CERN MAC
Introduction

26th October 2009

Steve Myers

Topics

- CERN MAC mandate
- CERN Accelerator Complex

LHC Status

- The 19th September “incident”
- Outcome of Chamonix workshop (Feb 2009)
- February through April 2009 (repair and consolidation)
- May 2009 “Copper Stabilizers”
- The decision on the energy at start up (August 2009)
- New Input since August Decision
- Running with Beam 2009 – 2010
- Planning for the future; operational consolidation
- Recent injection tests (finished yesterday)

CMAC Mandate

- Now that the LHC construction is completed, the CERN directorate has decided to form a CERN Machine Advisory Committee (MAC).
- The mandate of the MAC is to advise the CERN Directorate on all matters related to CERN accelerators. Special emphasis will be put on critical reviews of the operational efficiency of the LHC and its upgrades as well as the LHC injectors.

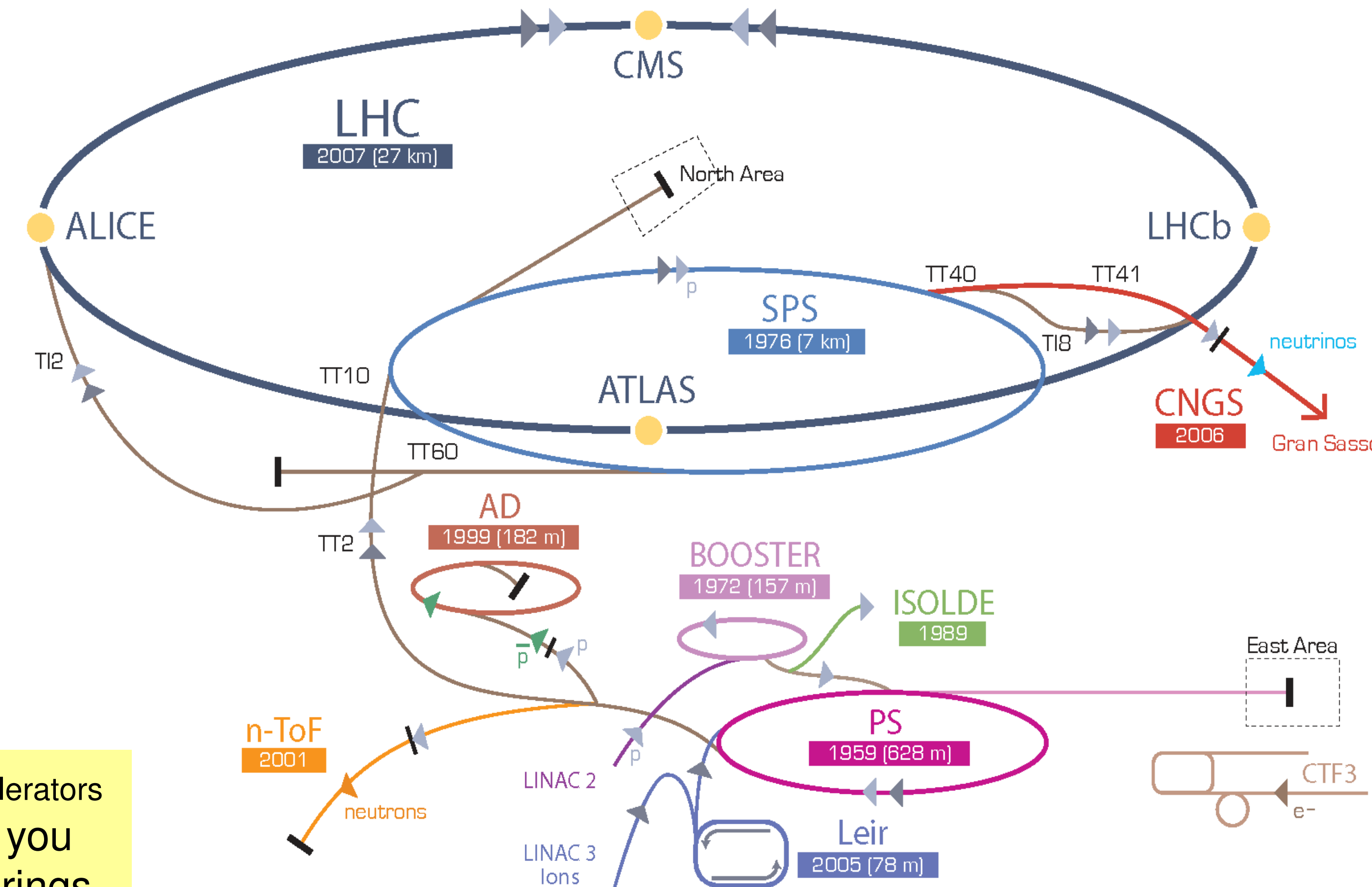
Membership

- The MAC will have a core membership consisting of eight specialists in high energy colliders and accelerators, and will, depending on which accelerator or experimental facility is to be reviewed, appoint additional ad hoc members who have special related knowledge in the required area….(We need to define a more detailed “modus operandi” possibly during this meeting)
- The duration of the mandate of core members will be three years with a onetime renewal possibility.
  - Need to avoid total renewal of the committee every 6 years
- The chair of the CERN MAC will be appointed as an ex-officio member of the CERN Scientific Policy Committee.

Composition of the Committee:

- Biscari, Caterina… INFN
- Brinkmann, Reinhard…DESY
- Fischer, Wolfram … BNL
- Oide, Katsunobu… KEK
- Roser, Thomas (chair)… BNL
- Seeman, John …SLAC
- Shiltsev, Vladimir… FNAL
- Zhang, Chuang…IHEP, Beijing

CERN Accelerator Complex



Total of 10 accelerators at CERN, 13 if you consider the 4 rings of the booster

▸ p (proton) ▸ ion ▸ neutrons ▸ p̄ (antiproton) proton/antiproton conversion ▸ neutrinos ▸ electron

LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

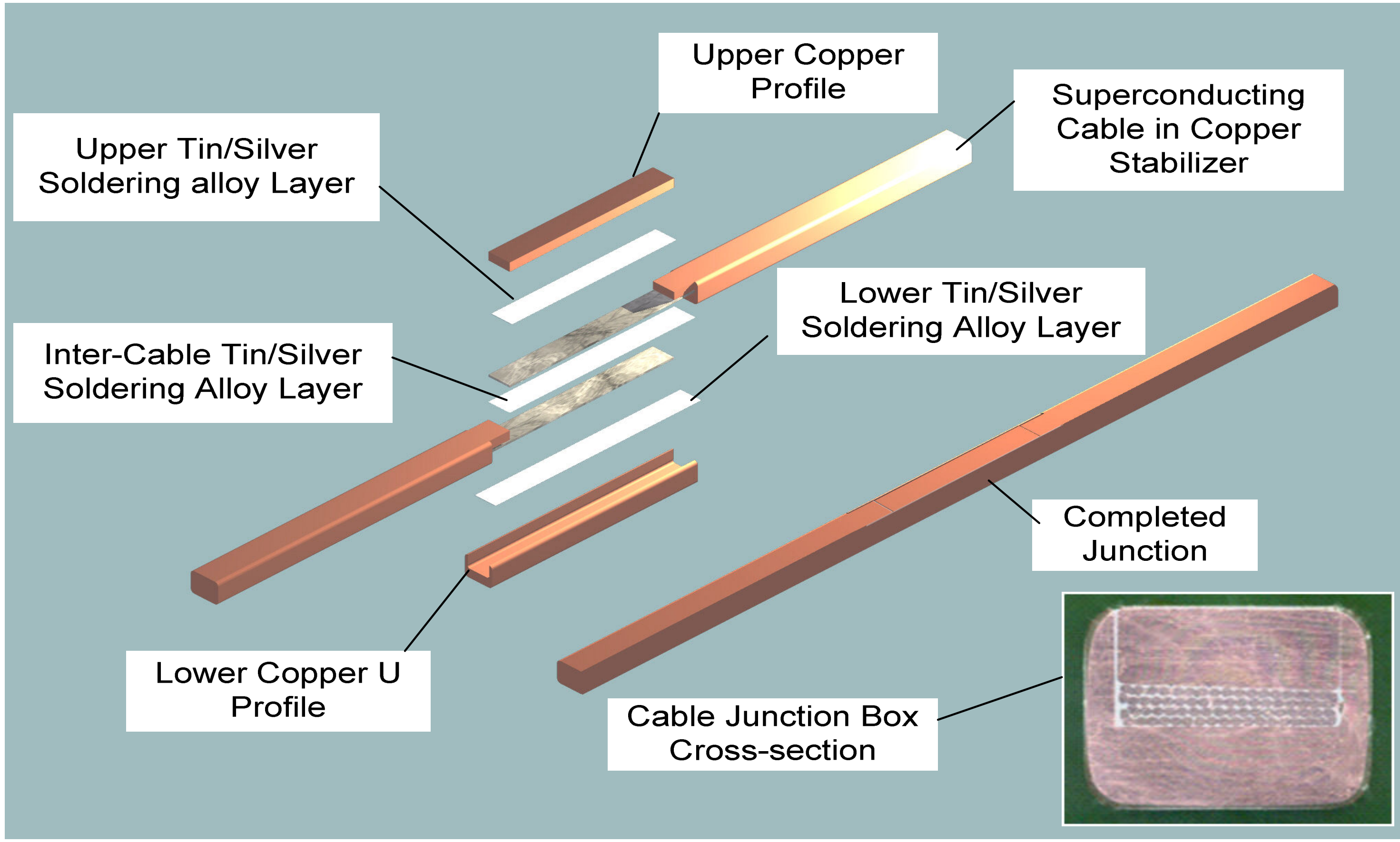
AD Antiproton Decelerator CTF3 Clic Test Facility CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice

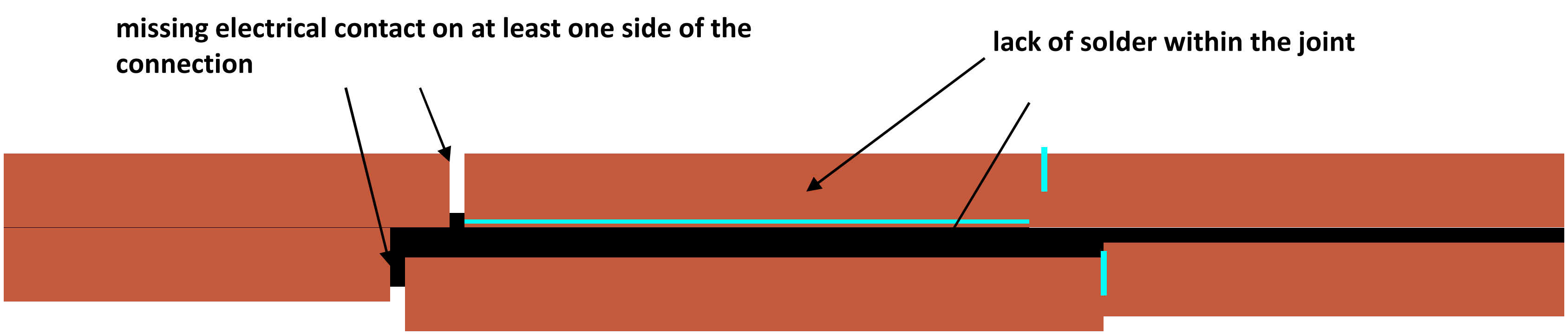
LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight

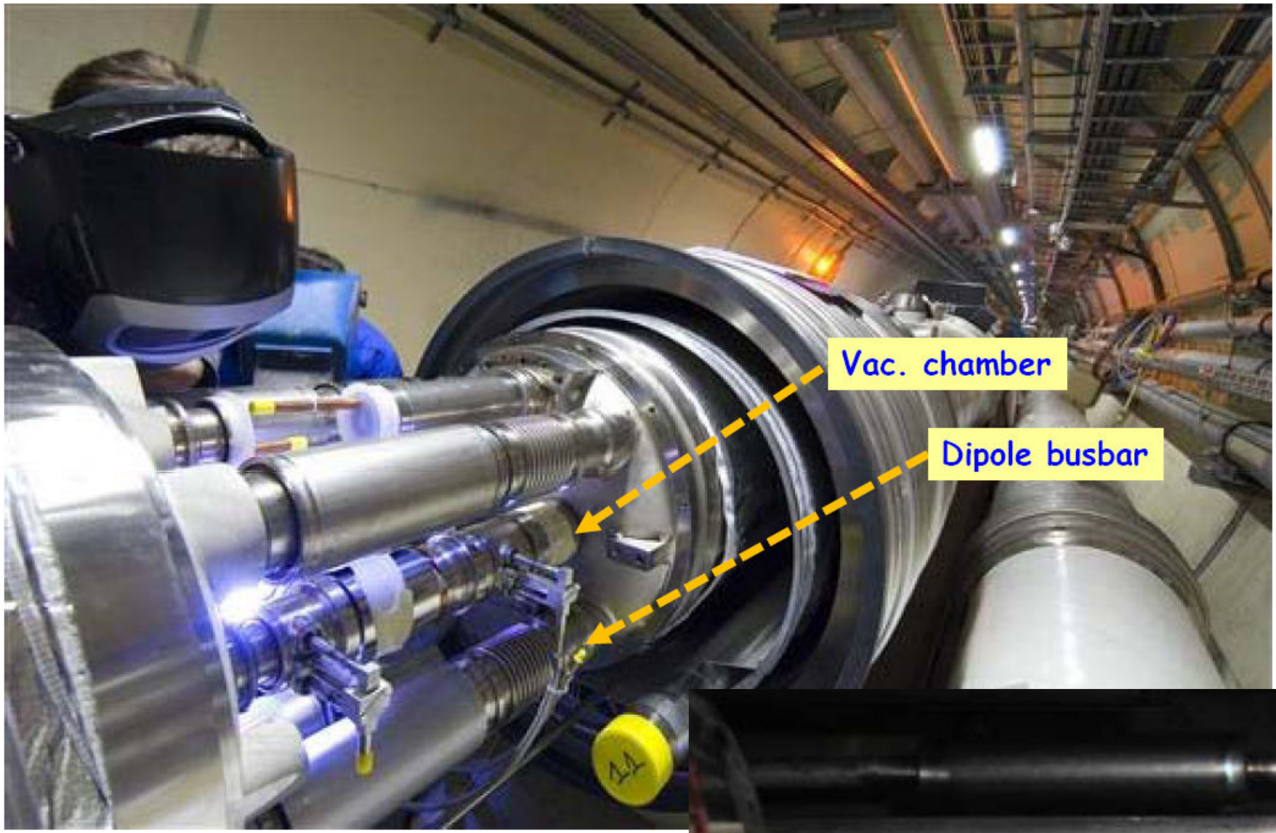
LHC Status

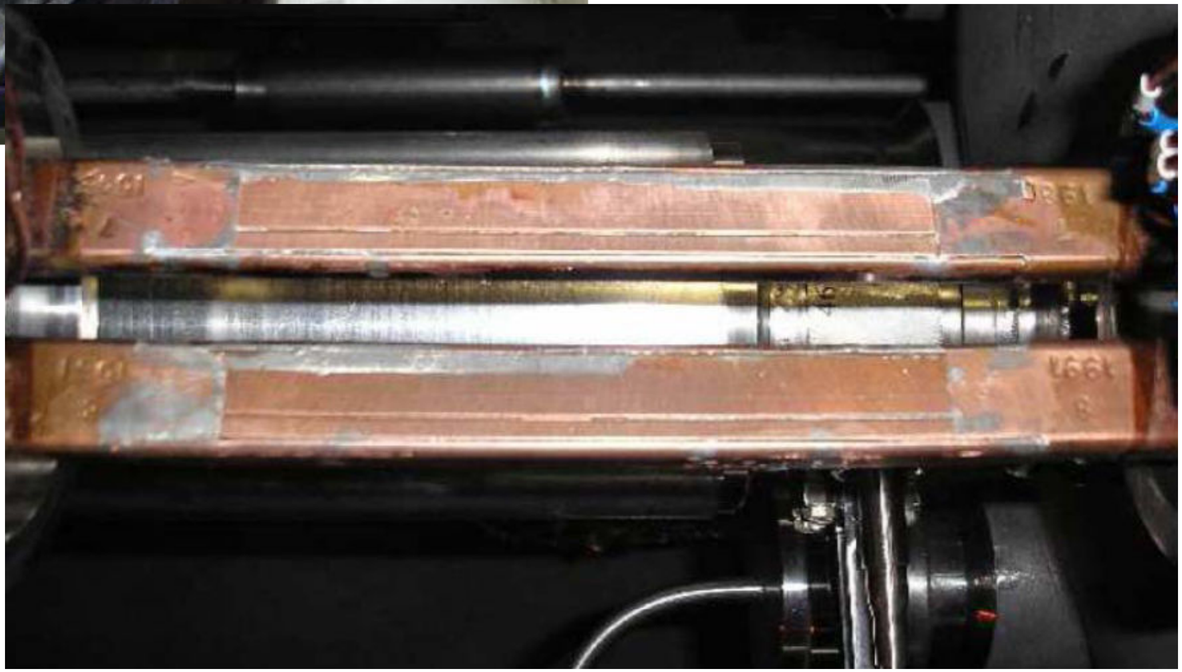
The Sector 3-4 incident

fault tree and corrective measures


Upper Copper Profile
Superconducting Cable in Copper Stabilizer
Upper Tin/Silver Soldering alloy Layer
Lower Tin/Silver Soldering Alloy Layer
Inter-Cable Tin/Silver Soldering Alloy Layer
Completed Junction
Lower Copper U Profile
Cable Junction Box Cross-section

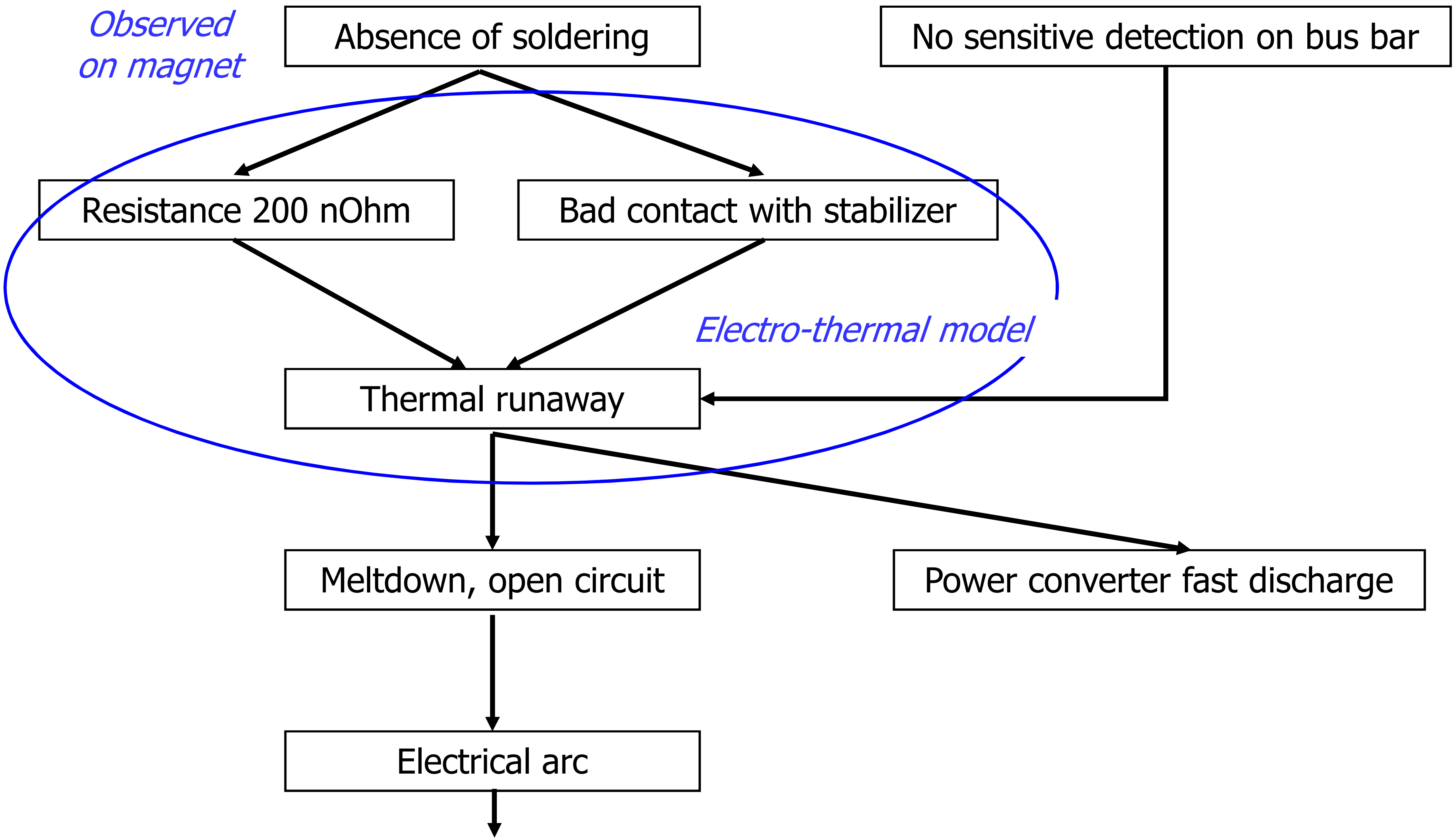

missing electrical contact on at least one side of the connection
lack of solder within the joint


Vac. chamber
Dipole busbar

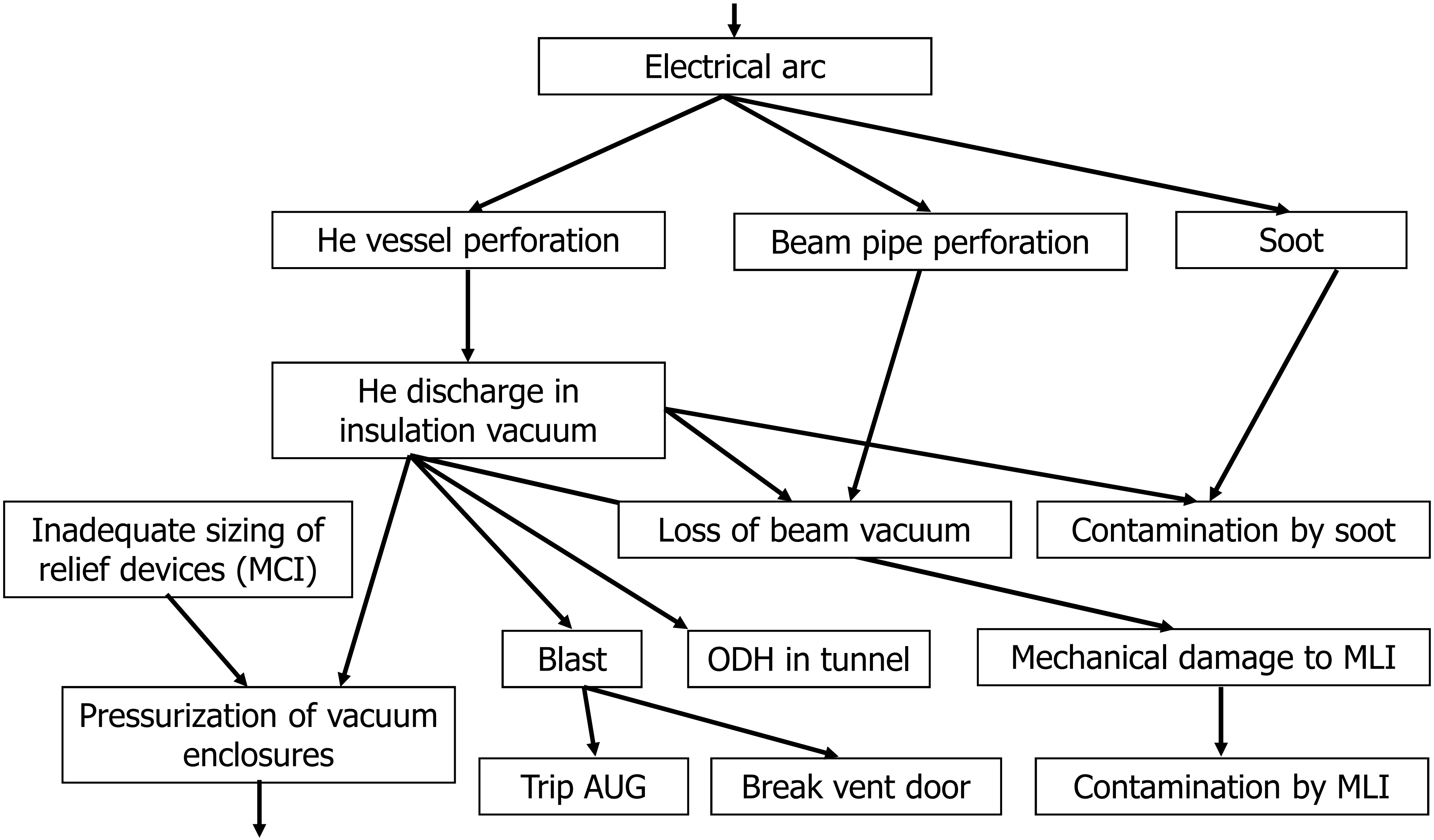


Internal fact finding group (P.Lebrun)

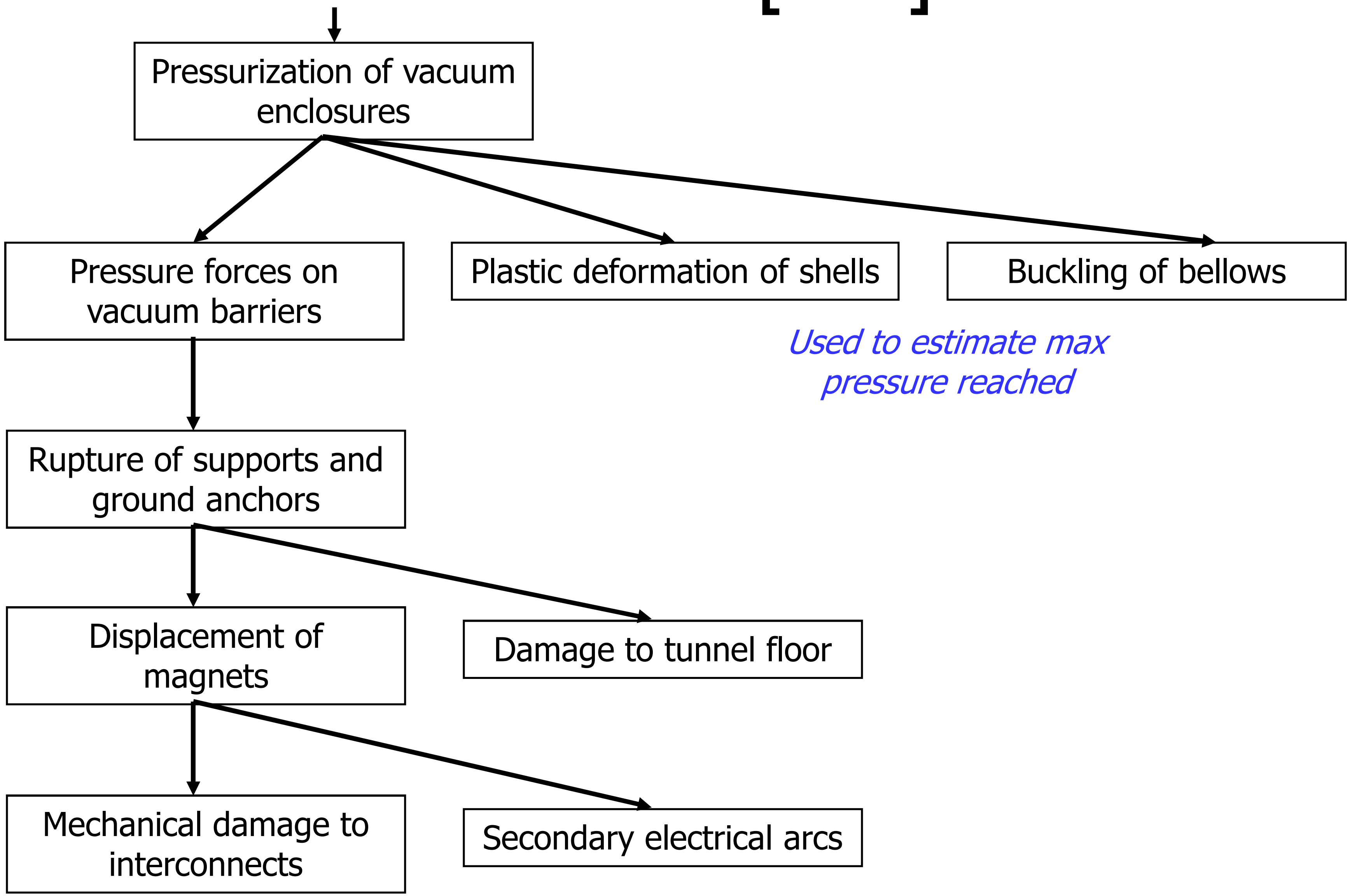
Fault tree [1/3]



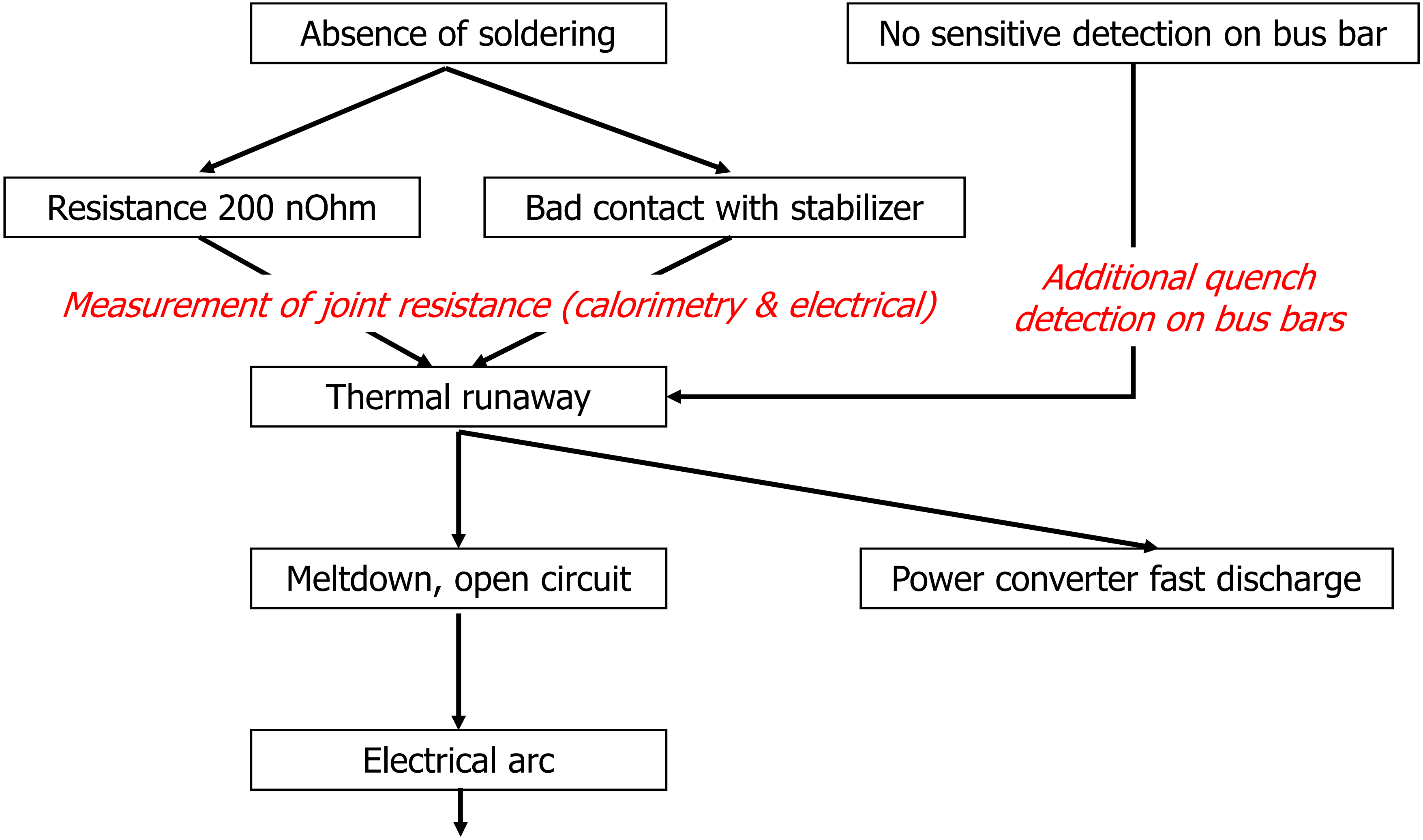
Fault tree [2/3]



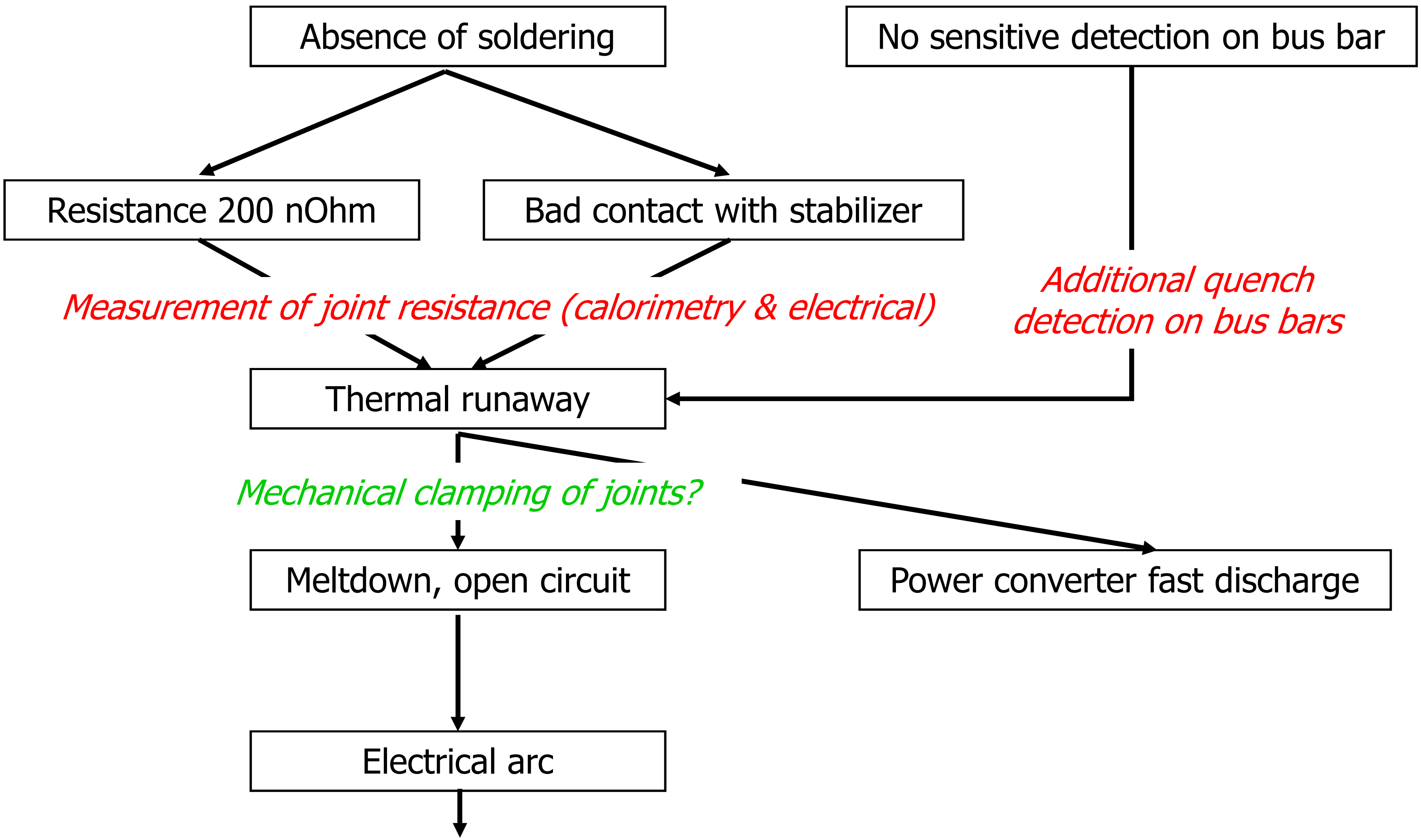
Fault tree [3/3]



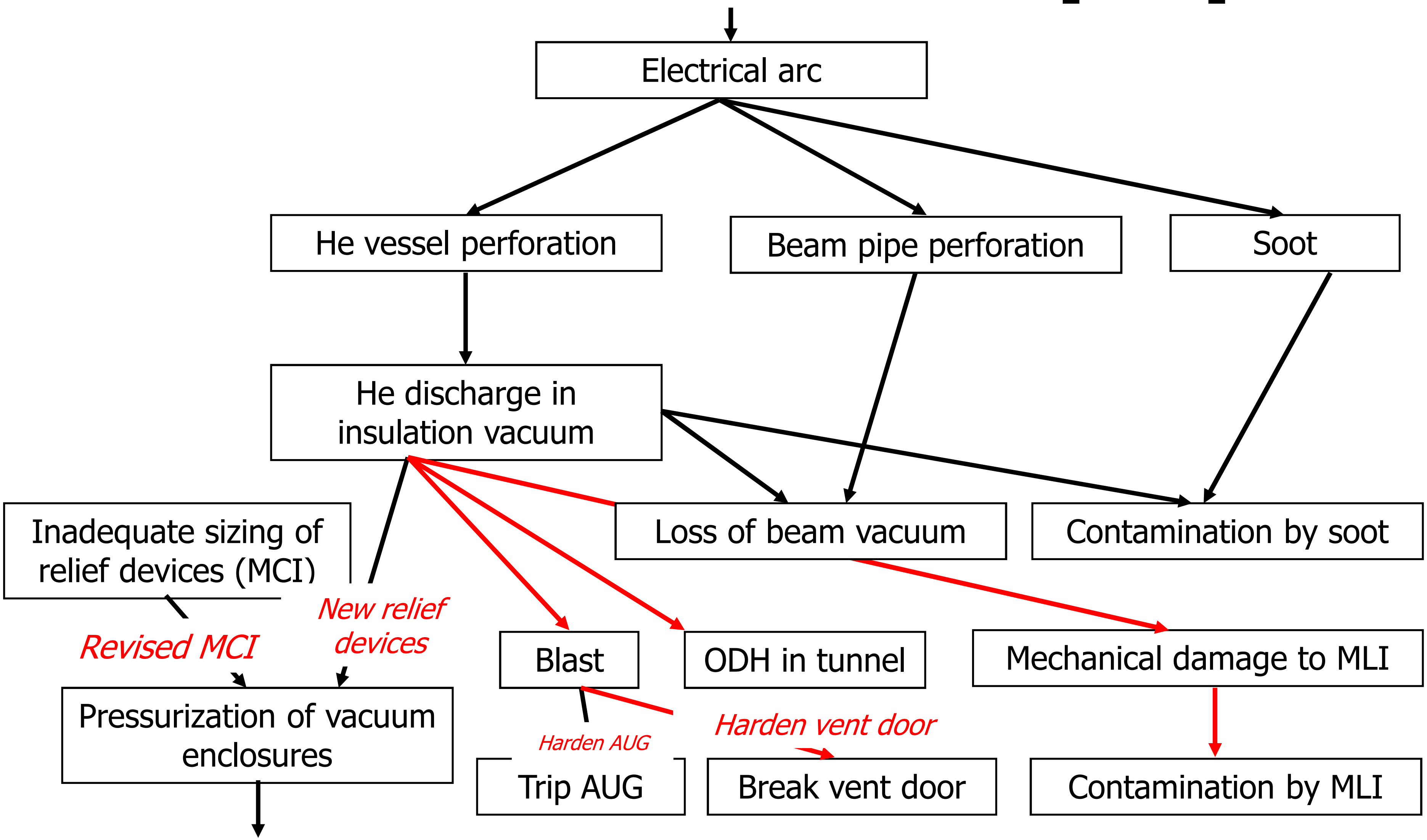
Corrective measures [1/3]



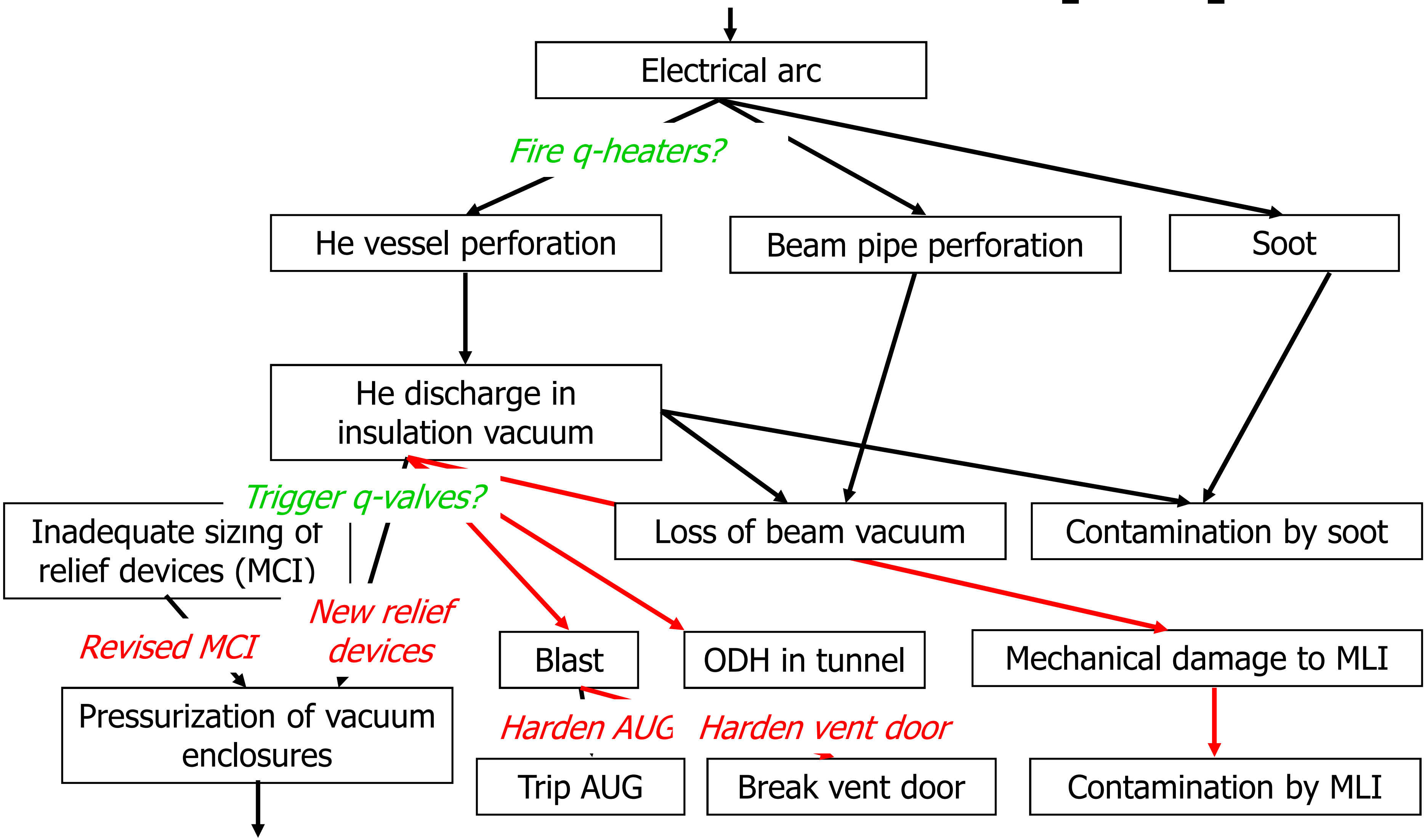
Corrective measures [1/3]



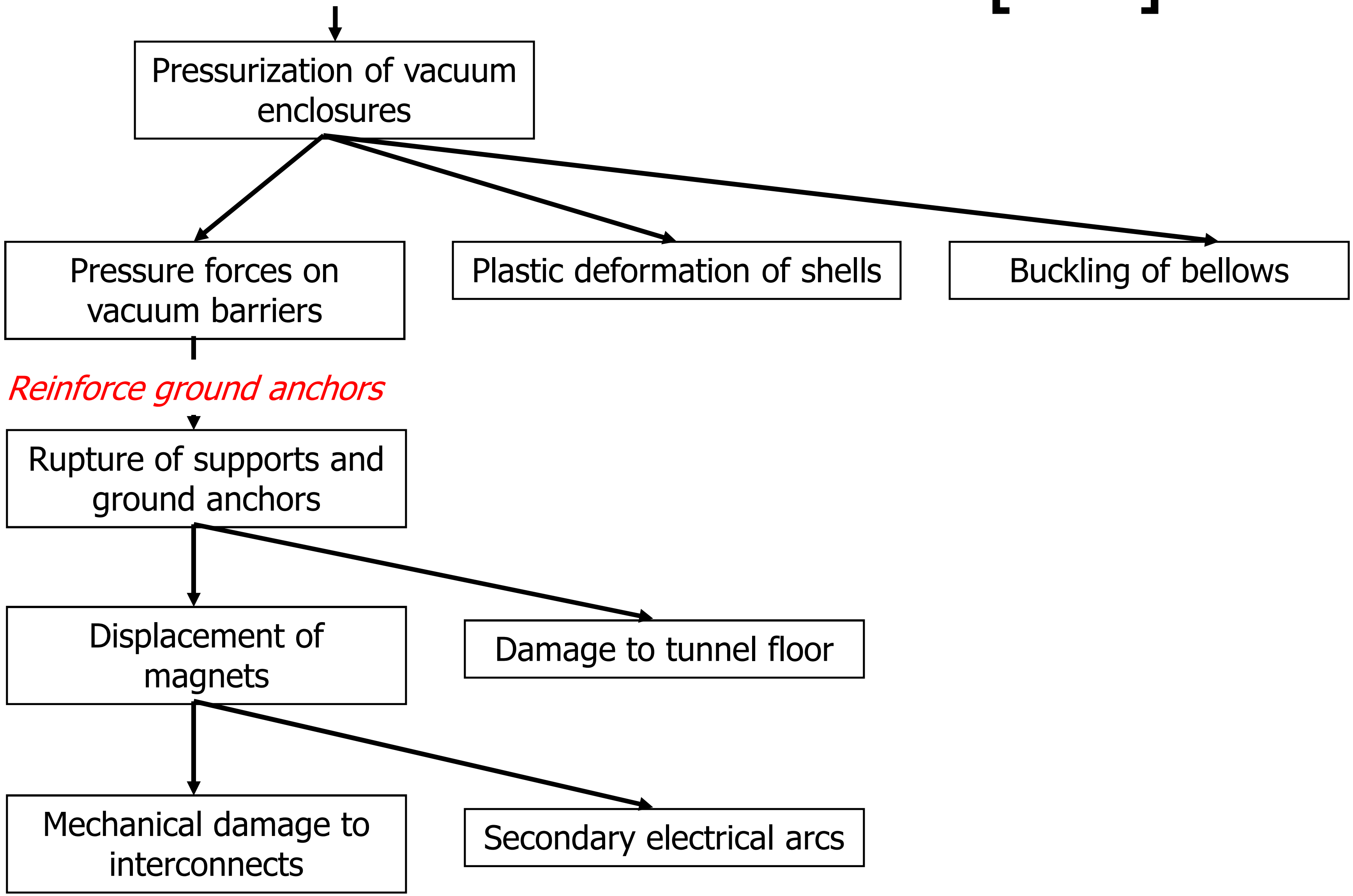
Corrective measures [2/3]



Corrective measures [2/3]



Corrective measures [3/3]



Early 2009

- Chamonix 2009
- Publication of fact finding report on accident
- External Review on LHC Risk
- External Review on the Quench Protection System
- Internal/External review on personnel safety underground
- Setting up many collaborations inside and outside CERN to help get LHC back in shape

Decisions for Chamonix

- Operating LHC through winter months?
- PRV scenarios?
- New QPS?
- Maximum beam energy?
- Physics running conditions?
- LHC schedule?

Physics Running Time

With Strictly No running of the machines in the winter months

– Present baseline schedule

- schedule allows very limited physics in 2009/2010 (24 weeks)
- Any slip of >1 month in the S34 repair will delay first LHC physics till August/September 2010!!
- Repair schedule has no contingency

Year	2009											2010											
Month	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Baseline	Shutdown								SU	PH		Shutdown (Relief V)						SU	PH				SH
	24 weeks physics possible																						

- **Must** have the possibility of running during winter months

Schedule with running in winter months

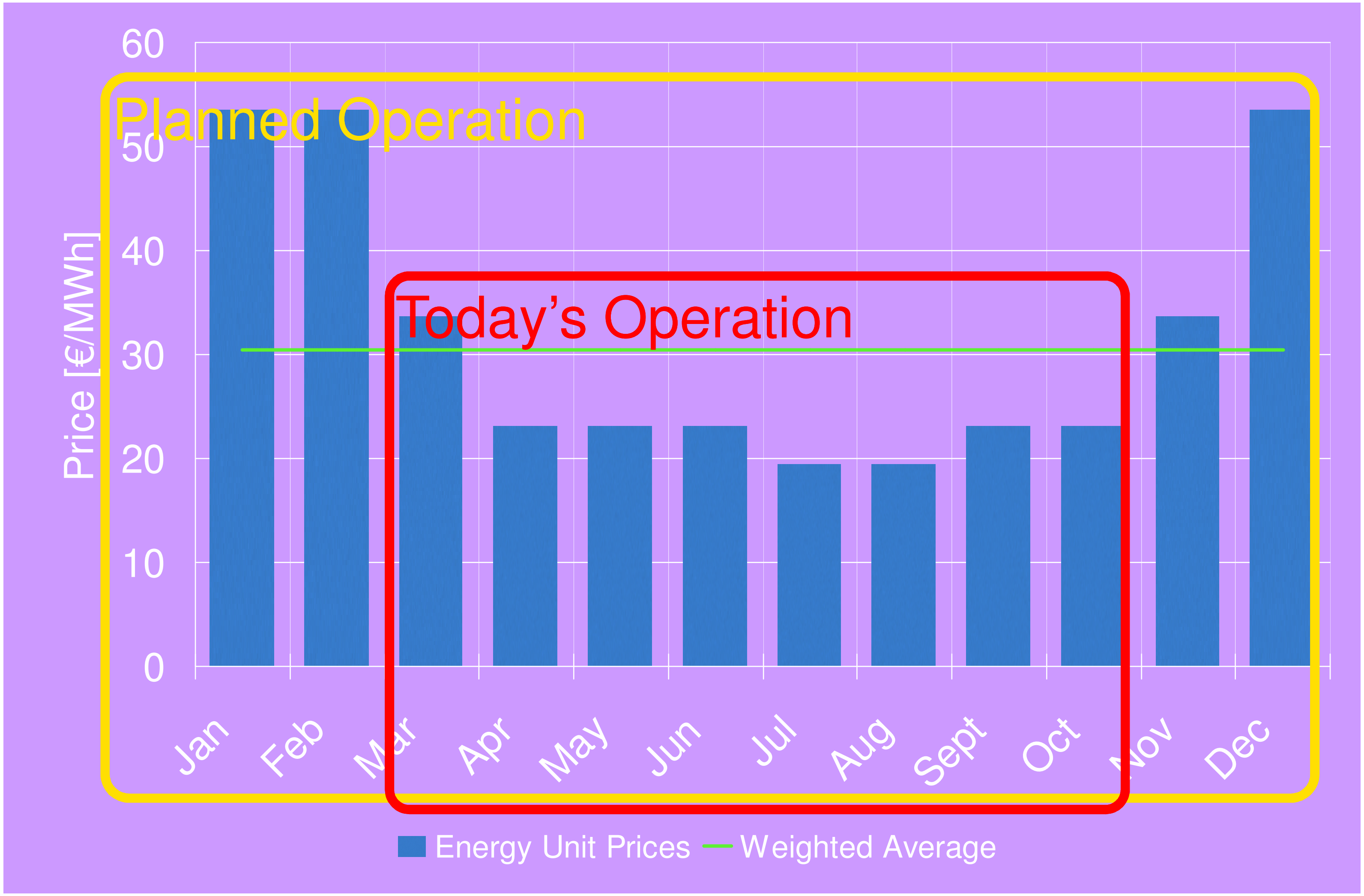
- Gains 20 weeks of LHC physics (independent of "slip")

Year	2009											2010														
Month	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Baseline	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH		SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	SH	SH	SH	SH
	24 weeks physics possible																									
Base '	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH	SH
	44 weeks physics possible																									
Delay (4W)	SH	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH
Delay (8W)	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH

Gain 20 weeks of physics in 2010 by running during winter months

HIGH price Electricity

Today's cheapest applicable EDF Tariff



Repair Scenarios

- Enhanced Quench Protection (Detection)
  - Busbar Detection (Protection)
  - "Symmetric" quench protection
  - QPS redundancy (UPS-QPS)

The FULL Quench System must be operational for beam collisions in 2009-2010 (unanimously agreed)

Update →

DN200 Pressure Relief Valves in Arcs

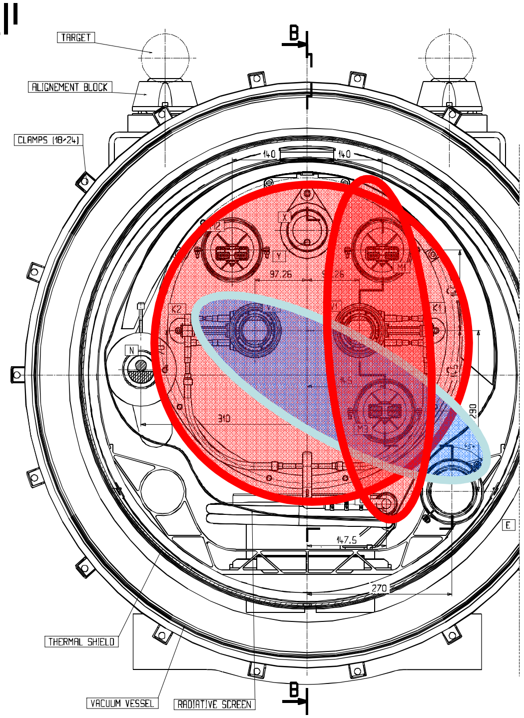
A: install 4 sectors (09-10) + 4 sectors (10-11)
+ first physics sooner: detectors debugging.. earlier warning
+ first beam sooner: ramp, squeeze, .. Sooner... earlier warning
+ focuses attention of repair teams

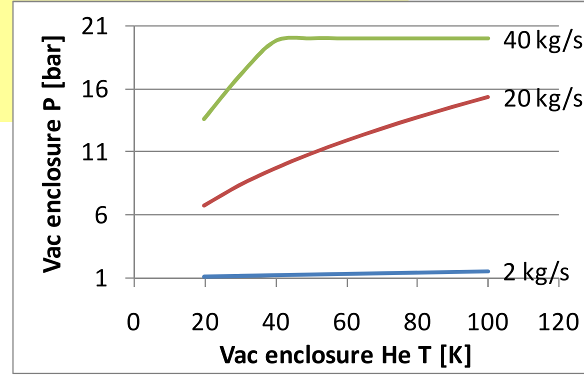
B: Installation 8 sectors (09-10)
+ reduced amount of collateral damage in event of a splice problem in 2010
+ reduced additional electricity bill
+ reduced overall shutdown time
+ reduced ALARA problems (2nd order)

Immediately after Chamonix the management decided on scenario A

MCI

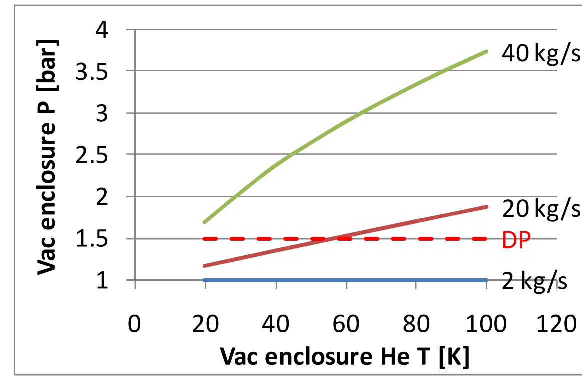
- It was decided to examine the all-out worst case risk impact. This “Maximum Conceivable Incident” (MCI) was identified as rupture of all enclosures connected to the magnets. The probability that this MCI would occur in the lifetime of the LHC has not been evaluated, but most specialist believe the probability to be approaching zero. The new QPS system would have protected the LHC last September and will protect in all imaginable similar failure modes.
- To mitigate against the collateral damage to the interconnects and the super-insulation under the MCI conditions, one should install (200mm diameter) additional relief valves on all dipole magnets.



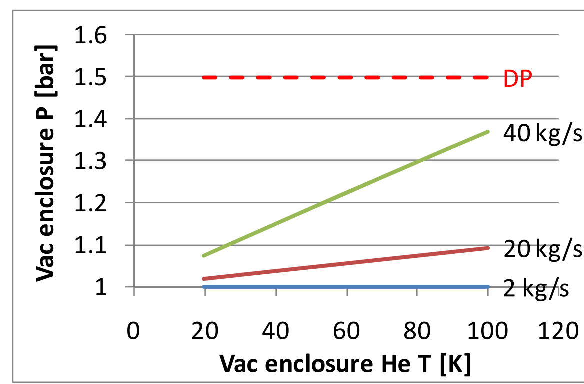


September 19

Add SSS valves



Add SSS valves +DN200



Maximum Energy Level for Operation

- Dipole field which can be reached
  - Time needed, reliability, and efficiency
- Risks associated with operating at field
  - sc cable splices stability (thermal runaway…)
  - Detection of poor sc cable splices
  - New effects of beams (?)
- Operational efficiency of other systems
  - Cryo recovery time etc

Dipole quenches during HWC

Sector	1st training quench [A]	I_max [A]	# training quenches	Starting in:		
				# ALS	# ANS	# NOE
1-2	-	9310	0	0	0	0
2-3	-	9310	0	0	0	0
3-4	-	8715 (bus)	0	0	0	0
4-5	9789	10274	3	0	0	3
5-6	10004	11173	27	0	1	26
6-7	-	9310	0	0	0	0
7-8	8965	9310	1	0	1	0
8-1	-	9310	0	0	0	0

Excluding S34, all sectors reached 8965 A (5.3TeV) without a quench
Excluding S34, all sectors reached 9310 A (5.5TeV) with 1 quench

A. Verweij,

Beam Conditions for Physics

- **Conclusion 5TeV/beam for Physics**
- Machine Protection will be Tested with beam (at 0.5TeV energy levels)
- 3.5 TeV "on the way" to 5TeV (limited in 2010)
- Estimated integrated luminosity
  - during first 100 days of operation.. ≈50pb-1
    - » Peak L of 5.10^{31} η (overall) = 10% gives 0.5pb-1/day
    - » Peak L of 2.10^{32} η (overall) = 10% gives 2.0pb-1/day
  - During next 100 days of operation.. ≈ 200pb-1?
- Then towards end of year ions (to be planned in detail soon)
- Start-up in Mid September

Repairs and Consolidation

- Sector 3-4 repair
  - Magnets
  - Vacuum cleaning
  - Re-installation
  - Interconnects
  - Anchoring improvements
- Pressure release valves Installation
  - Personnel Safety
- Magnet replacements
- Connection cryostats
- Protection of electronic crates (SEU)
- New Quench Protection System

In parallel with this there was an intensive campaign of measuring the quality of the sc cable joints at cold (calorimetric and electrical)

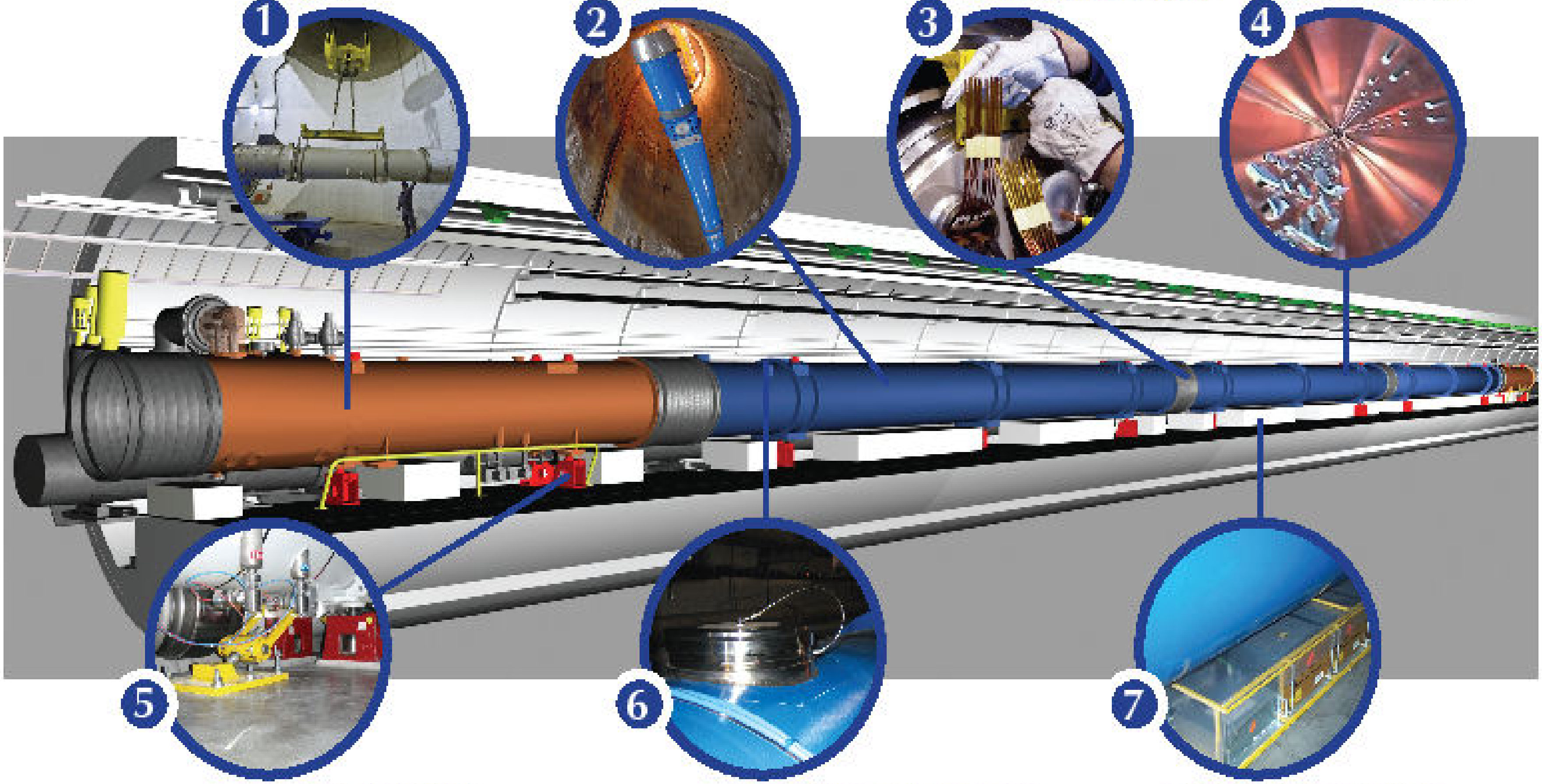
The LHC repairs in detail

14 quadrupole magnets replaced

39 dipole magnets replaced

54 electrical interconnections fully repaired. 150 more needing only partial repairs

Over 4 km of vacuum beam tube cleaned

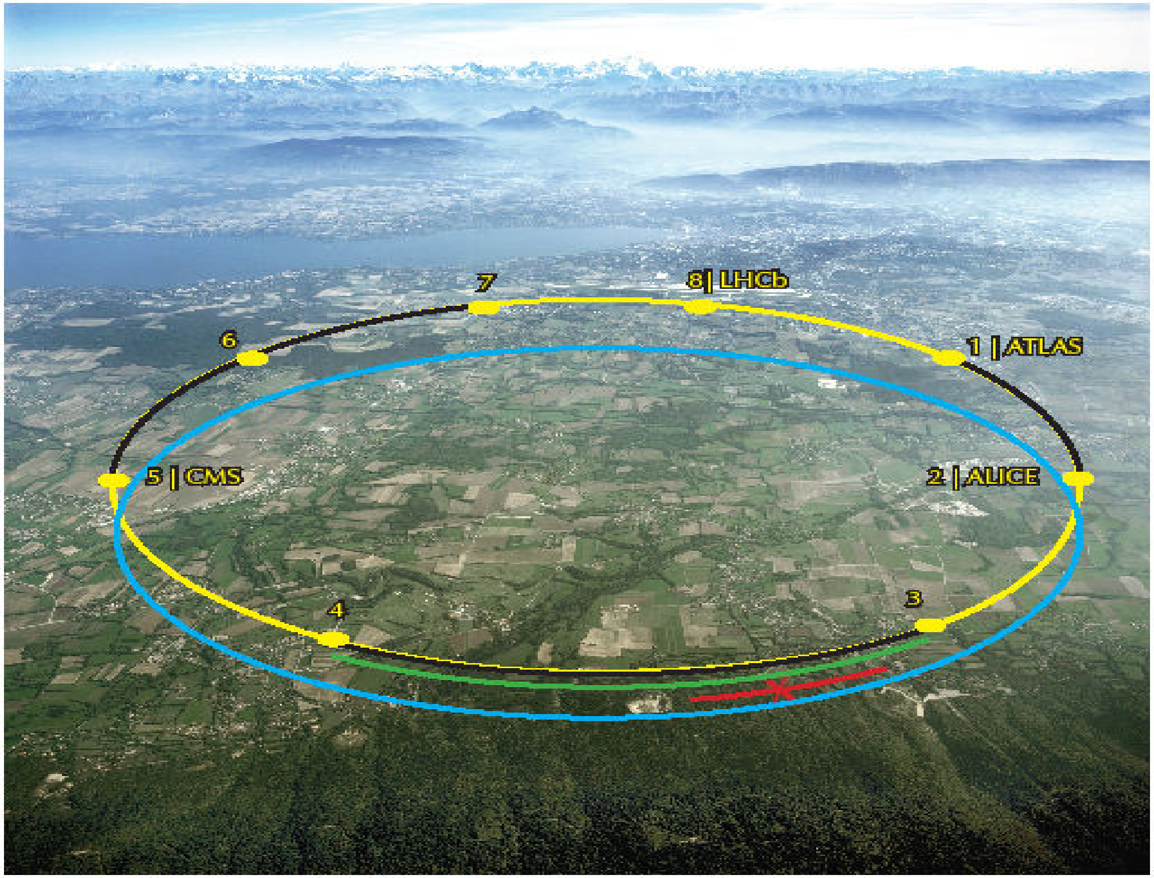


A new longitudinal restraining system is being fitted to 50 quadrupole magnets

Nearly 900 new helium pressure release ports are being installed around the machine

6500 new detectors are being added to the magnet protection system, requiring 250 km of cables to be laid

Where the repairs are happening



New pressure release ports fitted

Upgrade of magnet protection system

Cleaning ofvacuum beam tube

Dipole and quadrupole magnets replaced and electrical interconnections

LHC ring

X Incident

Magnet transport in the tunnel without a single incident

sector 3-4 : Magnet repair in SMI2

32

Last Repaired Magnet (SSS) going down (30/4/2009)

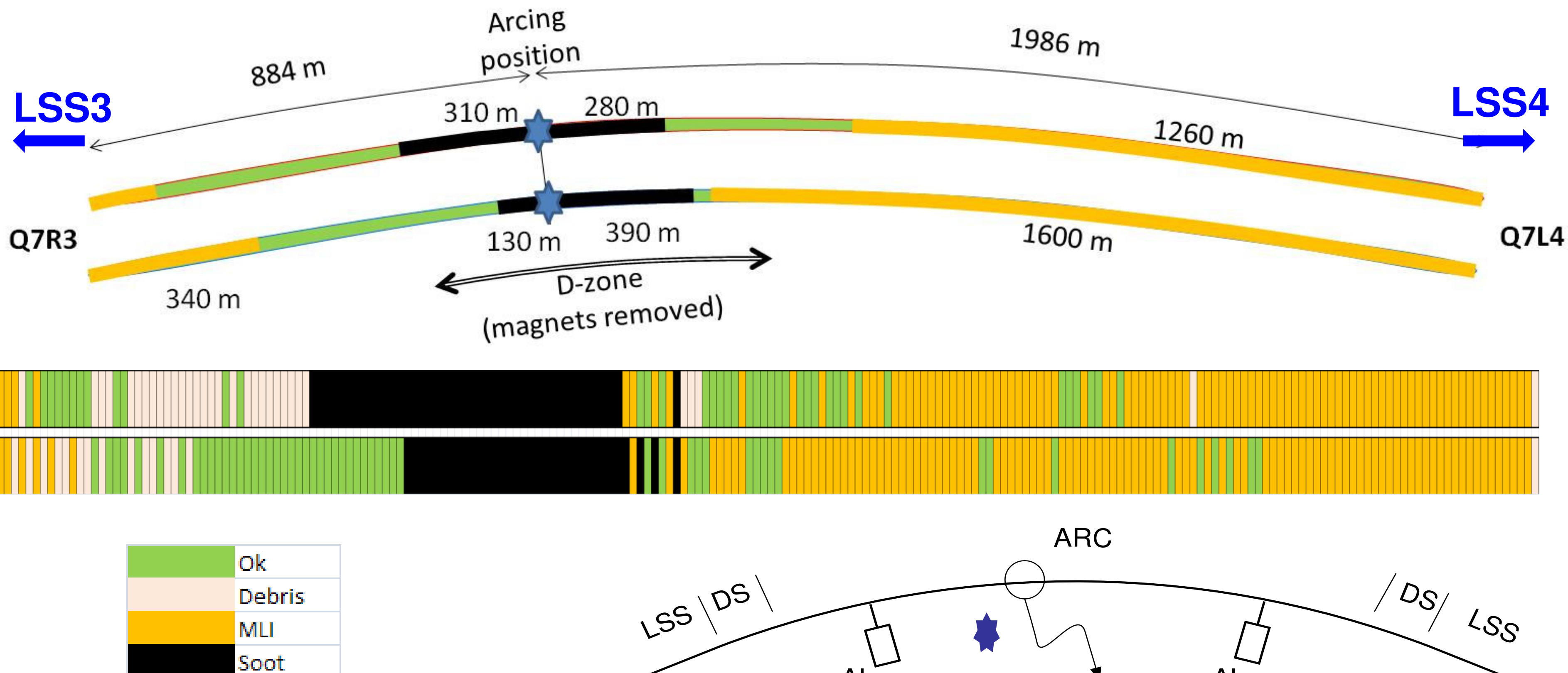
Repair of QRL service module in S3-4

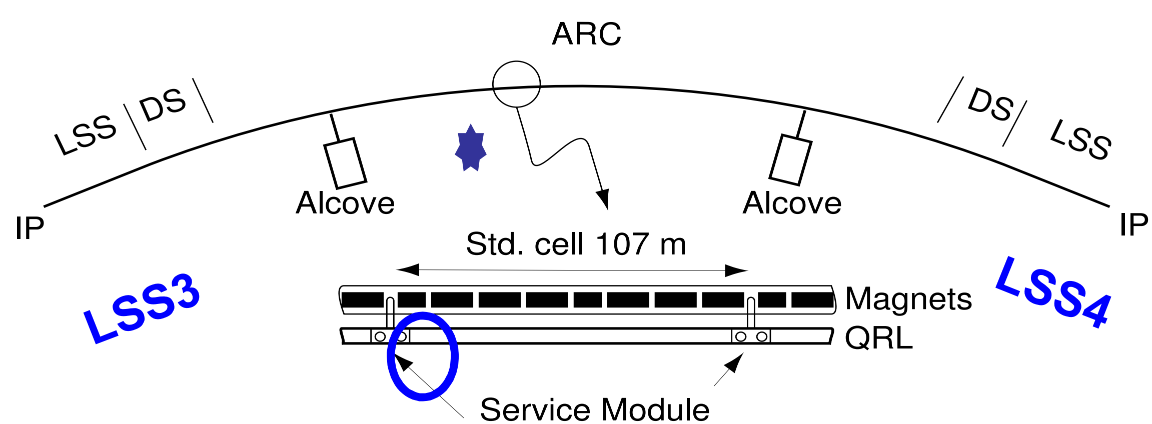
Before repair

After repair

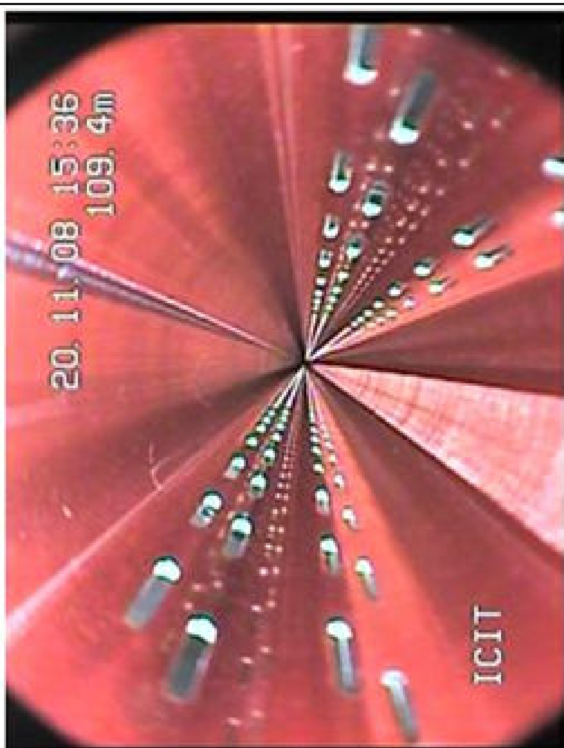
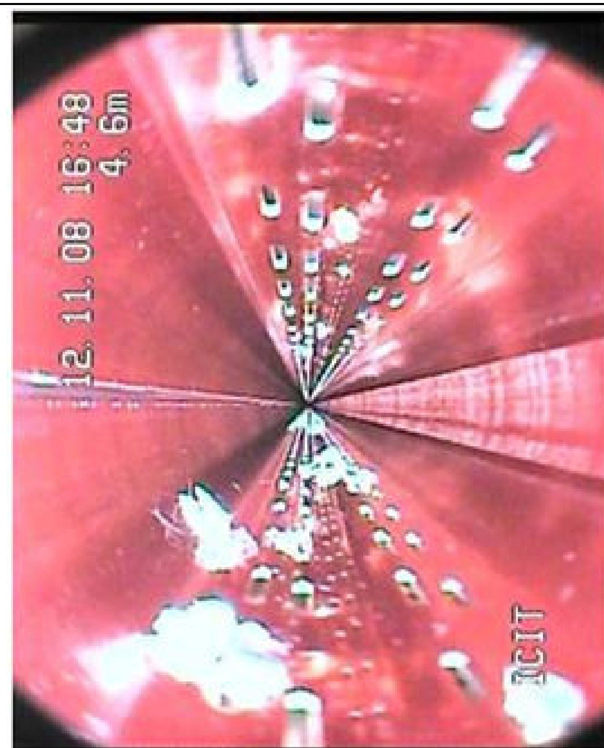
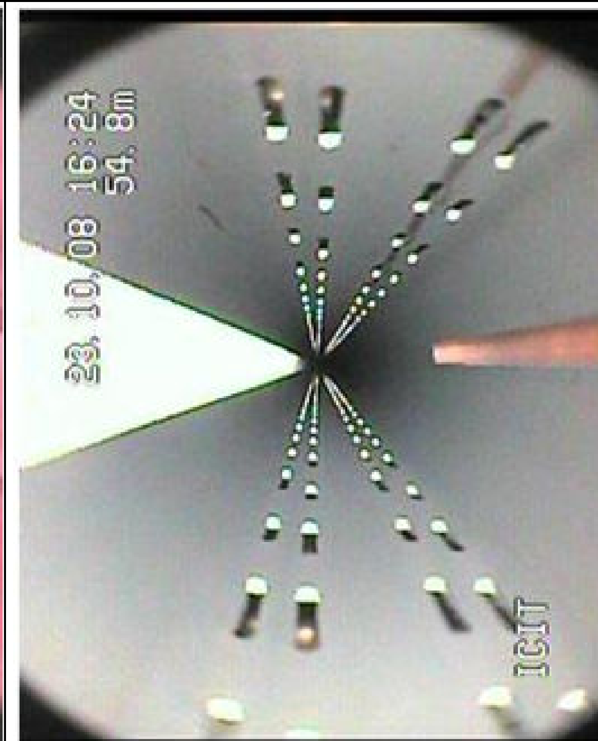
Q27

Beam vacuum recovery in sector 3-4
Review of Damages to Beam Vacuum





Beam vacuum recovery in sector 3-4
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.
		

Sectors 12, 67, 56

Sector 12 and 67: exchange of dipole magnets done (required warming up the sector)

(1-2 : RF ball OK; closed week 23)

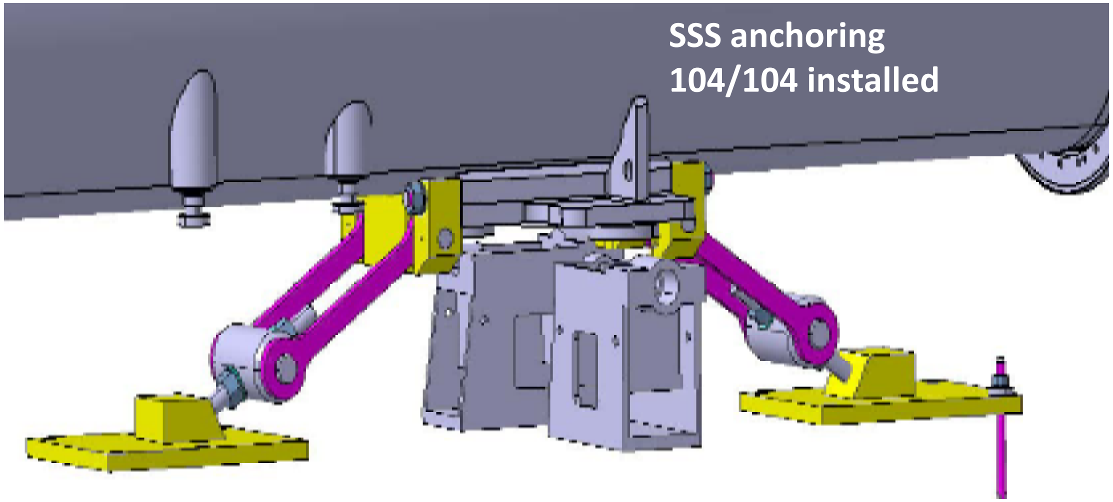
(6-7 : RF ball OK; interconnects repaired, closed week 27)

Sector 56 repair of connection cryostat

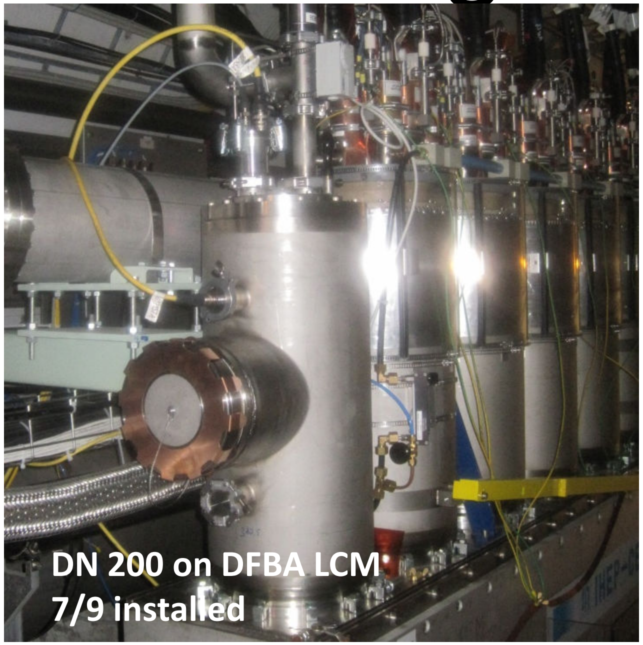
Repairs have also been made elsewhere. Eventually all will be done

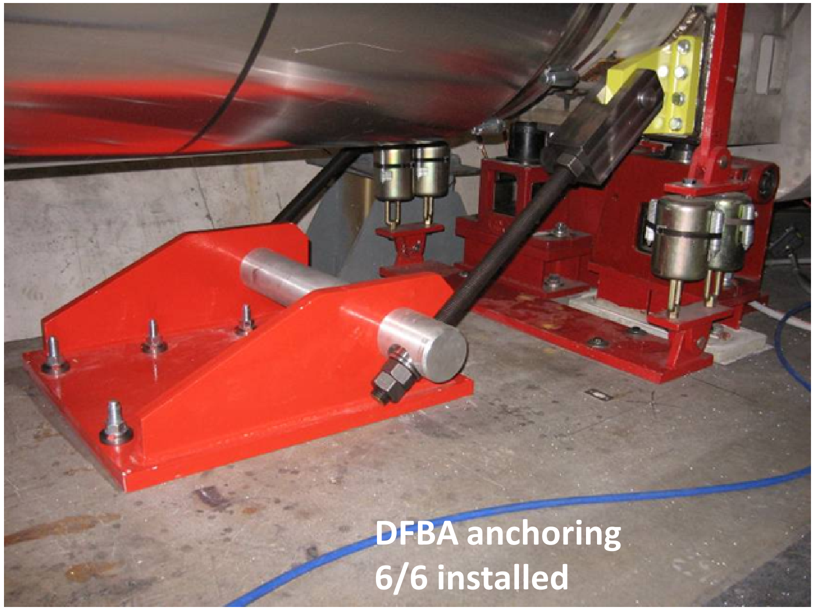
(RF ball OK; closed week 24)

Magnet protection and anchoring



DFB protection and anchoring





DSLC protection


DN160 on DSLC
2/2 installed

DN160 on DSLC
2/2 installed


DN200 on DSLC
2/2 installed

Enhanced QPS

Role of the Enhanced QPS System

- To protect against the new ‘problems’ discovered in 2008
  - The Aperture-Symmetric Quench feature in the Main Dipoles and
  - Defective Joints in the Main Bus-bars, inside or in-between the magnets.

Reminder

QPS Upgrade also allows

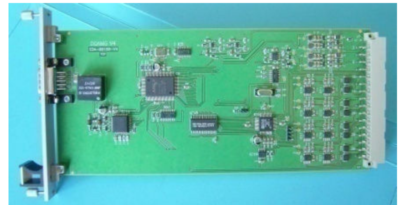
- precision measurements of the joint resistances at cold (sub-nΩ range) of every Busbar segment. This will allow complete mapping of the splice resistances (the bonding between the s.c. cables).

- To be used as the basic monitoring system for future determination of busbar resistances at warm (min. 80 K), to measure regularly the continuity of the copper stabilizers.

The nQPS project

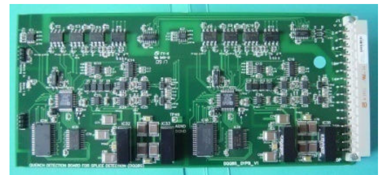
DQQTE board for ground voltage detection

(total 1308 boards, 3 units/crate)



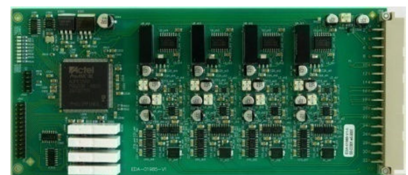
DQAMG-type S controller board

1 unit / crate, total 436 units



DQQBS board for busbar splice detection

5 such boards / crate, total 2180 units



DQQDS board for SymQ detection

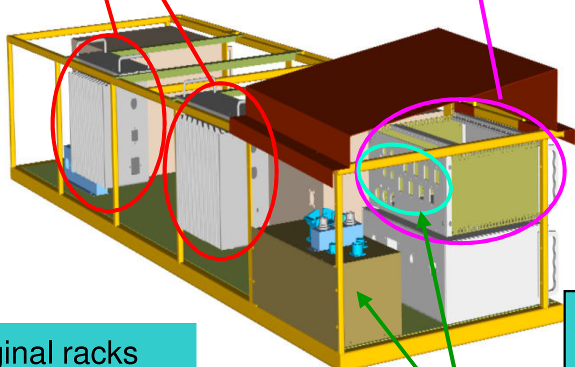
4 boards / crate, total 1744

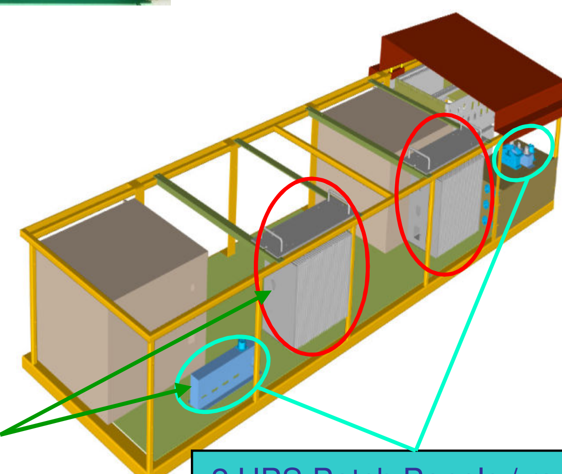
DQLPUS Power Packs

2 units / rack (total 872 units)

DQLPU-type S crate

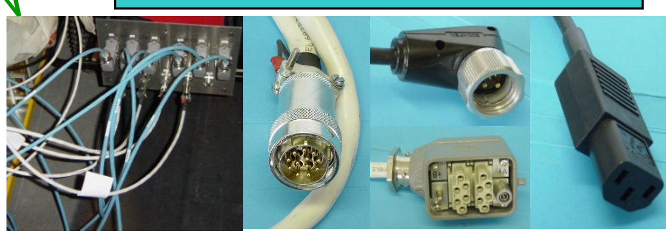
total 436 units





Original racks

'Internal' and 'external' **cables** for sensing, trigger, interlock, UPS power, uFIP (10'400 + 4'400)

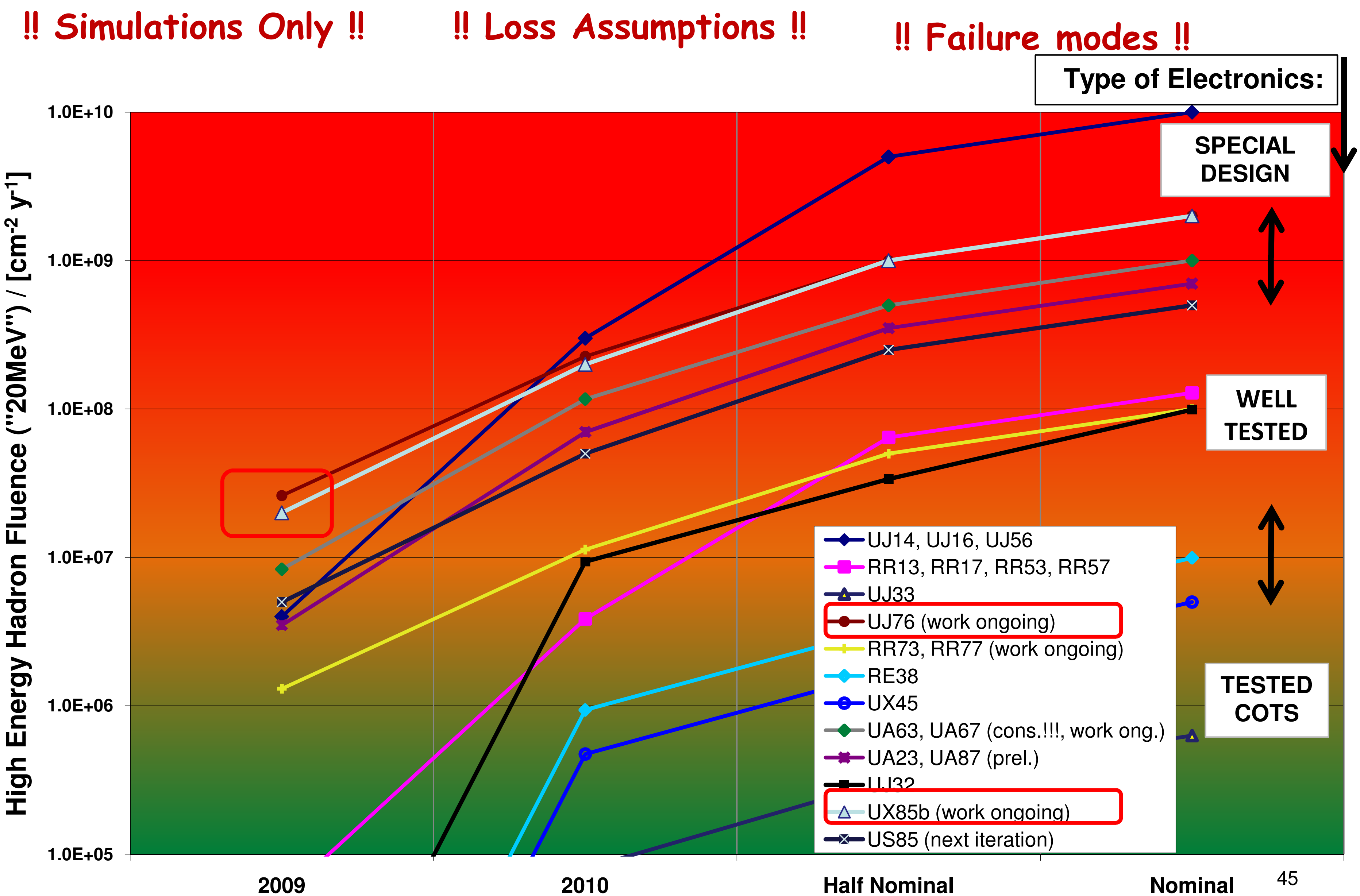


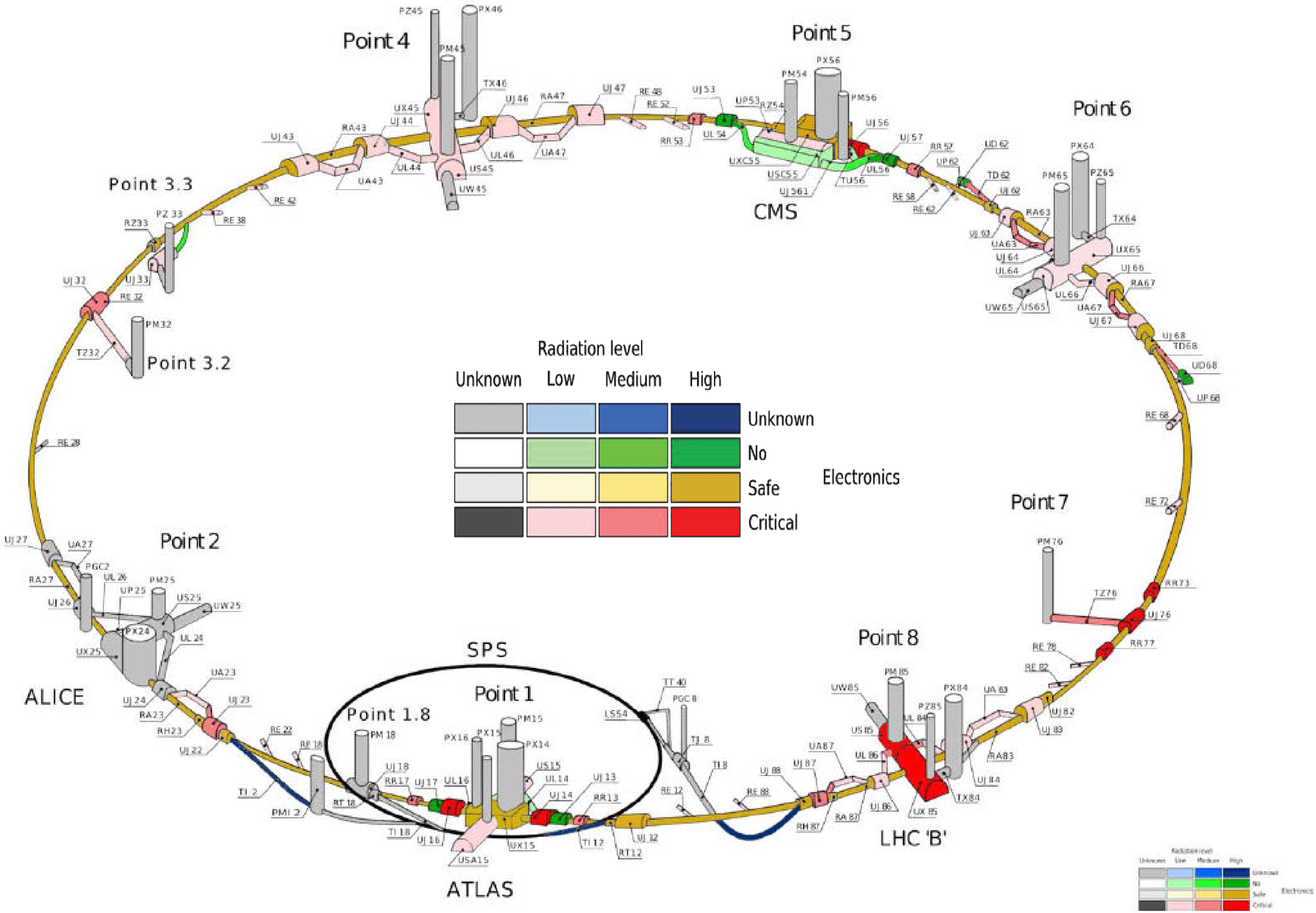
2 UPS Patch Panels / rack &
1 Trigger Patch Panel / rack
total 3456 panel boxes

Protection of Electronics from Radiation

(Single Event Upsets)

Radiation Levels – Evolution





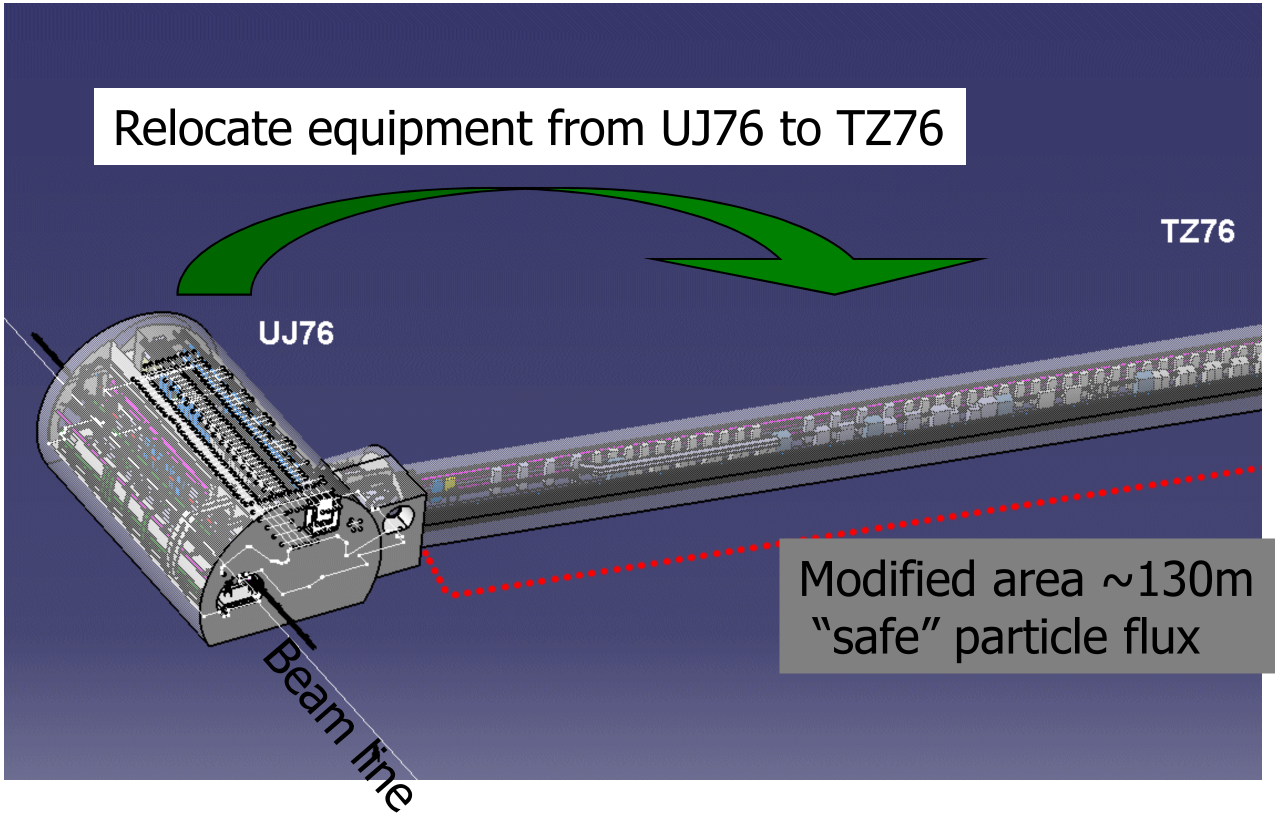
Overview of Regions – Colour Coded

Mitigation of Single Event Effect

(perturbation of equipment due to the passage of a single particle through its control electronics)

Strategy:

- Re-locate now to low radiation area the most critical equipment (ex UPS)
- Prepare relocation (space, cabling, cooling, network, etc.) of other equipment for next LHC shut-down (ex Power Converters)
- Shield with iron blocs whatever cannot be relocated (ex Safe room)




Preparation of space in TZ76


UPS re-installed in TZ76


Installation of services to relocate the Power Converters


Iron shielding wall to protect the Safe Room

Powering and Tunnel Access Restrictions

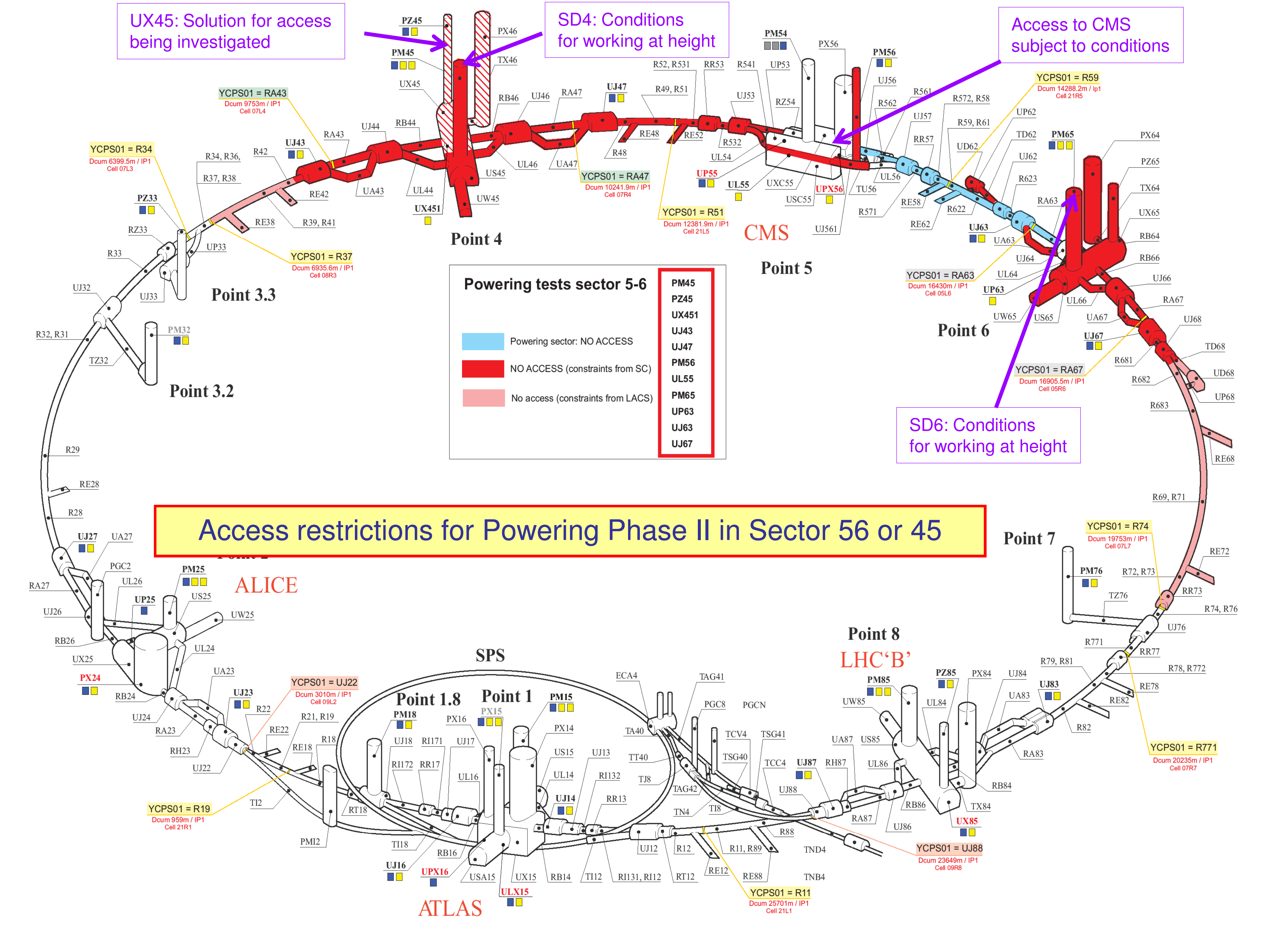
- Personnel safety
- Equipment safety

Two phases during the powering tests

- **PHASE I - Low current powering tests:**
  - Current limited to a value to be defined, with negligible risk of massive helium release
    - Restricted access to the tunnel, to powering sub-sectors where no test is ongoing
    - Access during powering tests only for people involved in the tests (PO, QPS and ELQA teams)
- **PHASE II - High current powering tests:**
  - The current in the circuits is not limited, massive helium release cannot be fully excluded
    - Access is closed & all necessary areas (tunnel AND service areas) are patrolled

For each circuit (type), defined the maximum current in powering phase I

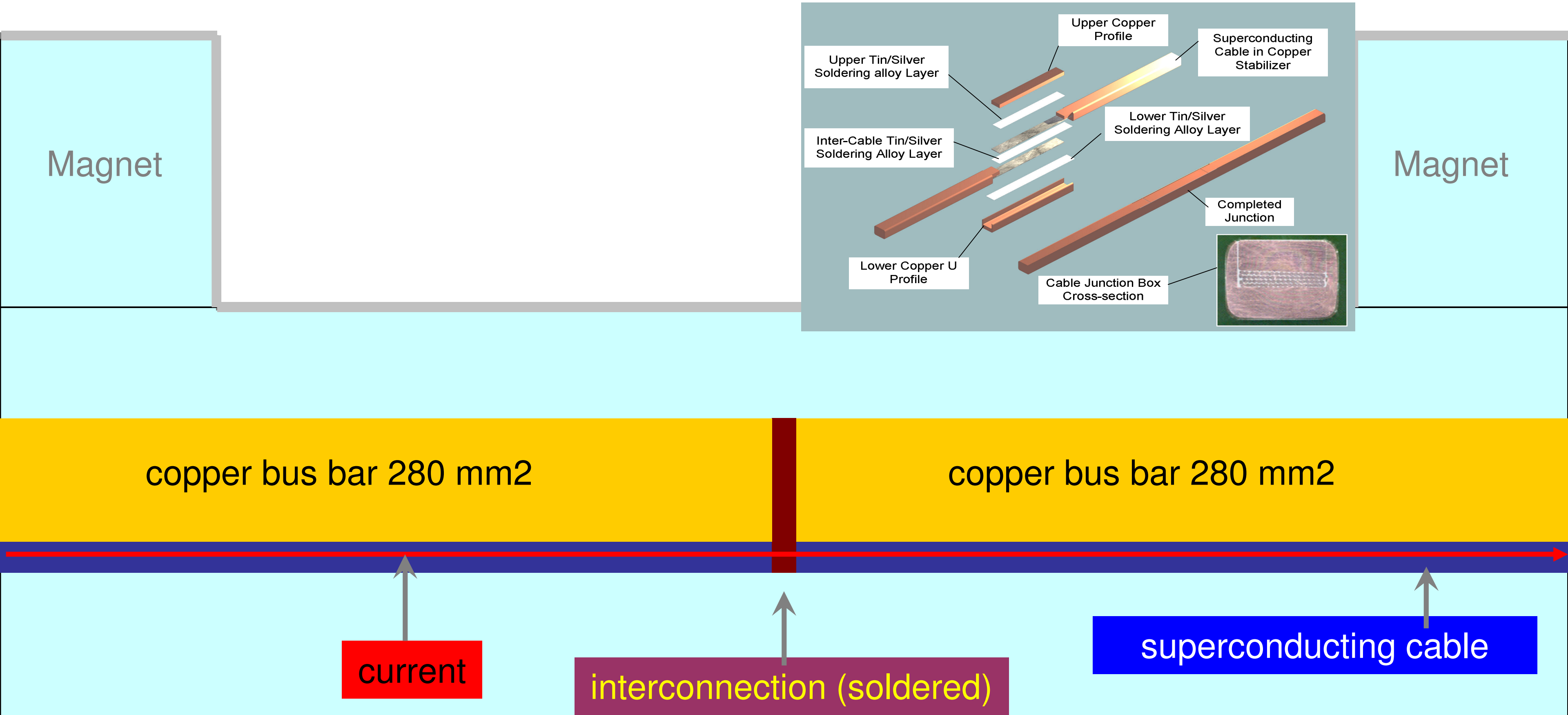
For powering phase II, define the areas that cannot be accessed


Access restrictions for Powering Phase II in Sector 56 or 45
UX45: Solution for access being investigated
SD4: Conditions for working at height
Access to CMS subject to conditions
SD6: Conditions for working at height
Powering tests sector 5-6
Powering sector: NO ACCESS
NO ACCESS (constraints from SC)
No access (constraints from LACS)
PM45
PZ45
UX451
UJ43
UJ47
PM56
UL55
PM65
UP63
UJ63
UJ67
Point 1
Point 1.8
Point 3.2
Point 3.3
Point 4
Point 5
Point 6
Point 7
Point 8
SPS
ATLAS
ALICE
CMS
LHC'B'
YCPS01 = RA43
Dcum 9753m / IP1
Cell 07L4
YCPS01 = R34
Dcum 6399.5m / IP1
Cell 07L3
YCPS01 = R37
Dcum 6935.6m / IP1
Cell 08R3
YCPS01 = RA47
Dcum 10241.9m / IP1
Cell 07R4
YCPS01 = R51
Dcum 12381.9m / IP1
Cell 21L5
YCPS01 = R59
Dcum 14288.2m / IP1
Cell 21R5
YCPS01 = RA63
Dcum 16430m / IP1
Cell 05L6
YCPS01 = RA67
Dcum 16905.5m / IP1
Cell 05R6
YCPS01 = R74
Dcum 19753m / IP1
Cell 07L7
YCPS01 = R771
Dcum 20235m / IP1
Cell 07R7
YCPS01 = UJ88
Dcum 23649m / IP1
Cell 09R8
YCPS01 = R11
Dcum 25701m / IP1
Cell 21L1
YCPS01 = UJ22
Dcum 3010m / IP1
Cell 09L2
YCPS01 = R19
Dcum 959m / IP1
Cell 21R1

Measurements of the Quality of the bus bar joints

- sc cable joints, (at cold nOhms)
- Cu stabilizer joints (at non sc temperatures micro-Ohms)

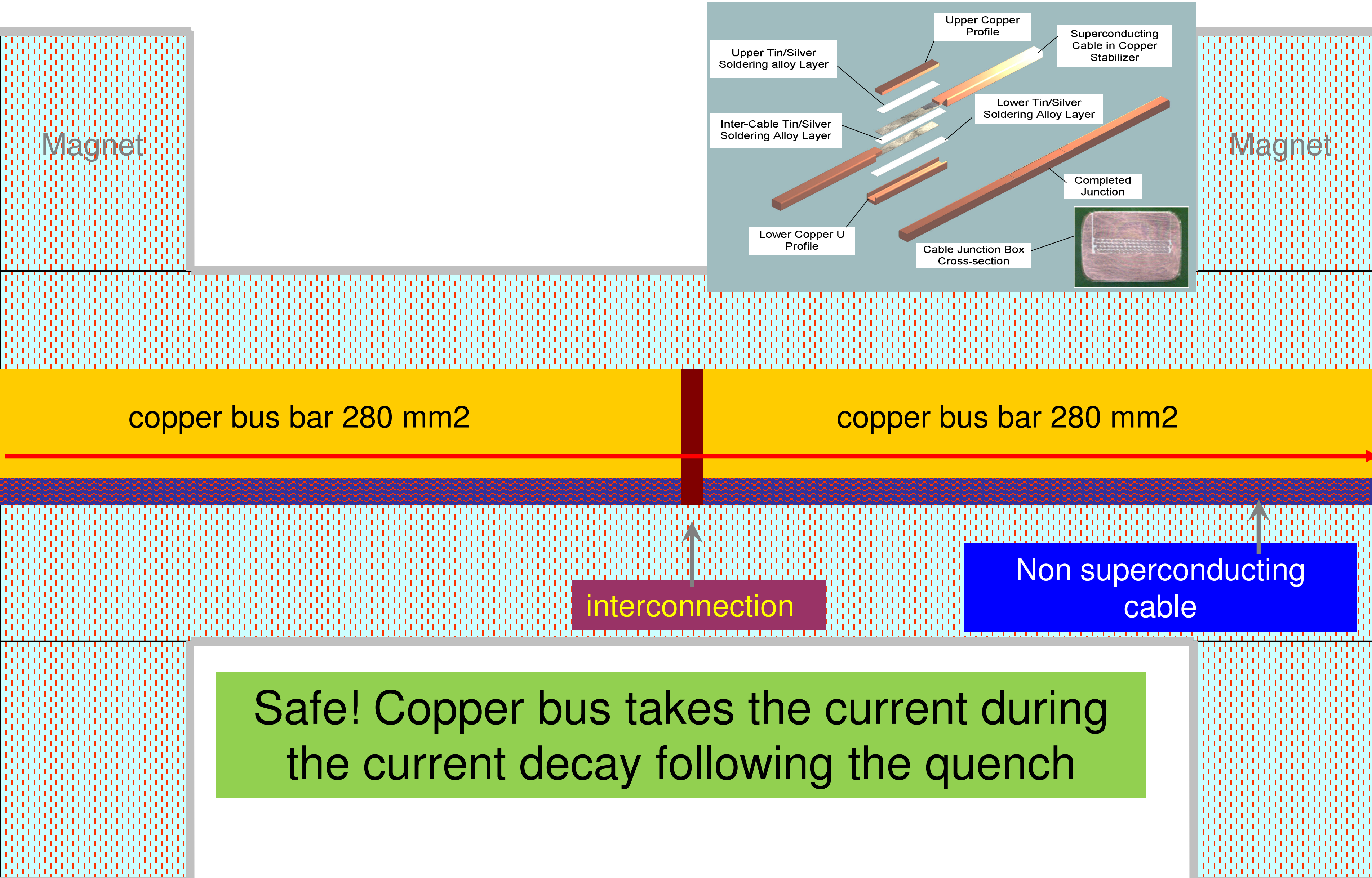
Good interconnect normal operation (1.9K)



We must be sure that the joint between the sc cables is good.

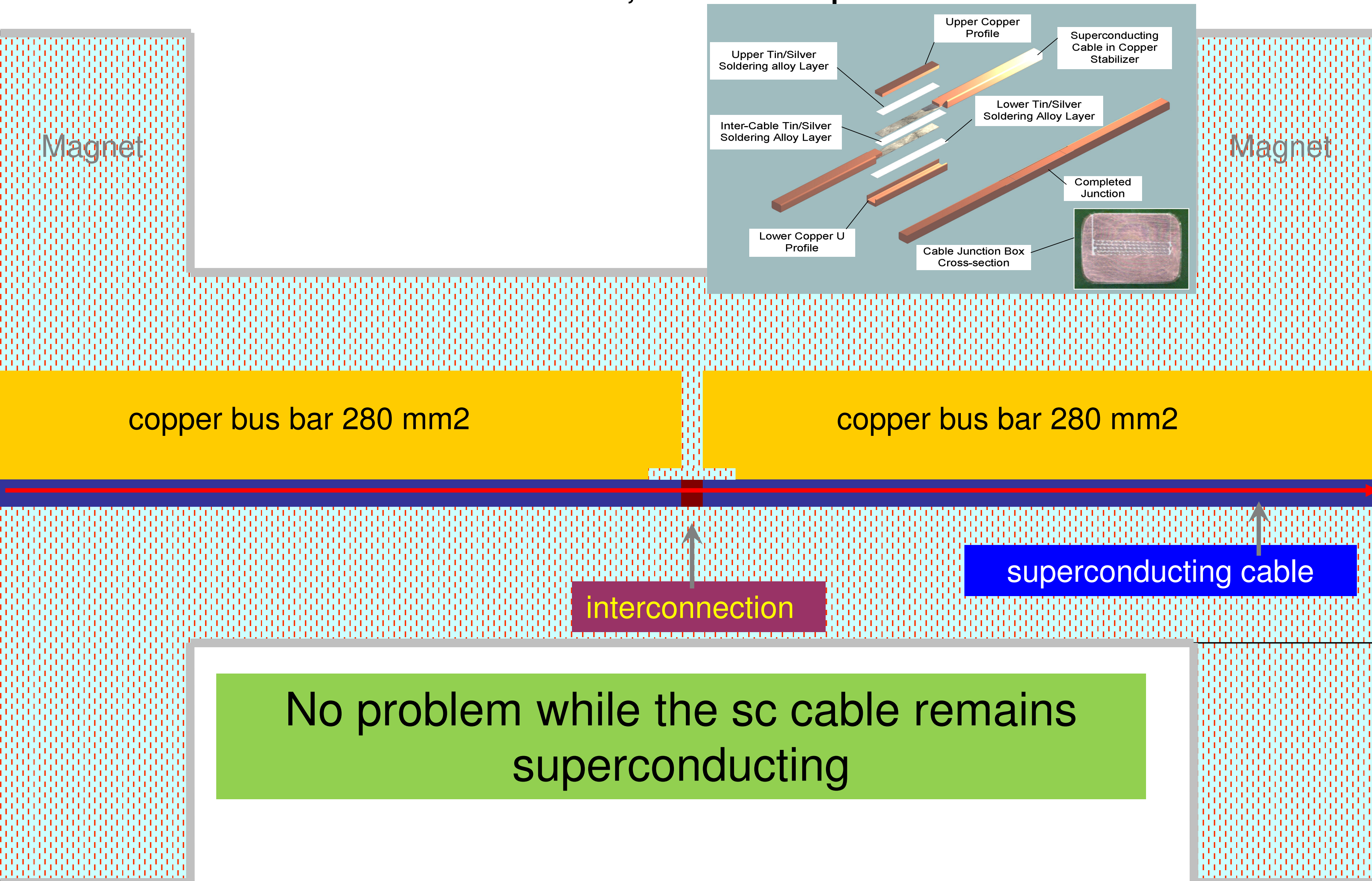
Measurements of nano-Ohms at 1.9K

good interconnect, after quench (>10K)



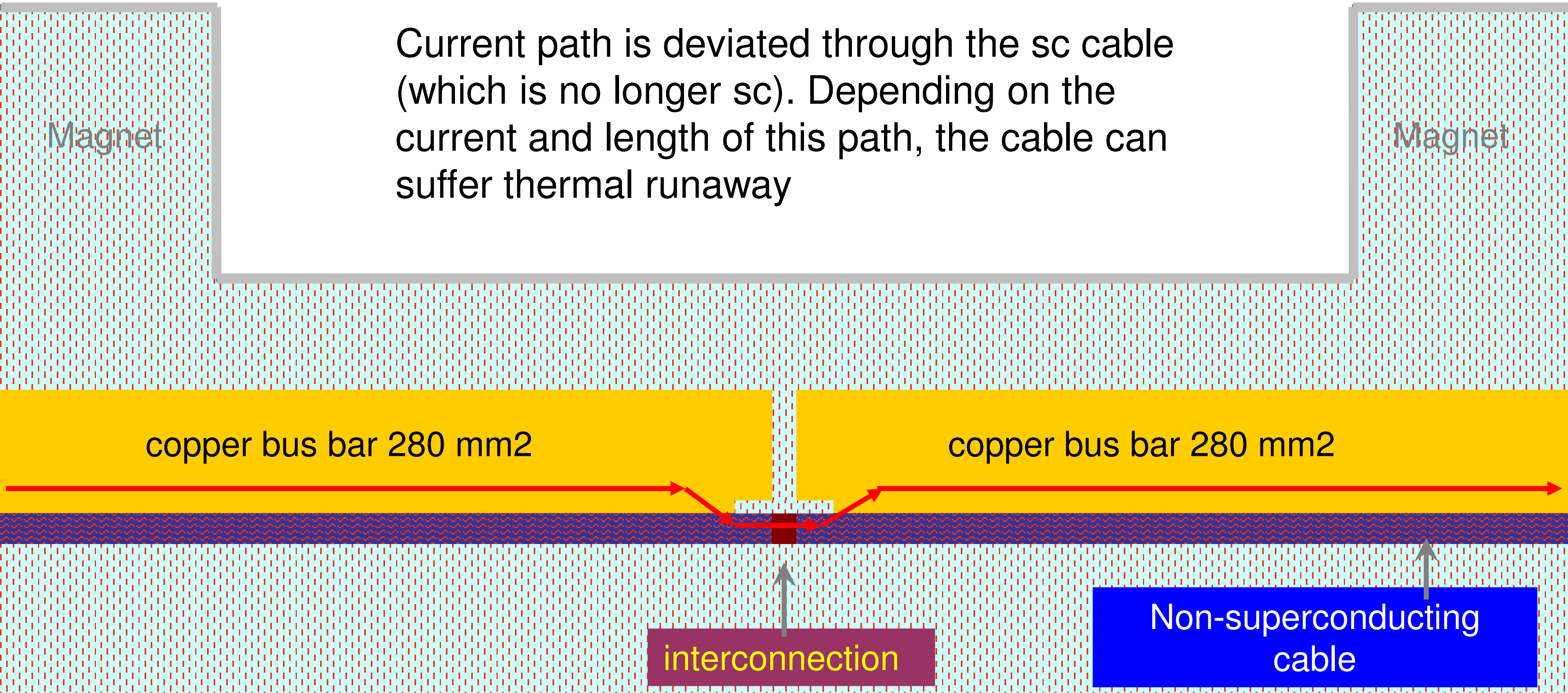
Safe! Copper bus takes the current during the current decay following the quench

Bad interconnect, normal operation 1.9K



Bad interconnect, after quench

Current path is deviated through the sc cable (which is no longer sc). Depending on the current and length of this path, the cable can suffer thermal runaway



Danger of melting the sc cable then electrical arc

We must be ensure that the copper stabiliser is continuous
Measurements of micro-Ohms at warm

Number of splices in RB, RQ circuits

circuit	splice type	splices per magnet	number of units	total splices
RB	inter pole	2	1232	2464
RB	inter aperture	1	1232	1232
RB	interlayer	4	1232	4928
RB	internal bus	1	1232	1232
RB	interconnect	2	1686	3372
RQ	Inter pole	6	394	2364
RQ	internal bus	4	394	1576
RQ	interconnect	4	1686	6744
total				23912

Methods for testing splices

- The methods we have at our disposal to measure spice resistances (either directly or indirectly) are four:
  - The ‘Keithley’ method
  - The ‘QPS snapshot’ method
  - The calorimetric method
  - *The ultrasound method*

Present approximate splice detection limits of LHC magnet measurements

From Chamonix February 2009: REMEMBER this was considered good for 5TeV/beam

Detection limit of splice resistance for MB and MQ (nano-Ohm) Red: thermal measurements, blue QPS

	Interconnect splice		Magnet splice	
Sector	MB	MQ	MB	MQ
A12	30	60	10	60
A23	60	60	60	60
A34	60	60	60	60
A45	60	60	60	60
A56	30	30	5	5
A67	30	30	15	5
A78	30	30	10	5
A81	30	30	10	5

N. Catalan Lasheras, Z. Charifoulline, M. Koratzinos, A. Rijllart, A. Siemko, J. Strait, L. Tavian, R. Wolf
Electrical and calorimetric measurements and related software

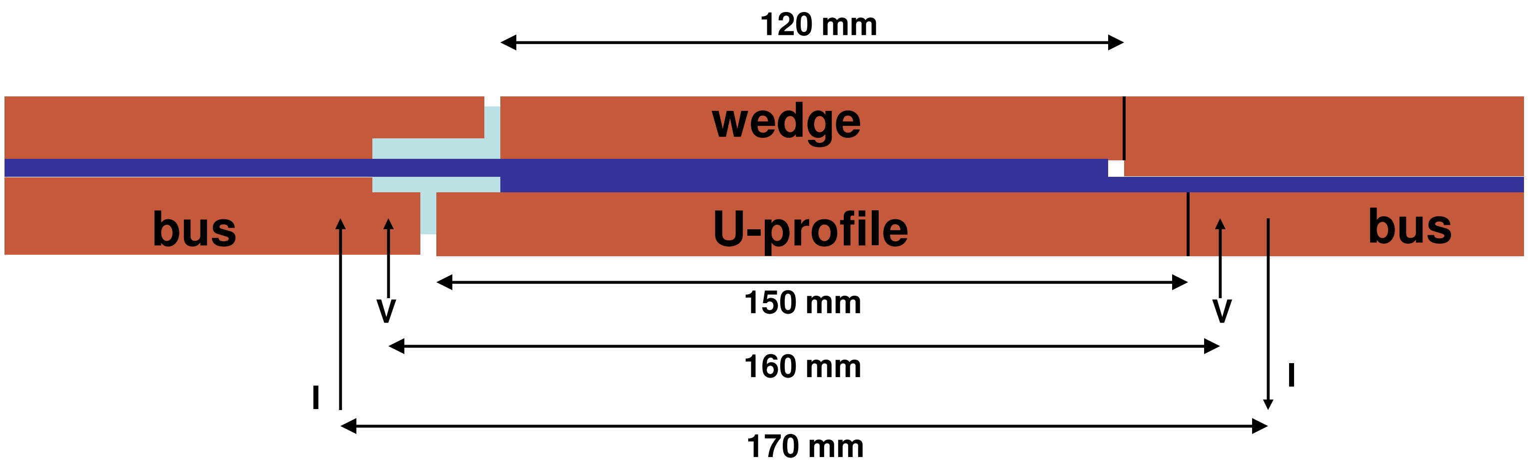
Z. Charifoulline, Int Comm.

SC splices nano-Ohms

Electrical Resistance Measurements at Warm Temperatures

- New electrical tests were developed
  - Warm measurements of R^{long} give possibility to detect surplus joint resistance larger than about 20-30 $\mu\Omega$ (RB).
    - Tests have been done for five sectors at room temperature and three sector at 80 K.
  - Warm measurements of the joint resistances (so-called local R^{16} measurement) give possibility to detect surplus joint resistance of a few $\mu\Omega$.

R-measurement at 300 K



The "R16 method" will give some indication whether wedge, U-profile, and bus stabilizer are in good electrical contact.

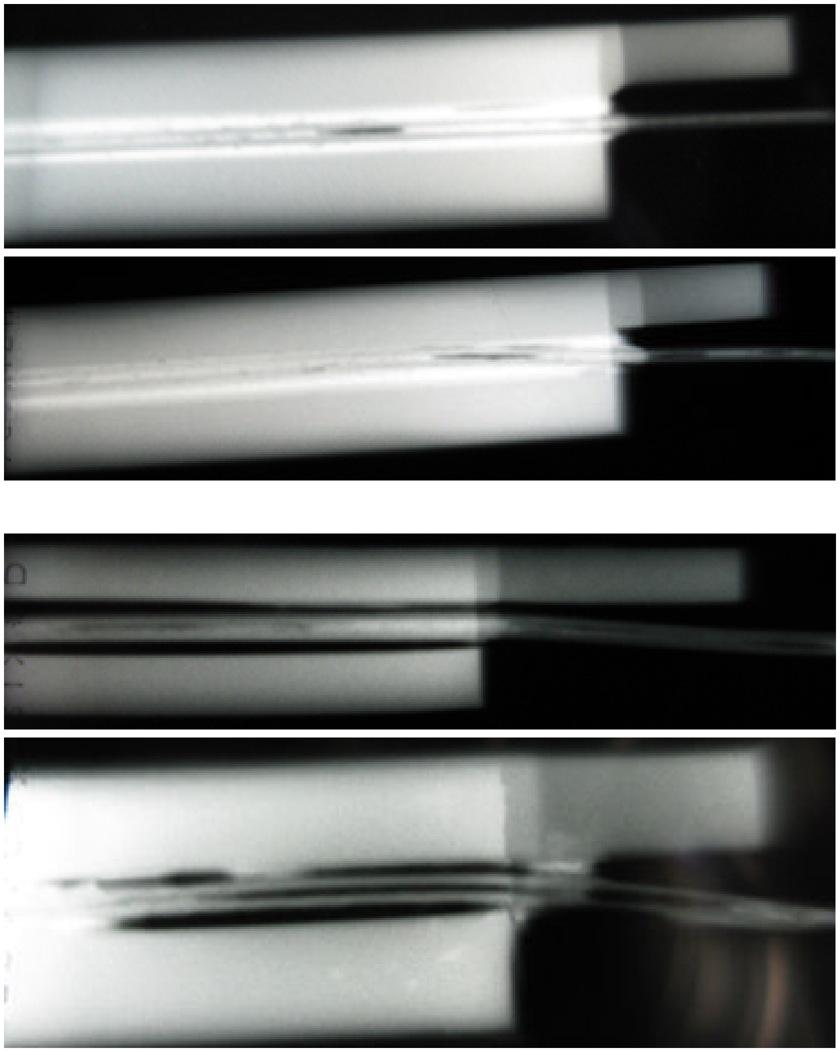
'Perfect' values for R16 are: (T=18 °C, gap is 0.1 mm fully filled with SnAg, perfect bonding everywhere, uniform current)

RB: 9.45 μΩ

RQ: 16.0 μΩ

What did we observe?

Dipole extremities in SMa18



MB2690 M2

MB2690 M3

Spare magnet

MB3118 M2

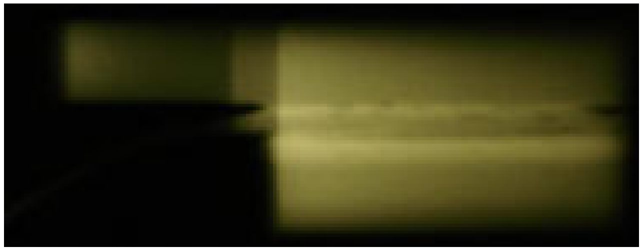
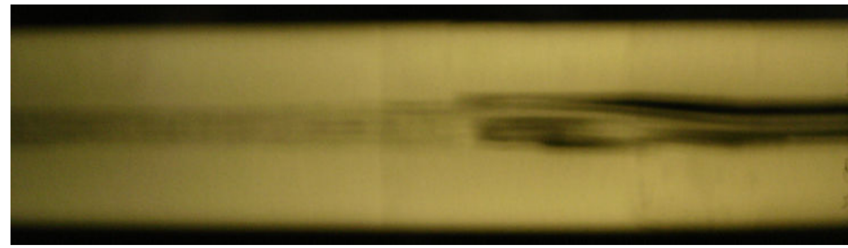
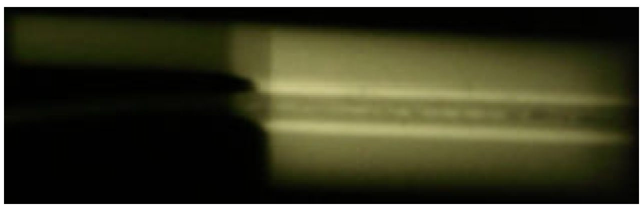
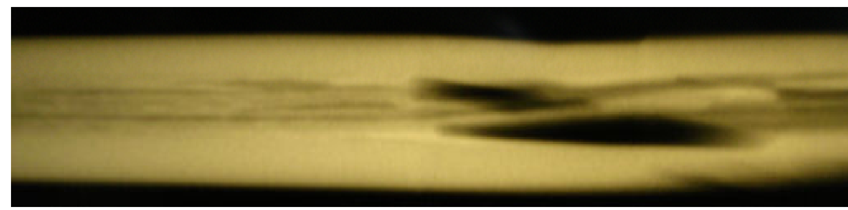
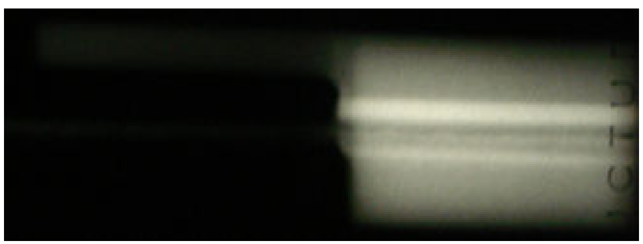
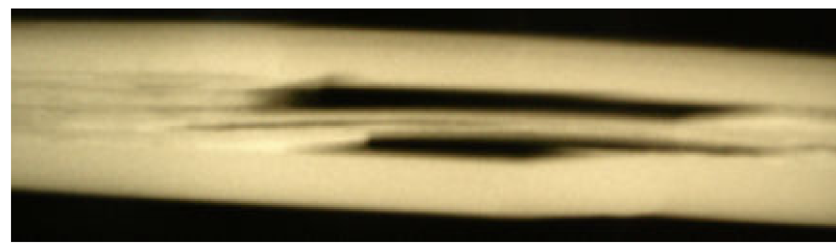
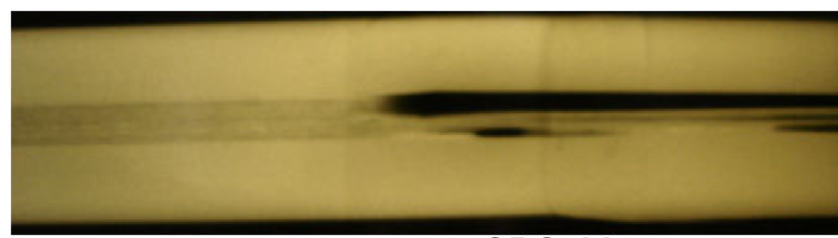
MB3118 M3

Magnet coming form the tunnel

What did we observe?

Spare magnets connections (April 2009)

12 samples tested (2 interconnections), those 4 are representative of the total

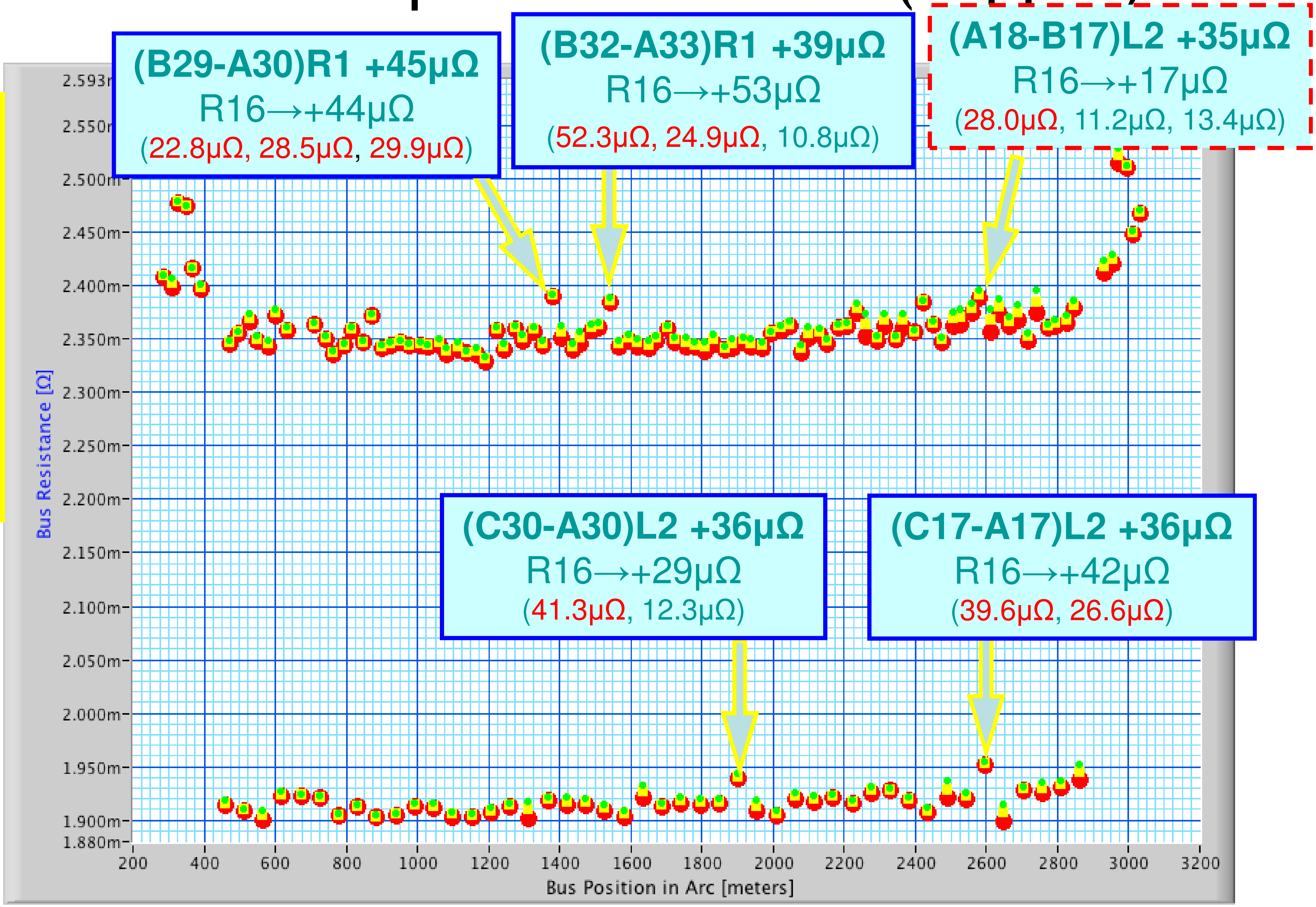
	before connection 8-04-09	after connection 16-04-09
MB2433 in QBBI.A23R3 M3 ext		
MB2433 in QBBI.A23R3 M2 int		
MB2439 in QBQI.24R3 M1 ext		
MB2439 in QBQI.24R3 M3 int		

Summary on Copper Stabilisers

- The enhanced quality assurance introduced during sector 3-4 repair revealed new facts concerning the copper bus bar in which the superconductor is embedded.
- Tests have demonstrated that the process of soldering the superconductor in the interconnecting high-current splices can cause discontinuity of the copper part of the busbars and produce voids which prevent contact between the superconducting cable and the copper
- This can cause danger for the joint in case of a quench
- Quality of the copper stabiliser joint determines maximum safe energy

  ⇨ Splice resistance measurement campaign
- Possible Mitigation
  - Faster discharge of the energy from circuits

1-2 M3 splice resistance (copper)



!

Courtes

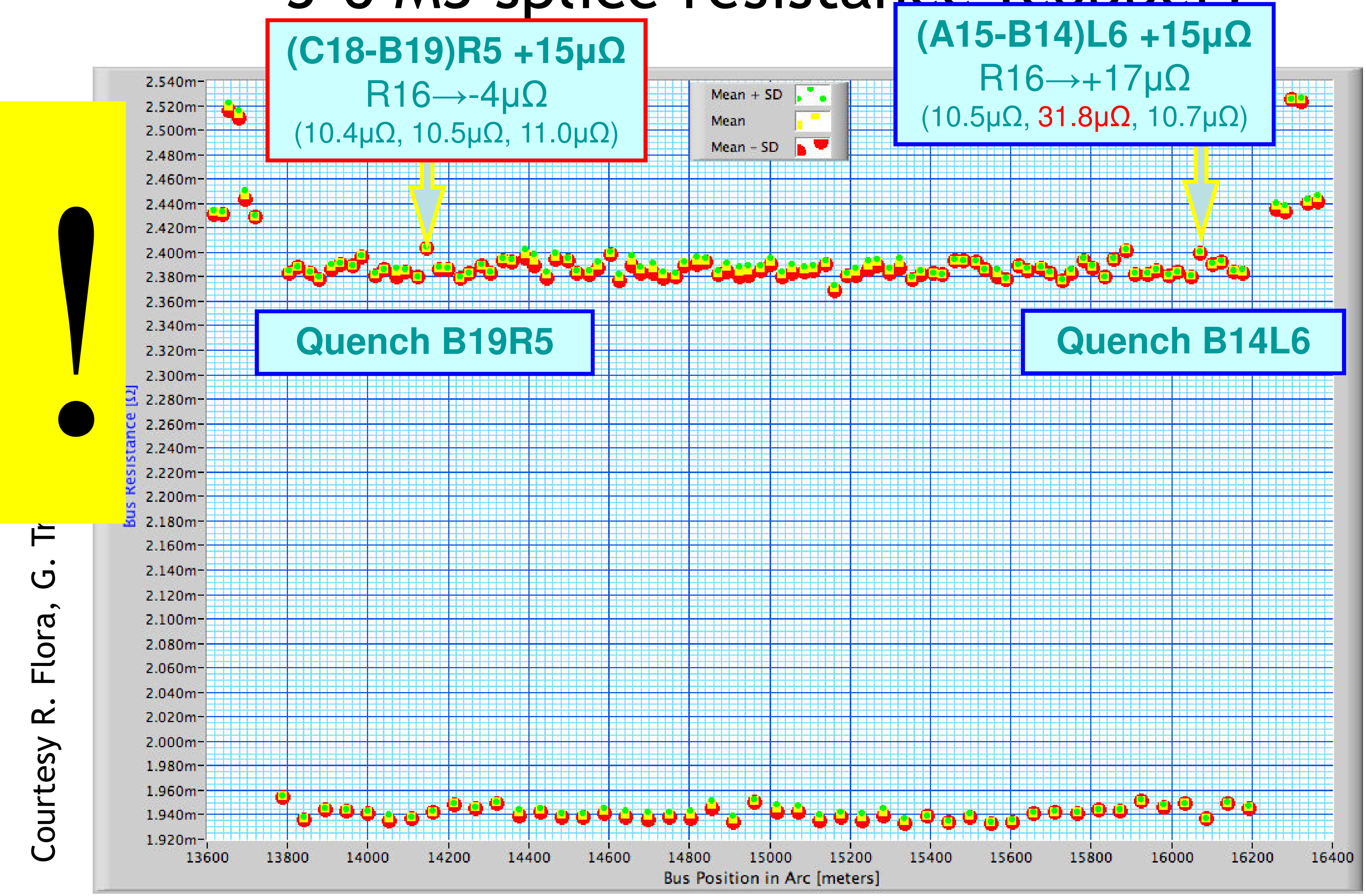
The cool-down of S12 was delayed in order to perform this “warm” measurement

1-2 M3 splice repair

Inter. number	Main bus bars	Photos (before unsoldering)	US-test (before unsoldering)	R-16 before unsoldering	Gamma ray control (before unsoldering)	Visual inspection and photos after repair	US-test after repair	R-16 after repair	Gamma ray control after repair	QC insulation main bus bars	QC insulation spools
1-2											
QBBI.B29 R1	M3-corridor	done	4 out of 4 OK	11.7	done 8.5.09, J.D.					OK, 2.6.09, C.S.	
	M3-cryoline	done	4 out of 4 OK	22.8	done 8.5.09, J.D.	OK, 28.5.09, G.T.	4 out of 4 OK	10.0	done, 2.6.06, J.D.	OK, 2.6.09, C.S.	
QBQI29R1	M3-corridor	done	4 out of 4 OK	12.2	done 8.5.09, J.D.					OK, 2.6.09, C.S.	
	M3-cryoline	done	4 out of 4 OK	28.5	done 8.5.09, J.D.	OK, 28.5.09, G.T.	4 out of 4 OK	11.5	done, 2.6.06, J.D.	OK, 2.6.09, C.S.	
QQBI29R1	M3-corridor	done	3 out of 4 OK	25.2	done 8.5.09, J.D.	OK, 29.5.09, C.S.	OK, 2.6.09, G.T.	10.7	done, 2.6.06, J.D.	OK, 2.6.09, C.S.	
	M3-cryoline	done	4 out of 4 OK	29.9	done 8.5.09, J.D.	OK, 29.5.09, C.S.	OK, 2.6.09, G.T.	10.4	done 2.6.06, J.D.	OK, 2.6.09, C.S.	
QBBI.B32 R1	M3-corridor	done	4 out of 4 OK	24.9	done 14.5.09, J.D.	OK, 29.5.09, C.S.	OK, 2.6.09, G.T.	10.2	done 2.6.06, J.D.	OK, 2.6.09, C.S.	
	M3-cryoline	done	4 out of 4 OK	11.2	done 14.5.09, J.D.					OK, 2.6.09, C.S.	
QBQI.32R1	M3-corridor	done	3 out of 4 OK	52.3	done 14.5.09, J.D.	OK, 29.5.09, C.S.	OK, 2.6.09, G.T.	10.2	done 2.6.06, J.D.	OK, 2.6.09, C.S.	
	M3-cryoline	done	4 out of 4 OK	12.5	done 14.5.09, J.D.	OK, 29.5.09, C.S.	OK, 2.6.09, G.T.		done 2.6.06, J.D.	OK, 2.6.09, C.S.	
QQBI.32R1	M3-corridor	done	4 out of 4 ok 2.2.09	10.8	done 19.5.09, J.D.	OK, 29.5.09, C.S.	OK, 2.6.09, G.T.	10.3	done, 2.6.06, J.D.	OK, 3.6.09, C.S.	
	M3-cryoline	done	4 out of 4 ok 2.2.09	10.8	done 19.5.09, J.D.	OK, 29.5.09, C.S.	OK, 2.6.09, G.T.	10.5	done 2.6.06, J.D.	OK, 3.6.09, C.S.	
QBBI.B30L2	M3-corridor	done	4 out of 4 OK	12.3	done 14.5.09, J.D.					OK, 2.6.09, C.S.	
	M3-cryoline	done	4 out of 4 OK	12.7	done 14.5.09, J.D.					OK, 2.6.09, C.S.	
QBBI.A30L2	M3-corridor	done	4 out of 4 OK	41.3	done 14.5.09, J.D.	OK, 29.5.09, C.S.	OK, 2.6.09, G.T.	10.2	done 2.6.06, J.D.	OK, 3.6.09, C.S.	
	M3-cryoline	done	4 out of 4 OK	13.3	done 14.5.09, J.D.					OK, 3.6.09, C.S.	
QBQI.18L2	M3-corridor	done	4 out of 4 OK	28.0		OK, 3.6.09, G.T.	OK, 3.6.09, G.T.	10.2		OK, 3.6.09, C.S.	
	M3-cryoline	done	4 out of 4 OK	25.6		OK, 3.6.09, G.T.	OK, 3.6.09, G.T.	10.6		OK, 3.6.09, C.S.	
QQBI.17L2	M3-corridor	done	4 out of 4 OK	11.2						OK, 3.6.09, C.S.	
	M3-cryoline	done	4 out of 4 OK	16.9		OK, 3.6.09, G.T.	OK, 3.6.09, G.T.	10.4		OK, 3.6.09, C.S.	
QBBI.B17L2	M3-corridor	done	4 out of 4 OK	13.4	done 8.5.09, J.D.					OK, 3.6.09, C.S.	
	M3-cryoline	done	4 out of 4 OK	26.6	done 8.5.09, J.D.	OK, 29.5.09, C.S.	OK, 2.6.09, G.T.	10.5	done 2.6.06, J.D.	OK, 3.6.09, C.S.	
QBBI.A17L2	M3-corridor	done	4 out of 4 OK	13.0	done 8.5.09, J.D.					OK, 3.6.09, C.S.	
	M3-cryoline	done	4 out of 4 OK	39.6	done 8.5.09, J.D.	OK, 29.5.09, C.S.	OK, 2.6.09, G.T.	10.3	done 2.6.06, J.D.	OK, 3.6.09, C.S.	

Courtesy C. Scheuerlein

5-6 M3 splice resistance (copper)



Decision; Beam Energy at Start-up (August 2009)

Choices

- Stick to 5TeV/beam and repair all necessary Cu stabilizer joints => warm up of several sectors and delay start of physics till 2010
- Aim for maximum safe energy with no additional repairs on CU stabilizers => allows us to gain experience up to this maximum energy (accelerator and detectors)

- Avoidance of thermal runaway (during a quench)
  - Maximum safe current flowing in joint (beam energy)
    - Electro-magnetic, thermo-dynamic simulations
    - Probability of simultaneous quench in magnet and joint (?beam losses FLUKA)
    - Quench propagation time from the magnet to the joint
  - Resistance of the copper stabilizers (measurements)
  - Quality of the copper in the sc cable and the Cu stabiliser (RRR)
  - Energy extraction time (modification of dump resistors quads and dipoles)
  - Gaseous cooling of the joint?

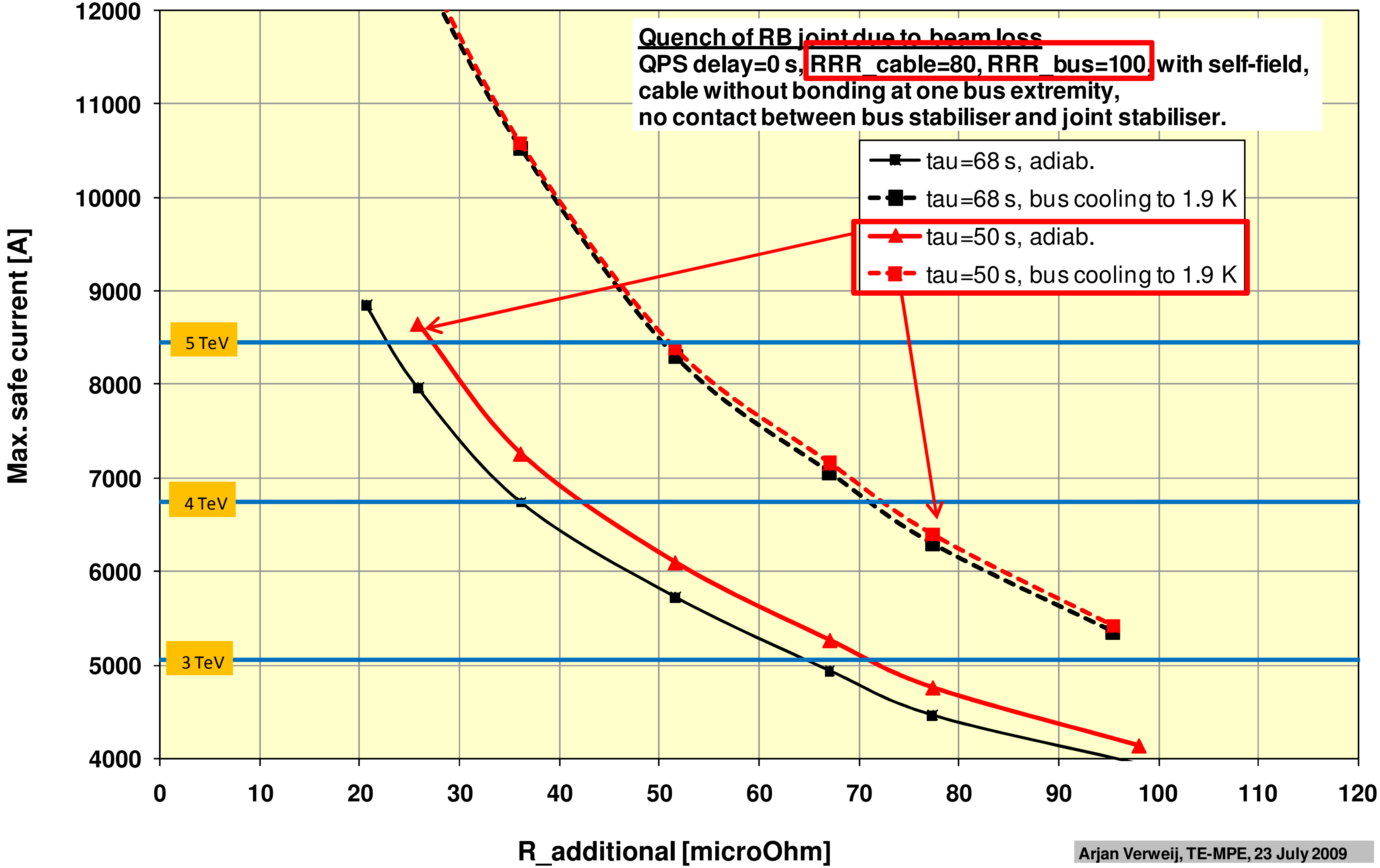
Simultaneous busbar and magnet quench?

FLUKA Simulations

- **Combined busbar and magnet quench can not be excluded but is highly unlikely**
- **Magnet will quench at a significantly lower level** of beam loss than adjacent bus bars (in inter-connects or the empty cryostat)
  - 10^6 protons sufficient to quench the magnets
  - 10^9-10^{10} protons required to quench the busbars
- According to the present studies it is **very unlikely to quench the busbar only (not observed in these studies)**

New RQ dump resistors; preparation was launched immediately

RB: case 1 (instantaneous quench in busbar/magnet)



Thermal propagation time (for case 2)

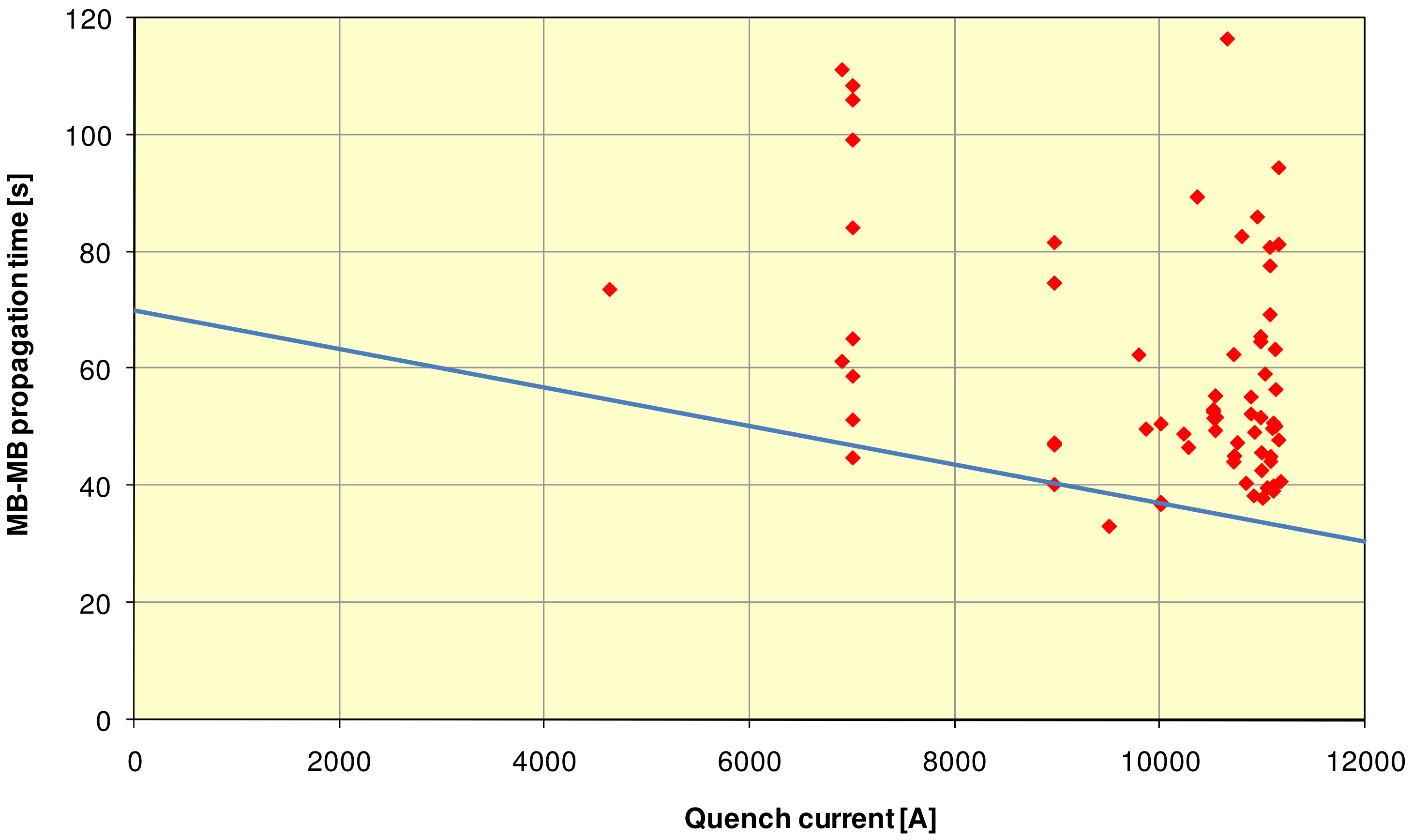
Experience from HWC for RB quenches at 7-11 kA.

Assume that the joint quenches after half the MB-MB thermal propagation time,

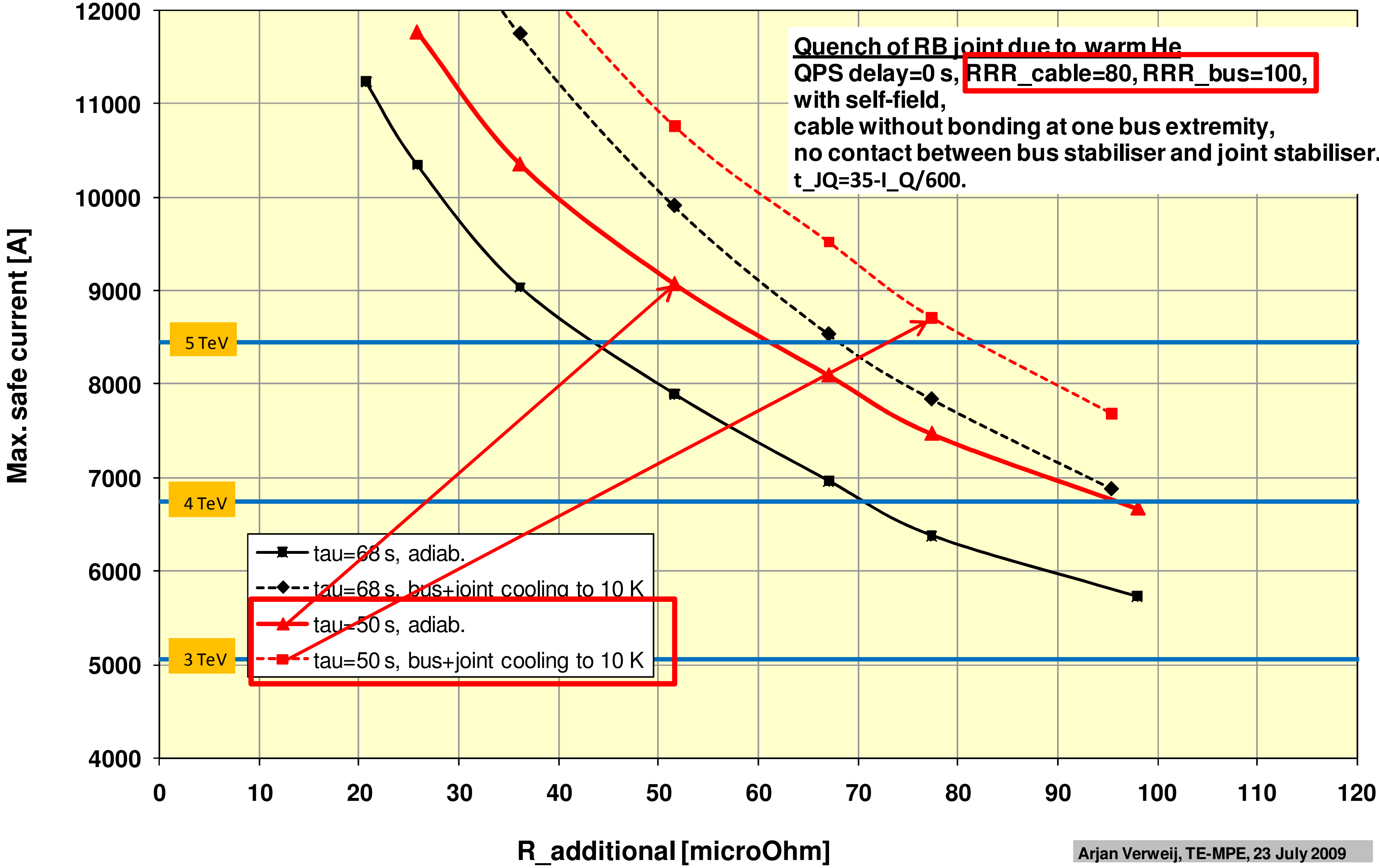
so $t_{JQ}=0.5*(70-I_Q/300)$

?

Maybe possible to get more accurate value from thermal analysis…..



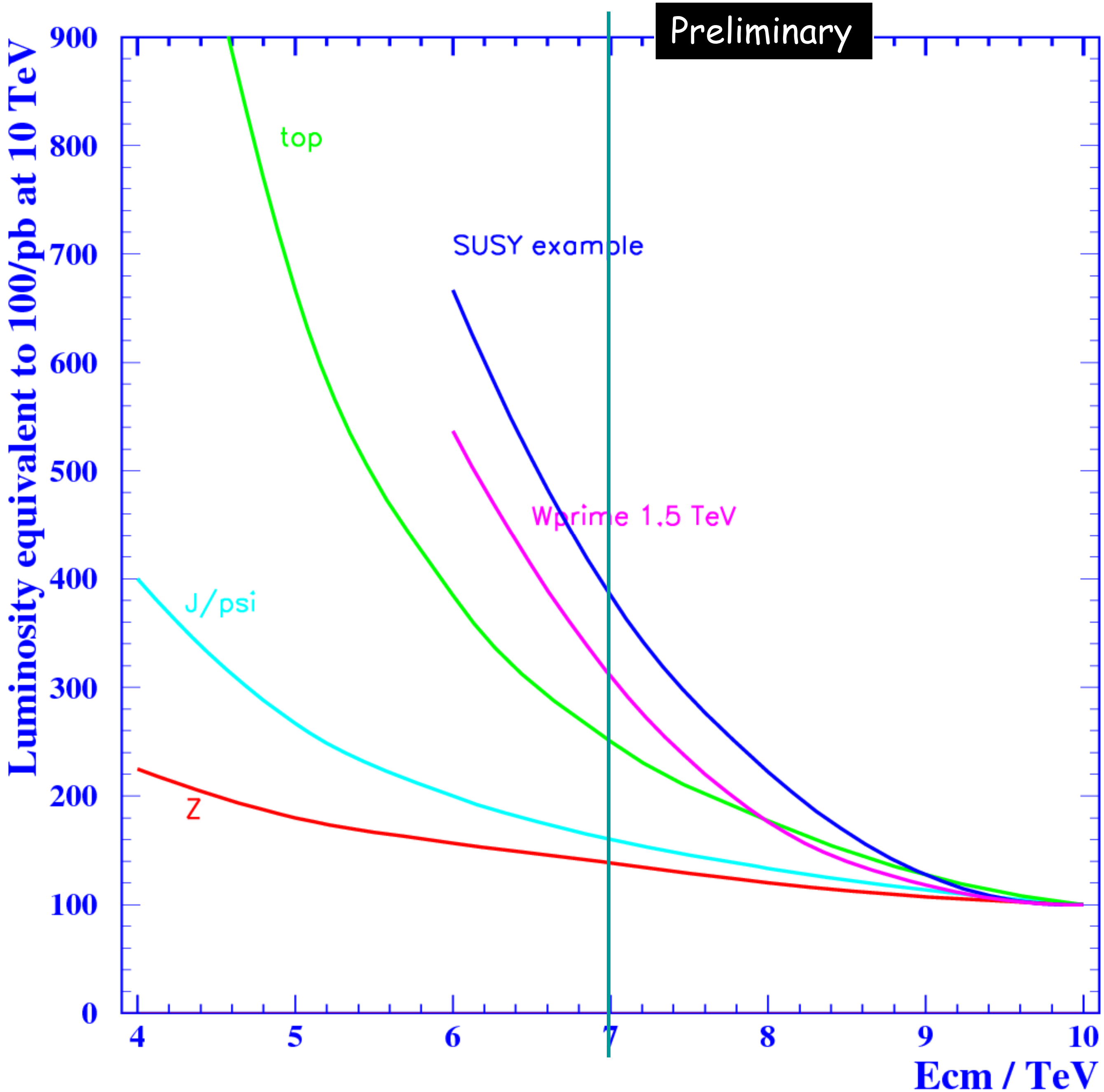
RB: case 2 (quench propagation from magnet to busbar)



Decision on Initial Beam Operating Energy

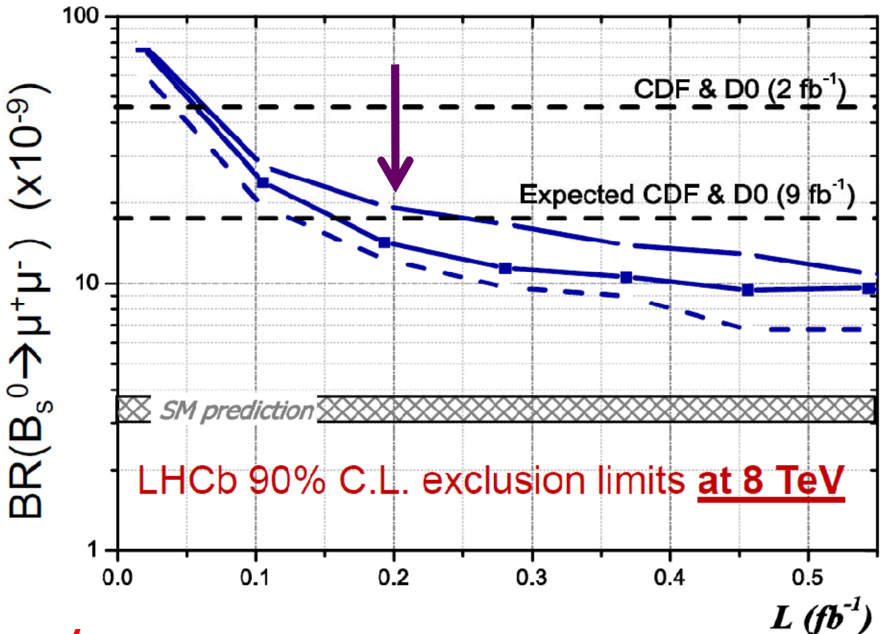
(August 2009)

- Highest measured value of excess resistance (R_{long}) in 5 sectors measured at 300K was 53$\mu\Omega$.
- Operating at 7TeV cm with a energy extraction times of 50s, 10s (dipoles and quadrupoles)
  - Simulations show that resistances of $\leq$120$\mu\Omega$ are safe from thermal runaway under conservative assumed conditions of worst case conditions for the copper quality (RRR) and no cooling to the copper stabilizer from the gaseous helium
- Operating at 10TeV cm with a dipole energy extraction time of 68 s
  - Simulations show that resistances of $\leq$67$\mu\Omega$ are safe from thermal runaway under conservative assumed conditions of worst case conditions for the copper quality (RRR), and with estimated cooling to the stabilizer from the gaseous helium
- Decision: Operation initially at 7TeV cm (energy extraction time of 50s,10s) with a safety factor or more than 2 for the worst stabilizers. During this time
  - monitor carefully all quenches to gain additional information.
  - Continue simulations and validation of simulations by experimentation (FRESCA)
- Then operate at around 10TeV cm.


Preliminary
Luminosity equivalent to 100/pb at 10 TeV
900
800
700
600
500
400
300
200
100
0
top
SUSY example
Wprime 1.5 TeV
J/psi
Z
4
5
6
7
8
9
10
Ecm / TeV

Prospects for most competitive measurements in 2010

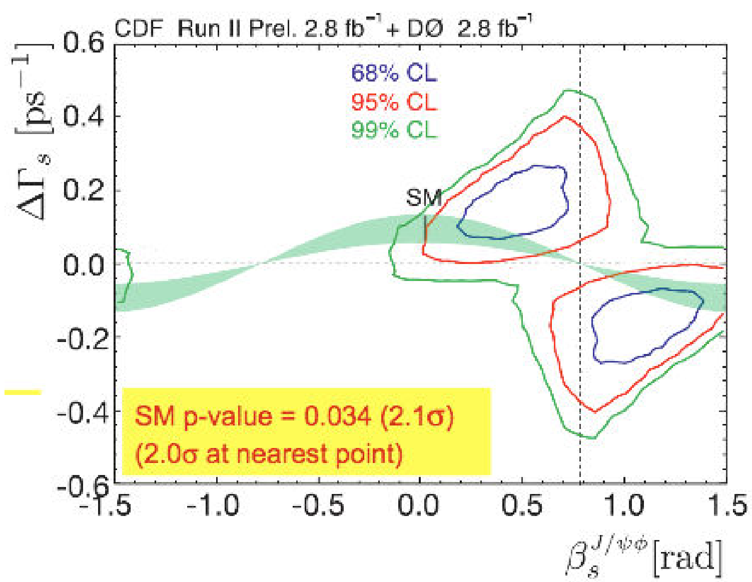
$B_s \rightarrow \mu\mu$

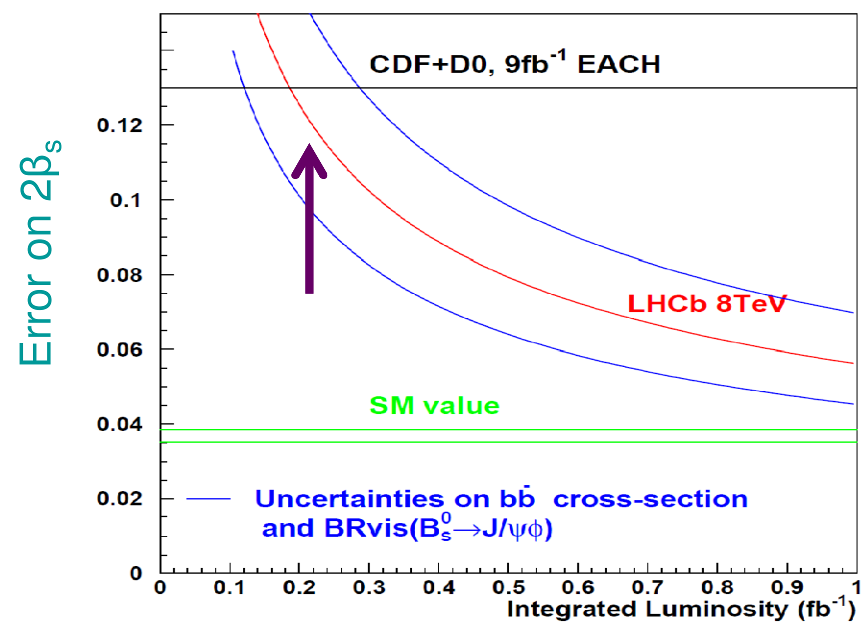


LHCb requests ~200 pb^{-1} int. lumi taken at stable conditions

***With this data sample LHCb should be able to improve Tevatron sensitivity for $B_s \rightarrow \mu\mu$ and ϕ_s** (present 'central' value from Tevatron would be confirmed at 5σ level)*

ϕ_s

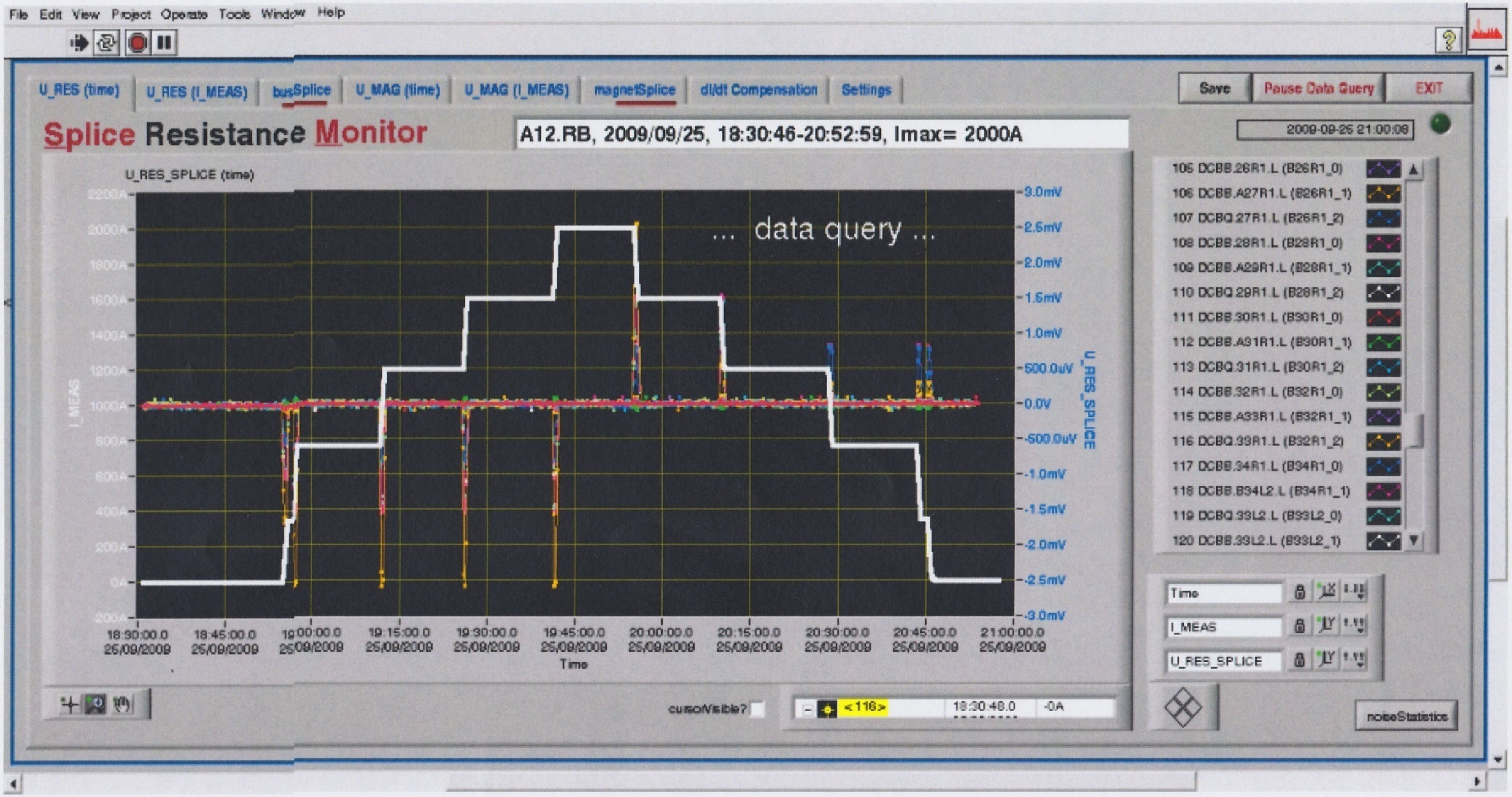




Since August

- Start of re-establishment of spares situation as it was before the incident
- Helium leak (flexible in the DFBs) in S45, S23, and S81. All repaired
- Magnet/busbar short to earth in S67 (detected and repaired)
- Vacuum “leak” (insulating vacuum) in S34 (mitigated by additional pumping)
- “bugs” associated with nQPS (delay in going to 6kA (3.5TeV)
- Priorities for 2009 re done
- New sc splice measurements
- Implementation of fast energy extraction
- Improved simulations
- Better understanding of quench propogation

New Results



Current profile and all Dipole Busbar voltages during inductive compensation tuning.

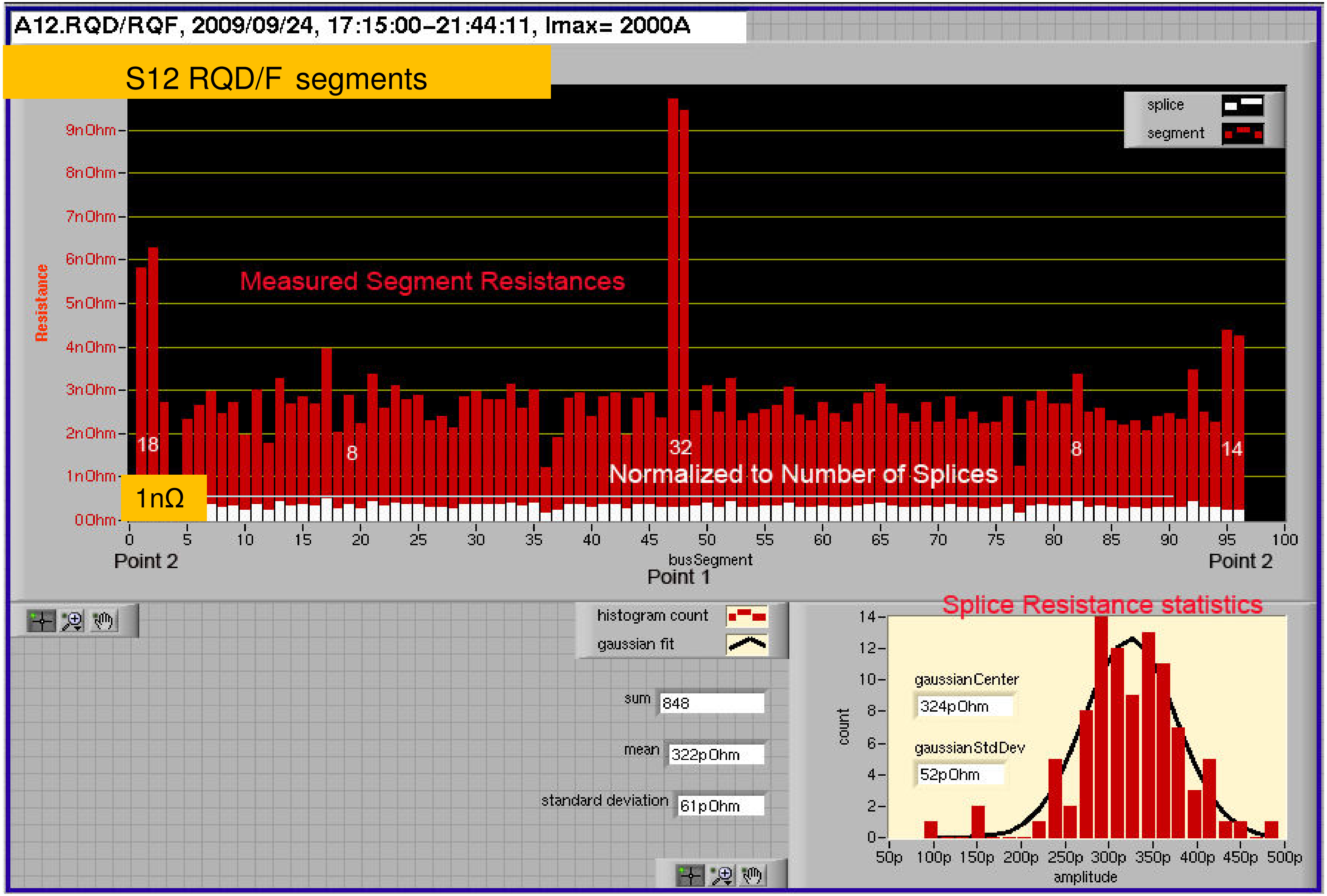
New Results

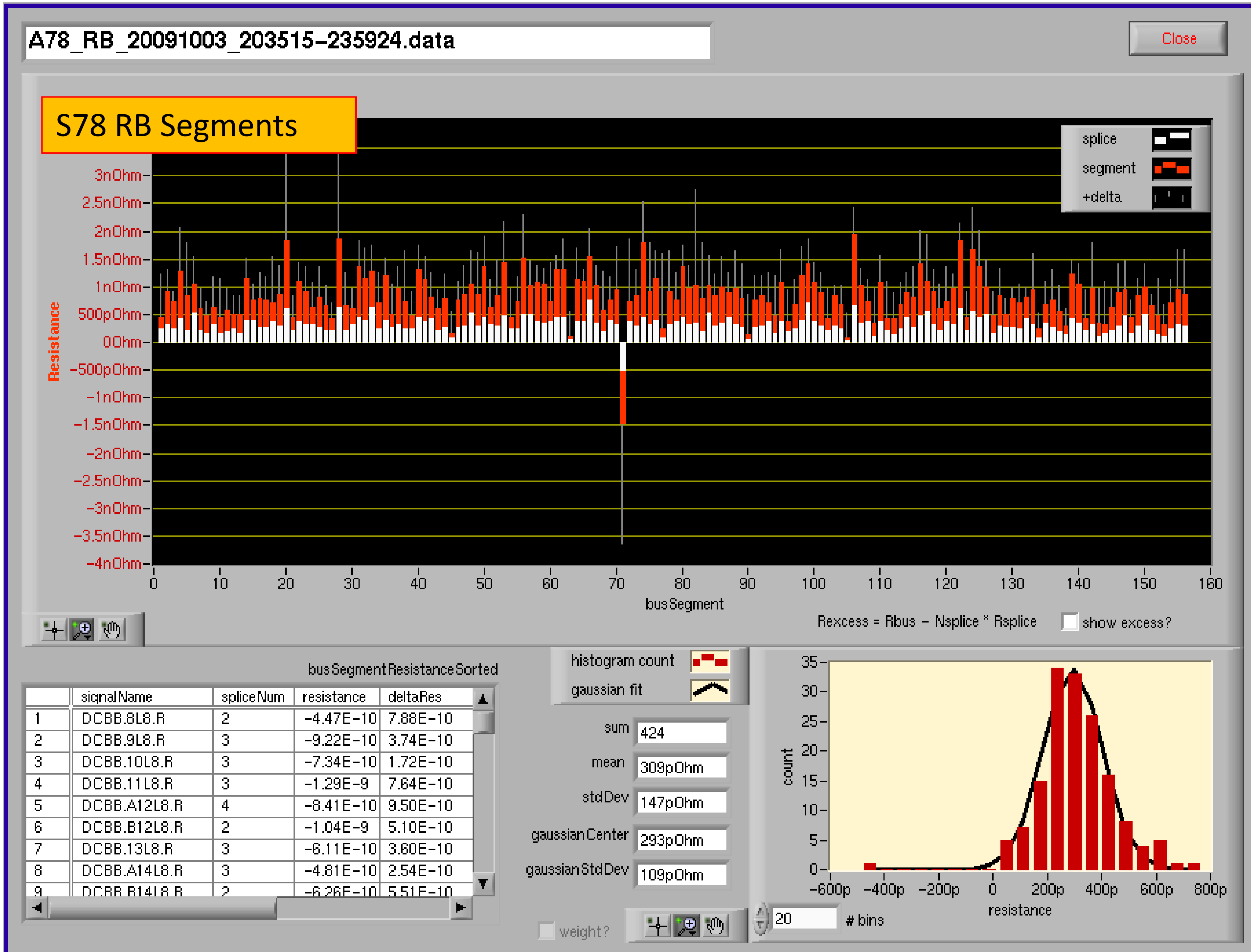
QPS team

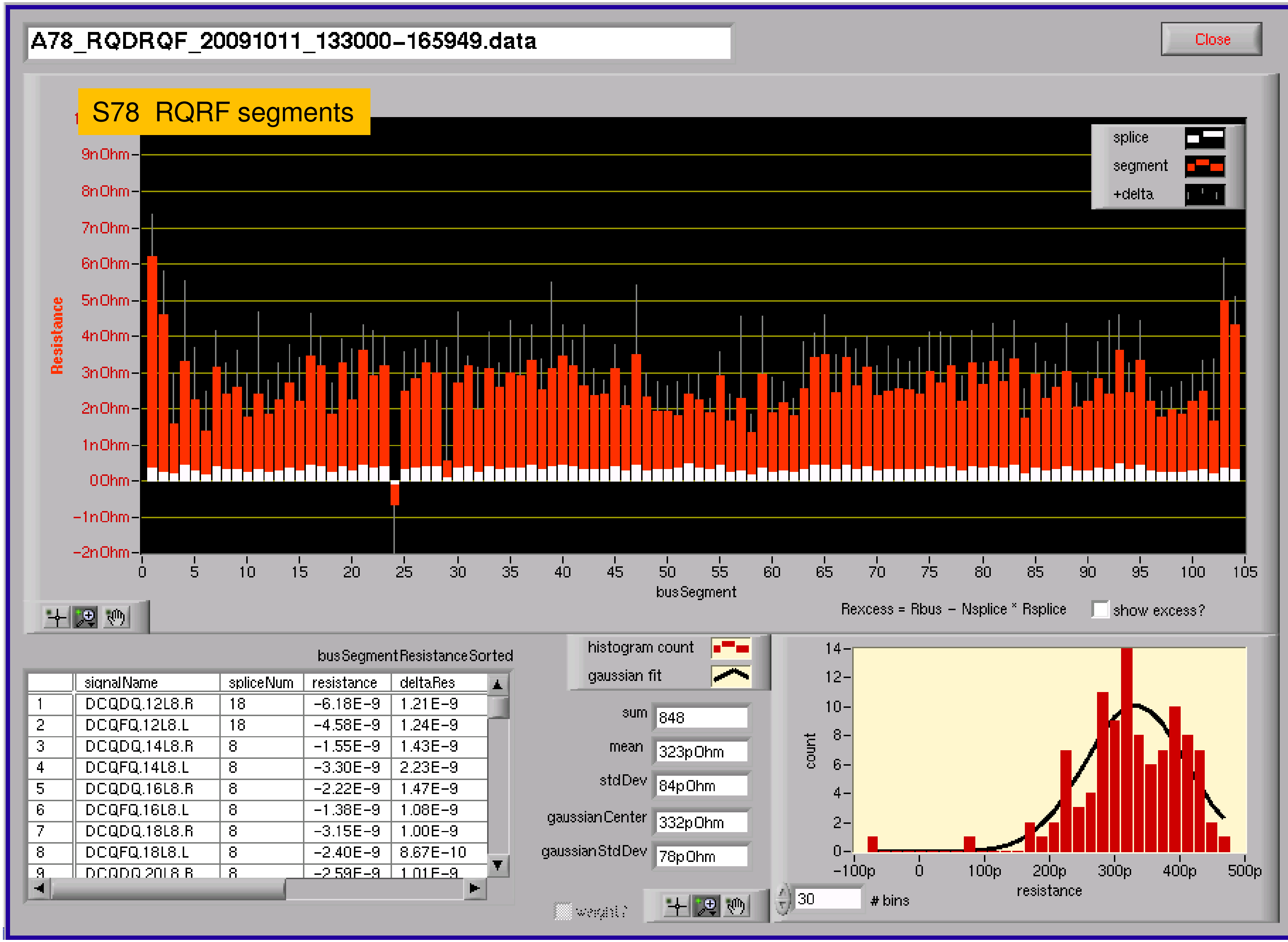
First Dipole Busbar Resistances from first scan to 2 kA

New Results

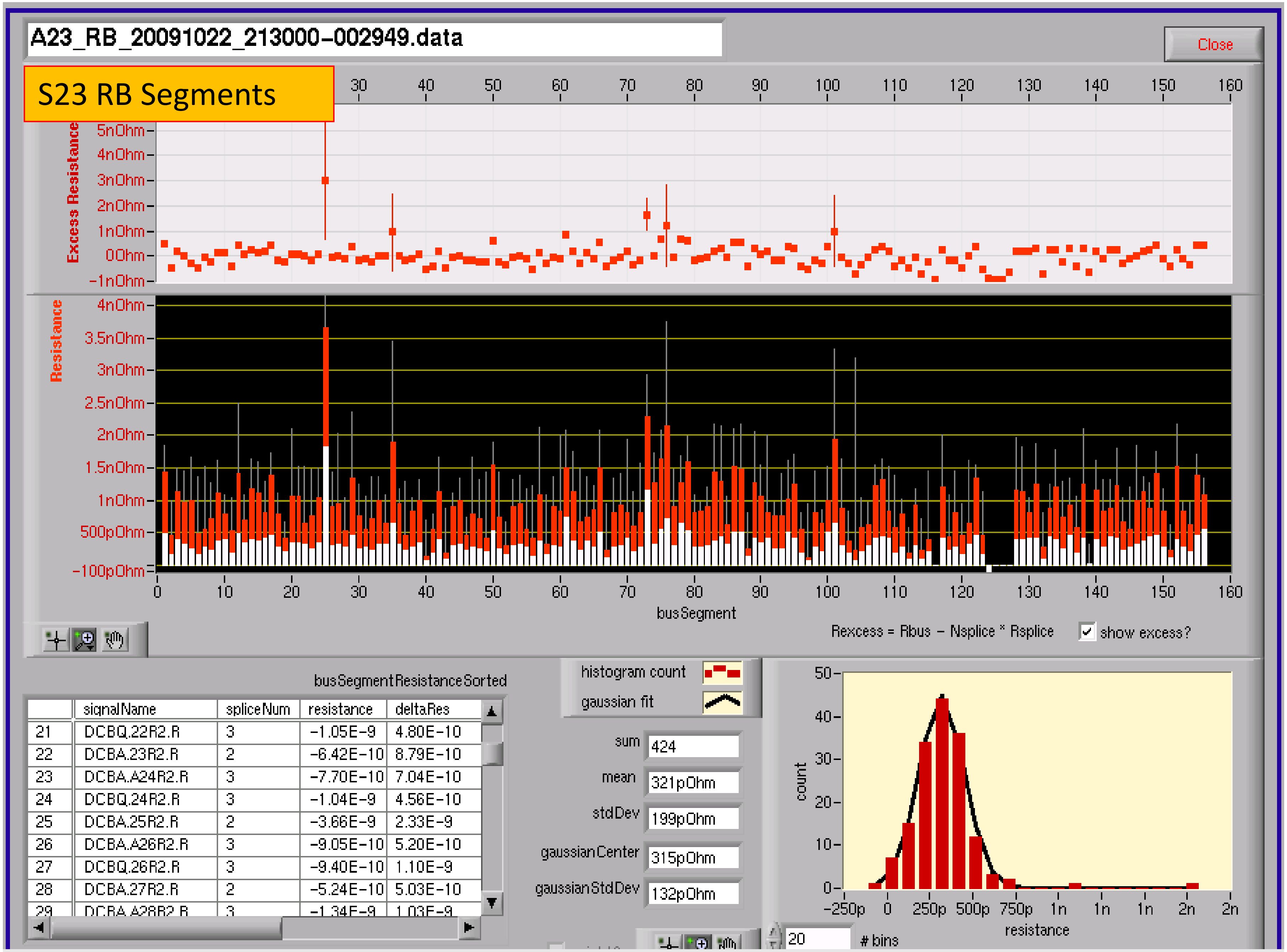
QPS team



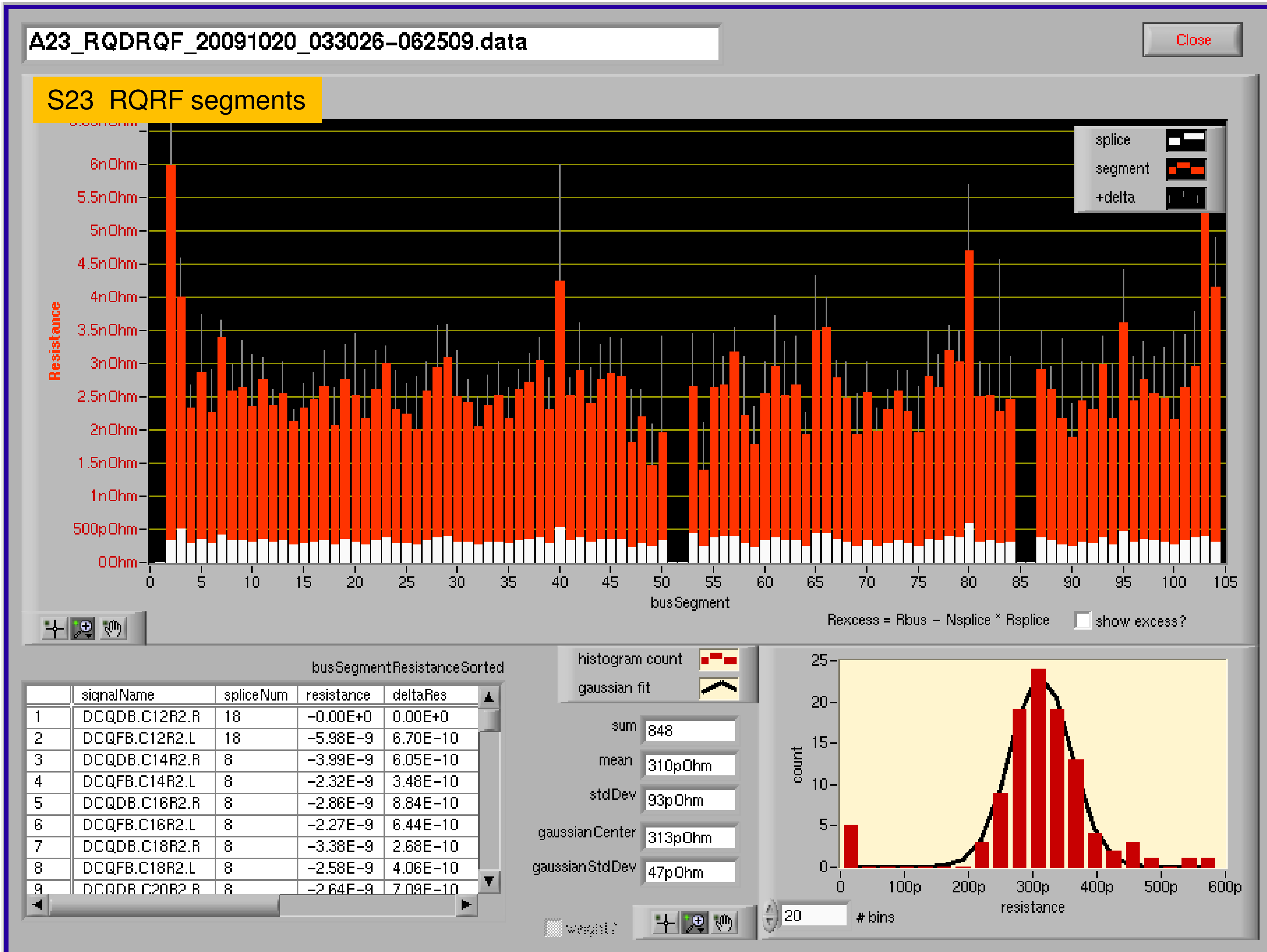

A78_RB_20091003_203515-235924.data
Close
S78 RB Segments
splice
segment
+delta
Resistance
3nOhm
2.5nOhm
2nOhm
1.5nOhm
1nOhm
500pOhm
0Ohm
-500pOhm
-1nOhm
-1.5nOhm
-2nOhm
-2.5nOhm
-3nOhm
-3.5nOhm
-4nOhm
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
busSegment
Rexcess = Rbus – Nsplice * Rsplice
show excess?
busSegmentResistanceSorted
signalName | spliceNum | resistance | deltaRes
1 | DCBB.8L8.R | 2 | -4.47E-10 | 7.88E-10
2 | DCBB.9L8.R | 3 | -9.22E-10 | 3.74E-10
3 | DCBB.10L8.R | 3 | -7.34E-10 | 1.72E-10
4 | DCBB.11L8.R | 3 | -1.29E-9 | 7.64E-10
5 | DCBB.A12L8.R | 4 | -8.41E-10 | 9.50E-10
6 | DCBB.B12L8.R | 2 | -1.04E-9 | 5.10E-10
7 | DCBB.13L8.R | 3 | -6.11E-10 | 3.60E-10
8 | DCBB.A14L8.R | 3 | -4.81E-10 | 2.54E-10
9 | DCBB.B14L8.R | 2 | -6.26E-10 | 5.51E-10
histogram count
gaussian fit
sum 424
mean 309pOhm
stdDev 147pOhm
gaussianCenter 293pOhm
gaussianStdDev 109pOhm
weight?
count
35
30
25
20
15
10
5
0
-600p -400p -200p 0 200p 400p 600p 800p
resistance
20
bins



	signalName	spliceNum	resistance	deltaRes
1	DCQDQ.12L8.R	18	-6.18E-9	1.21E-9
2	DCQFQ.12L8.L	18	-4.58E-9	1.24E-9
3	DCQDQ.14L8.R	8	-1.55E-9	1.43E-9
4	DCQFQ.14L8.L	8	-3.30E-9	2.23E-9
5	DCQDQ.16L8.R	8	-2.22E-9	1.47E-9
6	DCQFQ.16L8.L	8	-1.38E-9	1.08E-9
7	DCQDQ.18L8.R	8	-3.15E-9	1.00E-9
8	DCQFQ.18L8.L	8	-2.40E-9	8.67E-10
9	DCQDQ.20L8.R	8	-2.59E-9	1.01E-9



A23_RB_20091022_213000-002949.data
Close
S23 RB Segments
Excess Resistance
Resistance
busSegment
Rexcess = Rbus - Nsplice * Rsplice
show excess?
busSegmentResistanceSorted
signalName spliceNum resistance deltaRes
21 DCBQ.22R2.R 3 -1.05E-9 4.80E-10
22 DCBA.23R2.R 2 -6.42E-10 8.79E-10
23 DCBA.A24R2.R 3 -7.70E-10 7.04E-10
24 DCBQ.24R2.R 3 -1.04E-9 4.56E-10
25 DCBA.25R2.R 2 -3.66E-9 2.33E-9
26 DCBA.A26R2.R 3 -9.05E-10 5.20E-10
27 DCBQ.26R2.R 3 -9.40E-10 1.10E-9
28 DCBA.27R2.R 2 -5.24E-10 5.03E-10
histogram count
gaussian fit
sum 424
mean 321pOhm
stdDev 199pOhm
gaussianCenter 315pOhm
gaussianStdDev 132pOhm
count
resistance
20 # bins



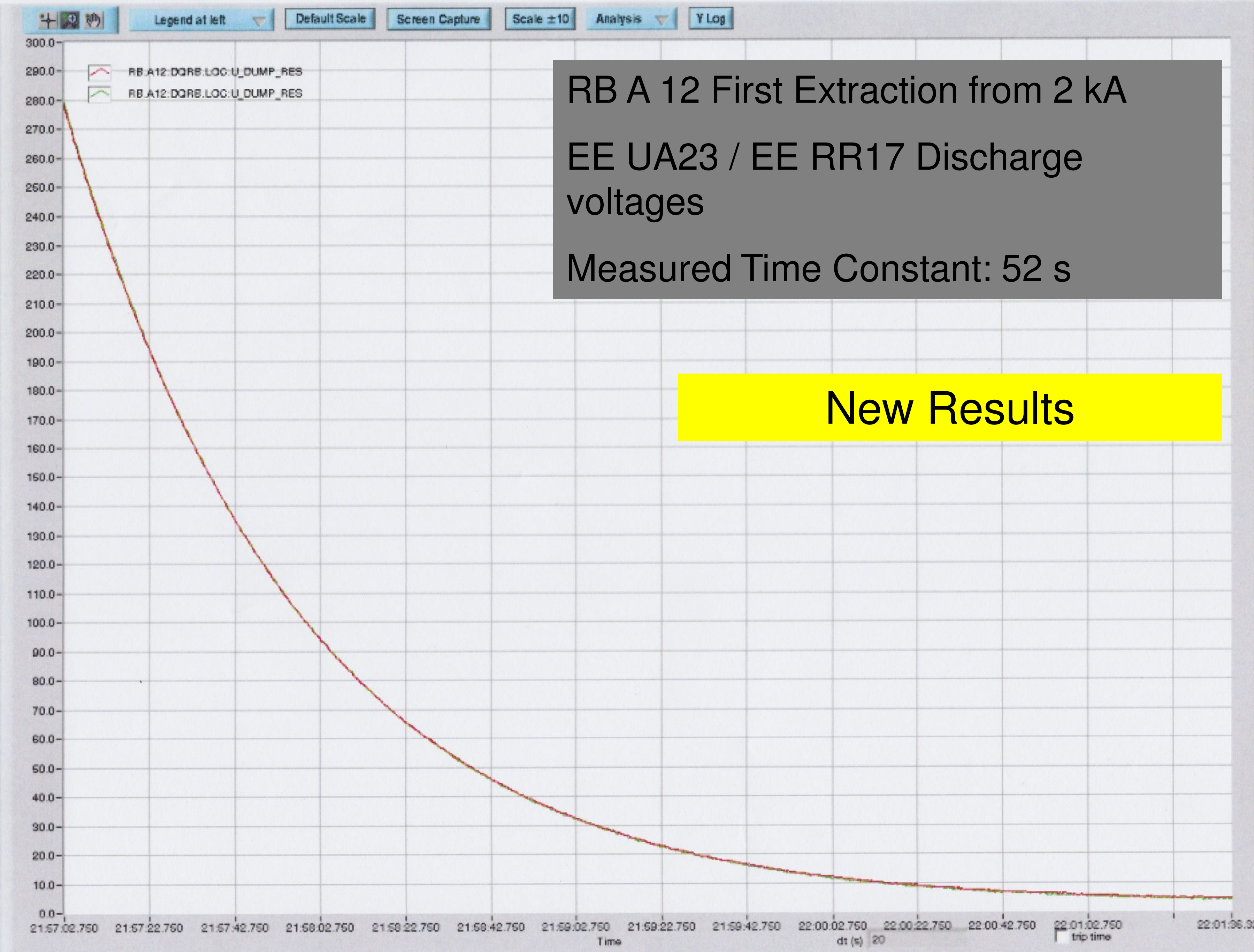
A23_RQDRQF_20091020_033026-062509.data
Close
S23 RQRF segments
splice
segment
+delta
Resistance
6nOhm
5.5nOhm
5nOhm
4.5nOhm
4nOhm
3.5nOhm
3nOhm
2.5nOhm
2nOhm
1.5nOhm
1nOhm
500pOhm
0Ohm
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105
busSegment
Rexcess = Rbus – Nsplice * Rsplice
show excess?
busSegmentResistanceSorted
signalName spliceNum resistance deltaRes
1 DCQDB.C12R2.R 18 -0.00E+0 0.00E+0
2 DCQFB.C12R2.L 18 -5.98E-9 6.70E-10
3 DCQDB.C14R2.R 8 -3.99E-9 6.05E-10
4 DCQFB.C14R2.L 8 -2.32E-9 3.48E-10
5 DCQDB.C16R2.R 8 -2.86E-9 8.84E-10
6 DCQFB.C16R2.L 8 -2.27E-9 6.44E-10
7 DCQDB.C18R2.R 8 -3.38E-9 2.68E-10
8 DCQFB.C18R2.L 8 -2.58E-9 4.06E-10
histogram count
gaussian fit
sum 848
mean 310pOhm
stdDev 93pOhm
gaussianCenter 313pOhm
gaussianStdDev 47pOhm
count
25
20
15
10
5
0
0 100p 200p 300p 400p 500p 600p
resistance
20 # bins

RB A 12 First Extraction from 2 kA

EE UA23 / EE RR17 Discharge voltages

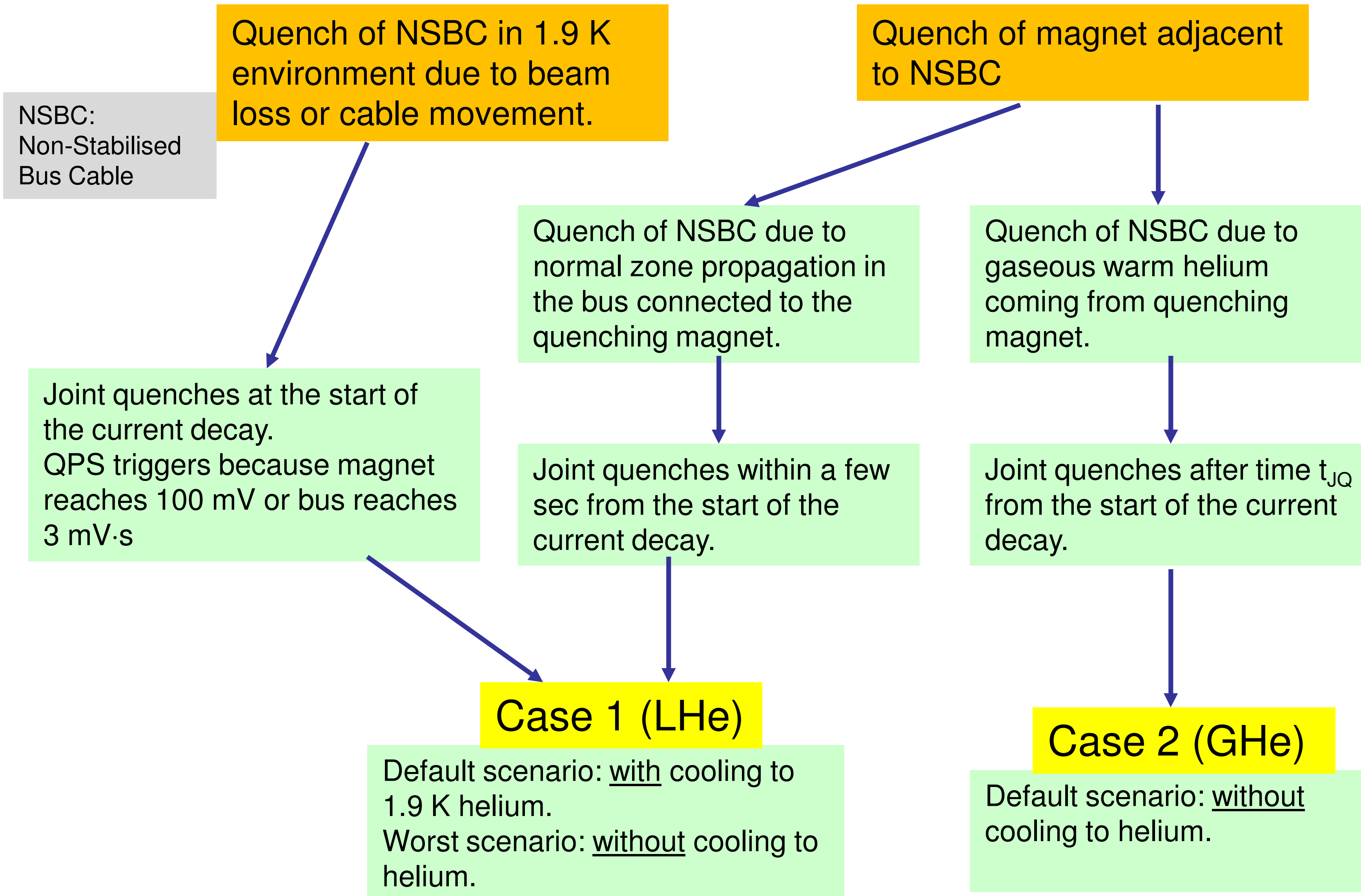
Measured Time Constant: 52 s

New Results



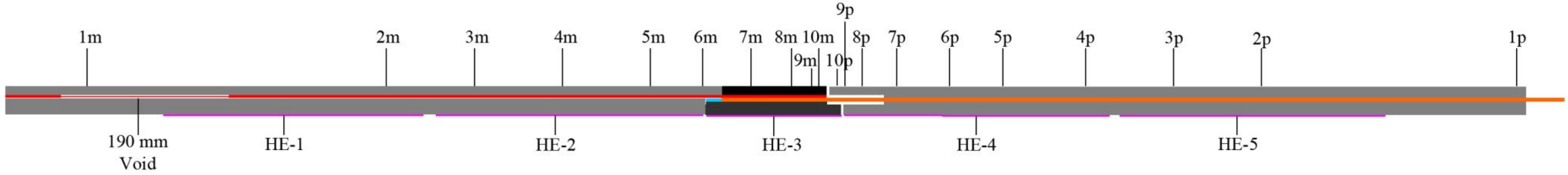
Measurements and simulations of splices

New Results

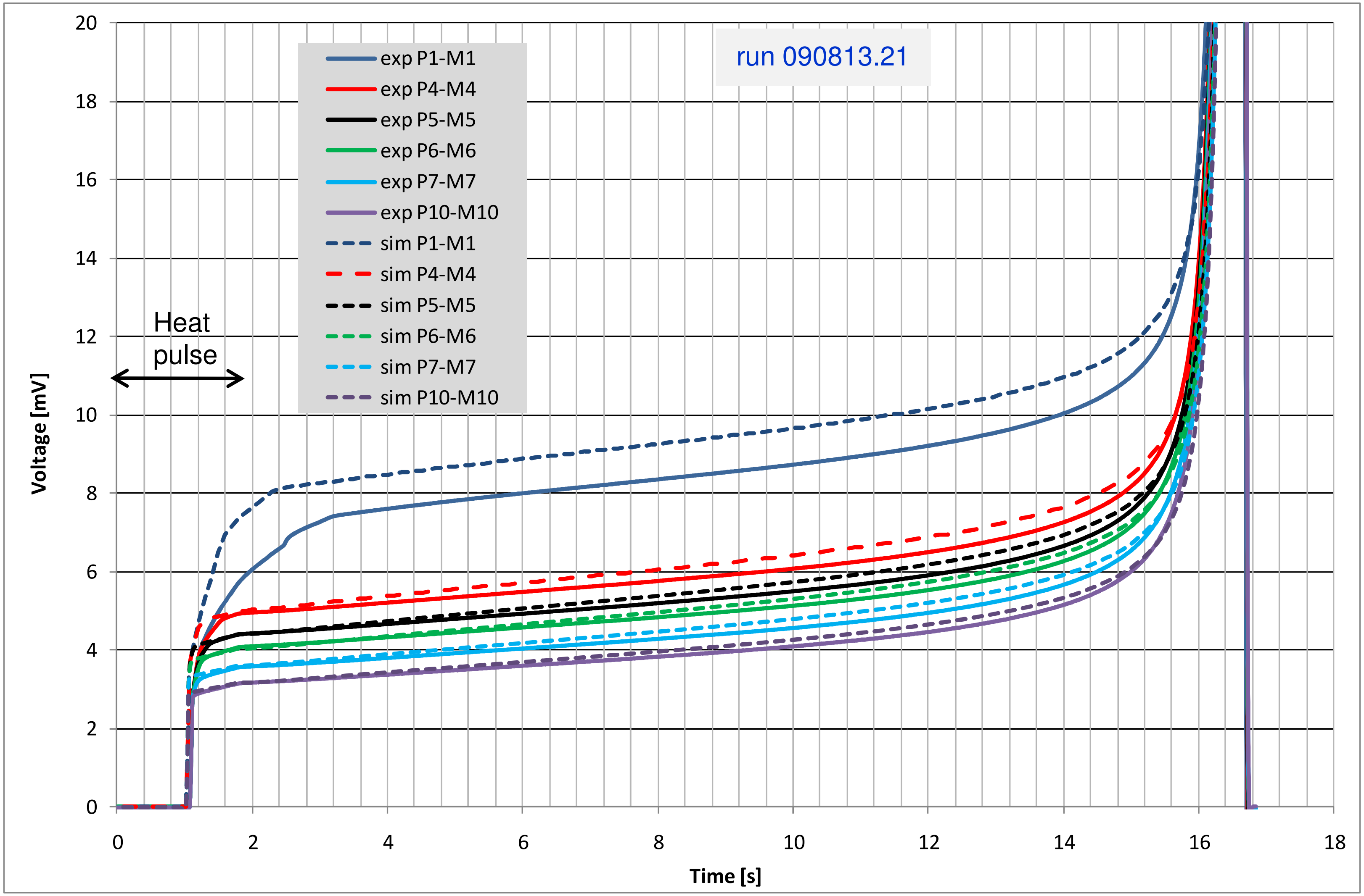

NSBC:
Non-Stabilised
Bus Cable
Quench of NSBC in 1.9 K environment due to beam loss or cable movement.
Quench of magnet adjacent to NSBC
Quench of NSBC due to normal zone propagation in the bus connected to the quenching magnet.
Quench of NSBC due to gaseous warm helium coming from quenching magnet.
Joint quenches at the start of the current decay. QPS triggers because magnet reaches 100 mV or bus reaches 3 mV·s
Joint quenches within a few sec from the start of the current decay.
Joint quenches after time t_{JQ} from the start of the current decay.
Case 1 (LHe)
Default scenario: with cooling to 1.9 K helium. Worst scenario: without cooling to helium.
Case 2 (GHe)
Default scenario: without cooling to helium.

Differences

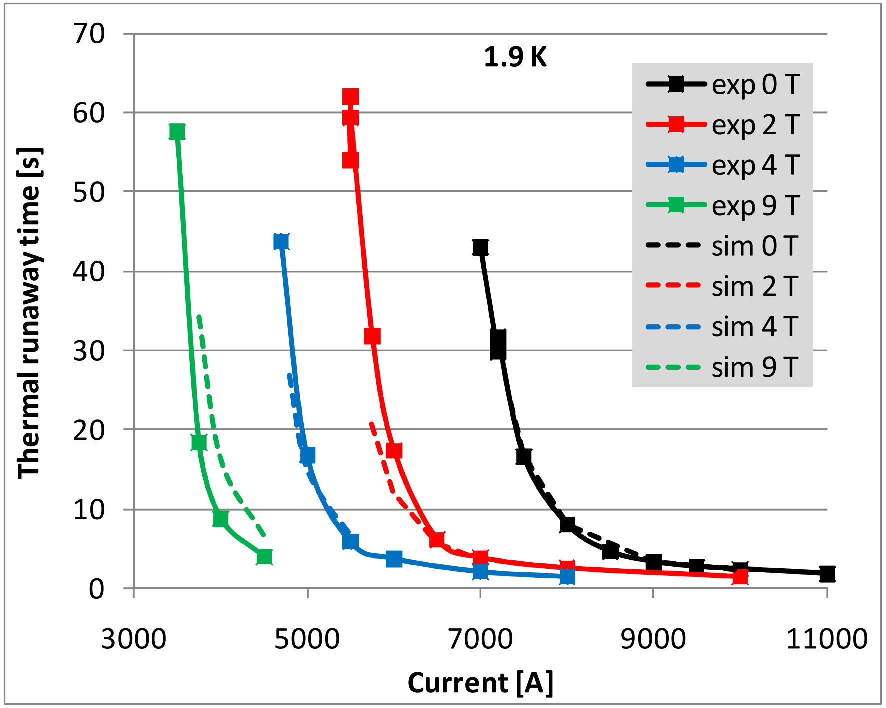
	FRESCA	Machine
Helium environment	LHe (case 1)	LHe (case 1) and GHe (case 2)
Tube position	Vertical	Horizontal
Tube diameter	72 mm	90 / 103 mm
RRR bus	About 300	100 (worst case)
RRR cable	About 180	120 (worst case) ?
Current profile	Constant	Exponential decay
Interconnect insulation	2 mm G10 + glue (length 24 cm)	2xU profile kapton + 2x U profile G10 (length 21-24 cm)
Effective cooled bus surface	25-60%	90-100%
Field	Self-field + 0-9 T (varying along length)	Self-field
Length NSBC	47 mm (R_{addit}=61 $\mu\Omega$)	Up to ??

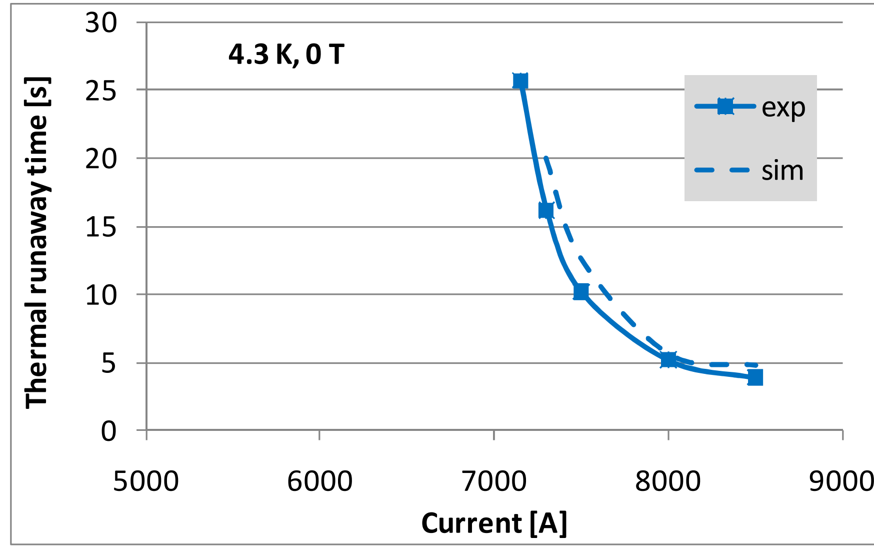


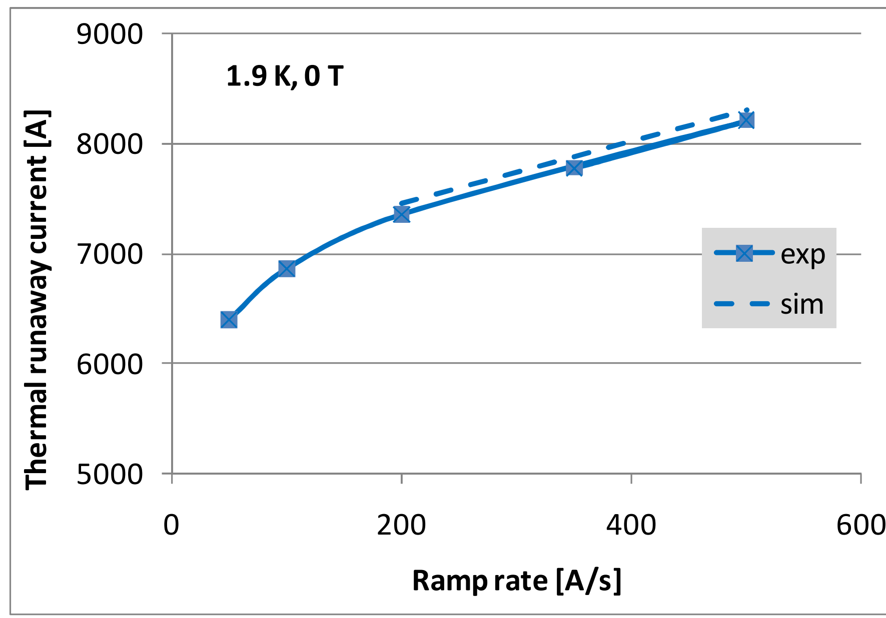
1.9 K, 0 T, 7.5 kA



A. Verweij, TE-







Correlation experiment vs. calculation

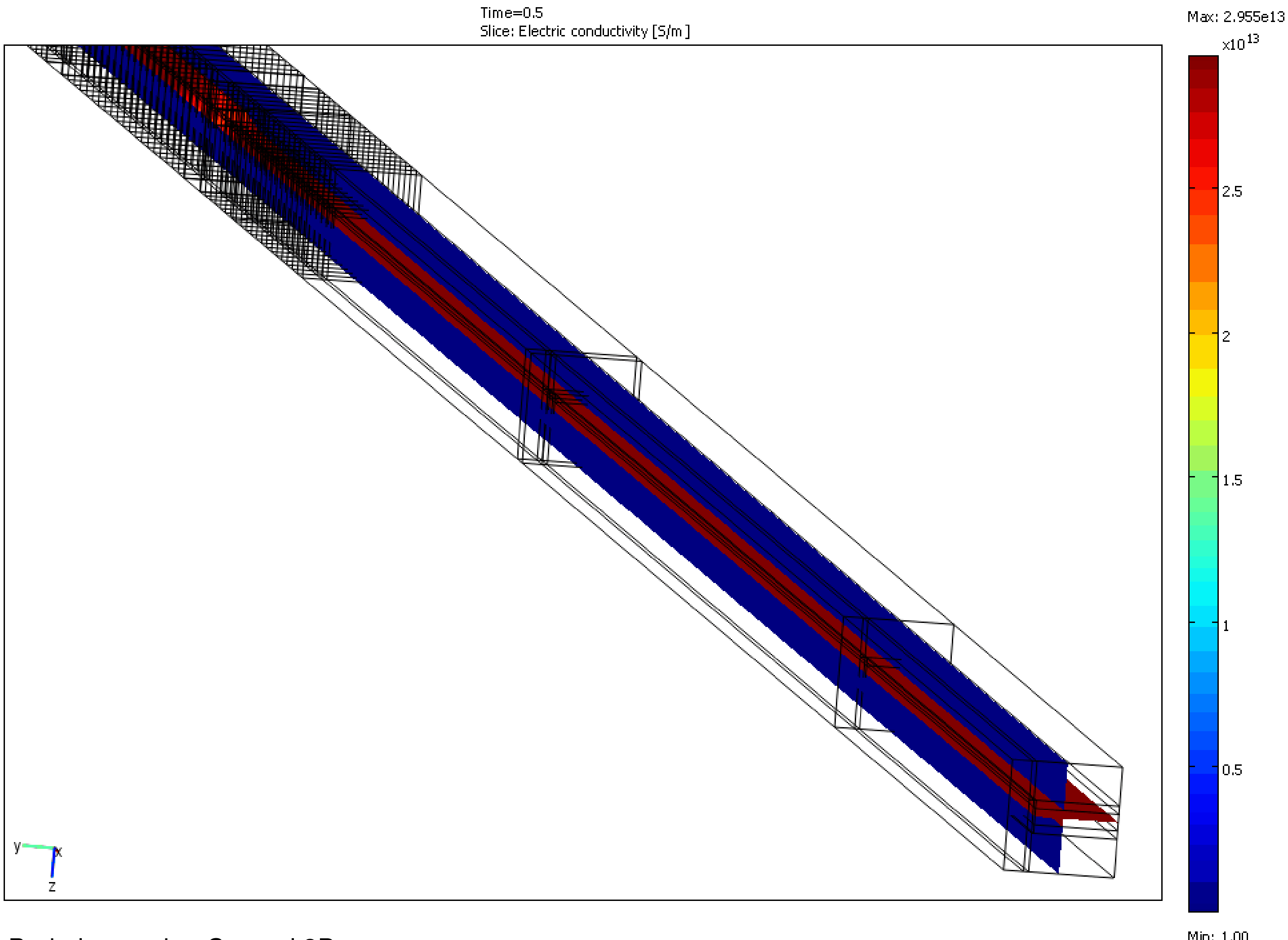
A. Verweij, TE-

Conclusion on ‘Analysis FRESCA test’

- The simulation code (QP3) is now validated!!! There is a good agreement between experiment and calculations for the voltage signals, the temperatures and the thermal runaway times (for 1.9 K and 4.3 K and currents from 2-12 kA). The quench currents of more than 50 test cases can be simulated with an accuracy better than a few hundred Amps.

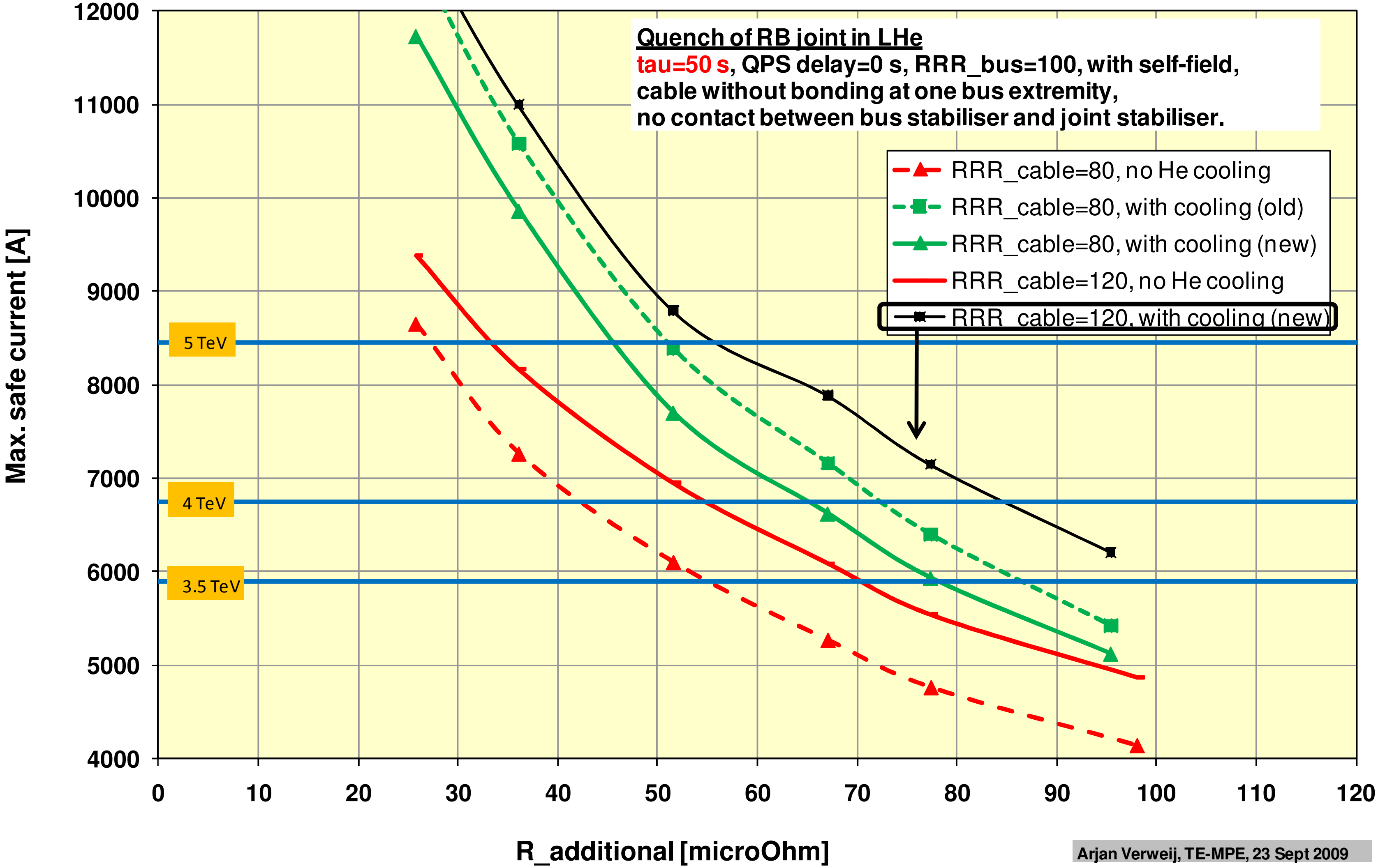
- To fit the calculations to the experiments, the cooling to helium had to be reduced by about 15% as compared to previous assumptions, possibly due to the presence of film boiling.

Quench propagation

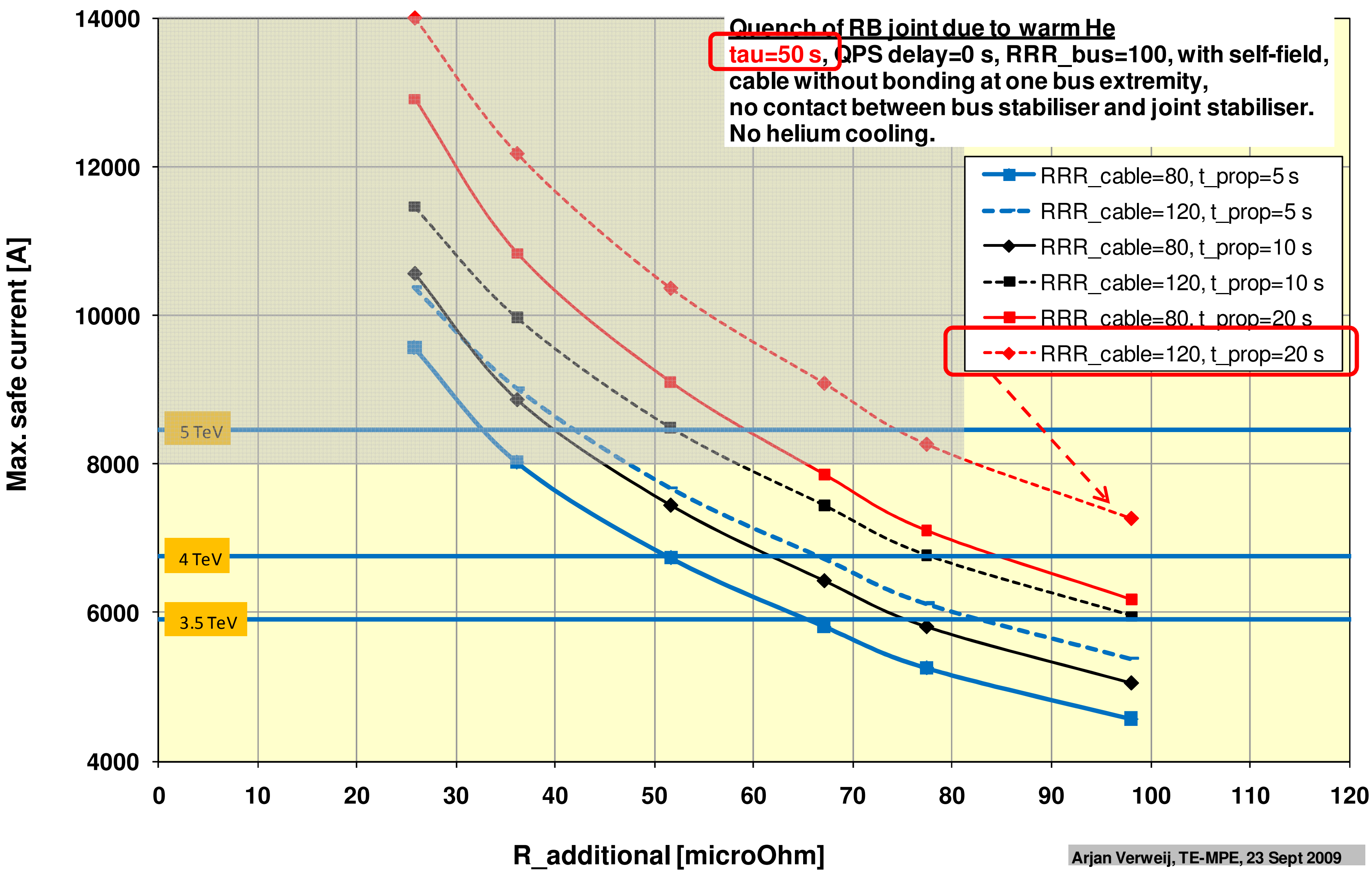


R. Berkelaar, using Comsol 3D

RB: case 1 (quench in 1.9 K environment)



RB: case 2 (quench in GHe environment)



Summary table of maximum allowable additional resistance for RB circuit with tau=50 s.
Safety margin not included

Case	3.5 TeV	4 TeV	5 TeV
LHe (case 1), RRR_{cable}=80, no He cooling	55	42	27
LHe (case 1), RRR_{cable}=120, no He cooling	70	55	33
LHe (case 1), RRR_{cable}=80, with He cooling	78	65	45
LHe (case 1), RRR_{cable}=120, with He cooling	102	84	55
GHe (case 2), RRR_{cable}=80, t_{prop}=10 s	75	62	(40)
GHe (case 2), RRR_{cable}=80, t_{prop}=20 s	103	85	(60)
GHe (case 2), RRR_{cable}=120, t_{prop}=10 s	98	78	(52)
GHe (case 2), RRR_{cable}=120, t_{prop}=20 s	120	110	(74)

tau=100 s	7 TeV
LHe (case 1), RRR_{cable}=120, with He cooling	26

For info

Summary table of maximum allowable additional resistance for RQ circuit with tau=10 s.
Safety margin not included

Case	3.5 TeV	4 TeV	5 TeV
LHe (case 1), RRR_{cable}=80, no He cooling	68	54	36
LHe (case 1), RRR_{cable}=120, no He cooling	94	73	48
LHe (case 1), RRR_{cable}=80, with He cooling	80	65	46
LHe (case 1), RRR_{cable}=120, with He cooling	104	85	59
GHe (case 2), RRR_{cable}=80, t_{prop}=10 s	>200	(>200)	(>200)
GHe (case 2), RRR_{cable}=80, t_{prop}=20 s	>200	(>200)	(>200)
GHe (case 2), RRR_{cable}=120, t_{prop}=10 s	>200	(>200)	(>200)
GHe (case 2), RRR_{cable}=120, t_{prop}=20 s	>200	(>200)	(>200)

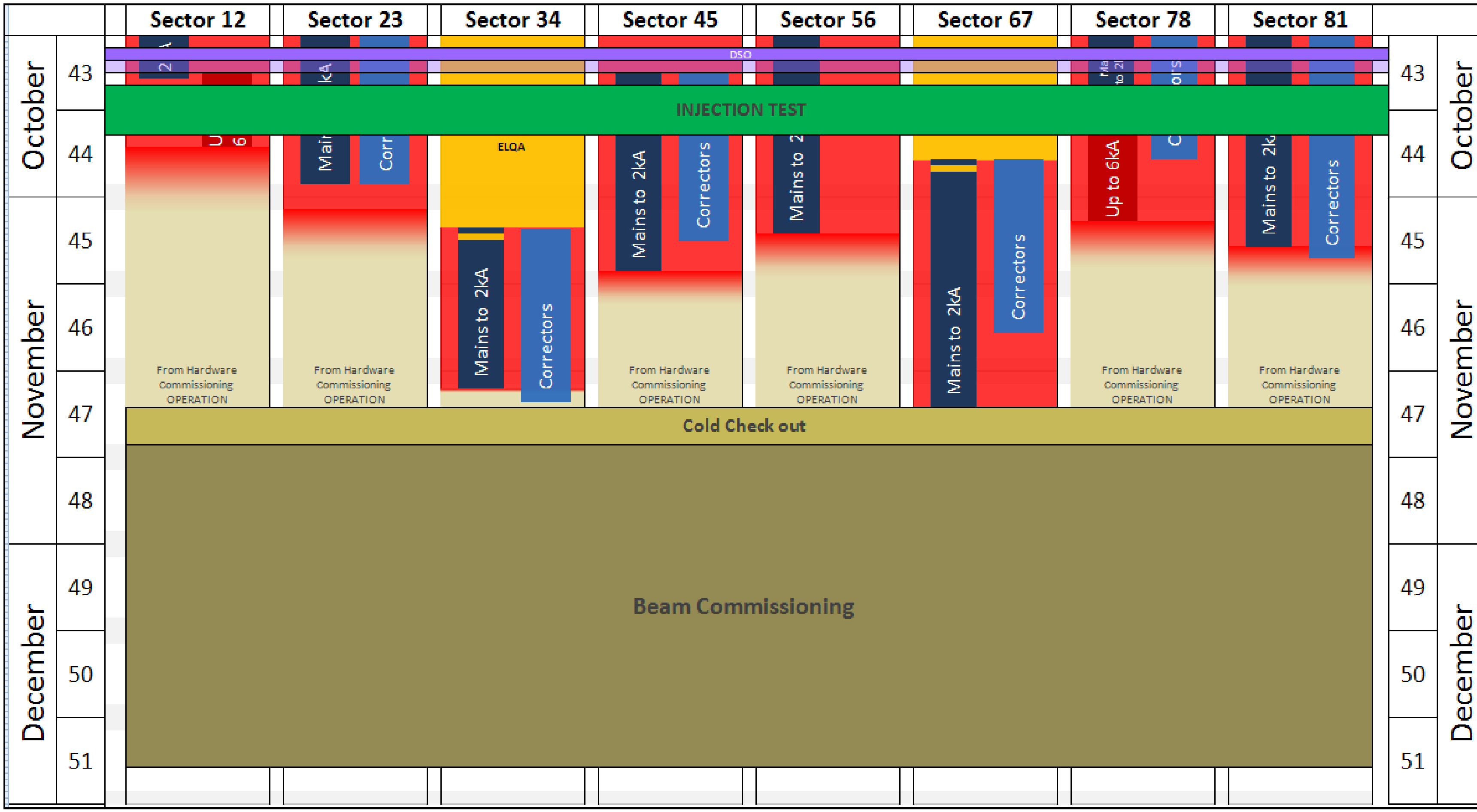
Conclusion on ‘Safe current calculations’:

- After analysis of the ‘FRESCA 61 μΩ test’ and taking RRR_{bus}=100, RRR_{cable}=120, tau_{RB}=50 s, tau_{RQ}=10 s, and assuming a pessimistic maximum R_{addit}=90 μΩ, one can conclude that **operating at 3.5 TeV is totally safe.** For same pessimistic assumptions,operation at 5 TeV seems “on the limit”, especially because at this energy a magnet quench could propagate quickly to the interconnect by propagation in the bus.

- A few more FRESCA tests in a ‘machine-type layout’ are planned for the coming months and will give additional experimental data for better understanding of the thermal processes. Samples containing low RRR_{bus} (100-150) and R_{addit} with values between 20 and 50 μΩ are most important.

LHC Schedule

Schedule



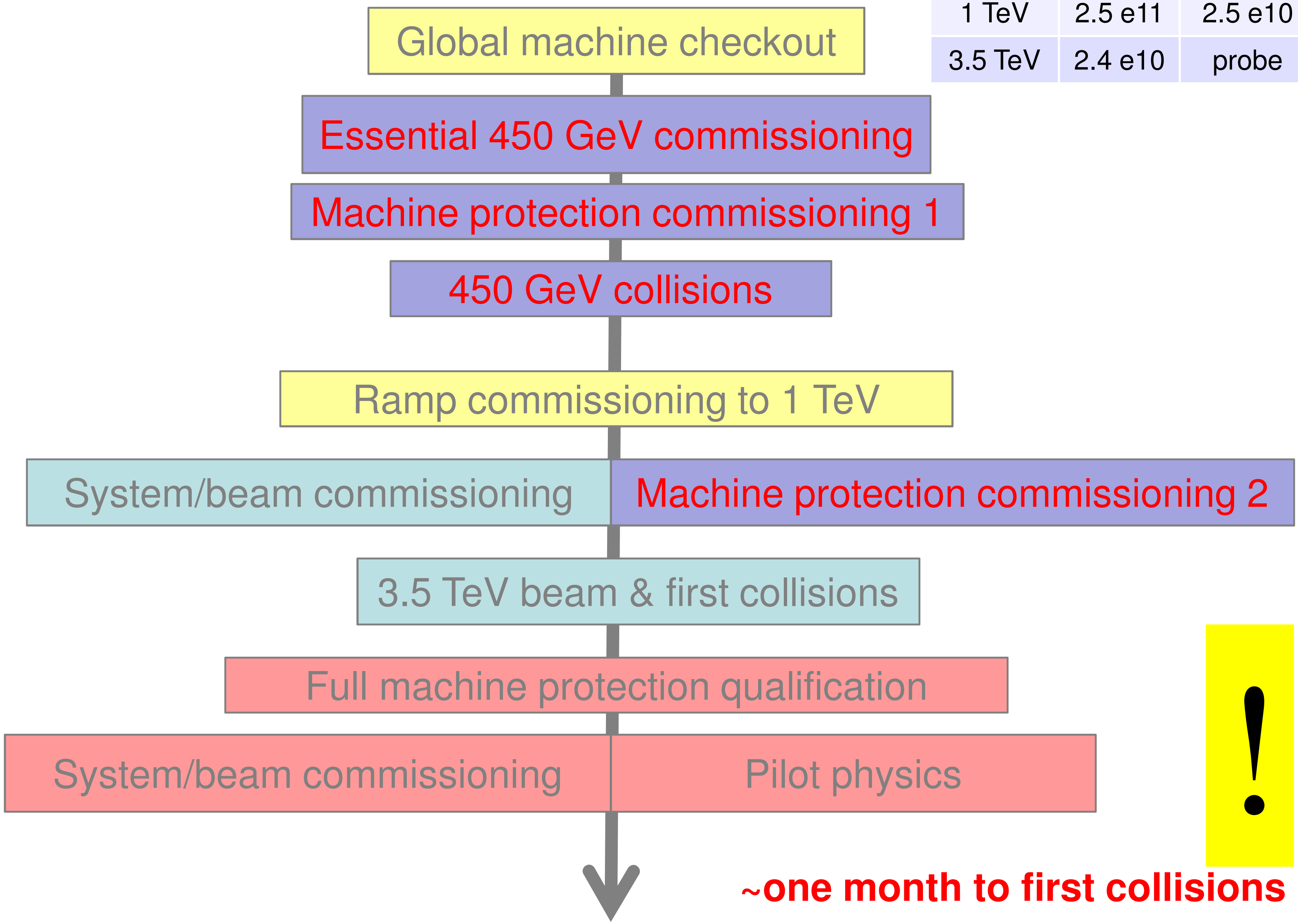
Sector 12
Sector 23
Sector 34
Sector 45
Sector 56
Sector 67
Sector 78
Sector 81
October
November
December
43
44
45
46
47
48
49
50
51
DSO
INJECTION TEST
ELQA
Mains to 2kA
Correctors
Up to 6kA
From Hardware Commissioning OPERATION
Cold Check out
Beam Commissioning

LHC 2009/2010 – running scenarios

this is the present plan which will almost certainly be modified on a daily/weekly basis once we start with beam commissioning.
BUT we need a plan!

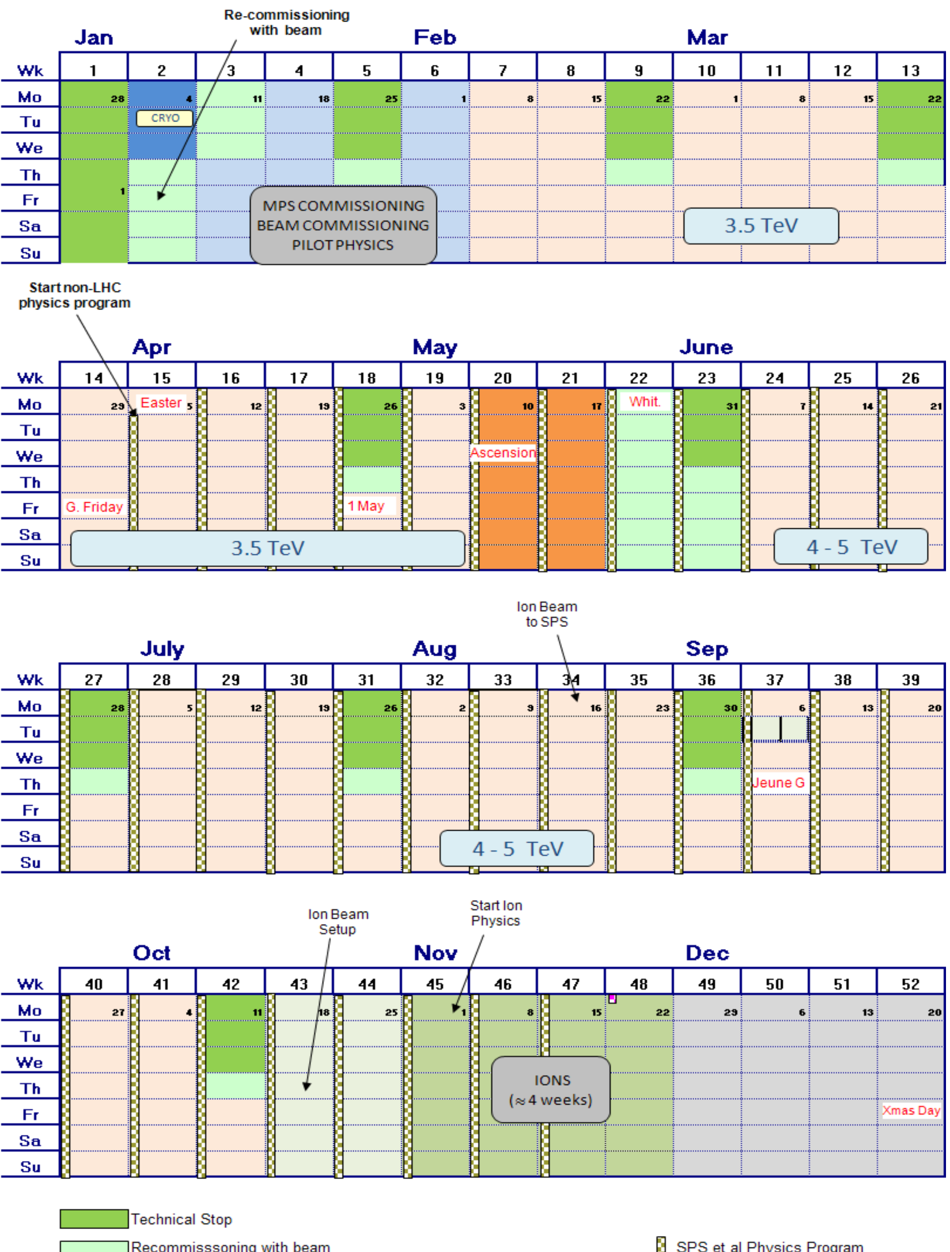
LHC beam commissioning

Energy	Safe	Very Safe
450	1 e12	1 e11
1 TeV	2.5 e11	2.5 e10
3.5 TeV	2.4 e10	probe



~one month to first collisions

LHC 2010 – very draft



- **2009**:
  - 1 month commissioning
- **2010**:
  - 1 month pilot & commissioning
  - 3 month 3.5 TeV
  - 1 month step-up
  - 5 month 4 - 5 TeV
  - 1 month ions

Possible evolution (2010)

Physics at 3.5 TeV
beta* = 2 m
no crossing angle, 156 bunches

Step up in energy

Ramp, squeeze, ramp to 4-5 TeV
beta* = 2 m
no crossing angle, 156 bunches

↓

Ramp, squeeze at 4-5 TeV
beta* = 2 m
crossing angle, 50 ns

Plugging in the numbers with a step in energy

Month	OP scenario	Max number bunch	Protons per bunch	Min beta*	Peak Lumi	Integrated	% nominal
1	Beam commissioning						
2	Pilot physics combined with commissioning	43	3×10^{10}	4	8.6×10^{29}	~200 nb^{-1}	
3		43	5×10^{10}	4	2.4×10^{30}	~1 pb^{-1}	
4		156	5×10^{10}	2	1.7×10^{31}	~9 pb^{-1}	2.5
5a	No crossing angle	156	7×10^{10}	2	3.4×10^{31}	~18 pb^{-1}	3.4
5b	No crossing angle – pushing bunch intensity	156	1×10^{11}	2	6.9×10^{31}	~36 pb^{-1}	4.8
6	Shift to higher energy: approx 4 weeks	Would aim for physics without crossing angle in the first instance with a gentle ramp back up in intensity					
7	4 – 5 TeV (5 TeV luminosity numbers quoted)	156	7×10^{10}	2	4.9×10^{31}	~26 pb^{-1}	3.4
8	50 ns – nominal Xing angle	144	7×10^{10}	2	4.4×10^{31}	~23 pb^{-1}	3.1
9	50 ns	288	7×10^{10}	2	8.8×10^{31}	~46 pb^{-1}	6.2
10	50 ns	432	7×10^{10}	2	1.3×10^{32}	~69 pb^{-1}	9.4
11	50 ns	432	9×10^{10}	2	2.1×10^{32}	~110 pb^{-1}	12

Summary beam commissioning

- First injection test – 24/25 October !
- With a bit of luck - first high energy collisions just before Christmas
- Step up in energy would take ~4 weeks physics to physics
- Would start at higher energy with a flat machine before bringing on crossing angle and exploiting 50 ns.
- Interesting times.

Preparations for the Future

Operational Consolidation

Operational Consolidation : Strategy

1. we have prepared an inventory of
   a) the existing spares and spare components for the LHC
   b) the existing spare components of the LHC infrastructure
   c) Consolidation needed to increase the efficiency of safe operation of the machine in the longer term
2. we have prepared a preliminary estimate of the total materials cost
3. In the MTP, we have planned a budget of 25MCHF/year to carry out this programme
4. The time prioritization of the operational consolidation work is being done by Risk Ranking of the inventory
5. The manpower needed to carry out this programme has not yet been identified

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Operational Consolidation

Materials cost only

- Spares (29MCHF)
- Helium storage (7.7MCHF)
- Cooling Tower maintenance and consolidation (LEP/LHC HVAC) (33MCHF)
- Electrical network consolidation (43MCHF)
- Radiation to electronics SEU; continuation of protection (4MCHF)

Vertical Pits/shafts (30MCHF)

- Tunnel modifications for overpressure: safety requirements (5MCHF)
- ARCOM-RAMSES replacement (10MCHF)
- Improvement in controlled access system (5MCHF)
- Clamping of busbar splices, development followed by campaign of replacements? (12MCHF)
- Vacuum consolidation to reduce collateral damage in case of splice rupture (+ protection of experiments)

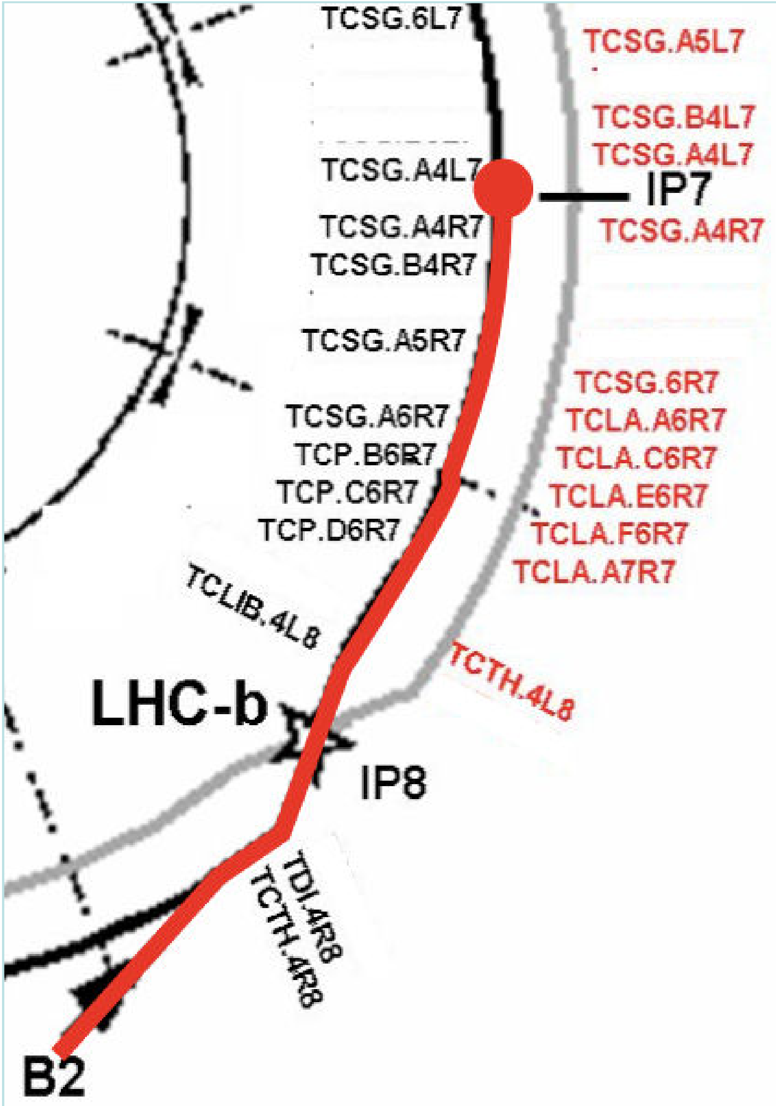
Not yet known how to do technically)

- Centralised radiation workshop (3.0MCHF)
- Consolidation workshops (3) Transport (12.8), Radio protection (4)...19.8MCHF
- Water cooled cable replacement (if FLOHE would not pay).. (4MCHF)

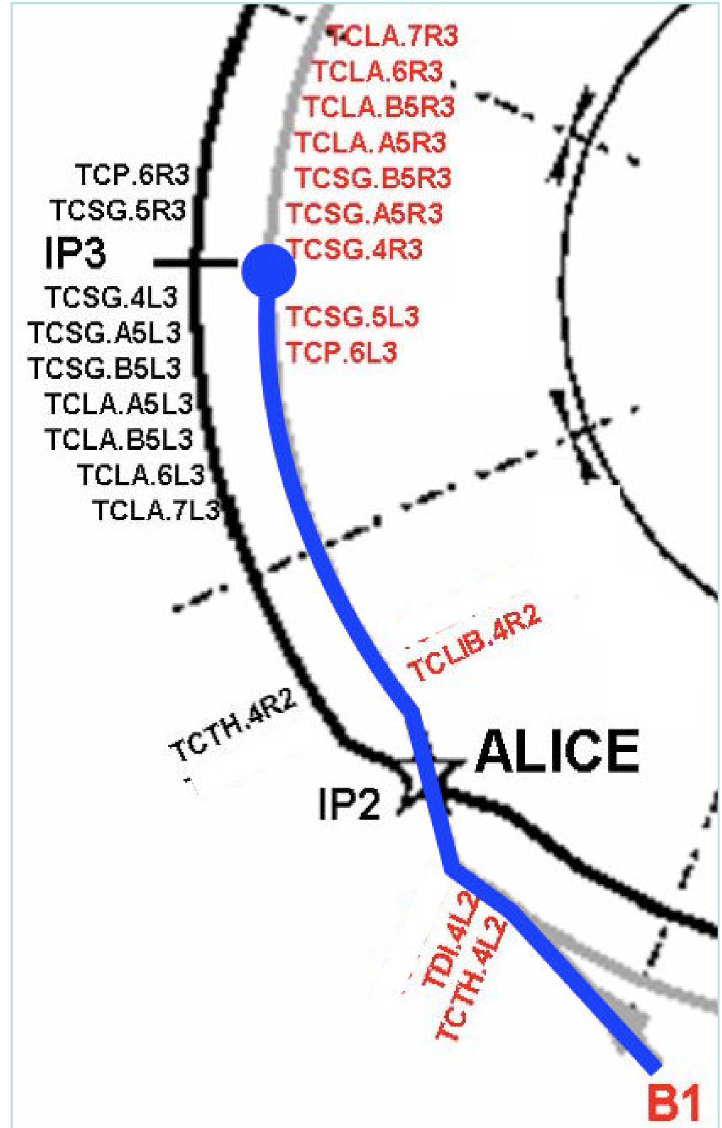
MTP Approved!

Very preliminary total cost 176MCHF or if shafts needed ~ 200MCHF + vacuum consolidation

Injection test(s) 2009



Injection tests 2009



Main Objectives

- Injection region
  - aperture, protection, kickers
- Threading, energy matching
- Optics measurements
  - check re-matched lines and dispersion into LHC
  - polarities
- Beam instrumentation system response
  - BLMs, BPM (BST triggered acquisition)
- Aperture checks
- Check spectrometers

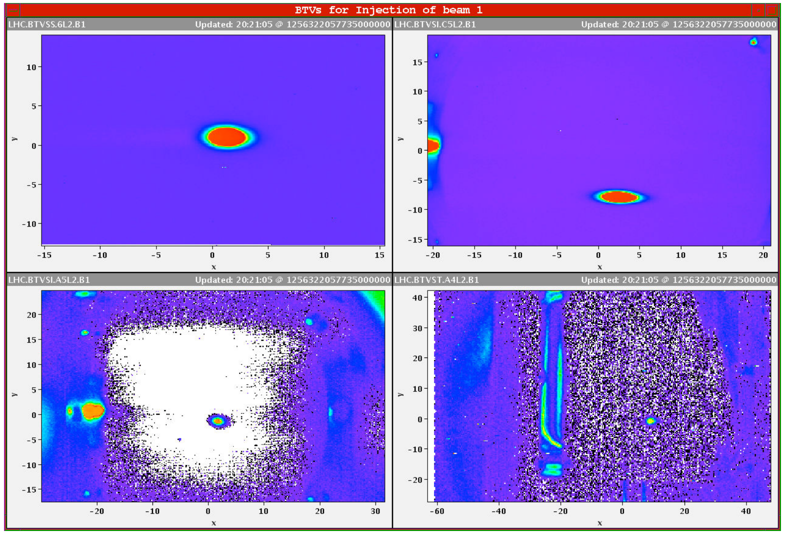
Pre-requisites and procedures detailed

Injection test: 23-27 October 2009

		Duration	Intensity	# shots	Σ Intensity	Comments
		h	p+		p+	
Friday 14:00	Close LHC					
approx 18:00	TI2 injection - ions	4	5E+09	720	3.6E+12	including 1 hour switch to p
22:00 - 24:00	S23 Injection region setup	3	5E+09	540	2.7E+12	
SAT 00:00 - 01:00	S23 dispersion	2	5E+09	360	1.8E+12	to IR7, BLM test
01:00 - 02:00	S23 dispersion	1	5E+09	180	9.0E+11	
02:00 - 07:00	S23 Kick response	4	5E+09	720	3.6E+12	upstream screens in. NB experiments
07:00 - 09:00	cycle	2				includes remeasuring 78
09:00 - 13:00	S23 Injection region setup	3	5E+09	540	2.7E+12	
13:00 - 19:00	Access x 3	1				
19:00 - 23:00	Set-up & 78 Threading & dispersion	1	5E+09	180	9.0E+11	to IR3
23:00 - 02:00	78 Higher order polarity checks	3	5E+09	540	2.7E+12	High priority circuits only
02:00 - 04:00	78 kick response	2	5E+09	360	1.8E+12	upstream screens in. NB experiments
4:00 - 8:00	78 arc aperture	5	5E+09	900	4.5E+12	screens for Alice
SUN 8:00 - 12:30	Spectrometer & compensation	4	5E+09	720	3.6E+12	Pre-cycle S23 in shadow
12:30 - 16:00	Injection protection	4	5E+09	720	3.6E+12	
16:00 - 22:00	injection region studies	6	5E+09	1080	5.4E+12	aperture, waveform studies, protection
22:00 - 02:00	23 Higher order polarity checks	4	5E+09	720	3.6E+12	
02:00 - 06:00	23 Arc aperture	4	5E+09	720	3.6E+12	screens for LHCb
	TOTAL	49		3420	3.9E+13	
	DAYS	2.0				

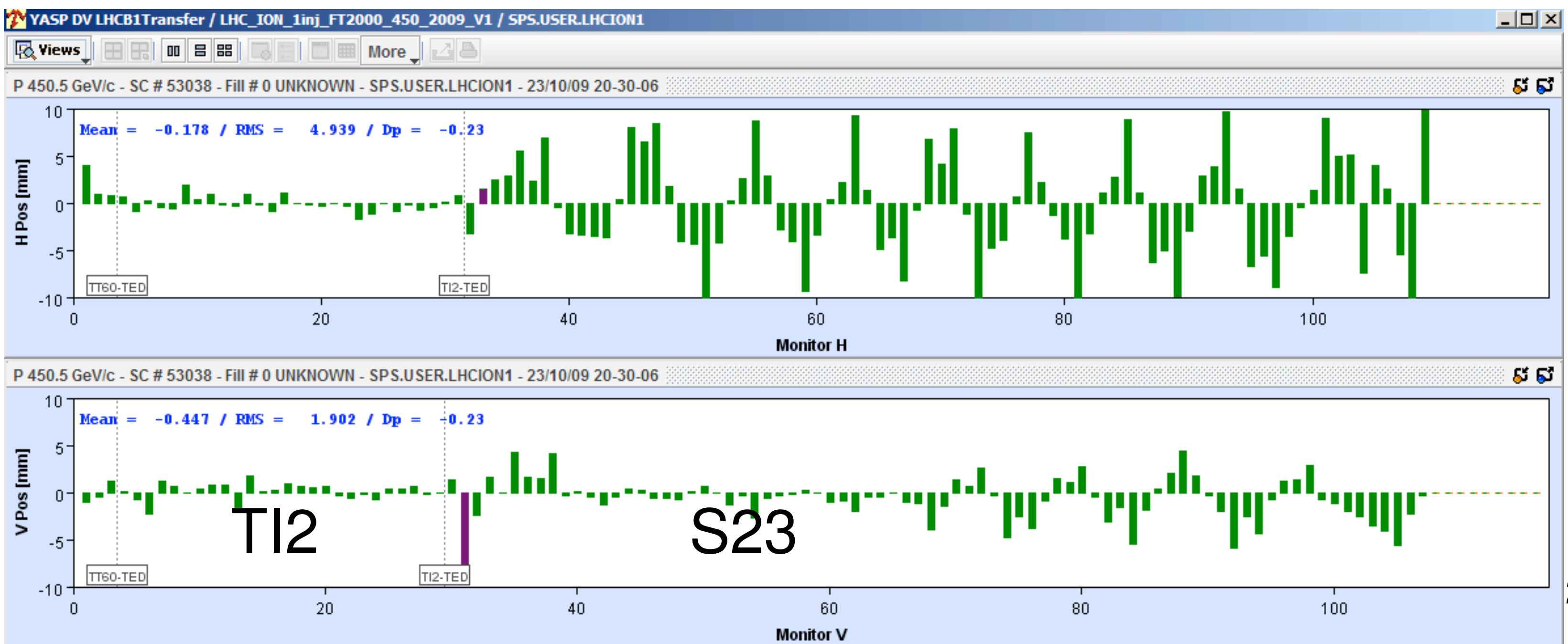
...

First lead ions in LHC

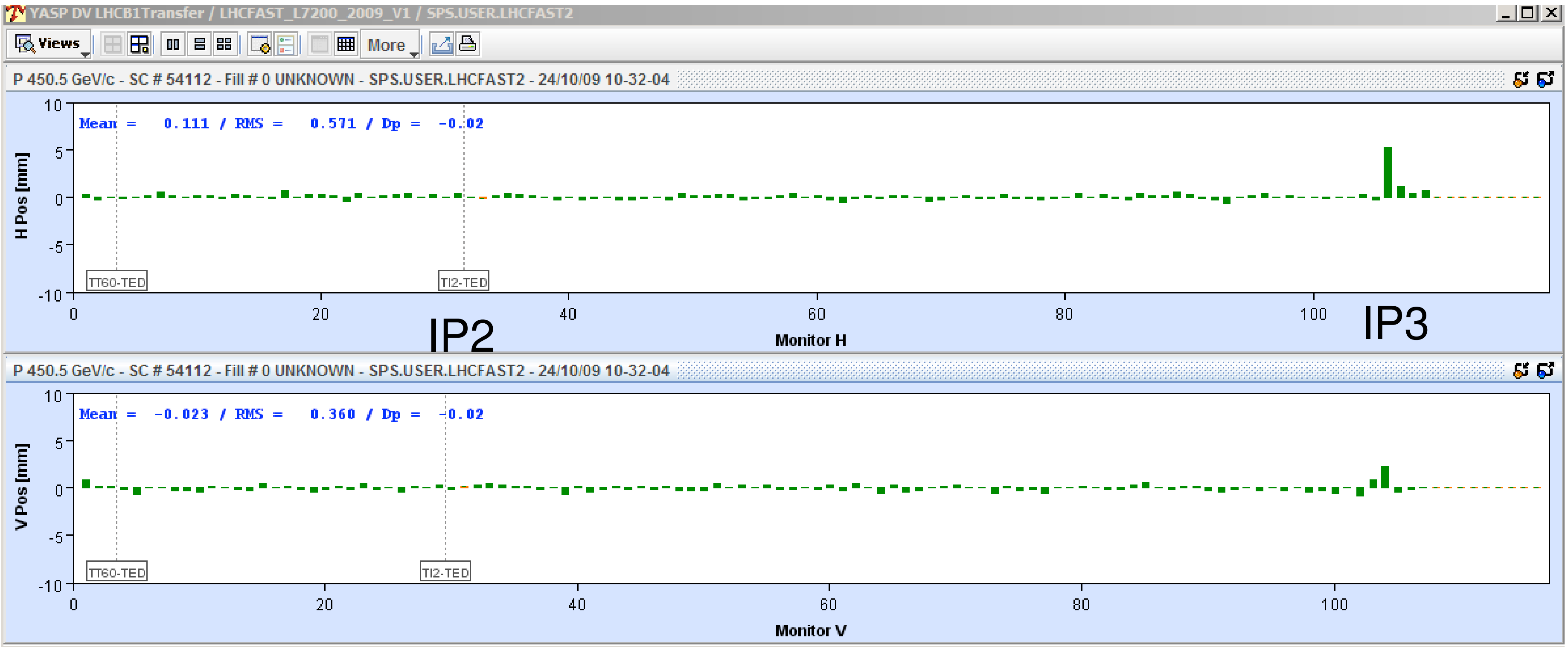


Injection region screens

TI2/S23 – first trajectory

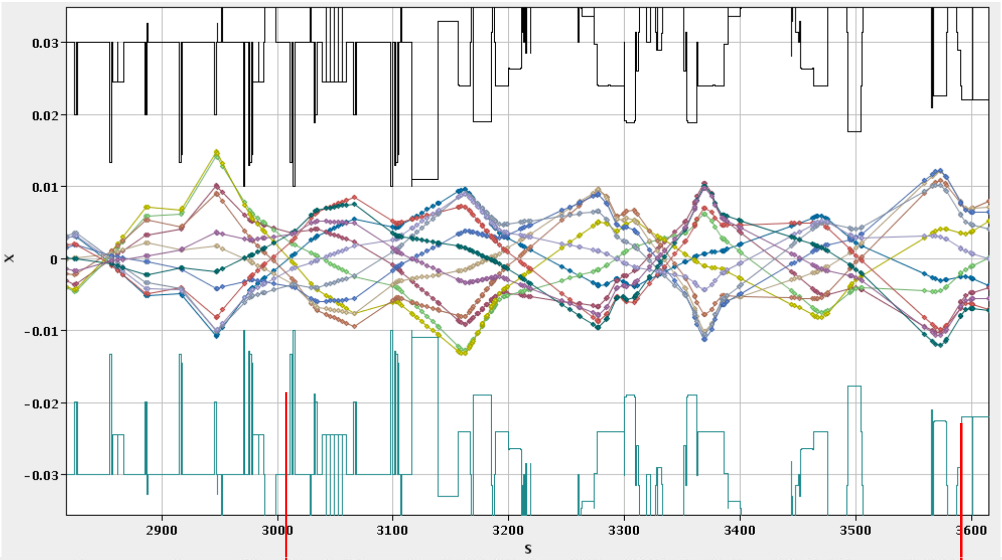


Trajectory difference before/after precycle

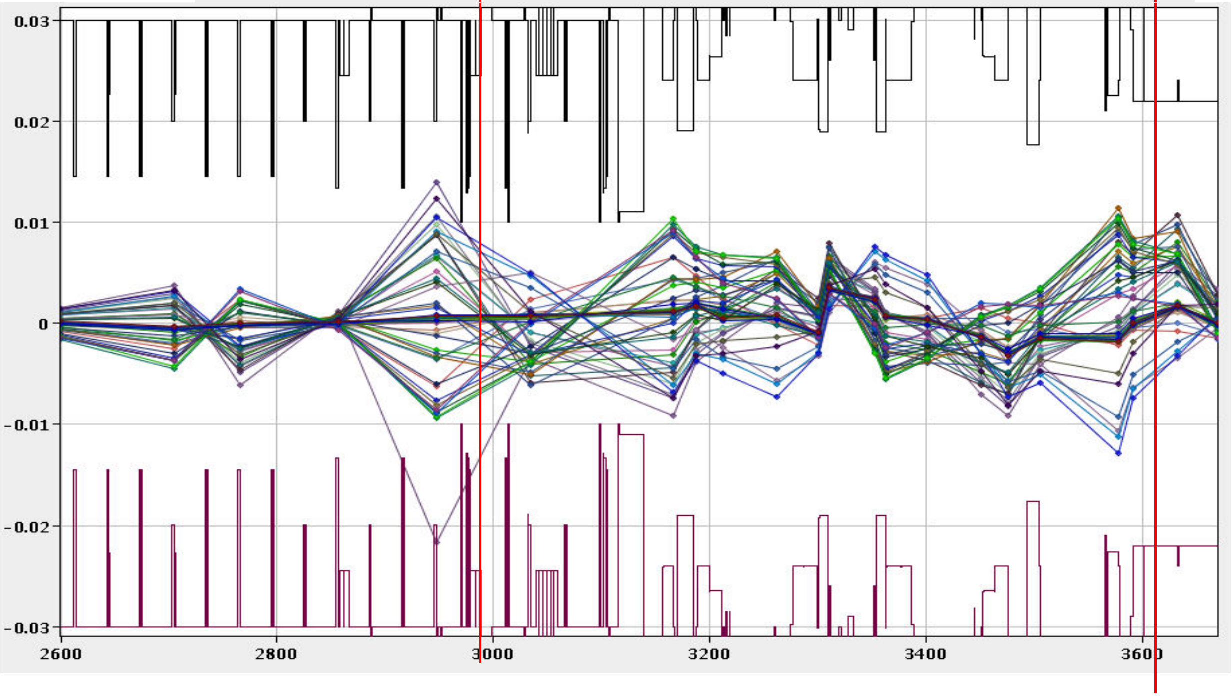


Reproducibility looks very good

Injection region aperture



Model



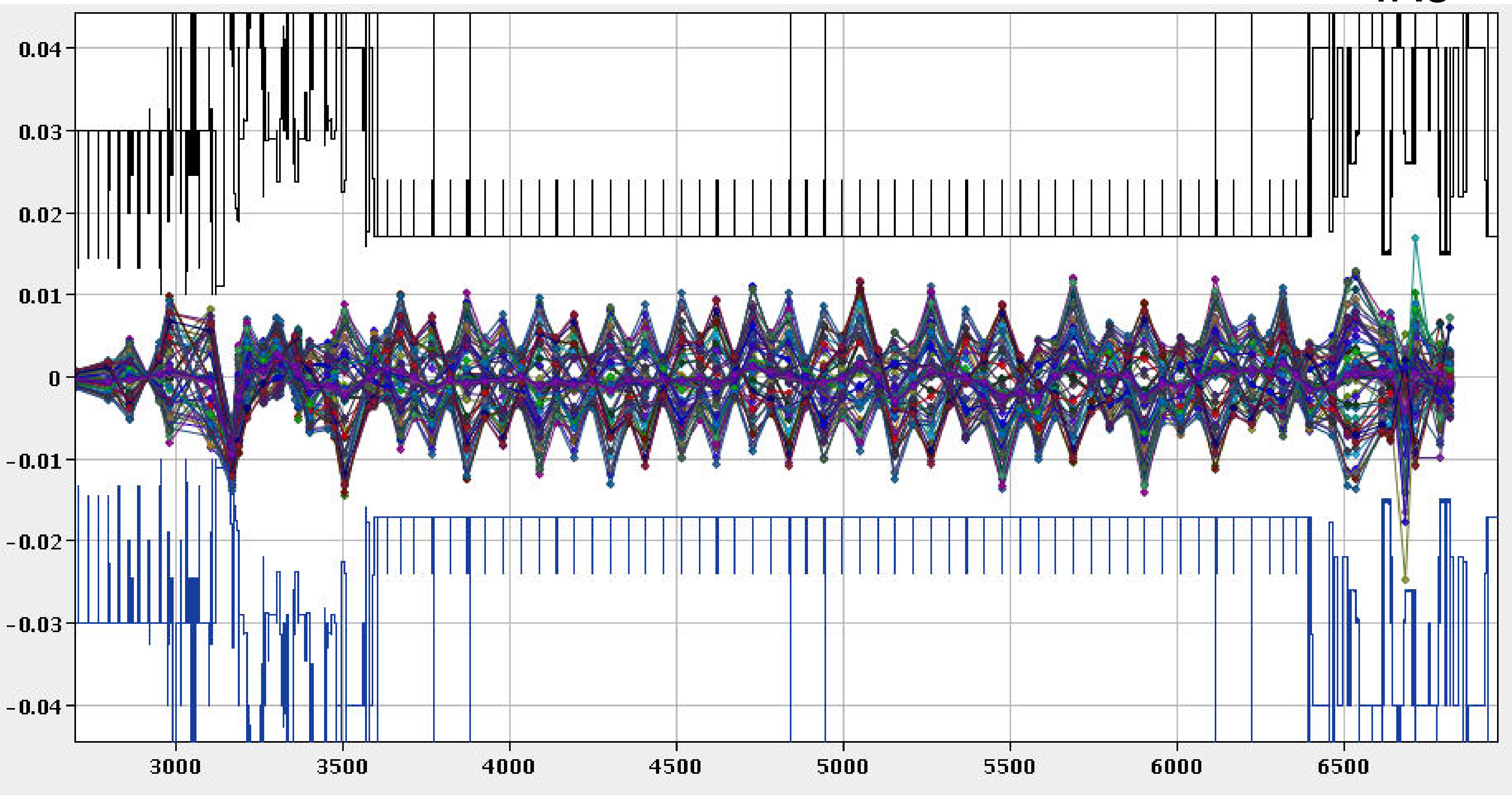
Measured

Brennan Goddard

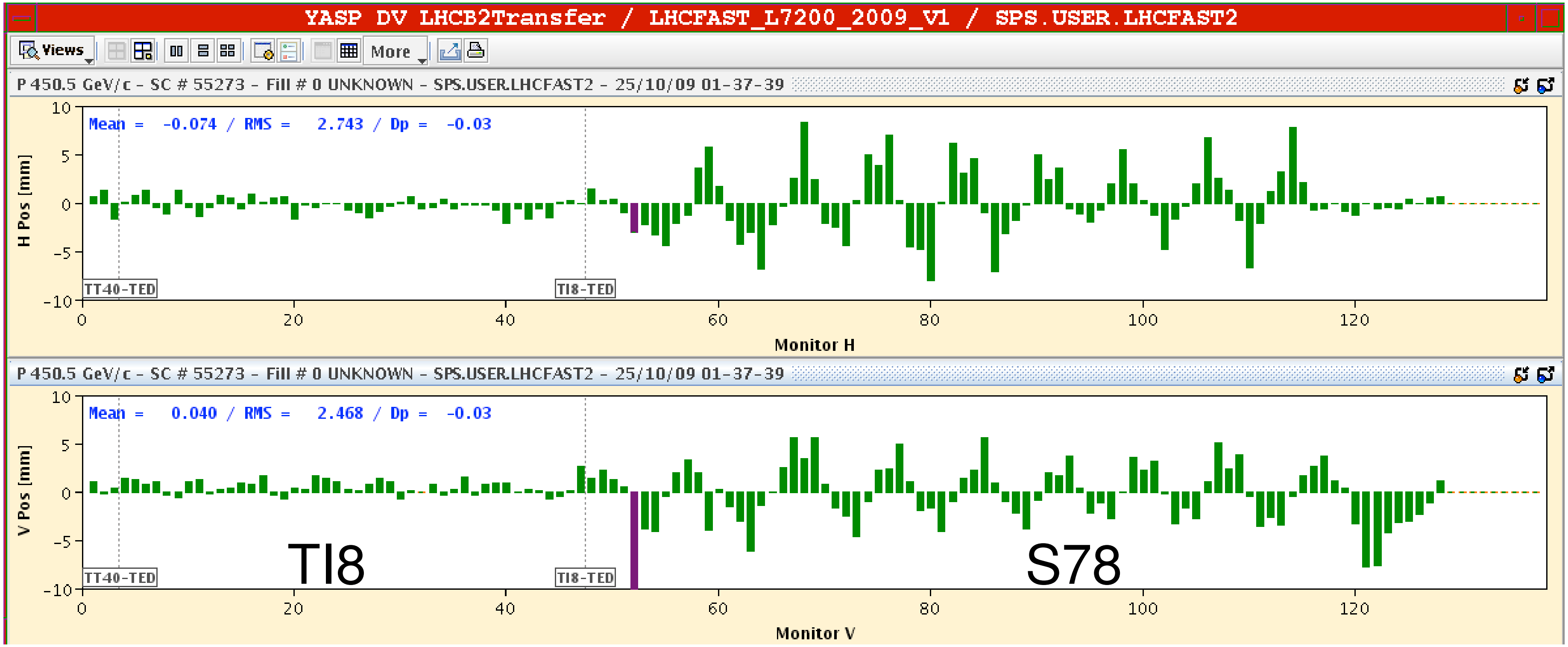
Injection region trajectories through arc

IR2

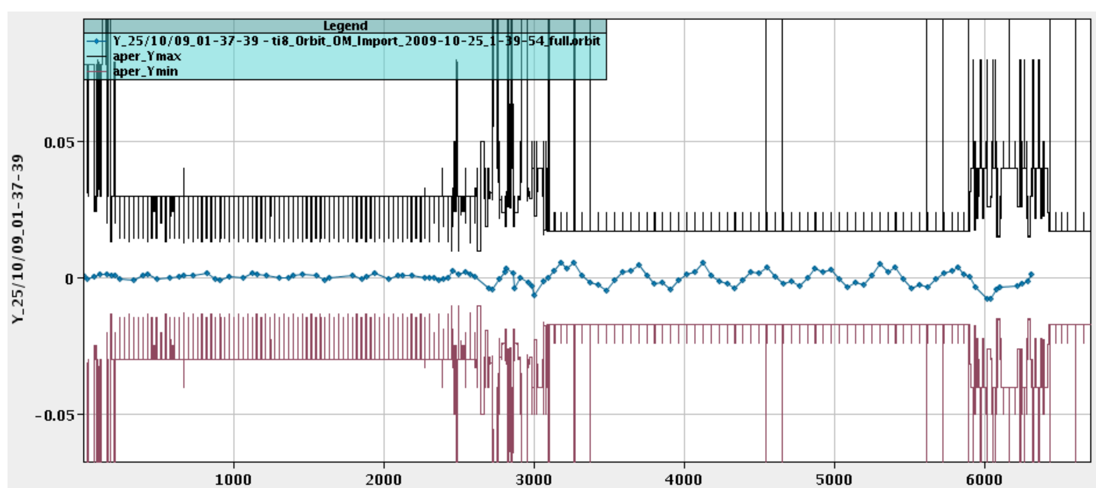
IR3



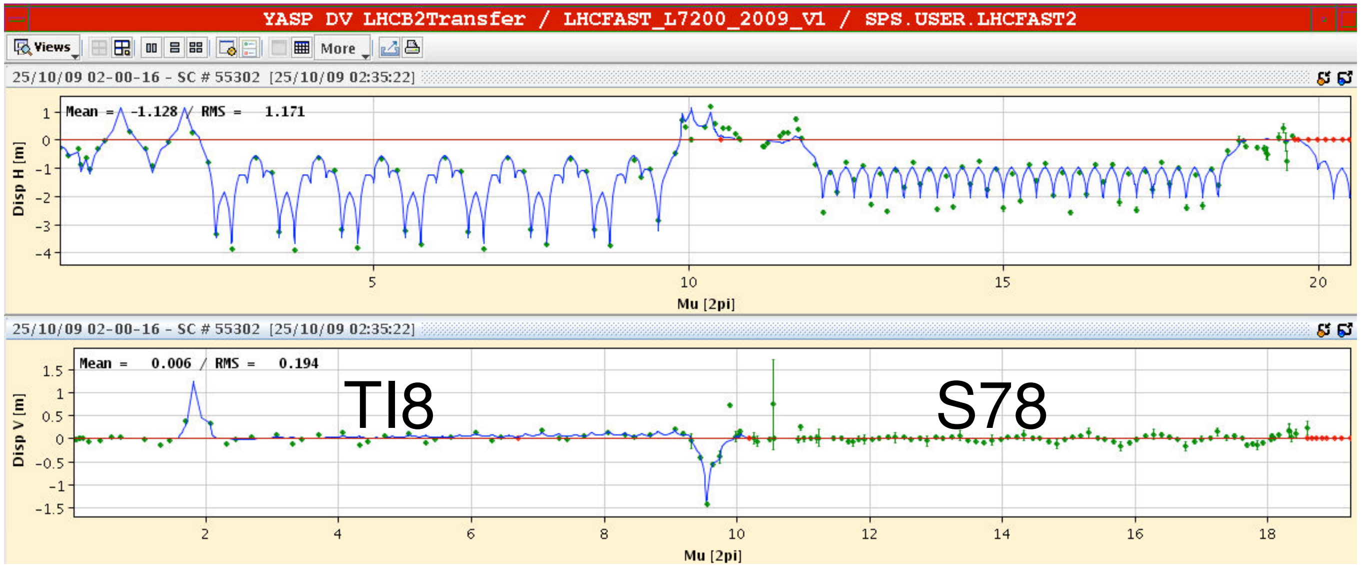
First beam to point 7



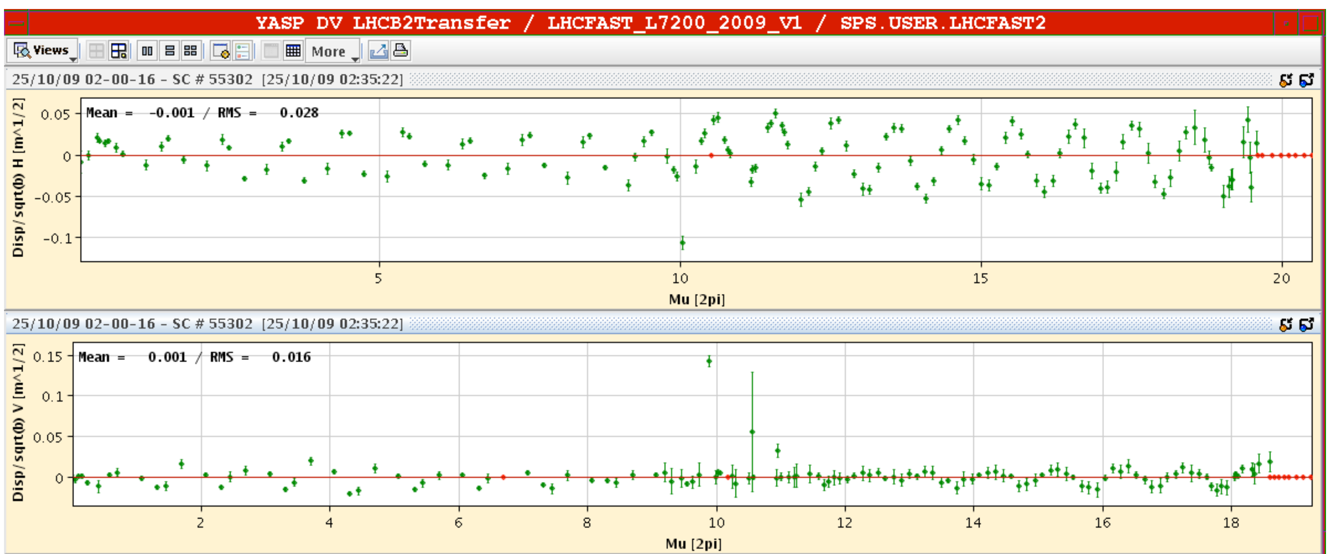
In the aperture model



Dispersion TI8/S78

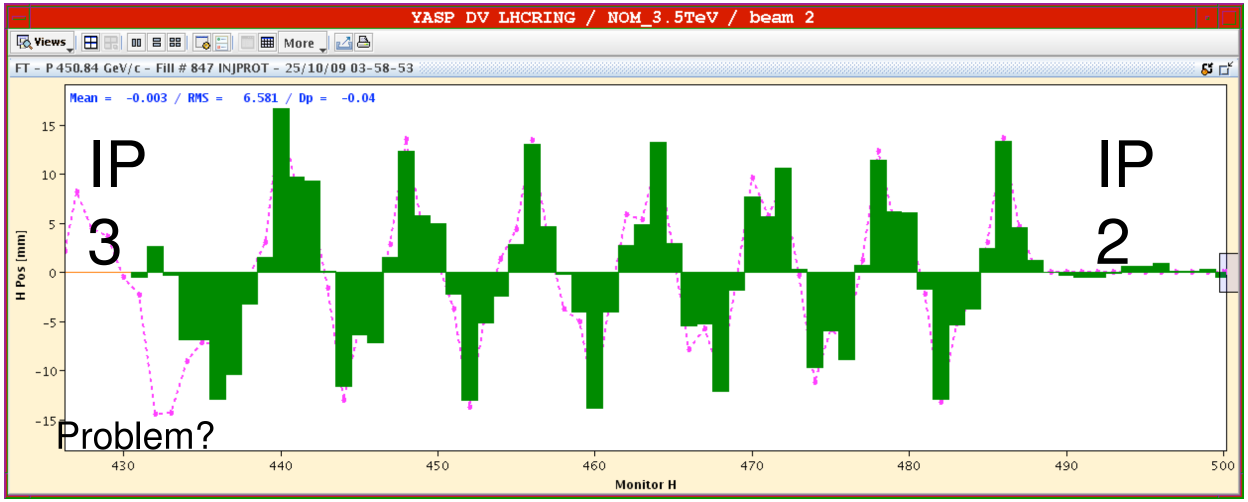


Measured v. model

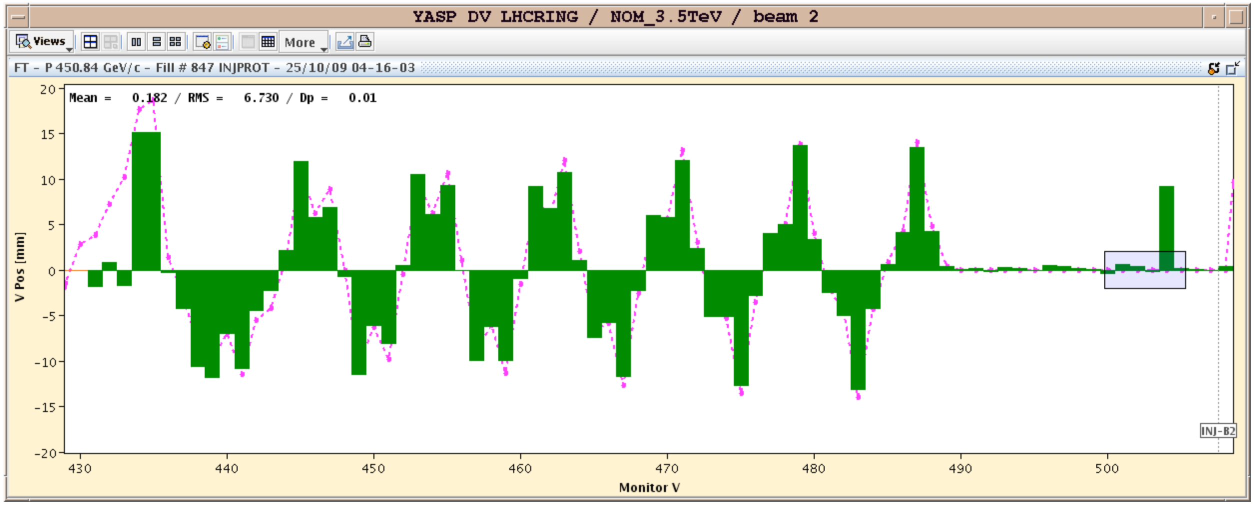


Normalized

Kick response



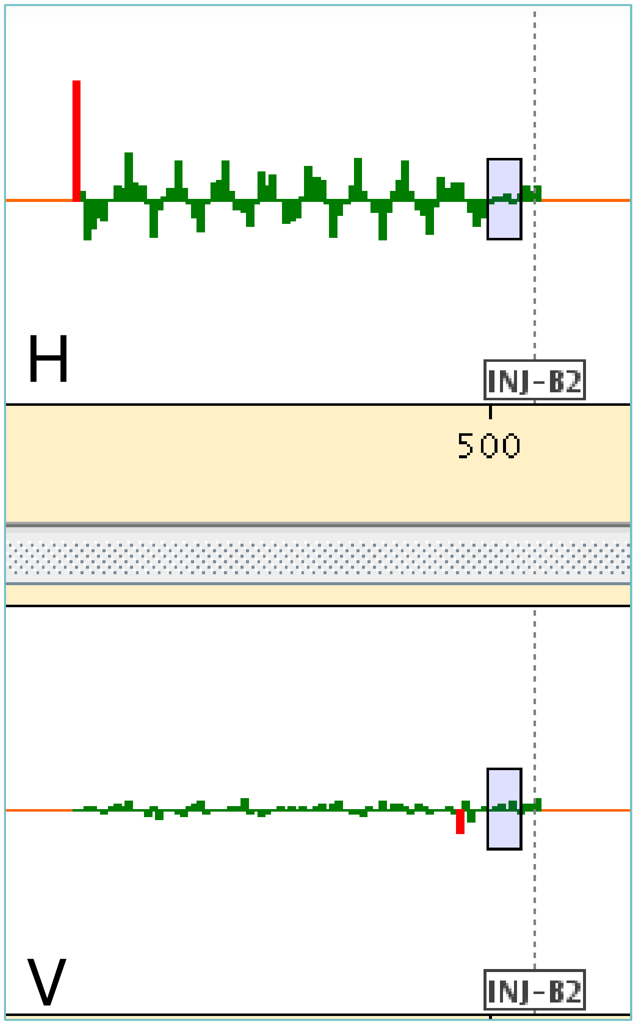
Beam



Green – Measured
Purple - model

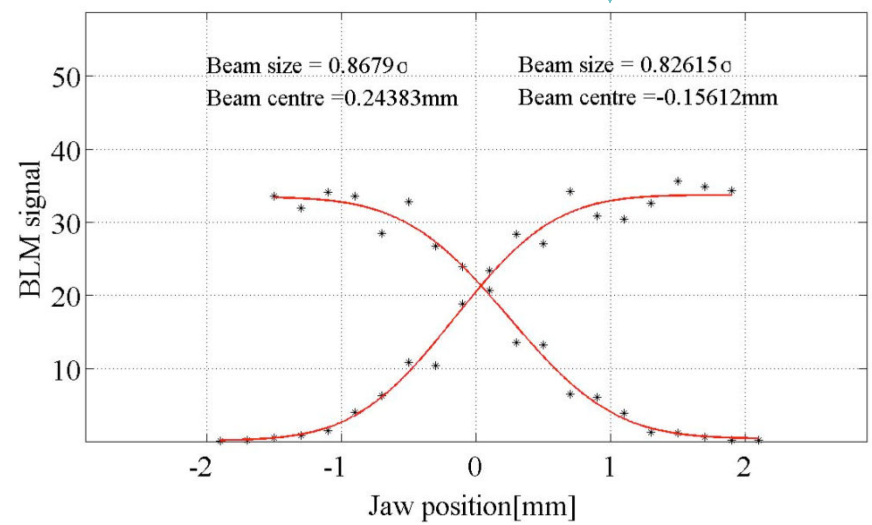
Sunday – Walter starts early…

56	06:10	Walter (with an old clock): after the first moments of dismay, start pre cycle of s23. For this we need to coordinate with the aperture measurements in s78, because the sequence changes the beam process



Beam

Collimator scan



Non-closure of LHCb dipole and compensators with LHCb dipole at full field (rms ~ 1 mm)

Thank you for your attention

END

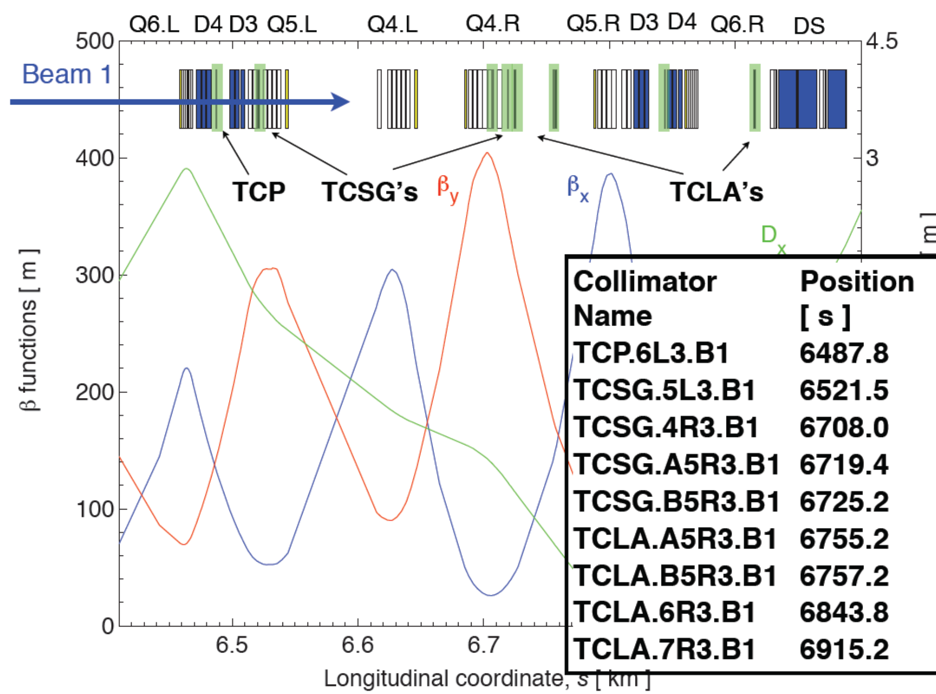

LIQUID HELIUM
LIQUID H

Beam

- Probe beam
  - single bunch of ~3 x 10^9 protons
- Total intensity injected:
  - maximum 4 x 10^{13} protons

Ions – a outside possibility

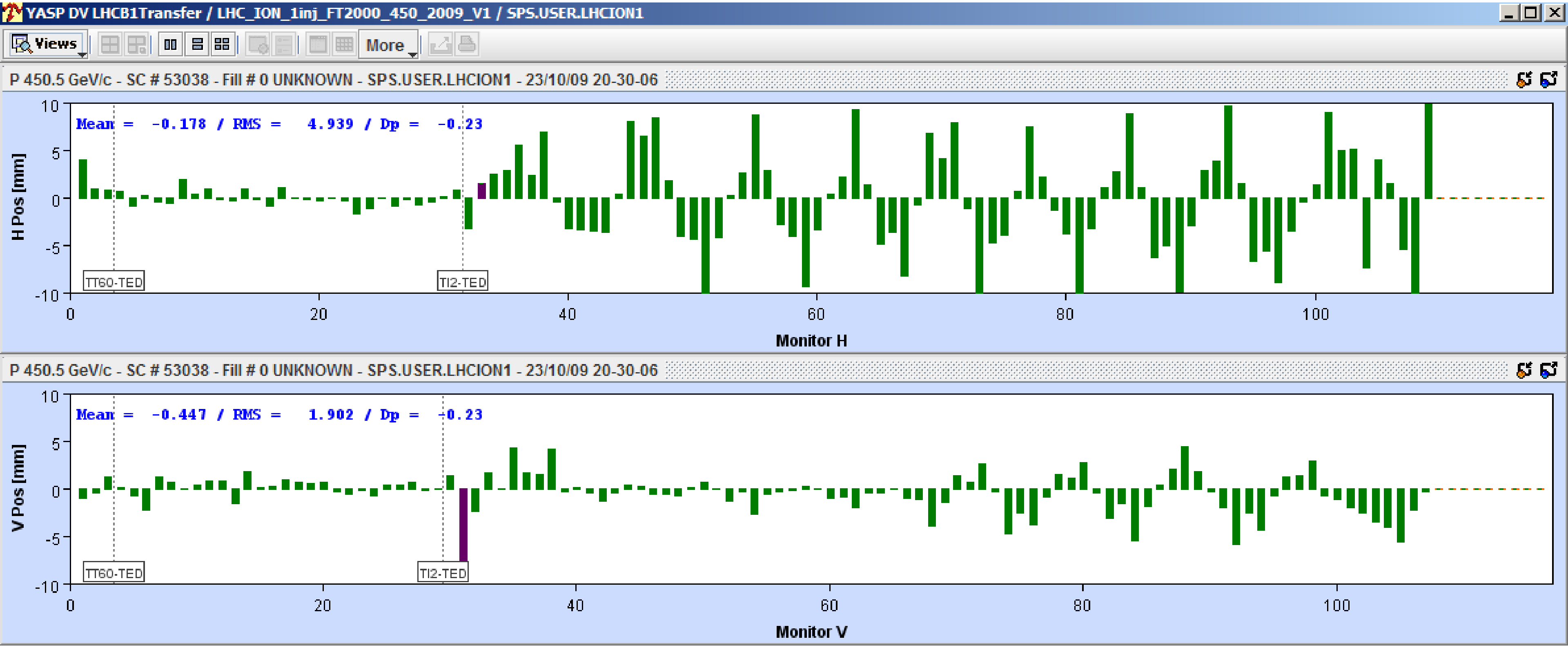
Stop on collimators IR3 & IR7



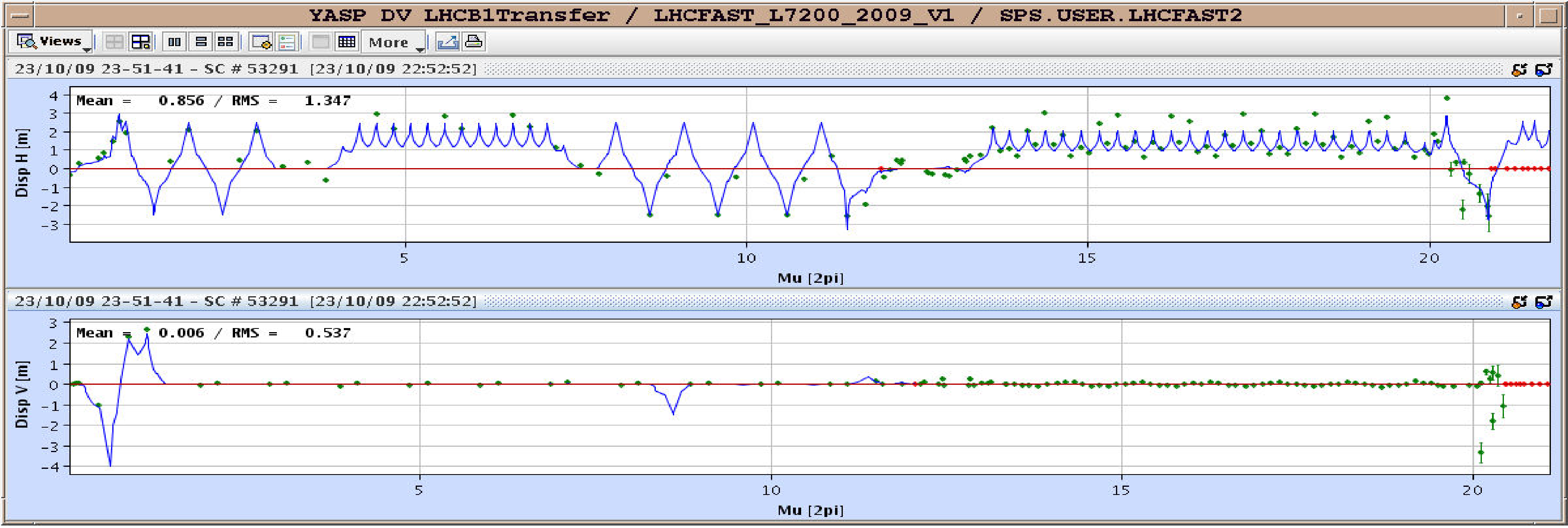
Collimator Name	Position [s]	Angle [deg]	Mat.
TCP.6L3.B1	6487.8	0.0	C
TCSG.5L3.B1	6521.5	0.0	C
TCSG.4R3.B1	6708.0	0.0	C
TCSG.A5R3.B1	6719.4	170.8	C
TCSG.B5R3.B1	6725.2	10.8	C
TCLA.A5R3.B1	6755.2	90.0	W
TCLA.B5R3.B1	6757.2	0.0	W
TCLA.6R3.B1	6843.8	0.0	W
TCLA.7R3.B1	6915.2	0.0	W

Injection tests 2009

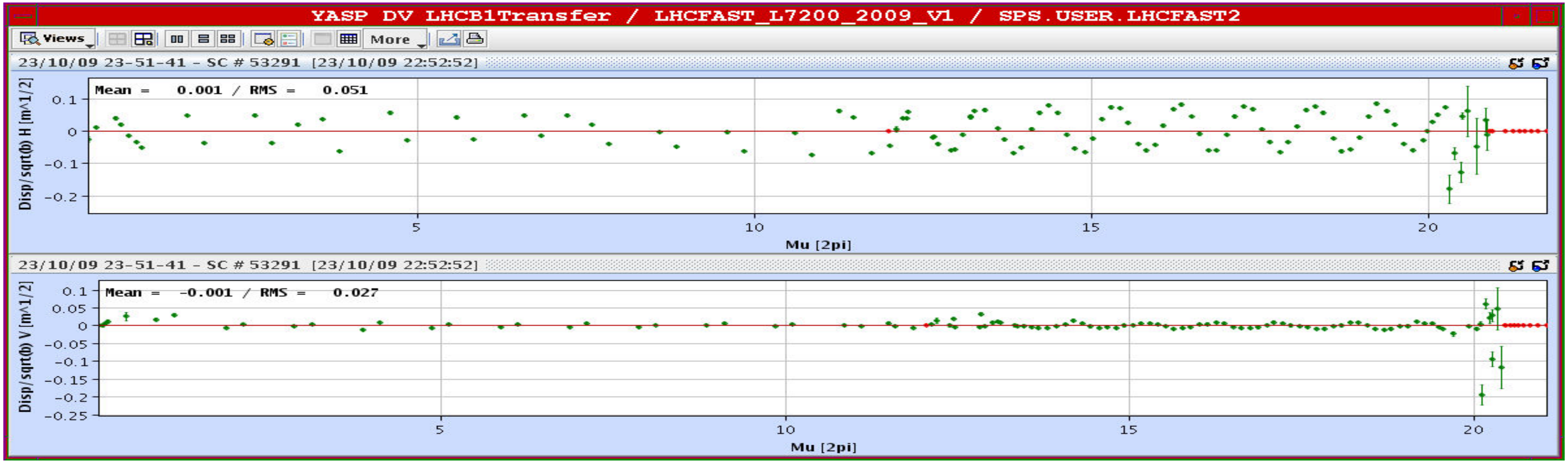
Stefano Redaelli



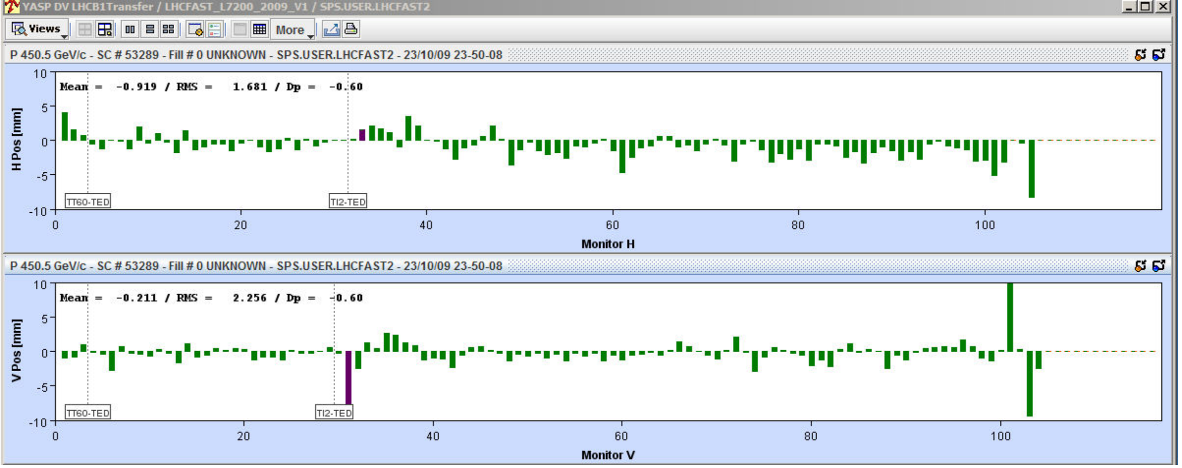
First Trajectory with Ions in the LHC



First dispersion measurement (lead ions)

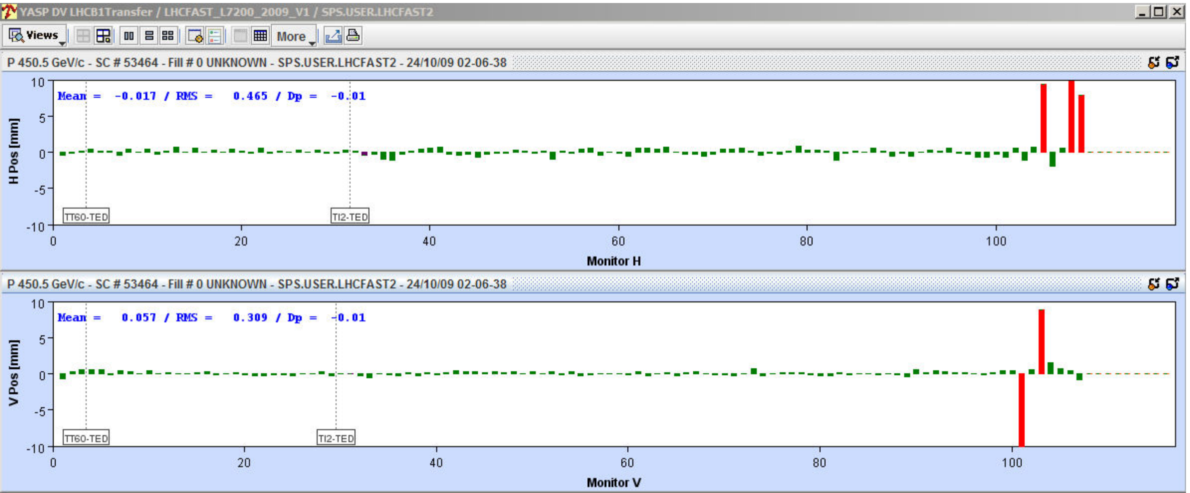


Normalized Dispersion difference to model shows a nice sine ;-) So maybe mainly initial conditions

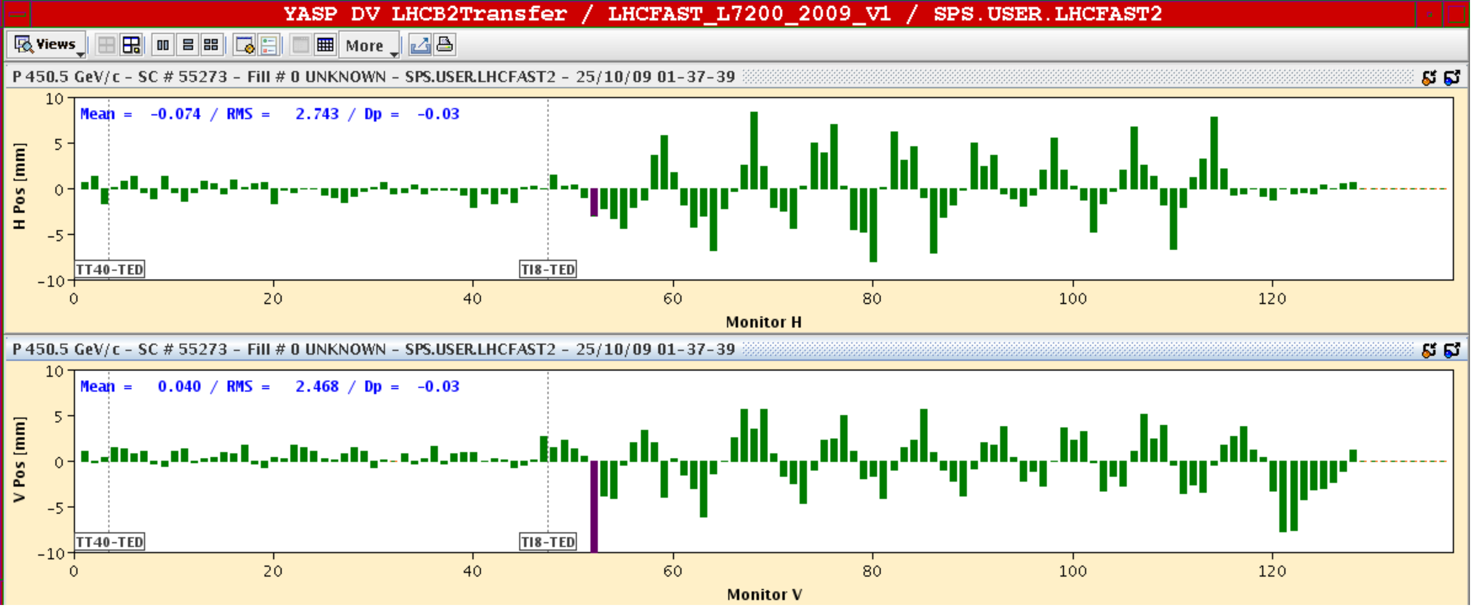


Protons TI2 before cycling magnets

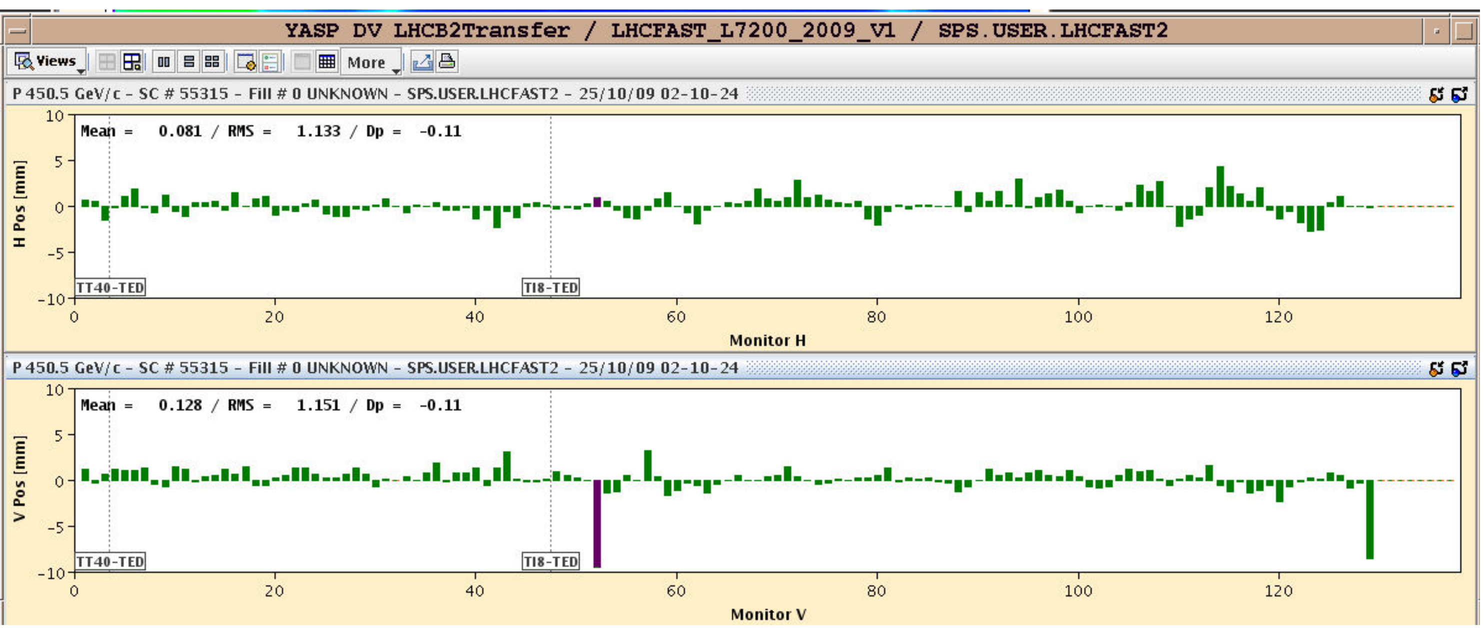
Protons TI2 after cycling magnets



Difference between before and after cycling



First TI8 + LHC Trajectory



After correction with 1 H and 1 V corrector at end of TI8