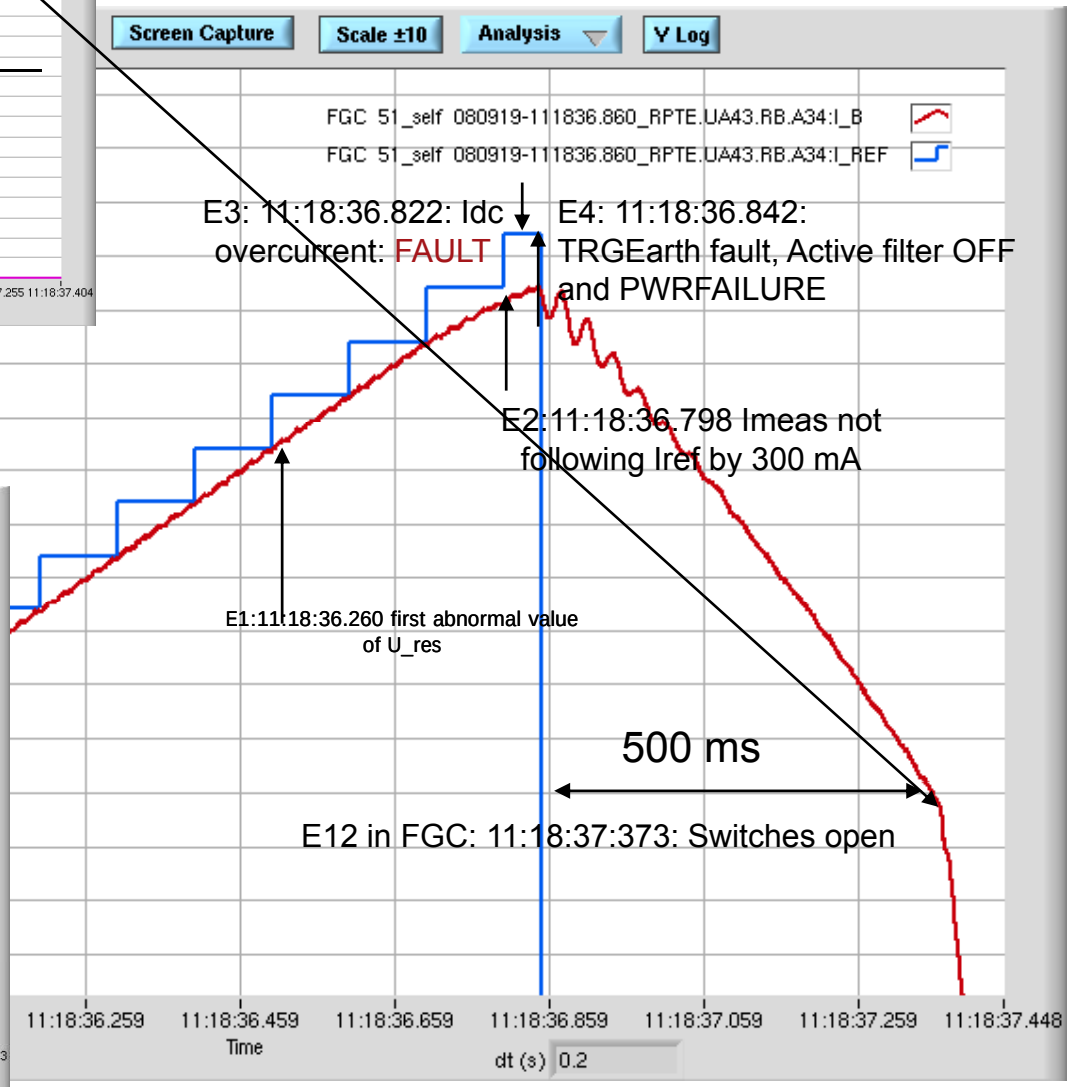
2008-09-19 11:18:36.822	DIM.AF	TRG|IDC_OVER_CURRENT	**FAULT**
2008-09-19 11:18:36.842	DIM.VS	TRG|EARTH_FAULT_(FROM_EXTERNAL_BOX)	**FAULT**
2008-09-19 11:18:36.842	DIM.LOOP	STA|ACTIVE_FILTER	**off**
2008-09-19 11:18:36.842	DIM.LOOP	STA|LOOP	ON
2008-09-19 11:18:36.842	DIM.LOOP	STA|VLOOP_OK	ACTIVE
2008-09-19 11:18:36.842	DIM.ACT	STA|MCB_ON	ACTIVE
2008-09-19 11:18:36.842	DIM.ACT	STA|MCB_OFF	inactiv
2008-09-19 11:18:36.842	DIM.ACT	STA|MCB_PLUG	ACTIVE
2008-09-19 11:18:36.842	DIM.ACT	STA|MCB_UNPLUG	inactiv
2008-09-19 11:18:36.842	DIM.ACT	STA|MCB_EARTH	inactiv
2008-09-19 11:18:36.842	DIM.ACT	STA|MCB_NOT_EARTH	ACTIVE
2008-09-19 11:18:36.842	DIM.ACT	STA|PREMAG_ON	inactiv
2008-09-19 11:18:36.842	DIM.ACT	STA|PREMAG_OFF	ACTIVE
2008-09-19 11:18:36.842	DIM.ACT	STA|DCCT_ZERO_CURRENT	no
2008-09-19 11:18:36.842	DIM.ACT	STA|INSULATION_SWITCH_IN	ACTIVE
2008-09-19 11:18:36.842	DIM.ACT	STA|INSULATION_SWITCH_OUT	inactiv
2008-09-19 11:18:36.842	DIM.ACT	STA|INSULATION_SWITCH_EARTH	inactiv
2008-09-19 11:18:36.842	DIM.ACT	STA|INSULATION_SWITCH_BLOCKED	ACTIVE
2008-09-19 11:18:36.842	DIM.ACT	STA|ACTIVE_FILTER	PRESENT
2008-09-19 11:18:36.842	STATE.PC	FLT_STOPPING	SET
2008-09-19 11:18:36.842	VS.STATE	VS_INVALID	SET
2008-09-19 11:18:36.842	DIG.STATUS	VSFAULT	SET
2008-09-19 11:18:36.842	DIG.STATUS	PWRFAILURE	**SET**
2008-09-19 11:18:36.842	DIG.STATUS	VSRUN	CLR
2008-09-19 11:18:36.842	DIG.COMMANDS	VSRUN_CMD	CLR
2008-09-19 11:18:36.842	DEVICE.FAULTS	VS_FAULT	SET
2008-09-19 11:18:36.842	FGC.ST_UNLATCHED	PWR_FAILURE	SET
2008-09-19 11:18:36.842	FGC.ST_UNLATCHED	POST_MORTEM	SET



Event Nr. 12 @ 11:18:37.373
Switches open

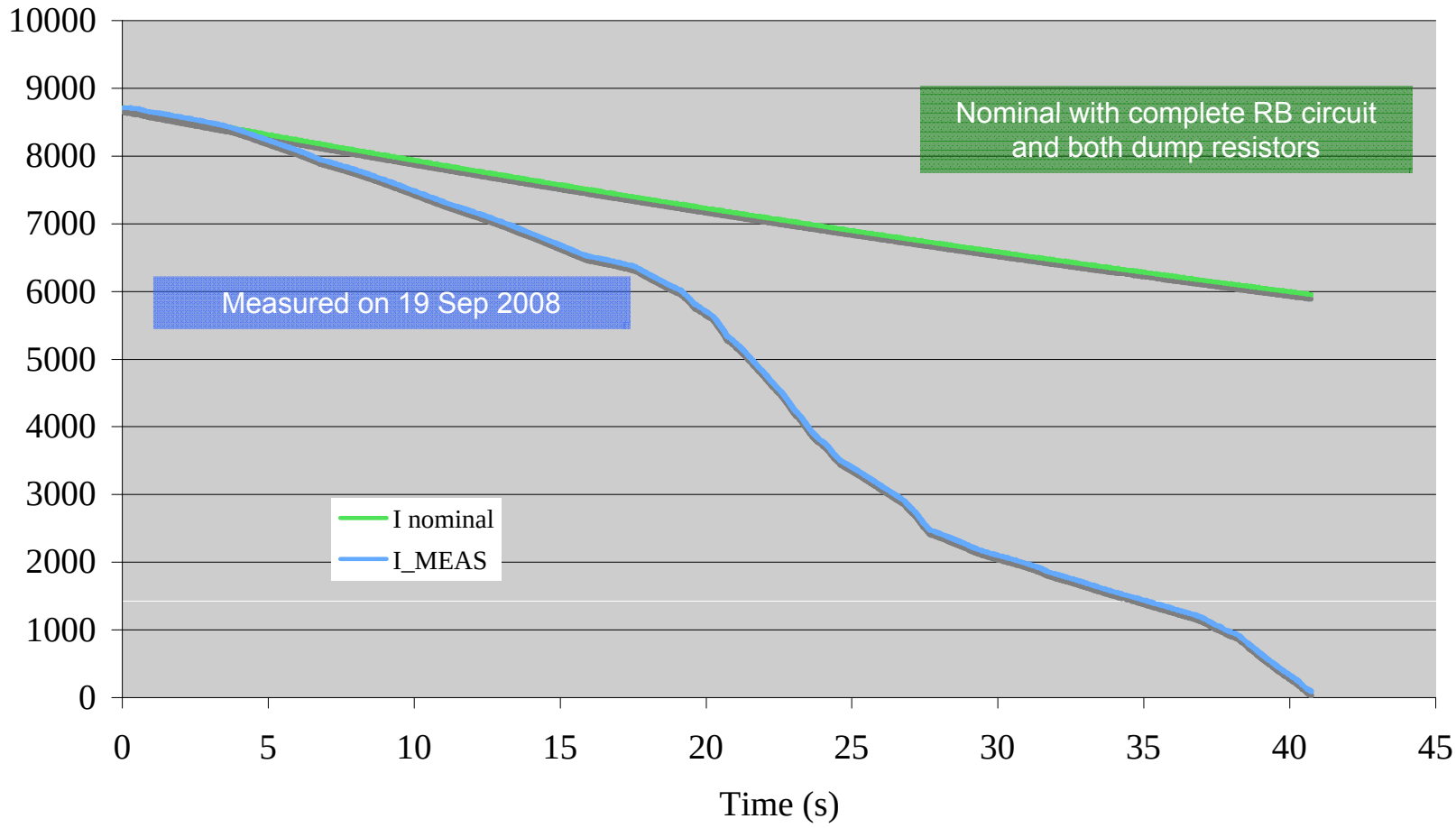






M. Bajko, N. Catalan, G. de Rijk, G. Kirby, S. Le Naour

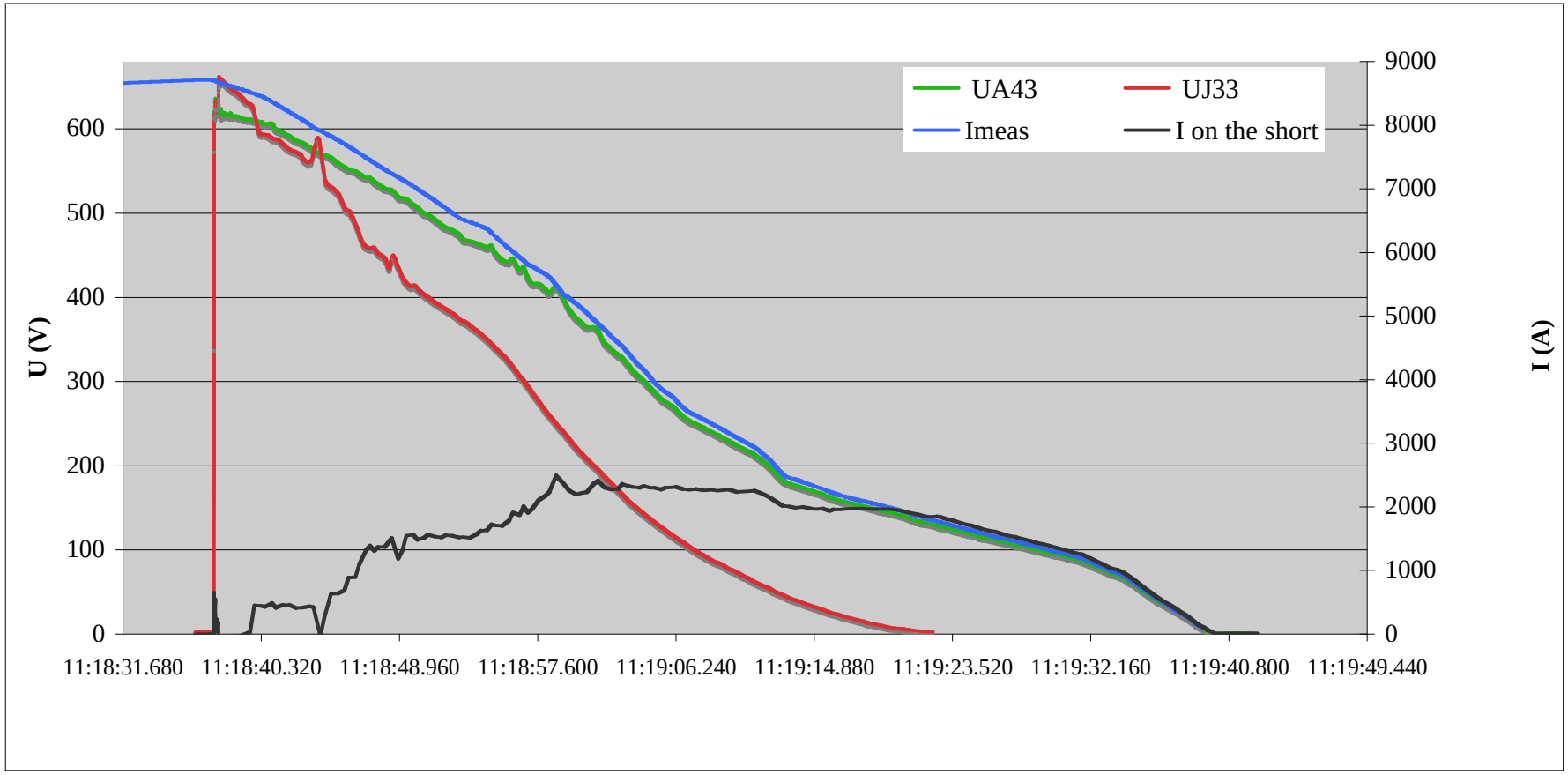
Current decay in dipole circuit from 8.7 kA



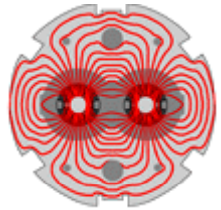
M. Bajko, N. Catalan, G. de Rijk, G. Kirby, S. Le Naour

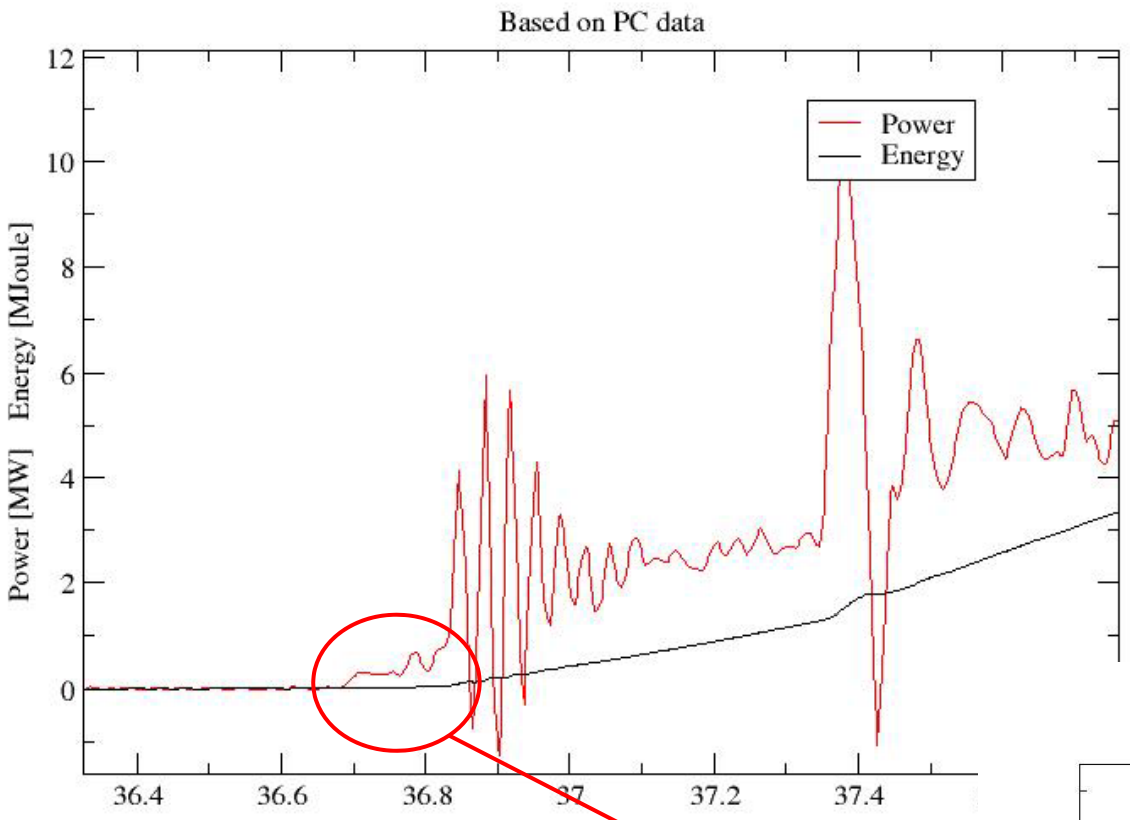
Decay of current in sub-circuits

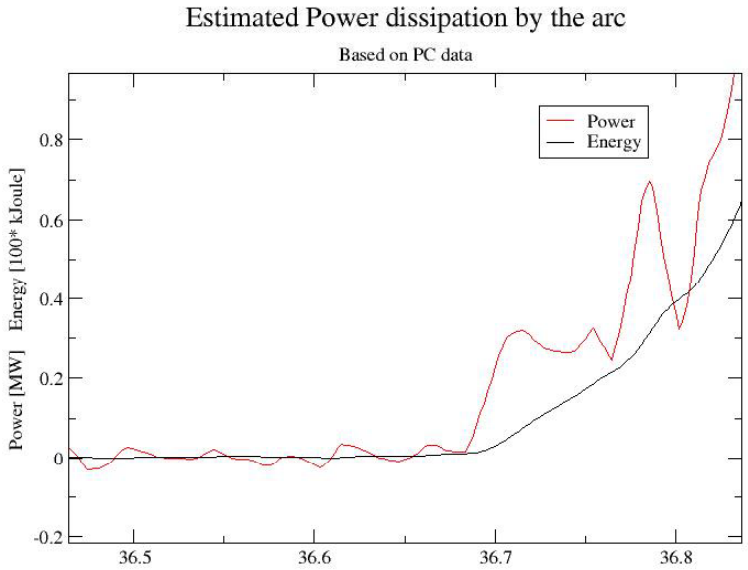
measured at DCCT & dump resistors on UJ33 and UA43



M. Bajko, N. Catalan, G. de Rijk, G. Kirby, S. Le Naour

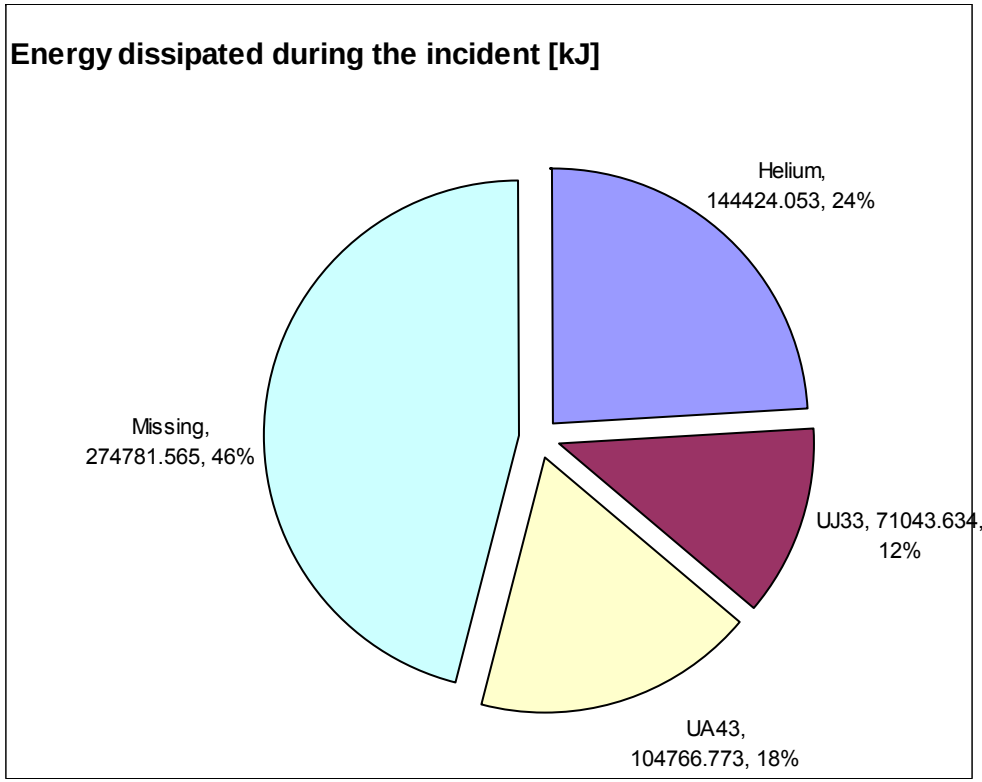



Estimated Power dissipation by the arc
Based on PC data
Power
Energy
Power [MW] Energy [MJoule]
12
10
8
6
4
2
0
36.4
36.6
36.8
37
37.2
37.4


Estimated Power dissipation by the arc
Based on PC data
Power
Energy
Power [MW] Energy [100* kJoule]
0.8
0.6
0.4
0.2
0
-0.2
36.5
36.6
36.7
36.8

S. Feher

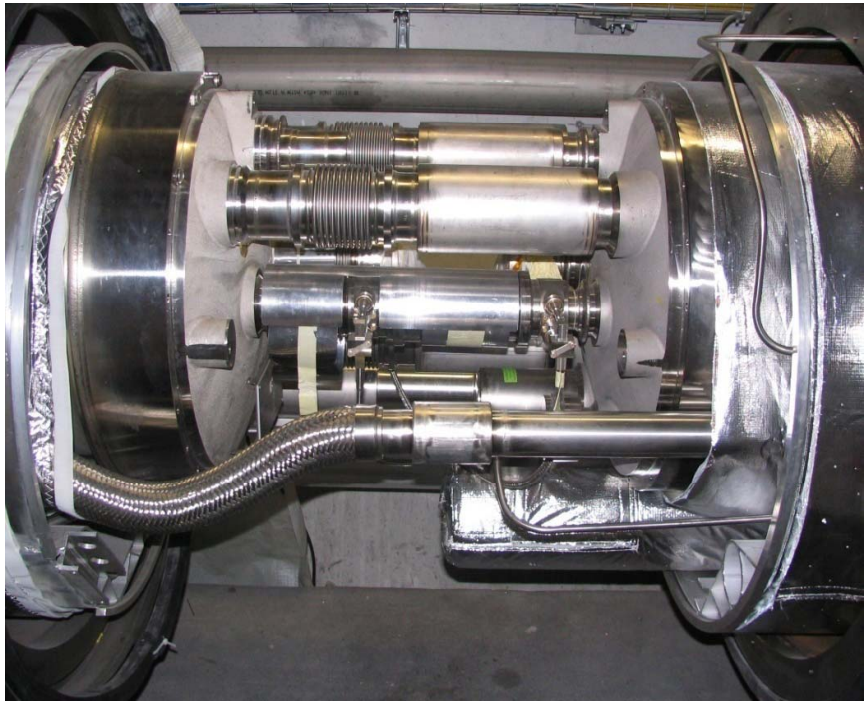
Energy balance in dipole circuit

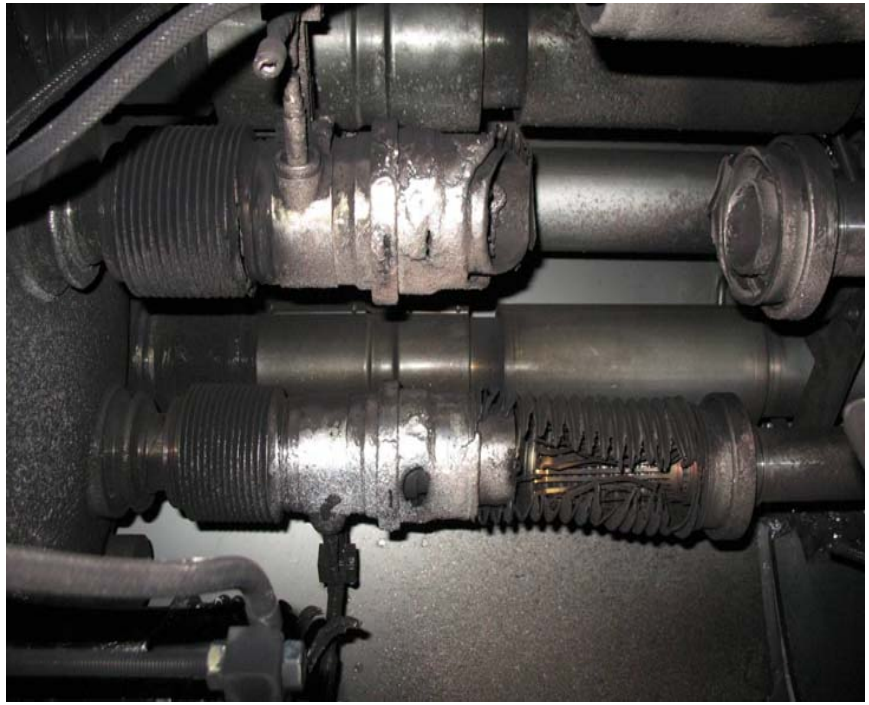


Energy	MJ	%
Stored in the magnets	595.0	100
Dissipated in UJ33	71.0	12
Dissipated in UA43	104.8	18
Dissipated in cold mass	144.4	24
Dissipated in electrical arcs	274.8	46

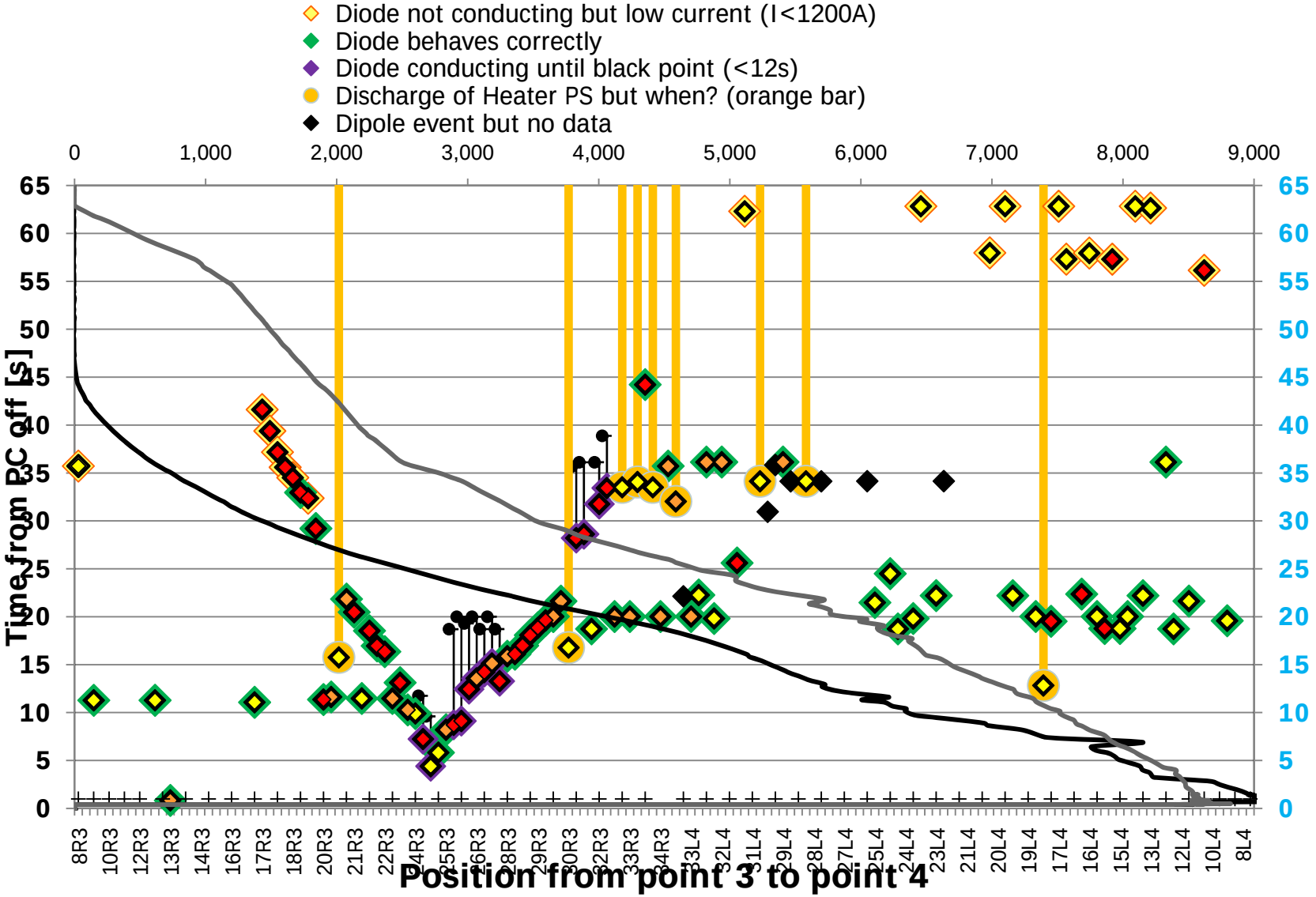
N. Catalan, S. Le Naour

Electrical arc between two magnets



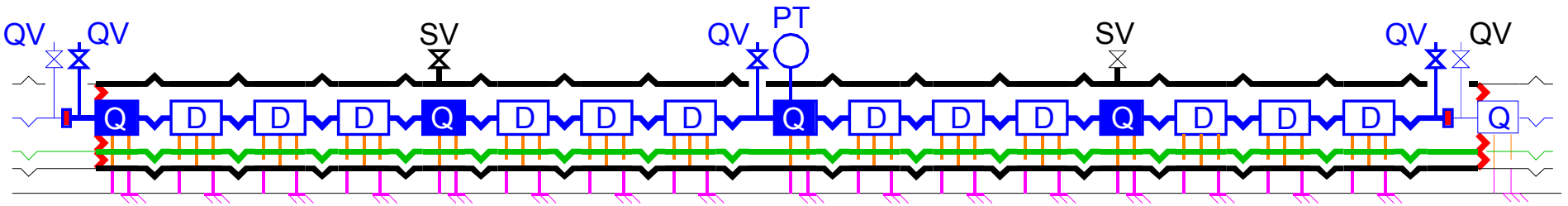


Long-distance propagation of quenches and quench triggers



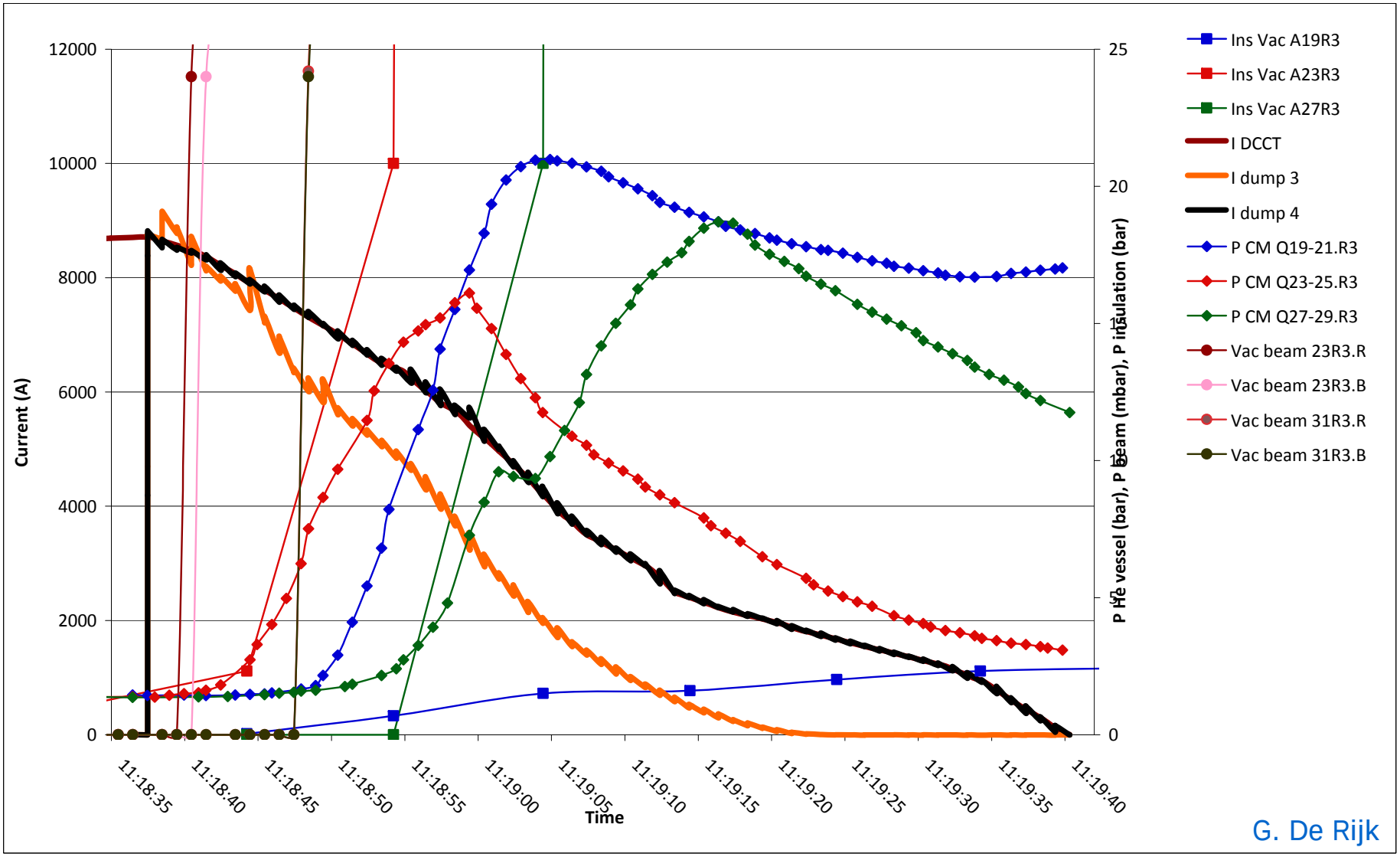
S. Le Naour

Simplified scheme of a sub-sector



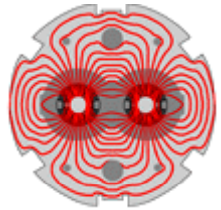
- Cold-mass
- Vacuum vessel
- Line E
- Cold support post
- Warm Jack
- Compensator/Bellows
- Vacuum barrier

Development of pressure in helium, insulation vacuum and beam vacuum enclosures

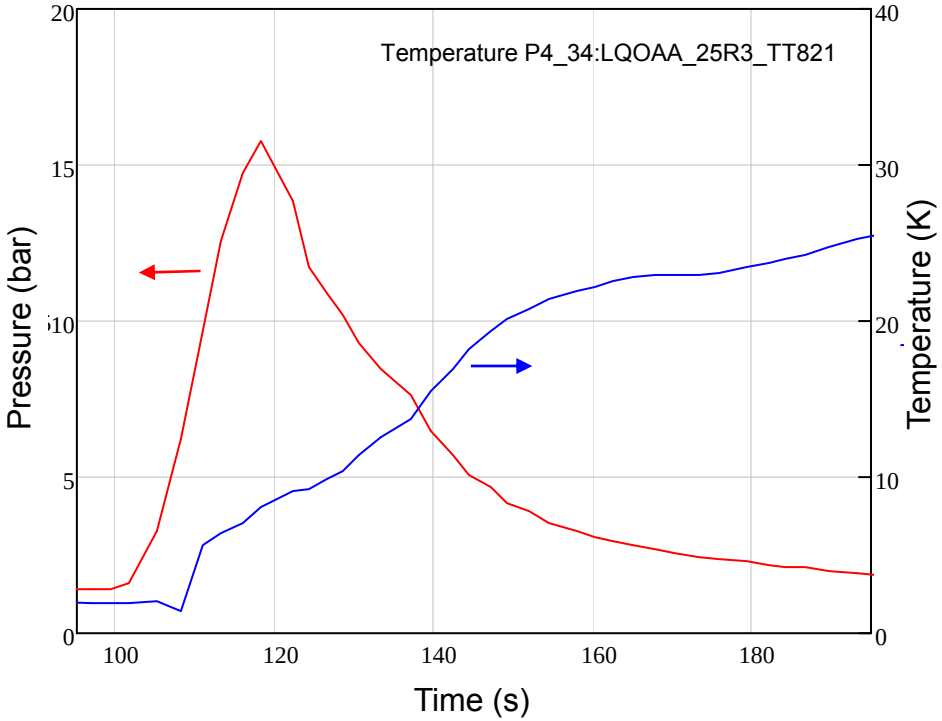


G. De Rijk

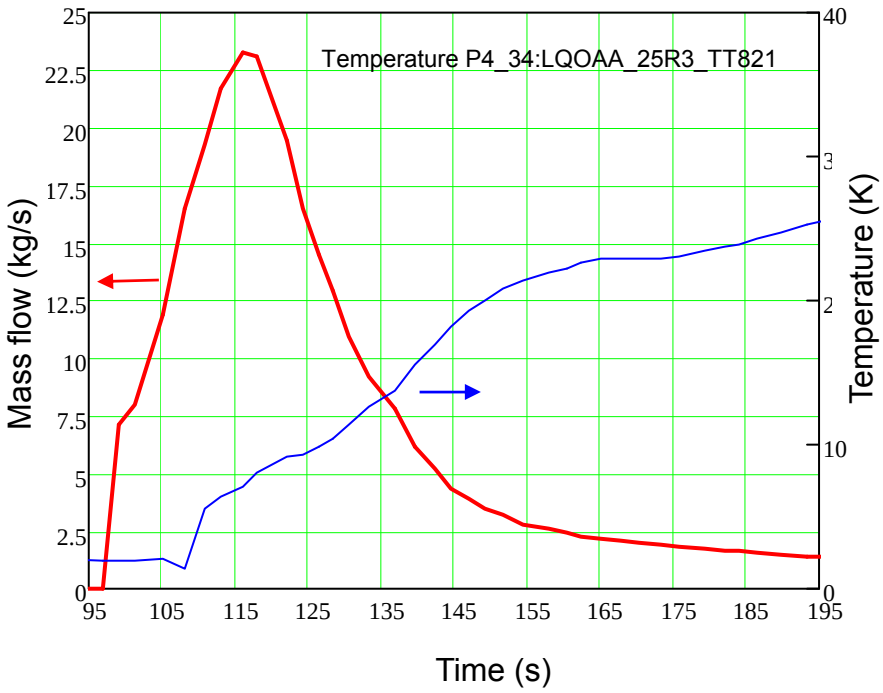
Estimation of helium discharge from cold mass



Recorded data



Estimated mass flow



Hypothesis:

Helium temperature given by sensor P4_34:LQOAA_25R3_TT821

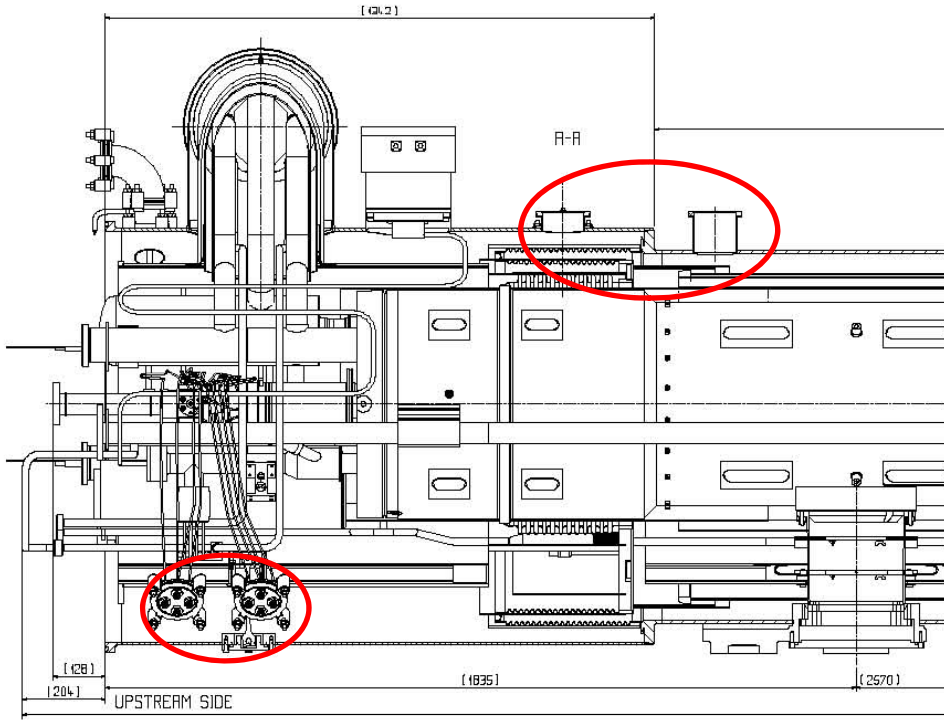
All helium discharged through 1 hole. No plug major failure.

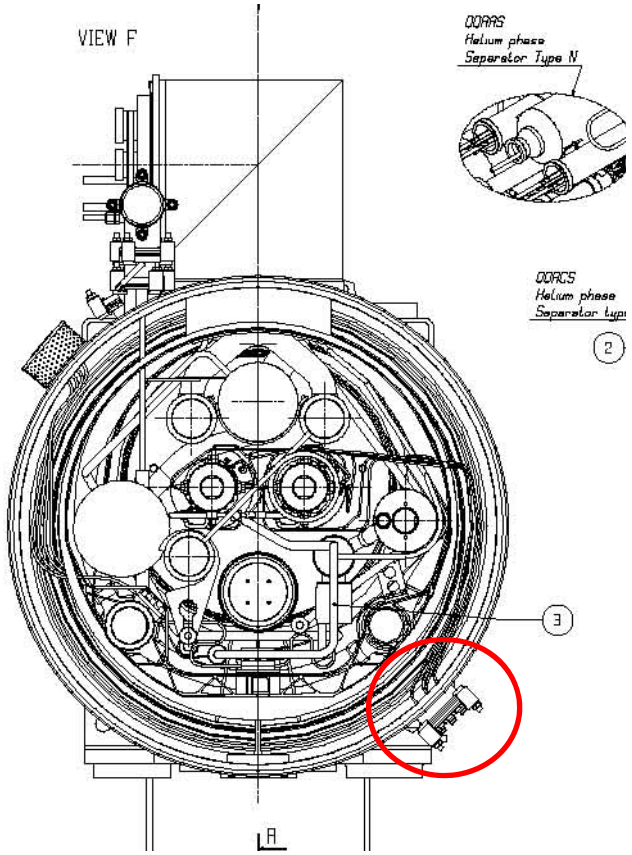
Constant hydraulic diameter 54 mm

Total mass of helium = 214 m x 0.026 m3/m x 147.8 kg/m3 = 822 kg

A. Perin

Existing ports on SSS vacuum enclosure





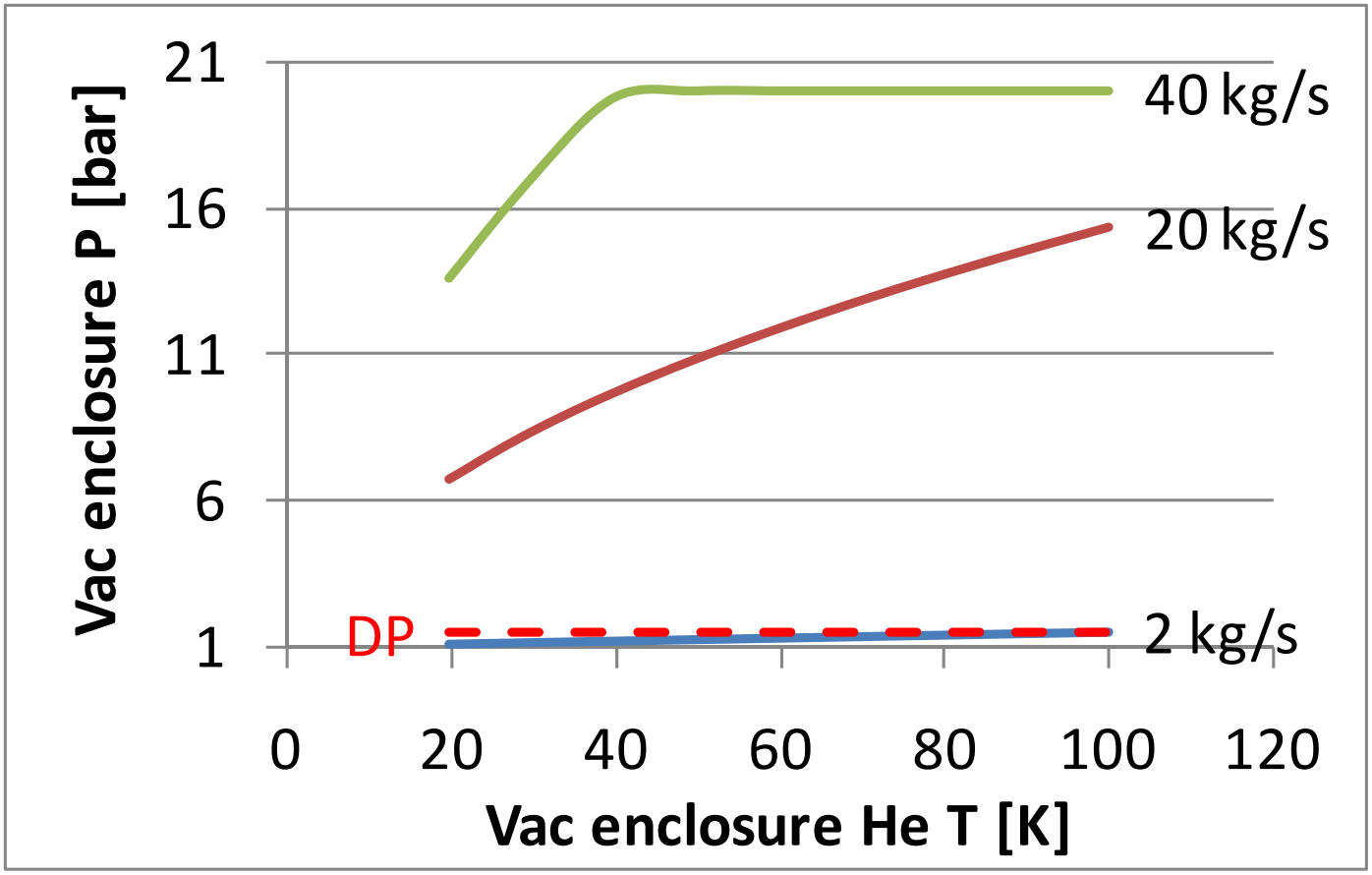
P. Cruikshank, V. Parma

Relief device on insulation vacuum enclosure

P. Cruikshank

Flow discharge characteristics of relief devices on insulation vacuum enclosure (per sub-sector)

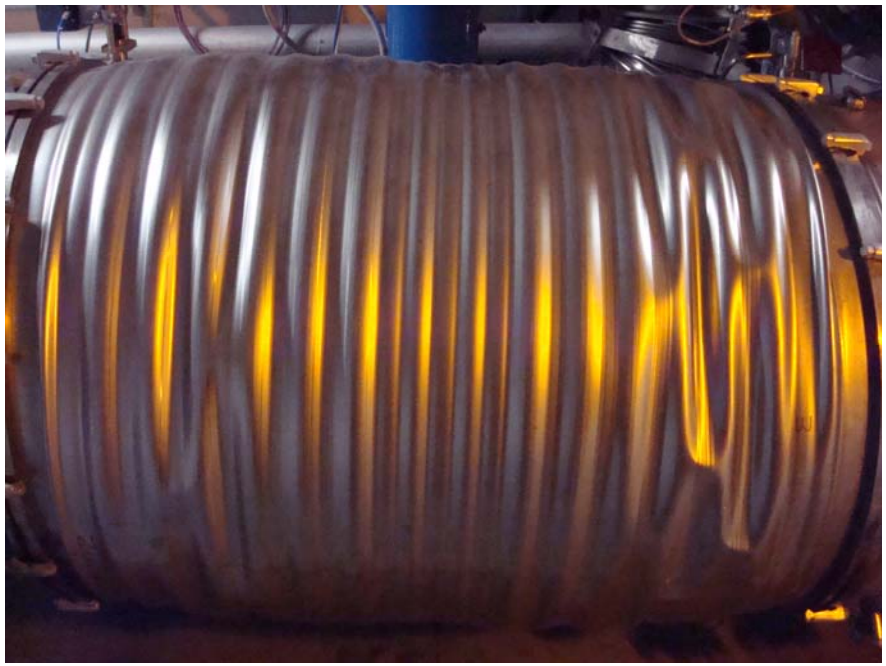
Present configuration: 2 DN90



(DP: Design Pressure)

L. Tavian

Assessment of maximum pressure in insulation vacuum enclosure from deformation of W sleeve



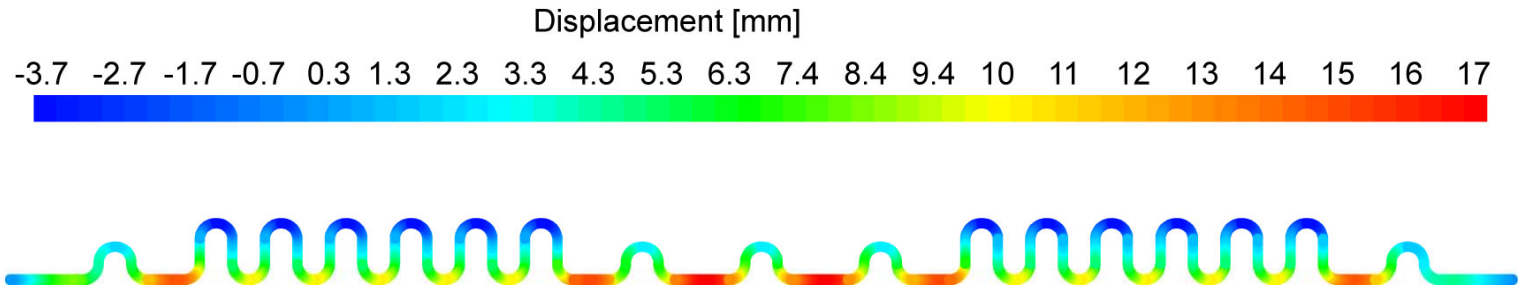
Corrugated sleeve of 1 mm thick AISI 316 L

Yield stress 275 MPa

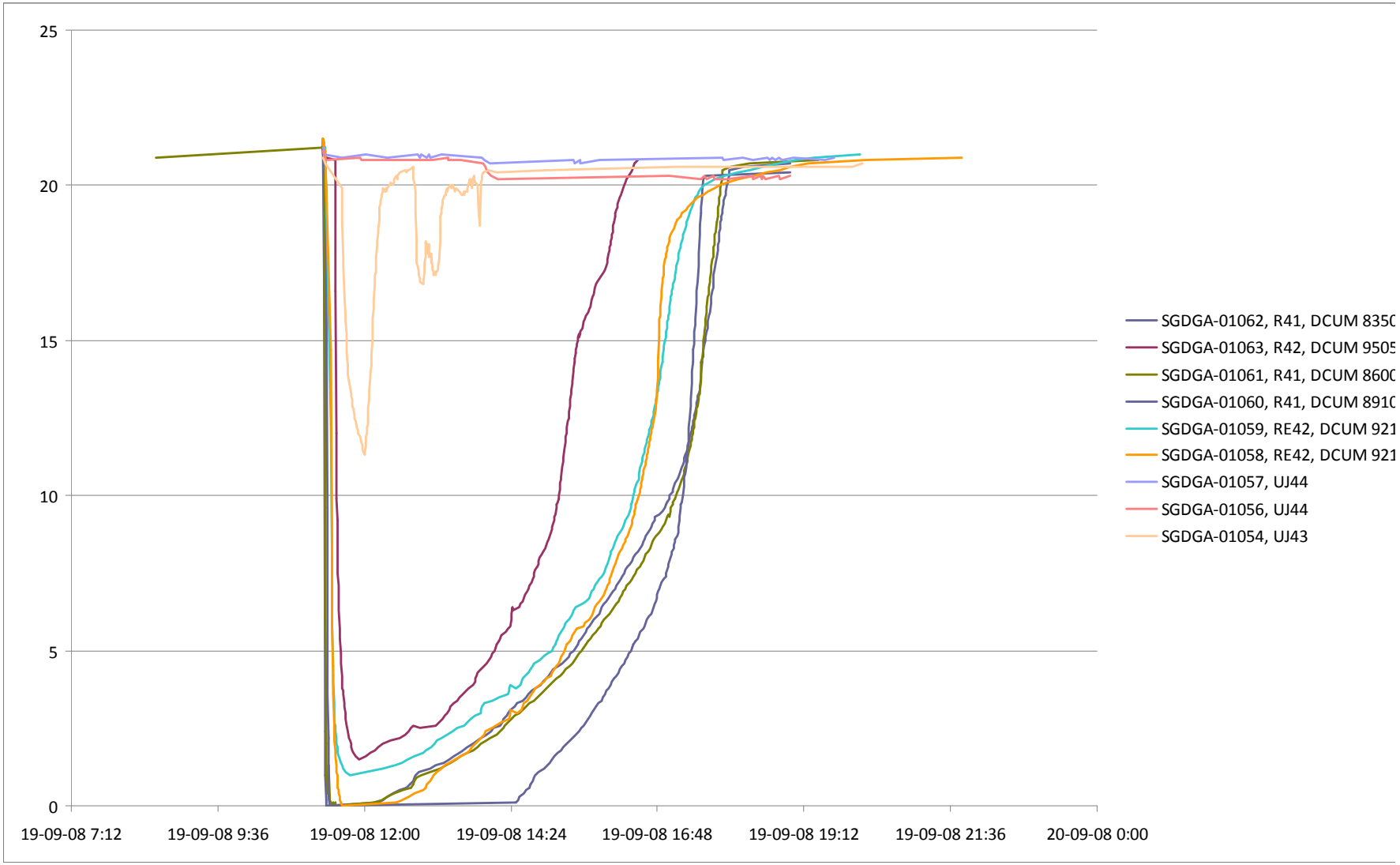
Nominal diameter 1016 mm

Maximum diameter 1055 mm

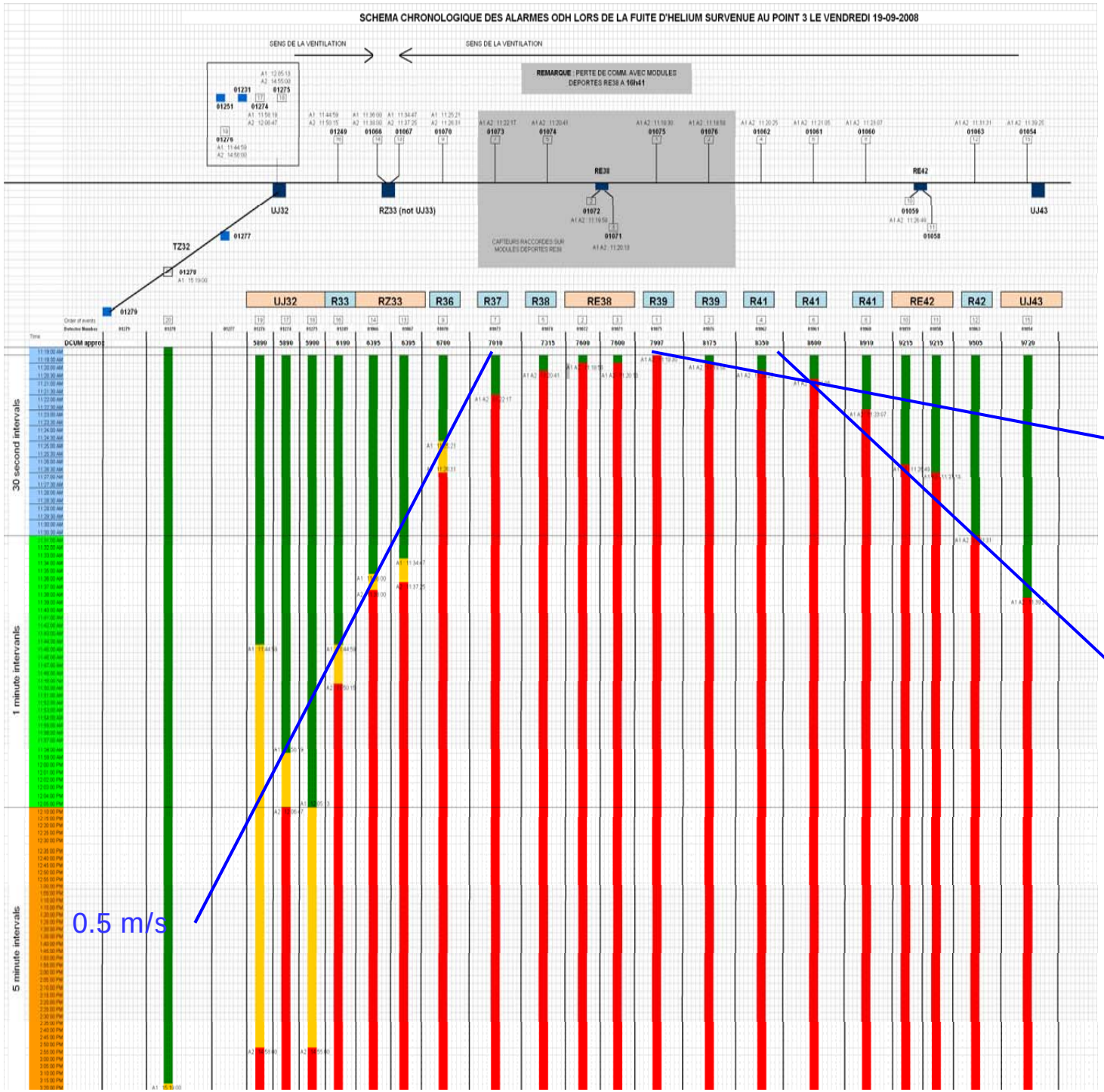
FE calculation in large displacement case (iterative geometry) gives 7 bar overpressure



Oxygen content [%] in tunnel (at ceiling)

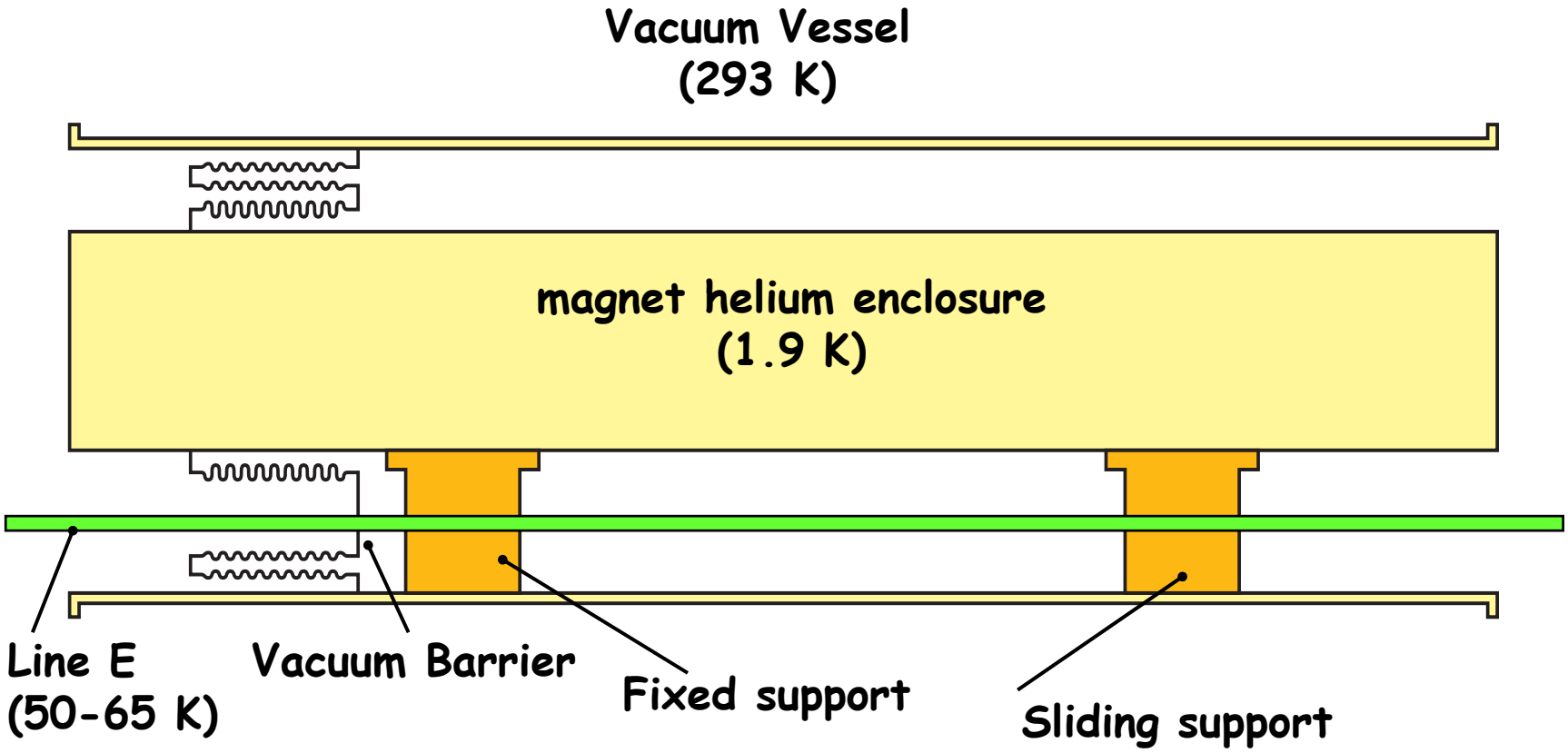


R. Nunes

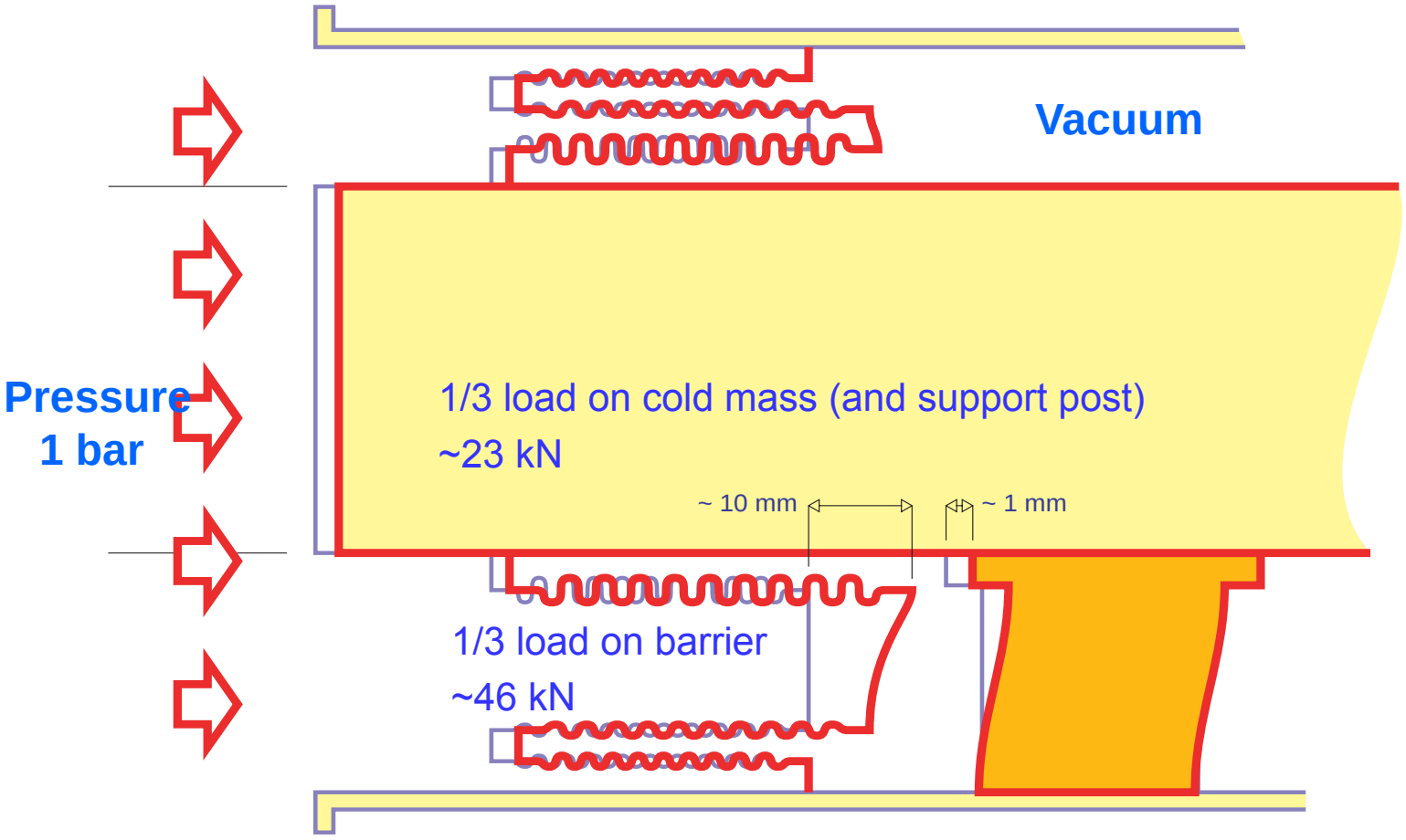

SCHEMA CHRONOLOGIQUE DES ALARMES ODH LORS DE LA FUITE D'HELIUM SURVENUE AU POINT 3 LE VENDREDI 19-09-2008
SENS DE LA VENTILATION
SENS DE LA VENTILATION
REMARQUE : PERTE DE COMM. AVEC MODULES DEPORTES RE38 A 16h41
UJ32
RZ33 (not UJ33)
RE38
RE42
UJ43
TZ32
UJ32 R33 RZ33 R36 R37 R38 RE38 R39 R39 R41 R41 R41 RE42 R42 UJ43
30 second intervals
1 minute intervals
5 minute intervals
0.5 m/s
7.3 m/s
1.5 m/s

R. Nunes

Simplified scheme of SSS with vacuum barrier



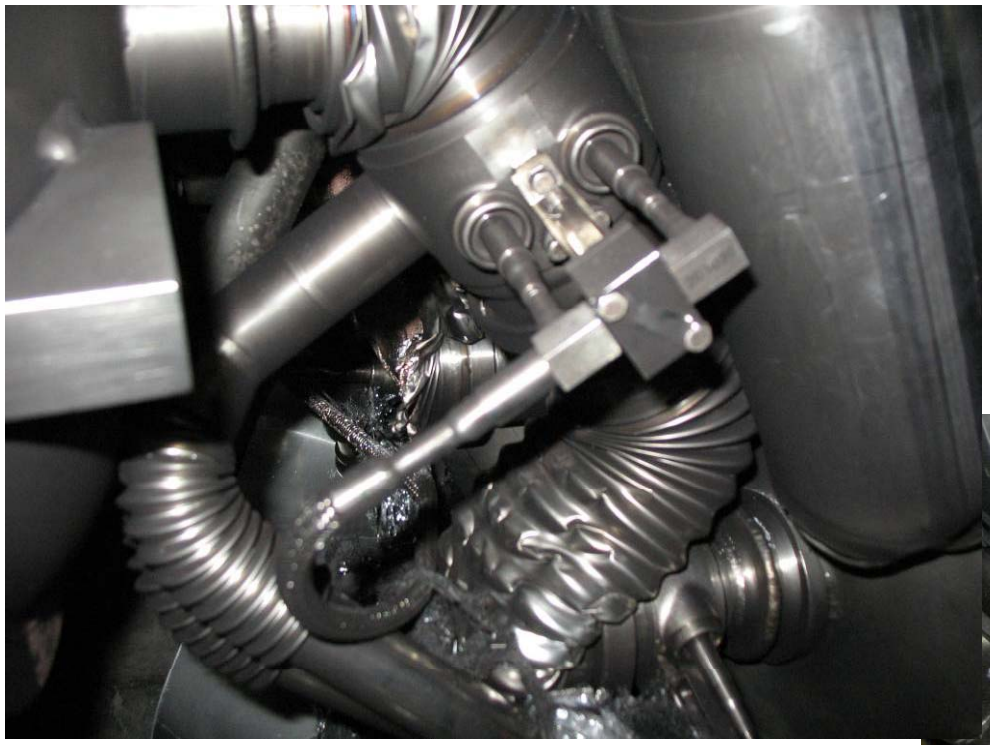
Pressure forces on SSS vacuum barrier



Collateral damage: magnet displacements

QQBI.27R3

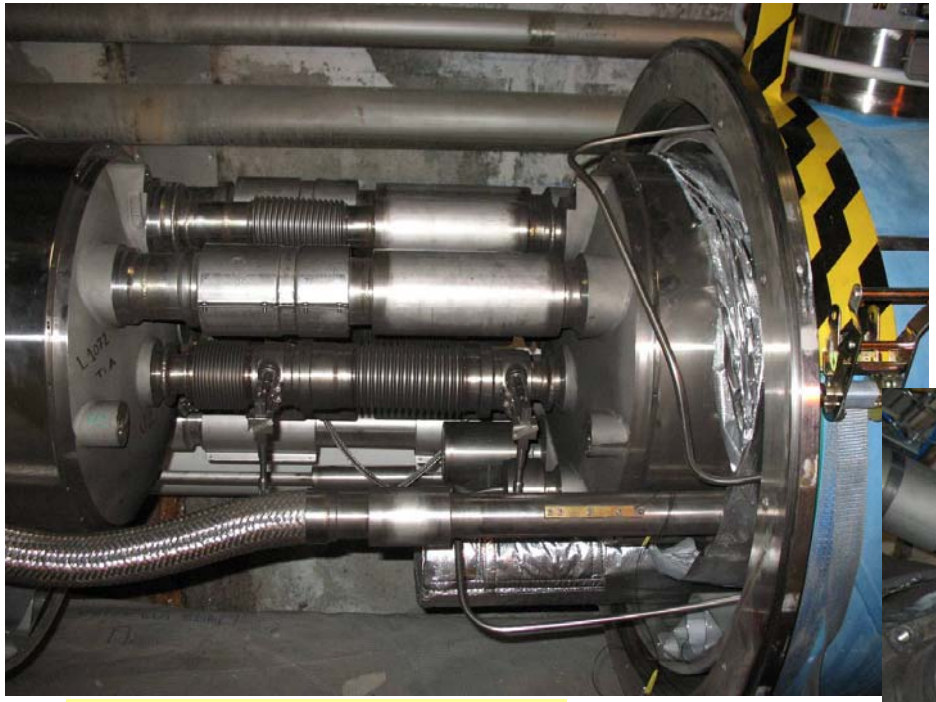
Collateral damage: magnet displacements



QQBI.27R3
V2 line

QQBI.27R3
N line

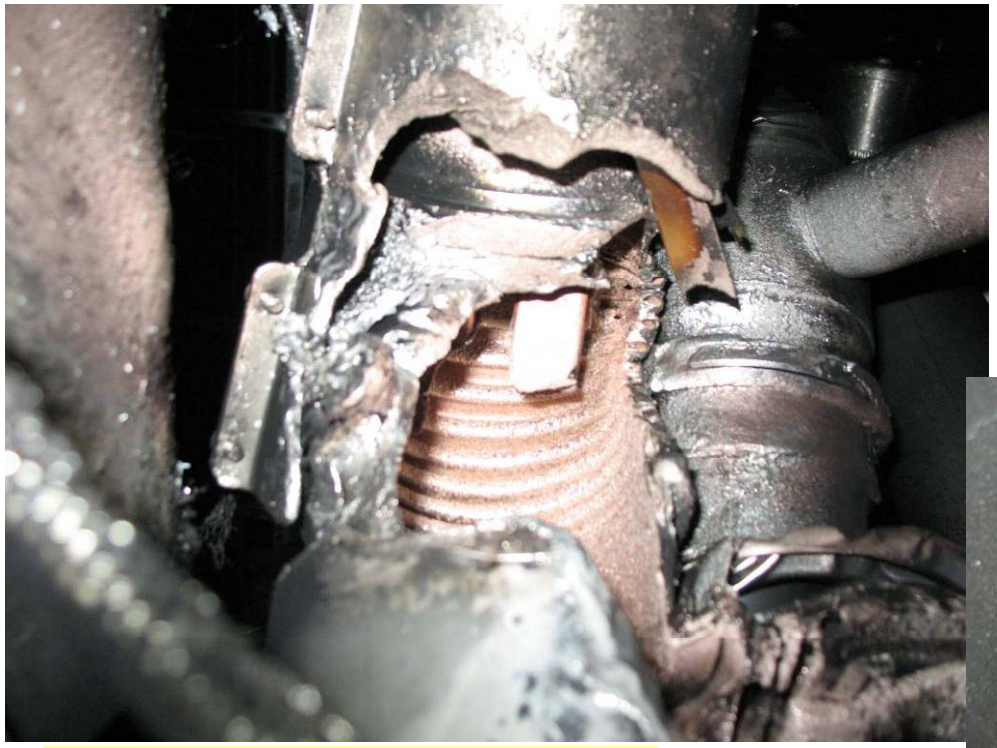
Collateral damage: magnet displacements



QBBI.B31R3
Extension by 73 mm

QBQI.27R3
Bellows torn open

Collateral damage: secondary arcs

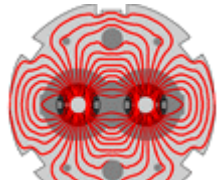


QQBI.27R3 Dipole bus line

QBBI.B31R3 M3 bus line

Collateral damage: ground supports

Longitudinal displacements in damaged area



Displacements status in sector 3-4 (From Q17R3 to Q33R3) : P3 side

Based on measurements by TS-SU, TS-MME and AT-MCS

	Q17	A18	B18	C18	Q18	A19	B19	C19	Q19	A20	B20	C20	Q20	A21	B21	C21	Q21
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cold mass	?	?	?	?	?	?	?	?	?	?	<5	<5	<5	<5	<5	<5	<5

	Q21	A22	B22	C22	Q22	A23	B23	C23	Q23	A24	B24	C24	Q24	A25	B25	C25	Q25
Cryostat	<2	<2	<2	<2	-7	<2	<2	<2	-187	<2	<2	<2	<2	<2	<2	<2	<2
Cold mass	<5	<5	<5	<5	-25	-67	-102	-144	<5	-190	-130	-60	<5	<5	<5	<5	<5

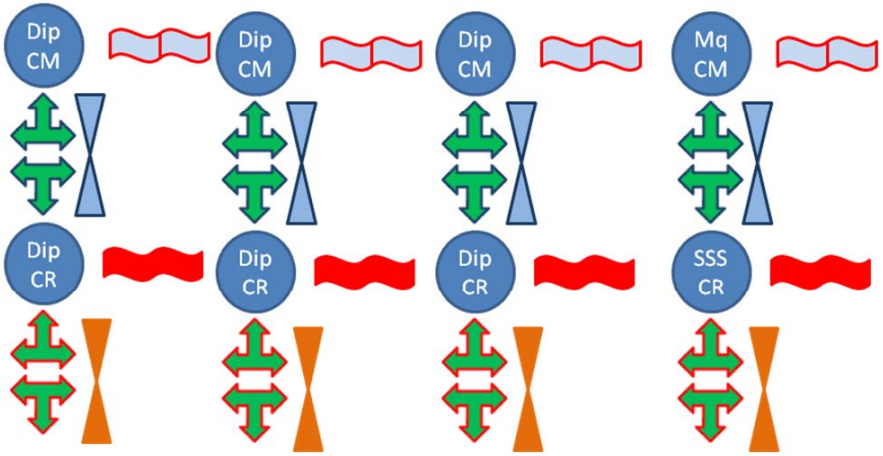
	Q25	A26	B26	C26	Q26	A27	B27	C27	Q27	A28	B28	C28	Q28	A29	B29	C29	Q29
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	474	-4	<2	<2	11	<2	<2	<2	<2
Cold mass	<5	<5	<5	<5	<5	57	114	150?	-45	230	189	144	92? Vert	50	35	<5	<5

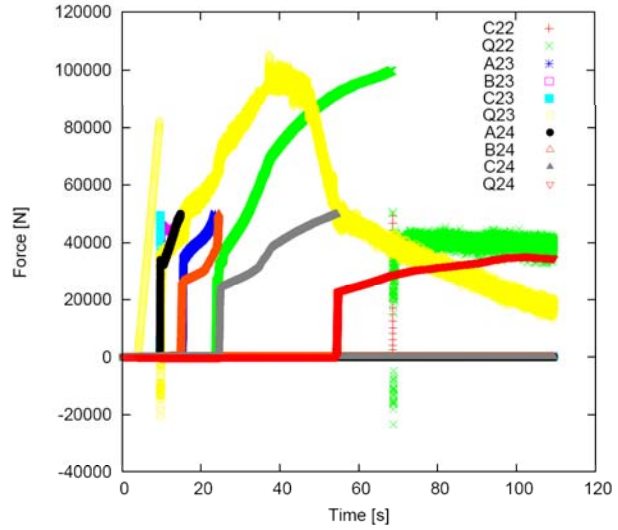
	Q29	A30	B30	C30	Q30	A31	B31	C31	Q31	A32	B32	C32	Q32	A33	B33	C33	Q33
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	188	<2	<2	<2	5	<2	<2	<2	<2
Cold mass	<5	<5	<5	<5	<5	19	77	148	<5	140	105	62	18	<5	<5	<5	?

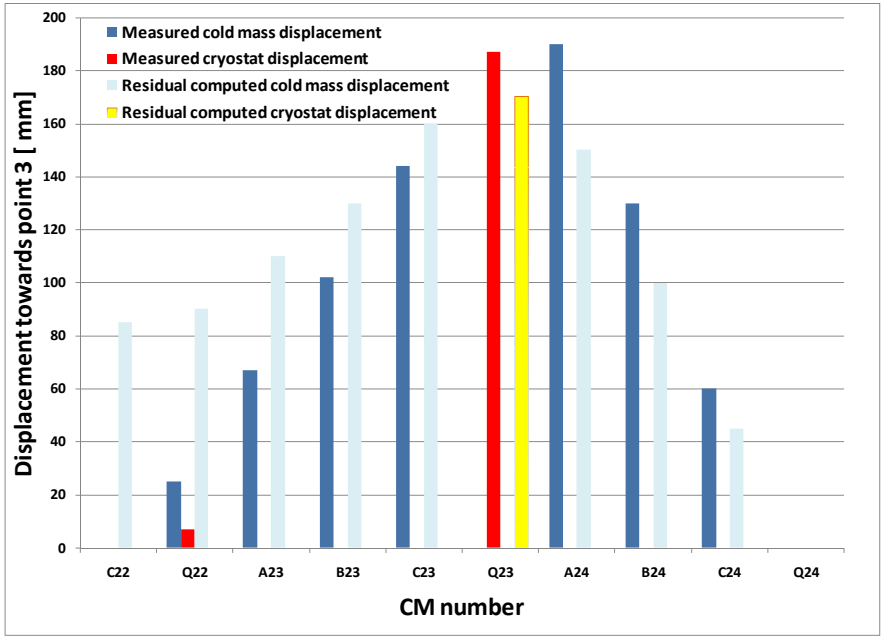
SSS with vacuum barrier
>0 Towards P4
[mm] Values are in mm
? Not measured yet
Cold mass displacement
Cryostat displacement
Open interconnection
Electrical interruptions
Dipole in short circuit
Electrically damaged IC
Buffer zones
Disconnected

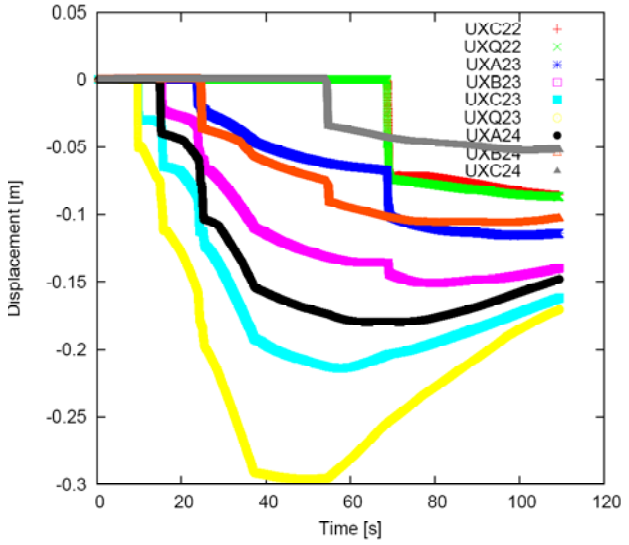
J.Ph. Tock

Lumped dynamic model of cryomagnet string



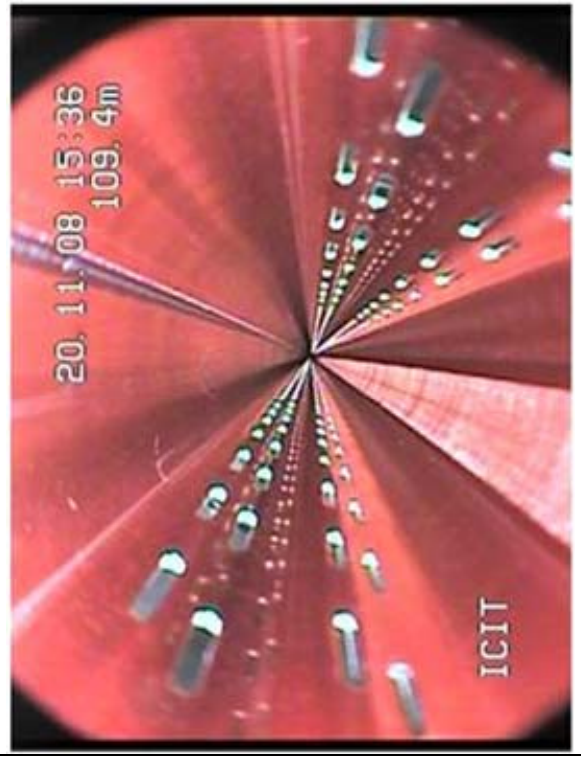
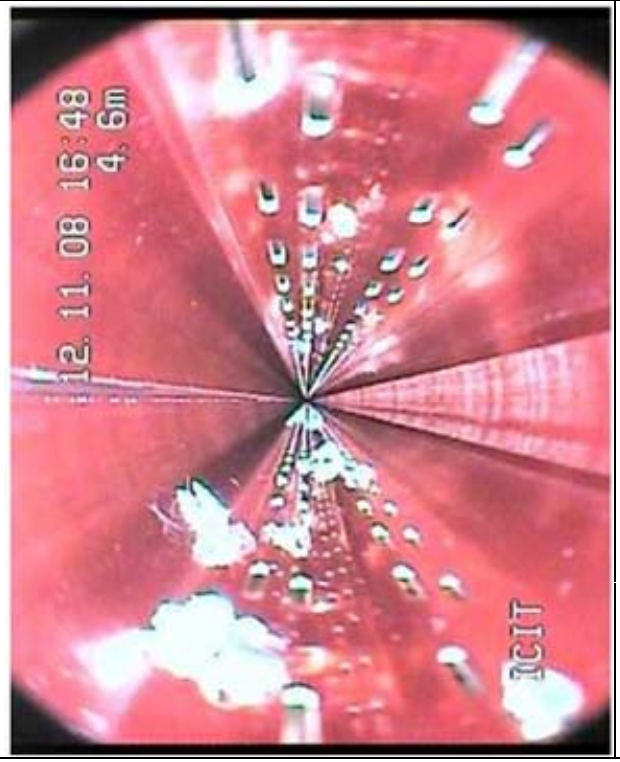
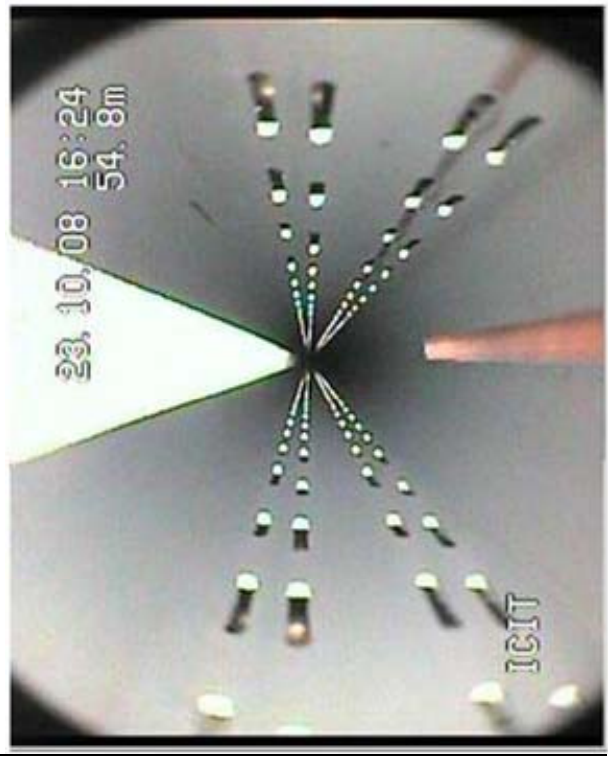






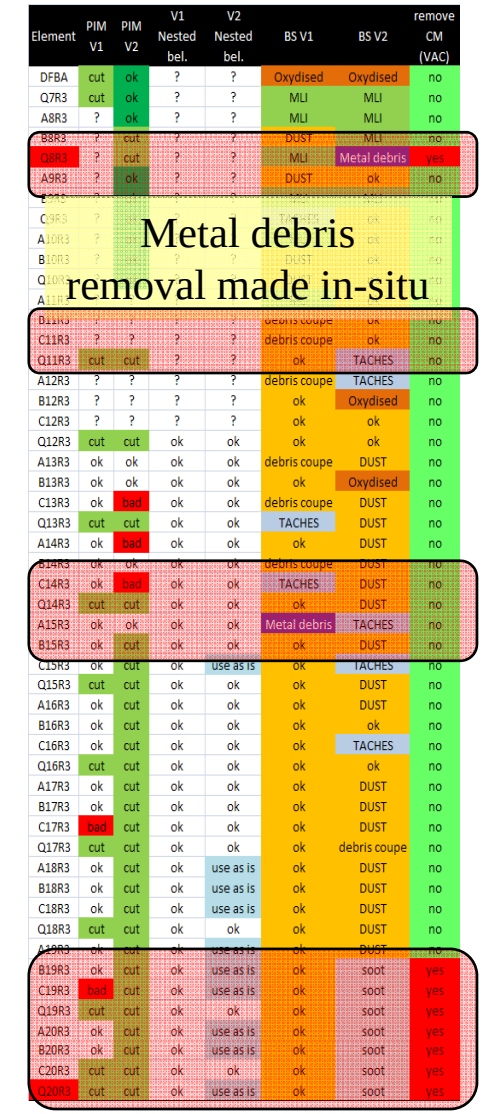
P. Fessia

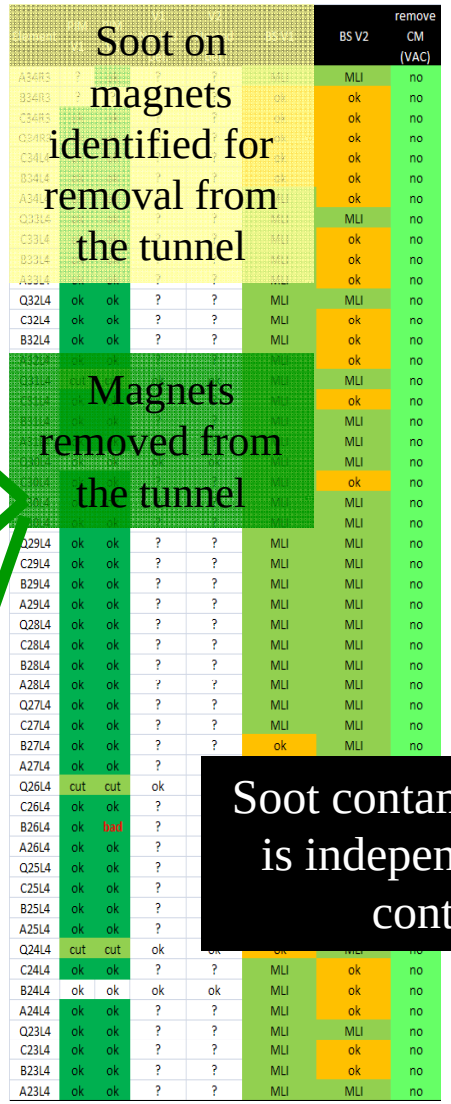
Beam vacuum contamination

Beam Screen (BS) : The red color is characteristic of a clean copper surface	BS with some contamination by super-isolation (MLI multi layer insulation)	BS with soot contamination. The grey color varies depending on the thickness of the soot, from grey to dark.
		

M. Jimenez

Beam vacuum contamination



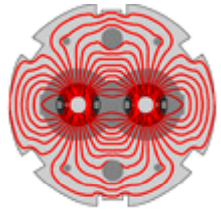


Soot contamination recovery is independent from MLI contamination

M. Jimenez

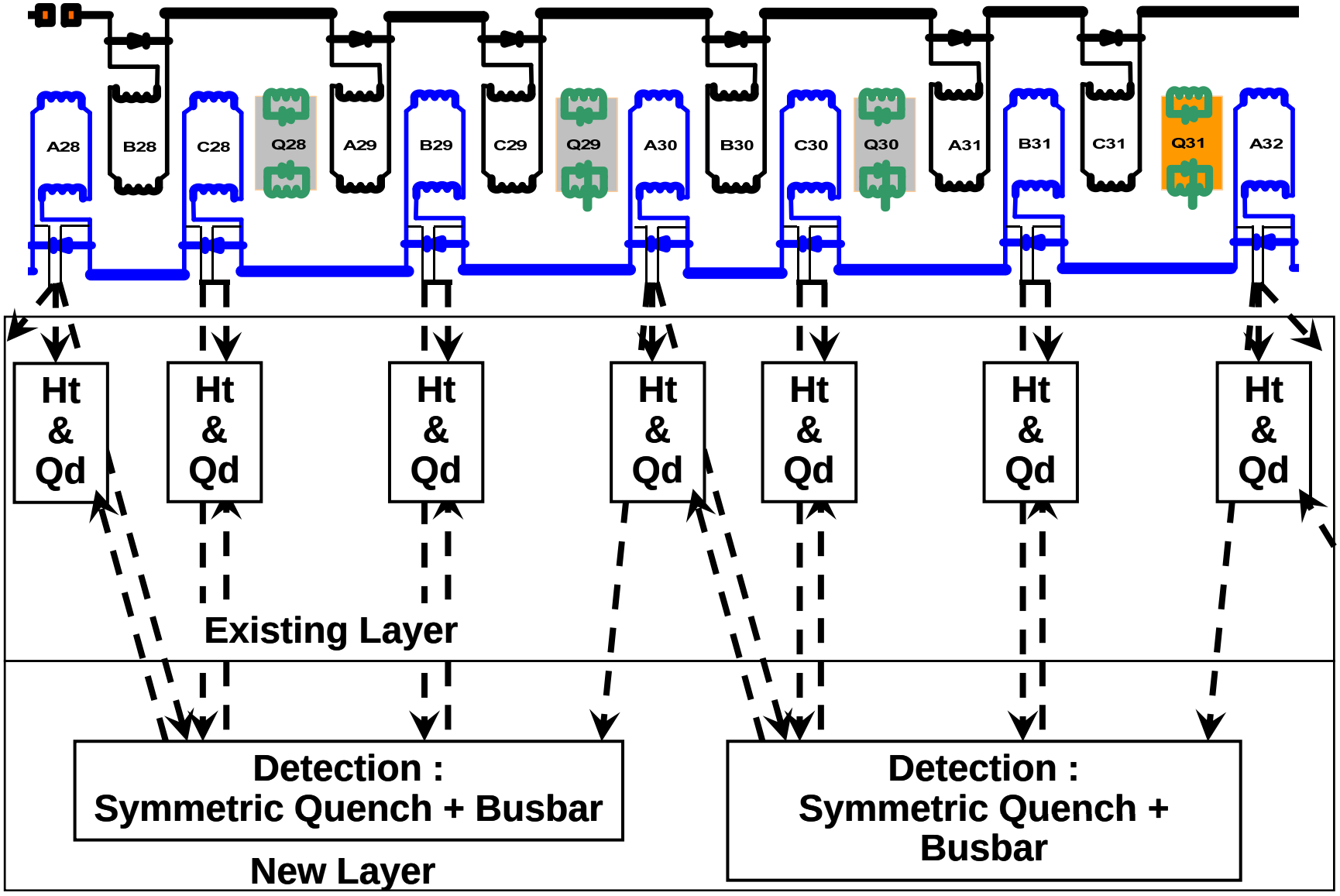
Recommendations

Prevention of initial fault



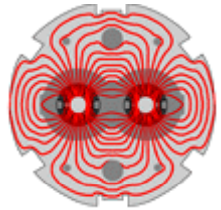
- Analyse thoroughly temperature evolution history of cold mass during past power tests to identify « doubtful » cells/subsectors/magnets
  - done in all sectors
- Perform electrical measurements with higher sensitivity (< 100 μV) on « doubtful » cells/subsectors powered at limited current
  - done in few locations (15-17R1)
- Track temperature evolution during further power tests, applying normalized ramp/flattop/deramp durations and normalized cryogenic configuration, filtered electrical measurements using quench recorder in « snapshot » mode
  - MB circuits: done on sectors 1-2, 5-6, 6-7, 7-8 and 8-1
  - MQ circuits: done on sectors 5-6, 6-7, 7-8 and 8-1
  - procedure to be established and included in power tests of sectors
- Modify quench detection system to include interconnects and bus bar splices, making use of available voltage taps to generate early warning & interlock signals
  - technical solution defined and implementation launched Dec 2008
- Consider option to measure currents in 13 kA circuits at both ends of sector and detect differentials
- Review possible improvement of mechanical clamping of interconnects and gradually implement whenever possible

Additional quench detection system



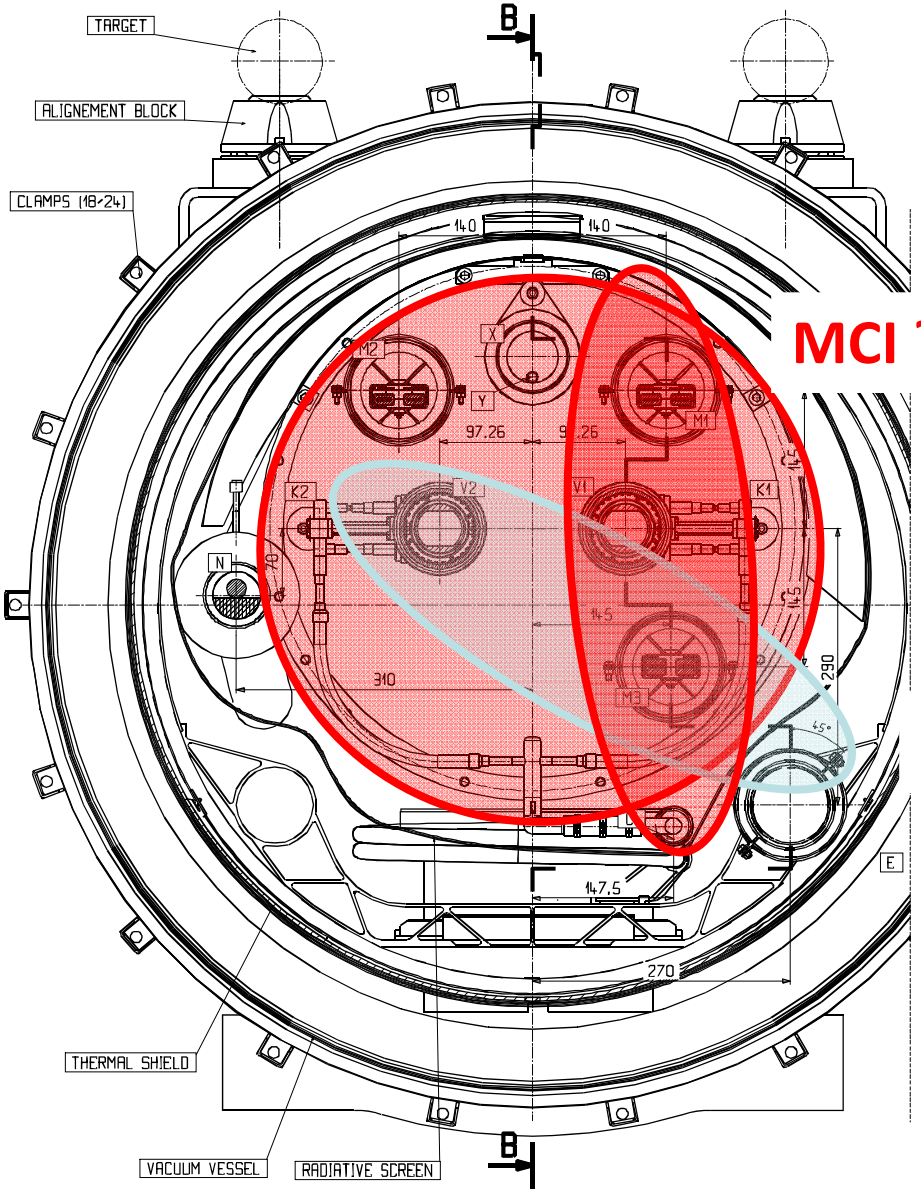
Recommendations

Mitigation of consequences



- Redefine MCI to cope with collateral effects of helium discharge from cold mass
  - done for electrical arcs
  - to be done for beam-induced damage
- Increase number/size of relief devices on cryostat vacuum vessels for coping with redefined MCI
  - equip SSS with increased-flow, spring-loaded devices on available DN100 and DN63 ports (can be implemented on cold SSS)
  - cut/weld DN 200 ports on cryodipoles and equip with spring-loaded devices (can only be implemented on warm cryodipoles)
  - implement compensatory measures for transitory phase on sectors not yet equipped with DN 200 relief devices
- Review number, size & position of pressure relief devices on beam vacuum system
- Review closure logic of beam vacuum sector valves
- Consider possibility of triggered opening of quench relief valves below set pressure
- Consider general firing of quench heaters pertaining to an electrical circuit as a measure to dissipate energy away from an electrical problem (e.g. arc) occurring in circuit
- Reinforce external anchoring at locations of vacuum barriers
  - will avoid displacement of vacuum vessels, but risk of additional damage to cold supports
- Reexamine personnel underground access rules when powering
  - including neighbouring underground spaces
- Review location of AUG in tunnel and protection from blast
- Review recorded signals, recording frequency and time stamping coherence among different systems

Revision of MCI due to electrical arc

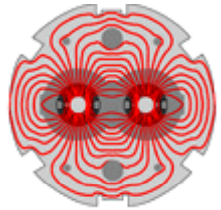


MCI ?

080919 incident

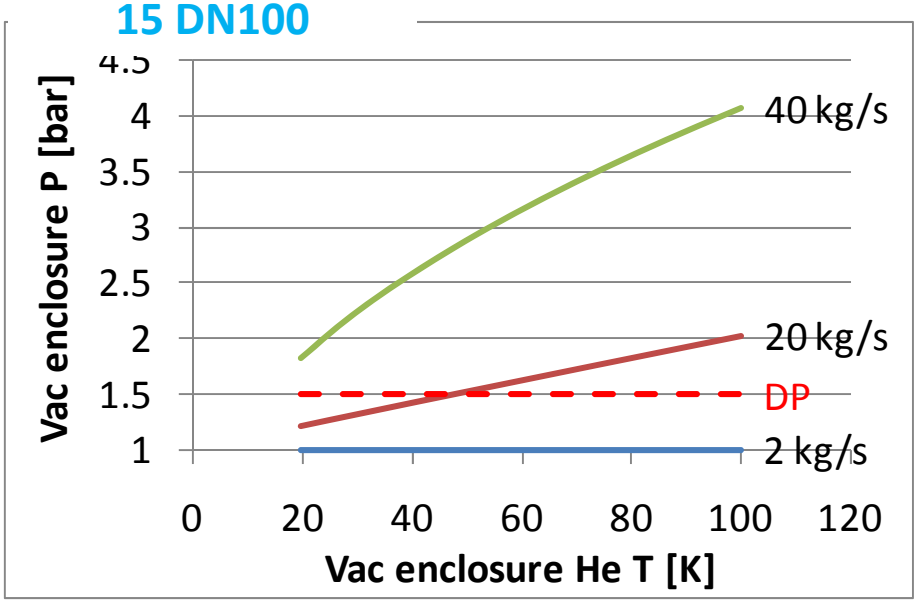
L. Tavian

Flow discharge characteristics of relief devices on insulation vacuum enclosure (per sub-sector)

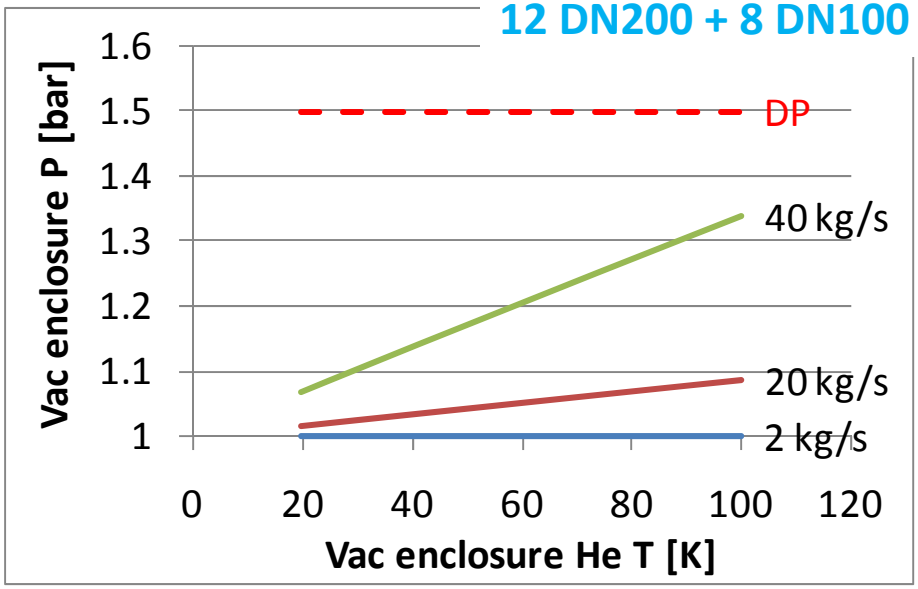


New configuration on cold sectors: 15 DN100

(DP: Design Pressure)

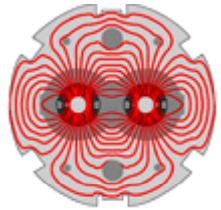


New configuration on warm sectors: 12 DN200 + 8 DN100



L. Tavian

Still to be found or understood



- Exact nature of initial fault
  - Primary evidence destroyed
  - Sample tests to reproduce interconnect with 200 nΩ resistance: only omission of soldering can account for such high resistance
  - Inter-aperture splice with 90 nΩ resistance on other magnet examined, confirming likelihood of defect
- Long-distance propagation mechanism of quenches to other magnets in sector
  - Electrical discharge of QPS in helium cloud? negative test!
  - In-rush of warm helium in beam vacuum pipes? simulations unconclusive!
  - Second sound in He II? hydraulic restrictions!
- Comprehensive extent of damage
  - to cold mass of magnets
  - to beam vacuum systems