Summary of Chamonix 09

Steve Myers

February 2009

Topics for Discussion/Decisions

- Road Map and Schedule
- Repair Scenarios (two)
- Dipole Field for Operation
- “Precautions for Running”
- Beam Conditions for Physics
- Future Improvements to convert LHC into an “Operational” Machine
- Safety Considerations

Topics for Discussion/Decisions

- Road Map and Schedule
- Repair Scenarios (two)
- Dipole Field for Operation
  - Training/re-training
- “Precautions for Running”
- Beam Conditions for Physics
- Future Improvements to convert LHC into an “Operational” Machine
- Safety Considerations

Road Map and Schedule (1)

- Physics Discovery Potential $D_p \approx \eta_{LHC}.L_{avg}.T_{run}.F(E)$

$D_p \approx \eta_{LHC}(E).L_{avg}(E).T_{run}.F(E)$

$\eta_{LHC}(E)$ is the operational efficiency (time in physics/scheduled time)

L_{avg} is the average luminosity during the physics run

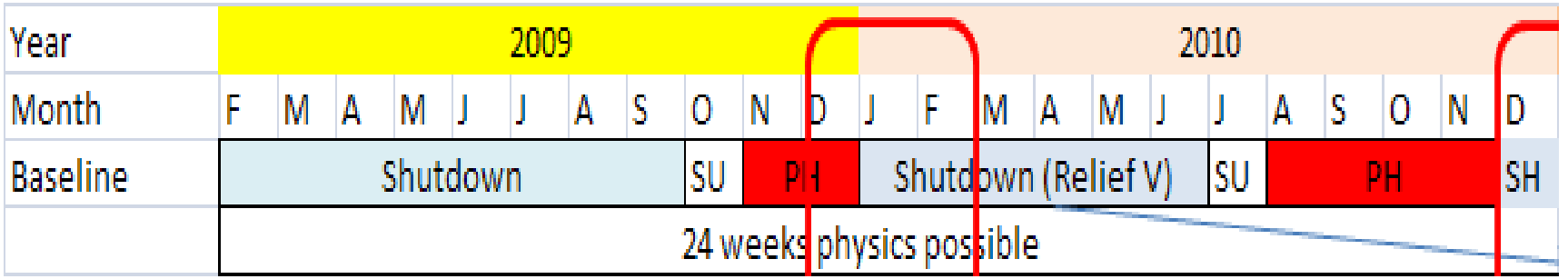
F(E) is given by the cross-section of the process being studies

  - T_{run} is the scheduled running time, is independent of energy, and should be maximised

Physics Running Time

With Strictly No running of the machines in the winter months

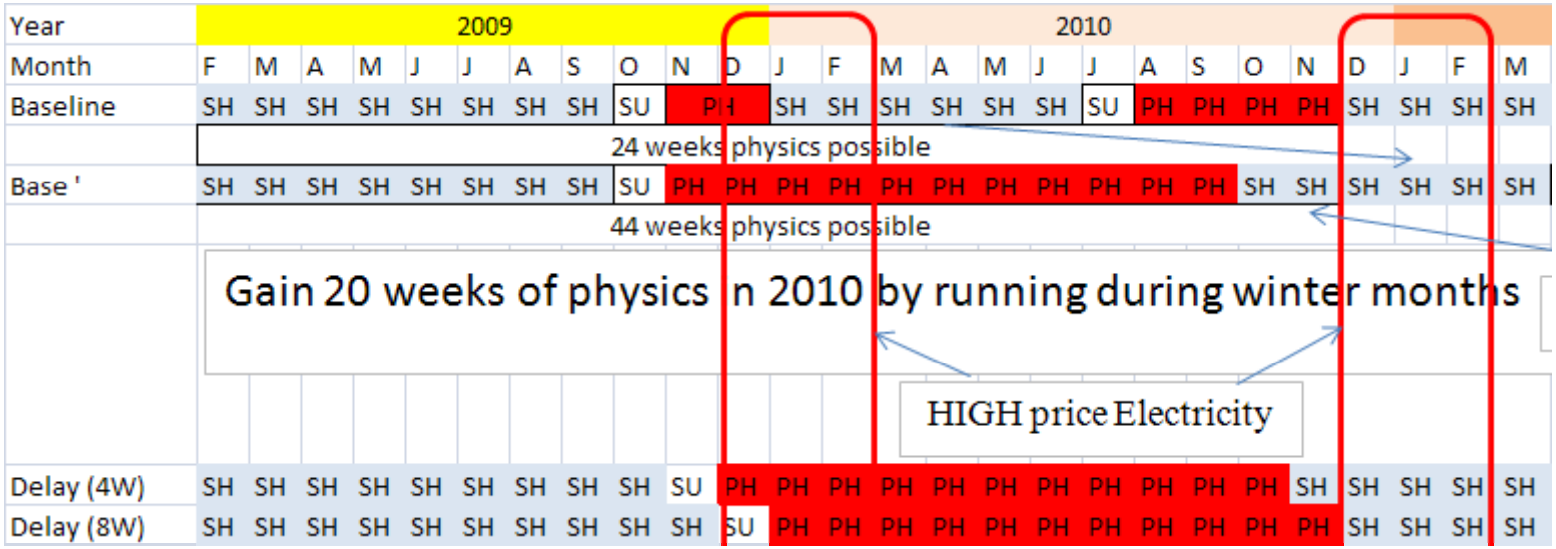
- Present baseline schedule
  - schedule allows very limited physics in 2009/2010 (24 weeks)
  - Any slip of >1 month in the S34 repair will delay first LHC physics till August/September 2010!!
  - Repair schedule has no contingency (comments from L. Rossi/F. Bertinelli/R. Denz, all "suggested" for 4 extra weeks)



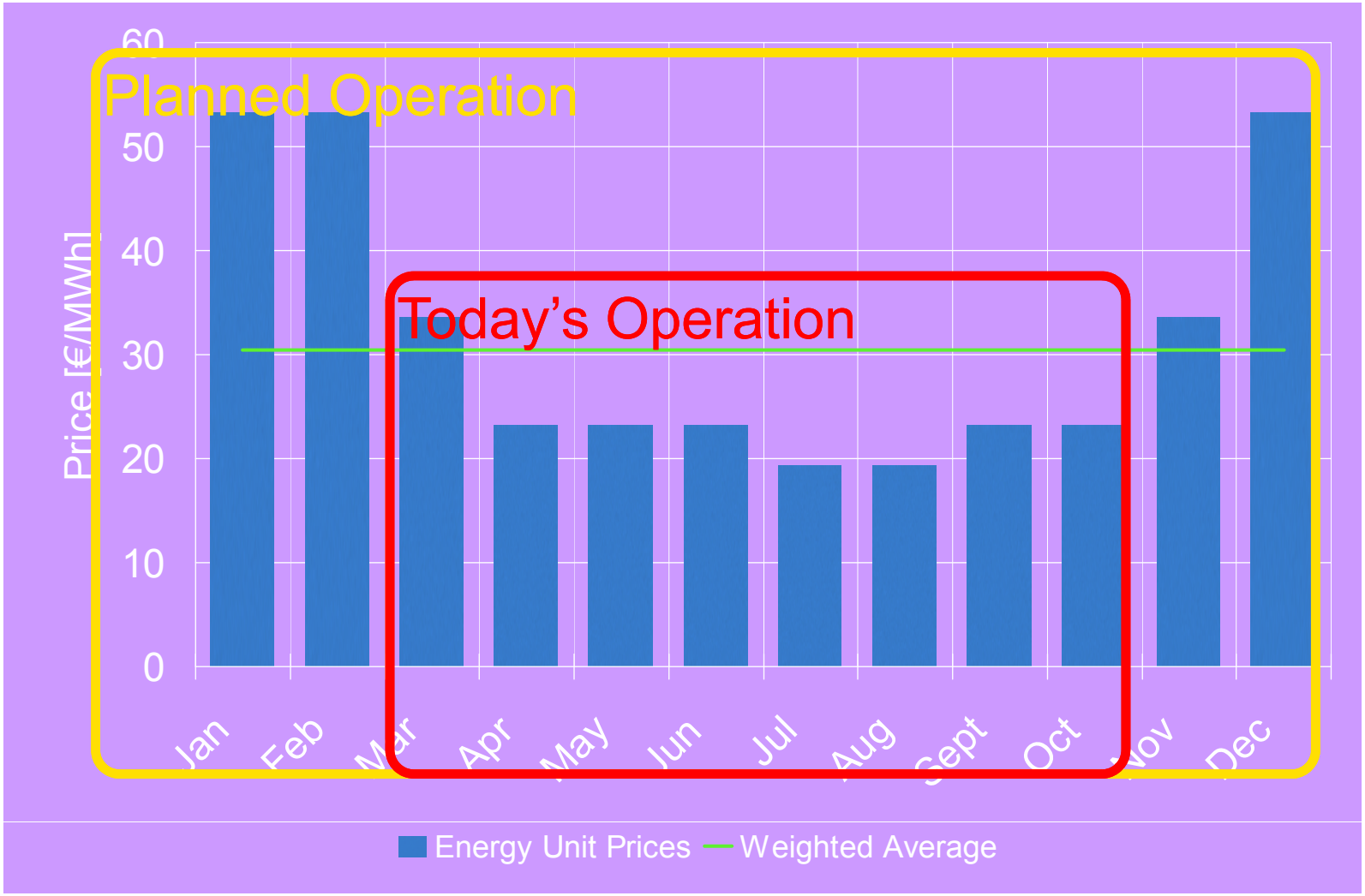
- **Must** have the possibility of running during winter months

Schedule with running in winter months

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



Today's cheapest applicable EDF Tariff



Impacts of Running During Winter Months (2009-2010)

- Electrical Costs!!
  - Assuming Full running through December to February
  - dedicated running of the injectors during winter and
  - reduced cryo power from 8MW to 5MW

  → **additional electricity bill of 8MEuros (+ possible 8%)**
- Impact on Scheduled Shutdown Work on other CERN accelerators
  - » POPS
  - » LINAC4 connection to PSB
  - » …
- Impact on Necessary Maintenance
  - » Cooling towers
  - » Electrical Network

FIRST PROPOSAL

Plan Electricity Provision for Running in Winter 2009-2010

Topics for Discussion/Decisions

- Road Map and Schedule
- Repair Scenarios
  - Clarifying statement (hopefully)
- Dipole Field for Operation
  - Training/re-training
- “Precautions for Running”
- Beam Conditions for Physics
- Future Improvements to convert LHC into an “Operational” Machine
- Safety Considerations

Statement on LHC Safety (1)

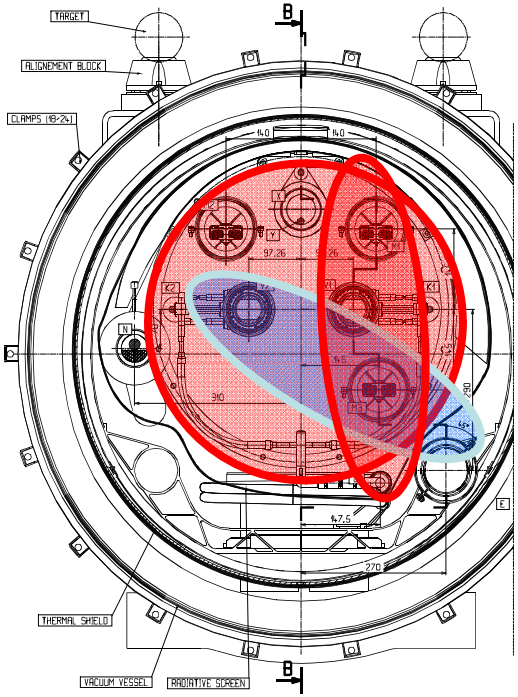
- Following the incident on 19 September the most crucial improvement foreseen was a more precise system to monitor (and protect) anomalously high resistance in a joint (splice) near the magnets.
- The development of this new enhanced ohmic resistance measurement is well under way and the new system will be installed and tested before beam operation. This will allow effective protection against thermal runaway in the magnet and interconnect splices. There is still no way to protect against an “instantaneous” rupture of a bus bar splice.
- It has been shown by simulations that the new system with a threshold trigger of 0.3mV (compared with the 1V of the system in place on 19 September) will protect the joints form thermal runaway “in all imaginable conditions”. Note if this system had been in operation the September incident would not have taken place.
- In the Risk analysis, we have mitigated against the re-occurrence of a thermal runaway of a splice. The risk-score is the product of the probability of the event and the level of the resulting impact.

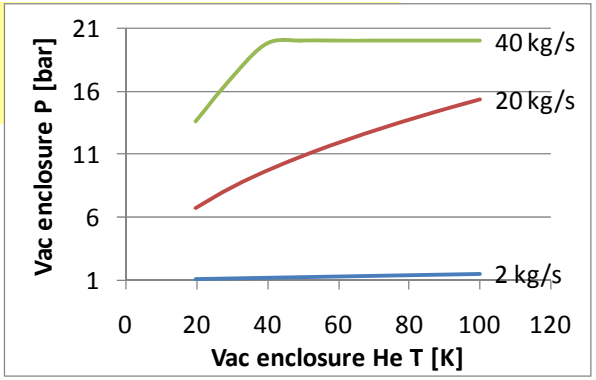
Statement on LHC Safety (2)

- For the September 19 incident, the high impact was caused by collateral damage by:
  1. High pressure build up damaged the magnet interconnects and the super-insulation
  2. Perforation of the beam tubes resulted in pollution of the vacuum system with soot from the vaporization and with debris from the super insulation.
- Until now and even after discussions in Chamonix there have not emerged any new ideas which would significantly reduce the pollution of the vacuum system in the event of a similar incident.
- However, measures will be taken to vent the Helium more rapidly and therefore reduce the pressure increase and consequently minimize (eliminate?) the damage done to interconnects and super-insulation.
- The already existing flanges in the Short straight sections (SSS) will be fitted with additional relief valves. Calculations have shown that this gives a factor of more than 9 with respect to the system existing on 19 September. These calculations show that the collateral damage (to the interconnects and super-insulation) which would be produced in a repeat incident of 19 September would be minor (significantly reduced). Such a repeat incident would not have a major impact on the spares situation for magnets . Whereas the collateral damage due to vacuum pollution would remain very similar to the September 19 incident.

MCI

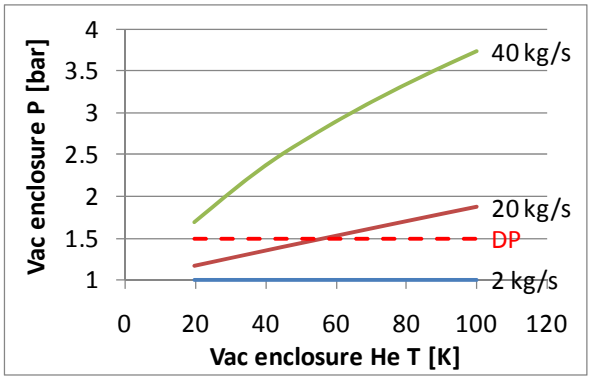
- It was decided to examine the all-out worst case risk impact. This “Maximum Conceivable Incident” (MCI) was identified as rupture of all enclosures connected to the magnets. The probability that this MCI would occur in the lifetime of the LHC has not been evaluated, but most specialist believe the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



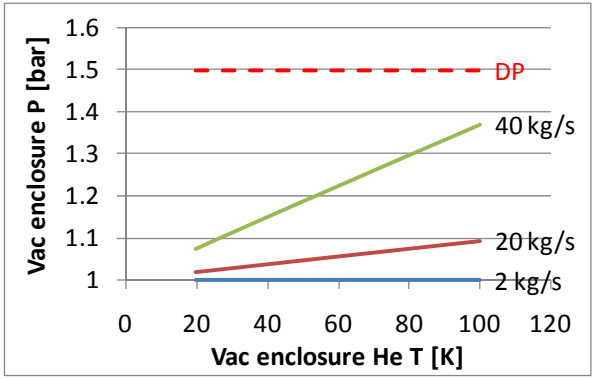


September 19

Add SSS valves



Add SSS valves +DN200



Don’t forget the vacuum

Repair Scenarios

- Enhanced Quench Protection (Detection)
  - Busbar Detection (Protection)
  - “Symmetric” quench protection

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)
+ present schedule allows calorimetry measurements in 23, 45 much sooner
+ 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)

Progress on QPS Since Chamonix – week 07/2009: Knud Dahlerup-Petersen

- The contact for the supply of 2'500 circuit boards for the new, distributed busbar detector and 500 boards of the control and acquisition unit of the associated crate was placed last week. These quantities cover the total needs for upgrade of all LHC sectors. The agreed delivery schedule will meet our planning requirements.
- Following the decision to upgrade the UPS power facilities and in order to make full use of the enhanced redundancy the necessary changes to the layout of new QPS layer have been applied. Fortunately, the adaptations only affect components which are not yet ordered, such as the chassis and the power packs.
- In the proposed system QPS will be powered from two independent UPS lines, one shared with the other users and one exclusively allocated to quench detection. The redundancy inside the QPS systems is based on the feature that the new boards for detection of aperture-symmetric quenches also detect 'classical' asymmetric quenches. The redundancy related to the quench heater power sources is achieved by distributing the units between the two UPS feeder lines.
- The final documentation for production of the remaining components can now be completed and the invitation to tender launched.
- The test equipment for verification of the 4'400 new signal cable segments, after their installation in the tunnel, is now ready for use. After training the two test teams will begin their work (S45, week 08).
- -Work has started on the software packages, which shall cover the automatic post treatment of the signals originating from the busbar splice resistance measurements and Snapshot campaigns. A first proposal will be tested in the lab on prototype detectors and will then be available for review external to QPS.

Repair Scenarios

- Enhanced Quench Protection (Detection)
  - Busbar Detection (Protection)
  - “Symmetric” quench protection

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

Update →

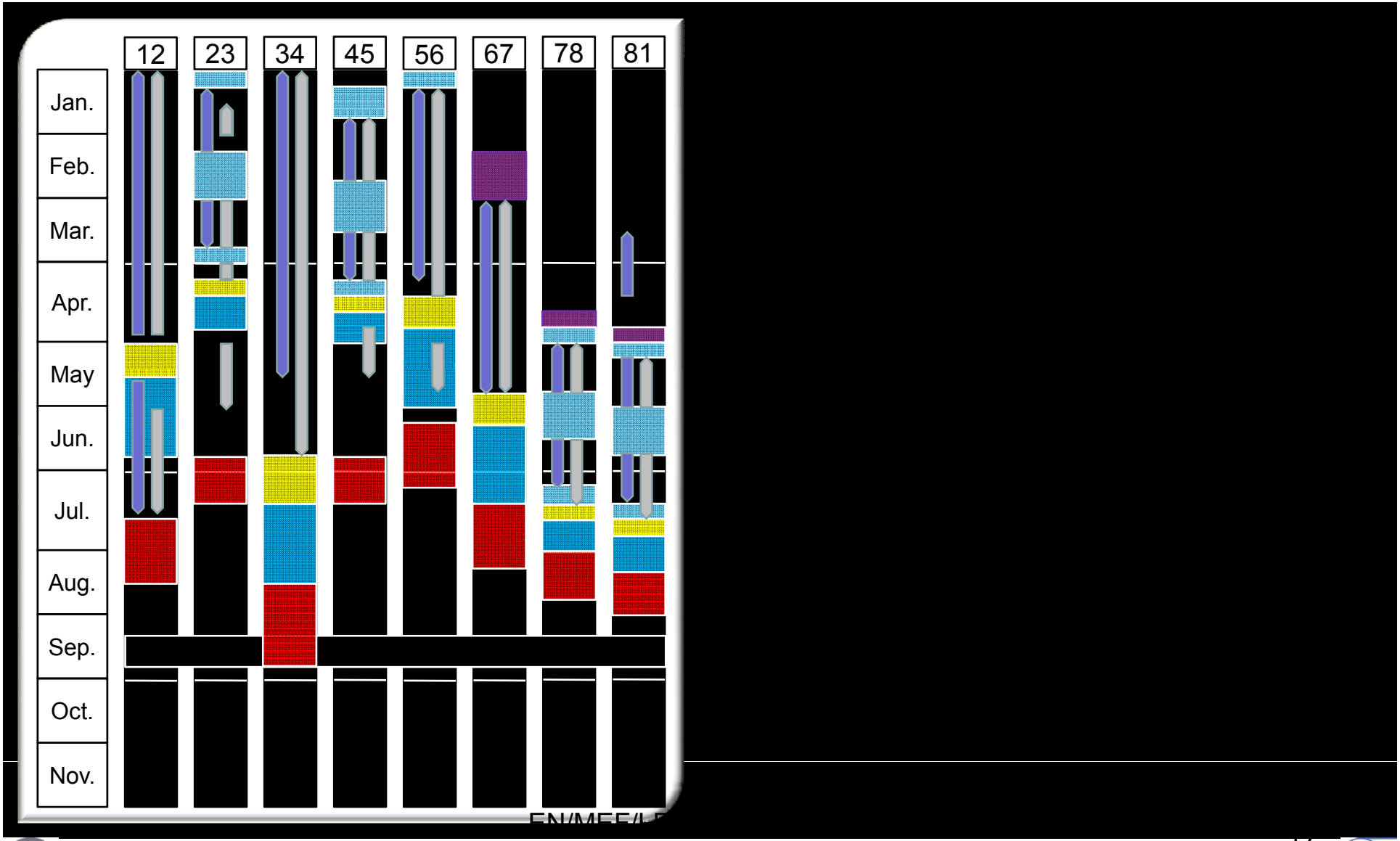
DN200 Pressure Relief Valves in Arcs

A: install 4 sectors (09-10) + 4 sectors (10-11)
+ present schedule allows calorimetry measurements in 23, 45 much sooner
+ first physics sooner: detectors debugging.. earlier warning
+ first beam sooner: ramp, squeeze, .. Sooner... earlier warning
+ focuses attention of repair teams

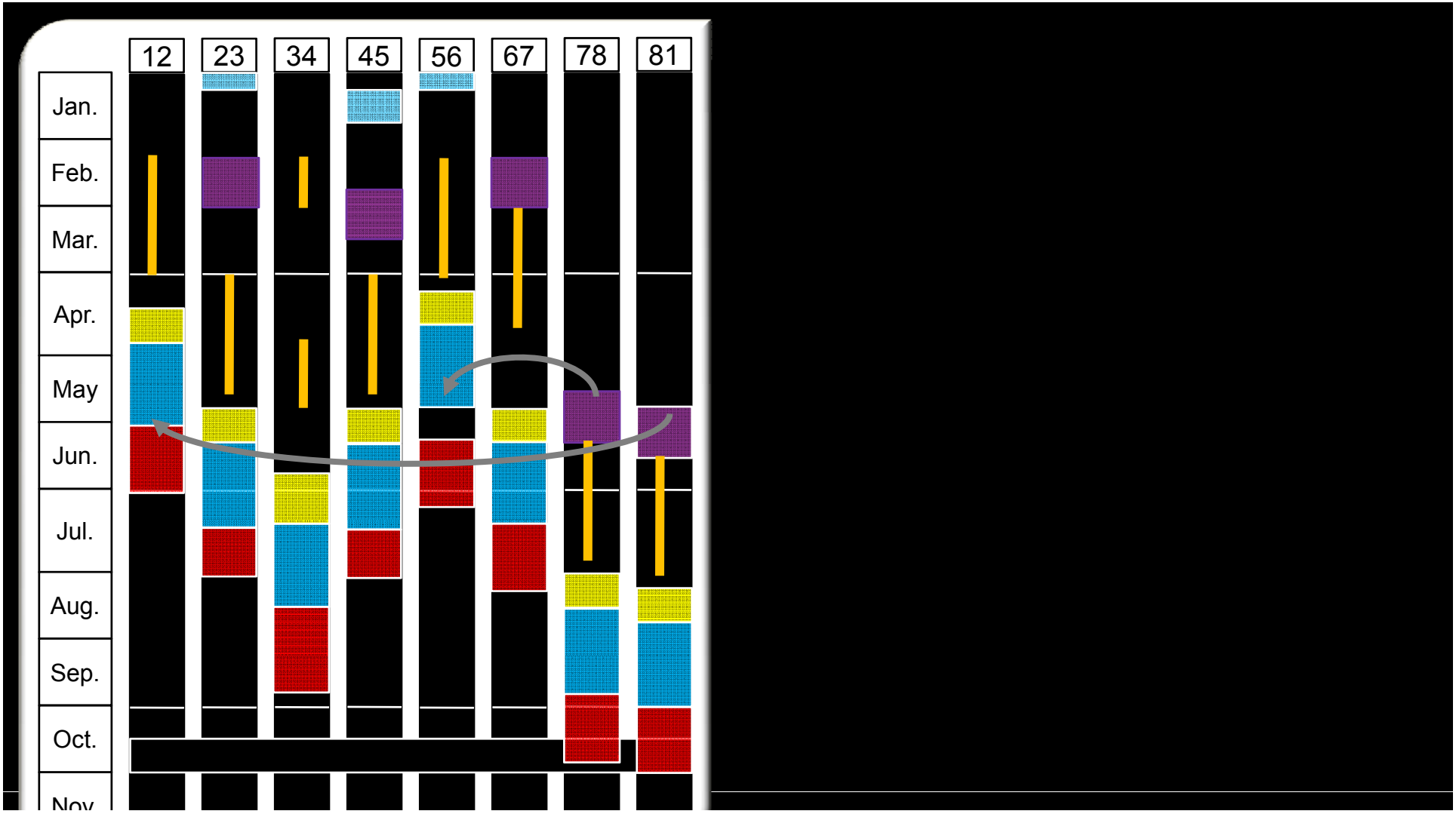
B: Installation 8 sectors (09-10)

+ 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)

Shutdown 08-09



Total warm-up



- Flushing / warm-up
- Consolidation
- Cool-down
- Intermediate CD
- ELQA & flushing
- Powering tests

Repair Scenarios

- Enhanced Quench Protection (Detection)
  - Busbar Detection (Protection)
  - “Symmetric” quench protection

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)
+ present schedule allows calorimetry measurements in 23, 45 much sooner
+ 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)

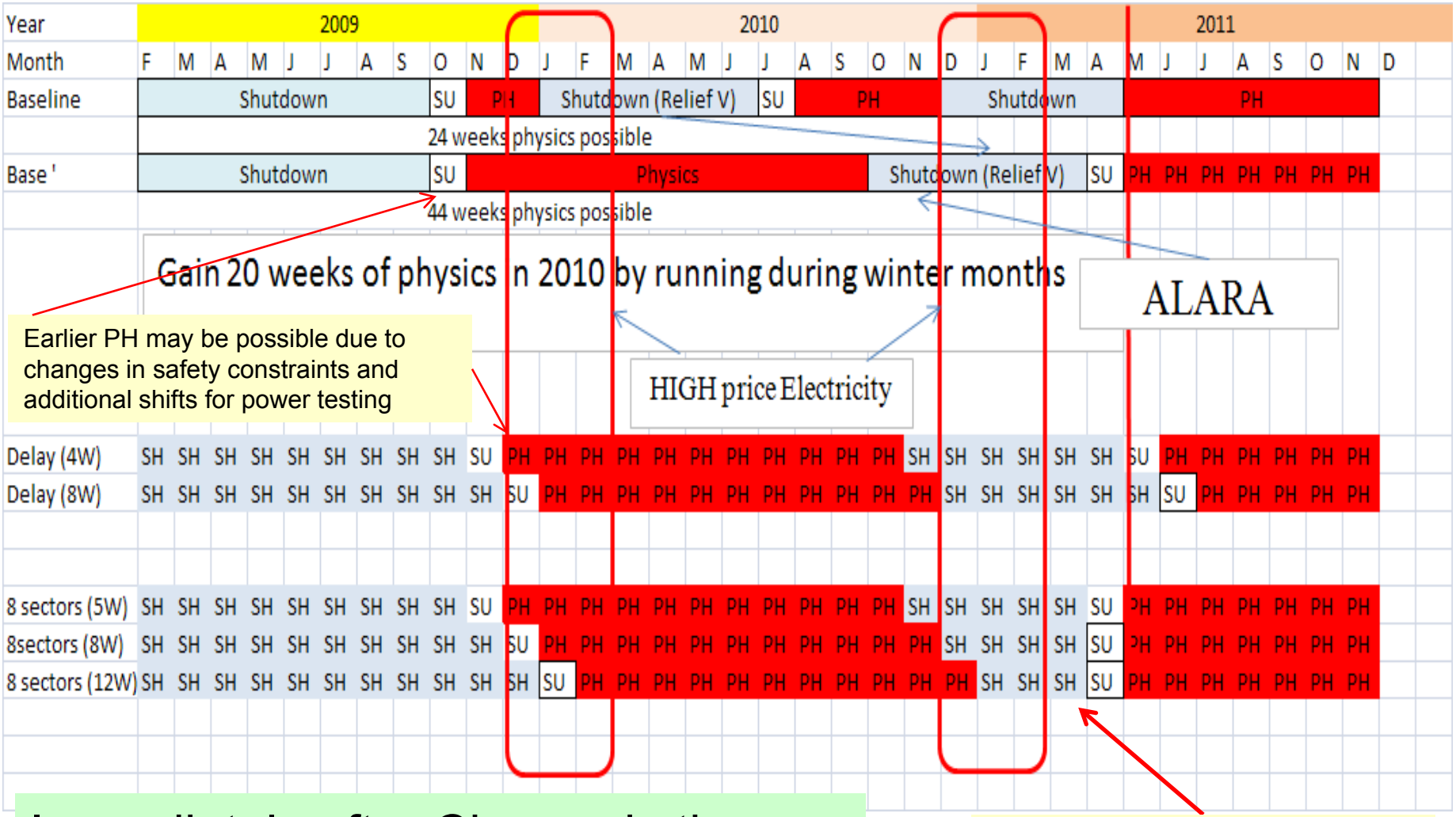
No consensus in Chamonix

Discussion on Schedule

- Key Drivers for schedule;
  - Safety constraints, access, transport,…
  - Helium storage
  - Maintenance: cooling towers, electrical network…
  - Cryo maintenance, PIMs…
- "Blowing Off" Helium in 78/81 gains 2 weeks and would cost 1.2MCHF

We are working on these issues both for the present shutdown and future ones

Summary on Schedule



Immediately after Chamonix the management decided on scenario A

Here it is assumed that these shutdowns will be long enough in case of problems seen during the preceding PH running

Topics for Discussion/Decisions

- Road Map and Schedule
- Repair Scenarios (two)
- Energy Level for Operation
- “Precautions for Running”
- Beam Conditions for Physics
- Future Improvements to convert LHC into an “Operational” Machine
- Safety Considerations

Energy Level for Operation

- Dipole field which can be reached
  - Time needed, reliability, and efficiency
- Risks associated with operating at field
  - Splices stability (thermal runaway…)
  - Detection of poor splices (see later)
  - New effect 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,

Estimated dipole training to reach 6 and 6.5 TeV

Sector	Number of magnets			Number of quenches	
	ALS	ANS	NOE	@ 6 TeV (±2)	@ 6.5 TeV (±30%)
1-2	49	96	9	0	4
2-3	56	60	38	1	8
3-4	56	65	33	1	8
4-5	46	46	62	2	12
5-6	28	42	84	1	15
6-7	57	36	61	2	12
7-8	54	40	60	2	12
8-1	64	24	66	2	13
Total	**154**	**154**	**154**	**11**	**84**

Estimated 11 (84) quenches to reach 6 (6.5) TeV

A. Verweij,

Conclusion

The original design 1 V QPS threshold was much too high to safely protect the dipole busbars..

Two possible origins of the incident are identified, that fulfill the observed facts (about 11 W @ 7 kA, Imax=8.7 kA, Dt_runaway≅1 s), namely:

1) Resistive joint with very bad bonding to wedge and U-profile, and longitudinal discontinuity of the copper (bus).

2) Resistive cable with bad contact to bus at the start of the joint, and longitudinal discontinuity of the copper (bus). The cable can be resistive due to strongly reduced critical current or due to mechanical movement below 7 kA.

Both origins would have been detected with a QPS threshold voltage <1 mV long before the start of the thermal runaway.

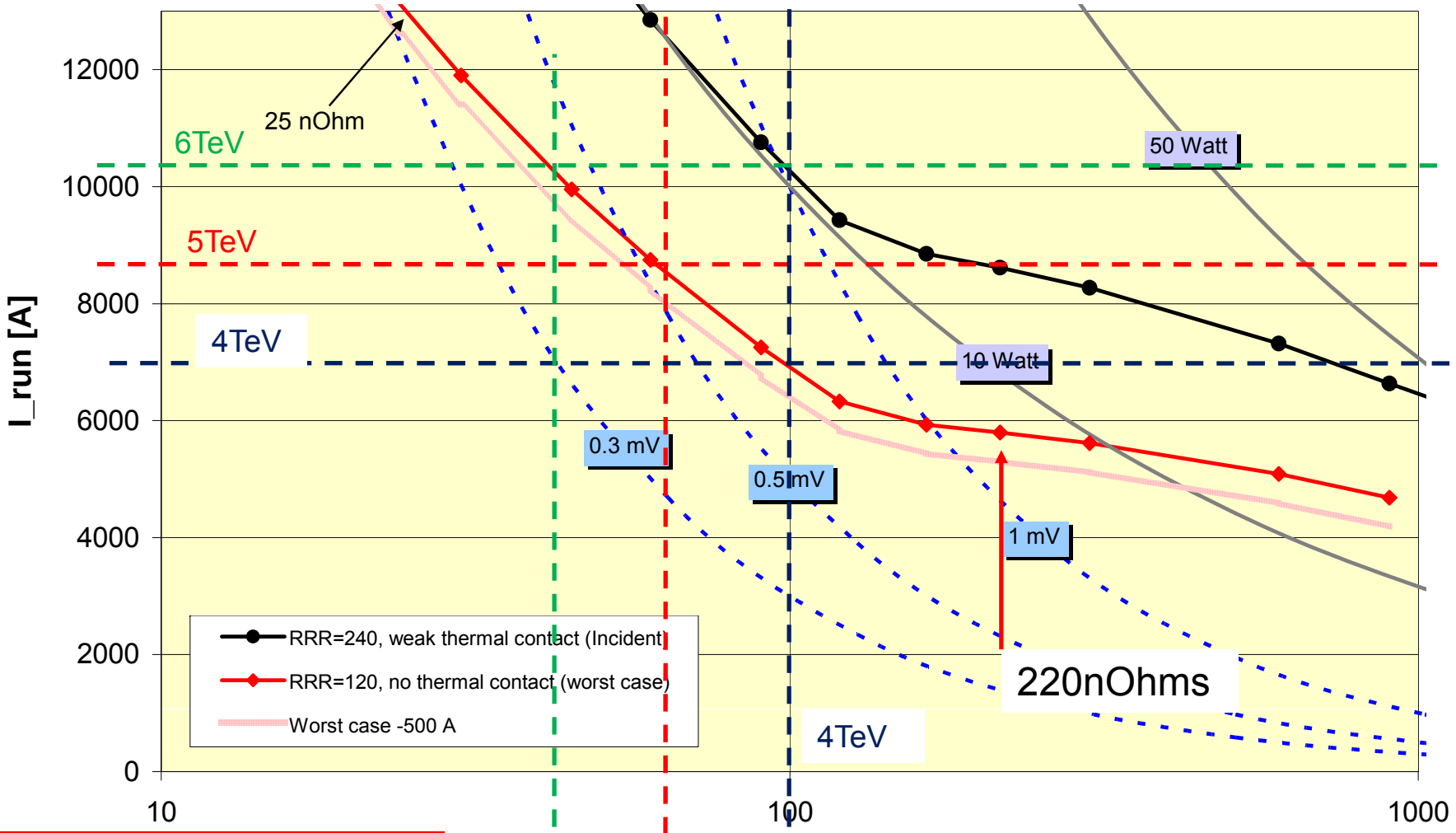
A QPS threshold of 0.3 mV is needed to protect the RB bus and the joints in all imaginable conditions.

Fast thermal run-aways resulting from sudden transient disturbances (without intermediate stable heating) are unprotectable by any QPS system (whatever the threshold).

To avoid such fast thermal runaways one needs to assure a good thermal contact between joint and U-profile/wedge (by means of clamping) or to assure a good electrical and thermal contact between bus and joint (perfect soldering between bus and joint).

A. Verweij,

Setting for the new QPS upgrade



This simulation result is critical for our decision and should be independently confirmed

Remember 1V previously!

A. Verweij

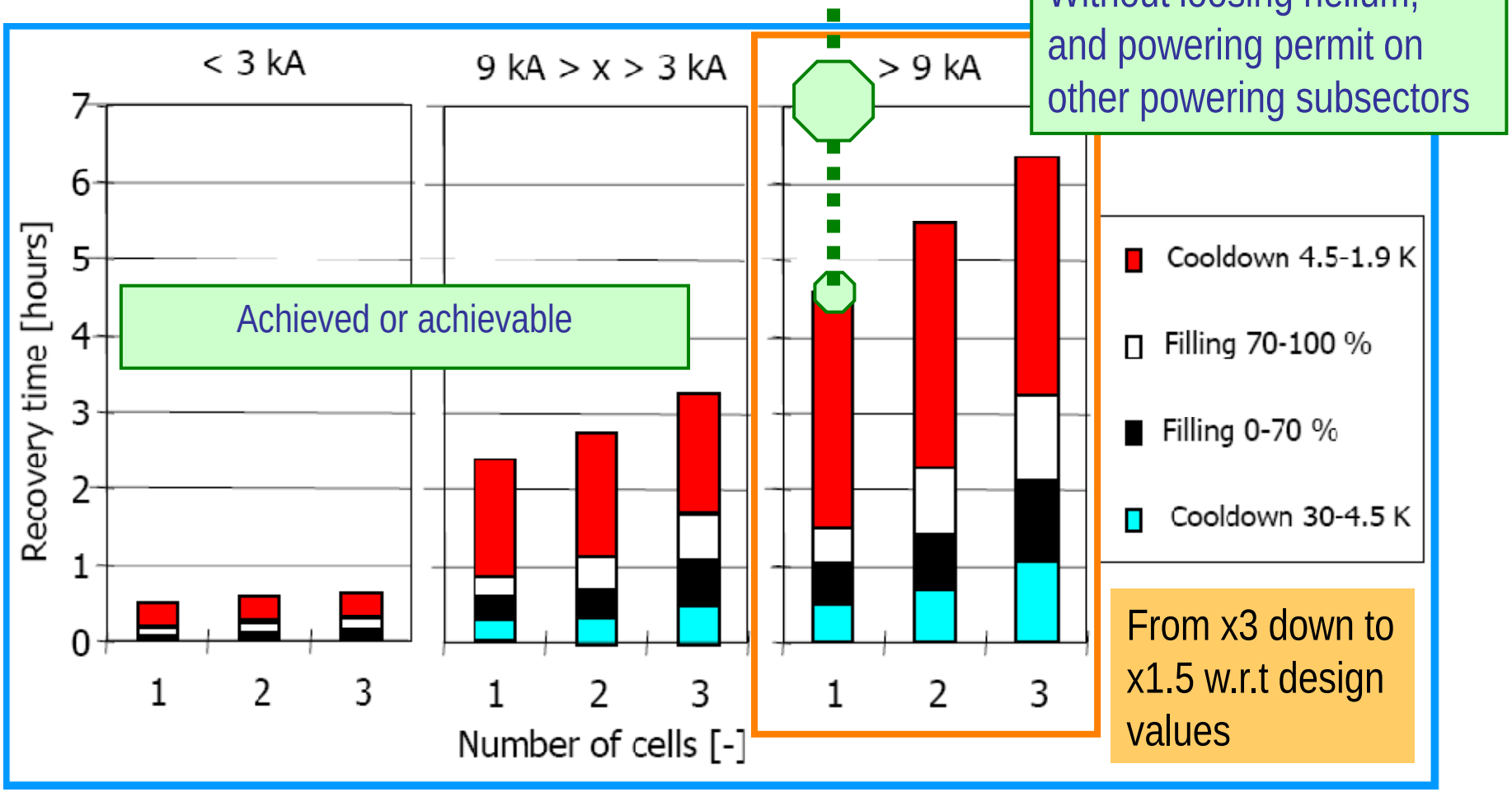
Conclusion

A small gap (up to a few mm) between bus and joint is acceptable as long as there is a good thermal contact between joint and U-profile/wedge.
Of course, the QPS system cannot protect the circuit in case of a sudden mechanical opening of the joint (without precursor 100 sec before).

Very similar conclusions hold for the RQF/RQD circuits, but what about all the other joints, busbars, pigtails, ……..

Recovery Time after Limited Resistive Transitions

(Predictions at design stage)



- More than 14 cells or full sector: recovery up to 48 hours
- In case of fast discharge (even w/o quench): 2 h recovery (heating due to eddy currents).

Topics for Discussion/Decisions

- Road Map and Schedule
- Repair Scenarios (two)
- Dipole Field for Operation
  - Training/re-training
- “Precautions for Running”
- Beam Conditions for Physics
- Future Improvements to convert LHC into an “Operational” Machine
- Safety Considerations

Beam Conditions for Physics

- **Conclusion 5TeV/beam for Physics**
- Machine Protection will be Tested with beam (at 0.5TeV energy levels)
- 4 TeV “on the way” to 5TeV (limited in 2010)
- Estimated integrated luminosity
  - during first 100 days of operation.. ≈100pb-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)

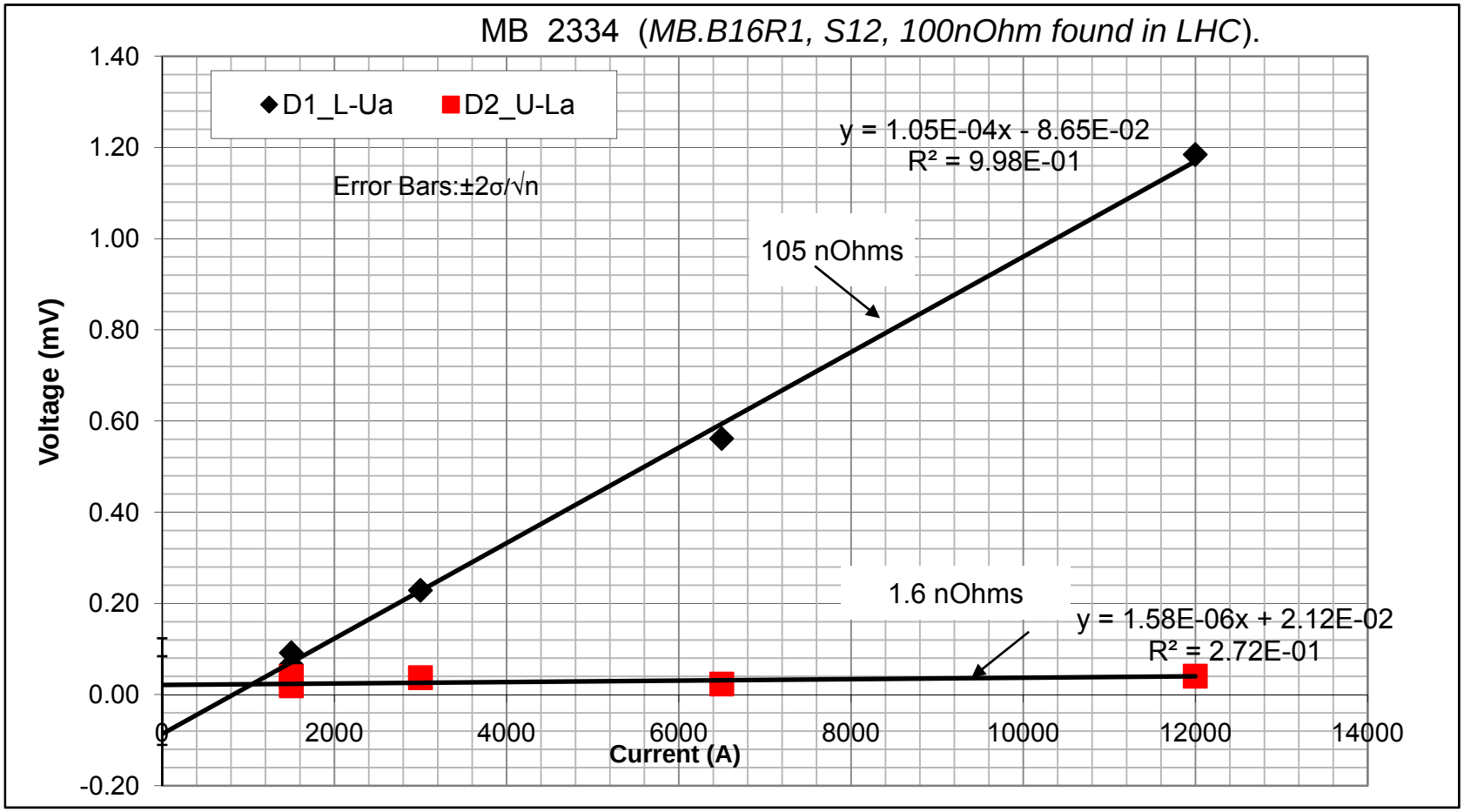
Topics for Discussion/Decisions

- Road Map and Schedule
- Repair Scenarios (two)
- Dipole Field for Operation
  - Training/re-training
- “Precautions for Running”
- Beam Conditions for Physics
- Future Improvements to convert LHC into an “Operational” Machine
- Safety Considerations

Precautions before Running with Beam

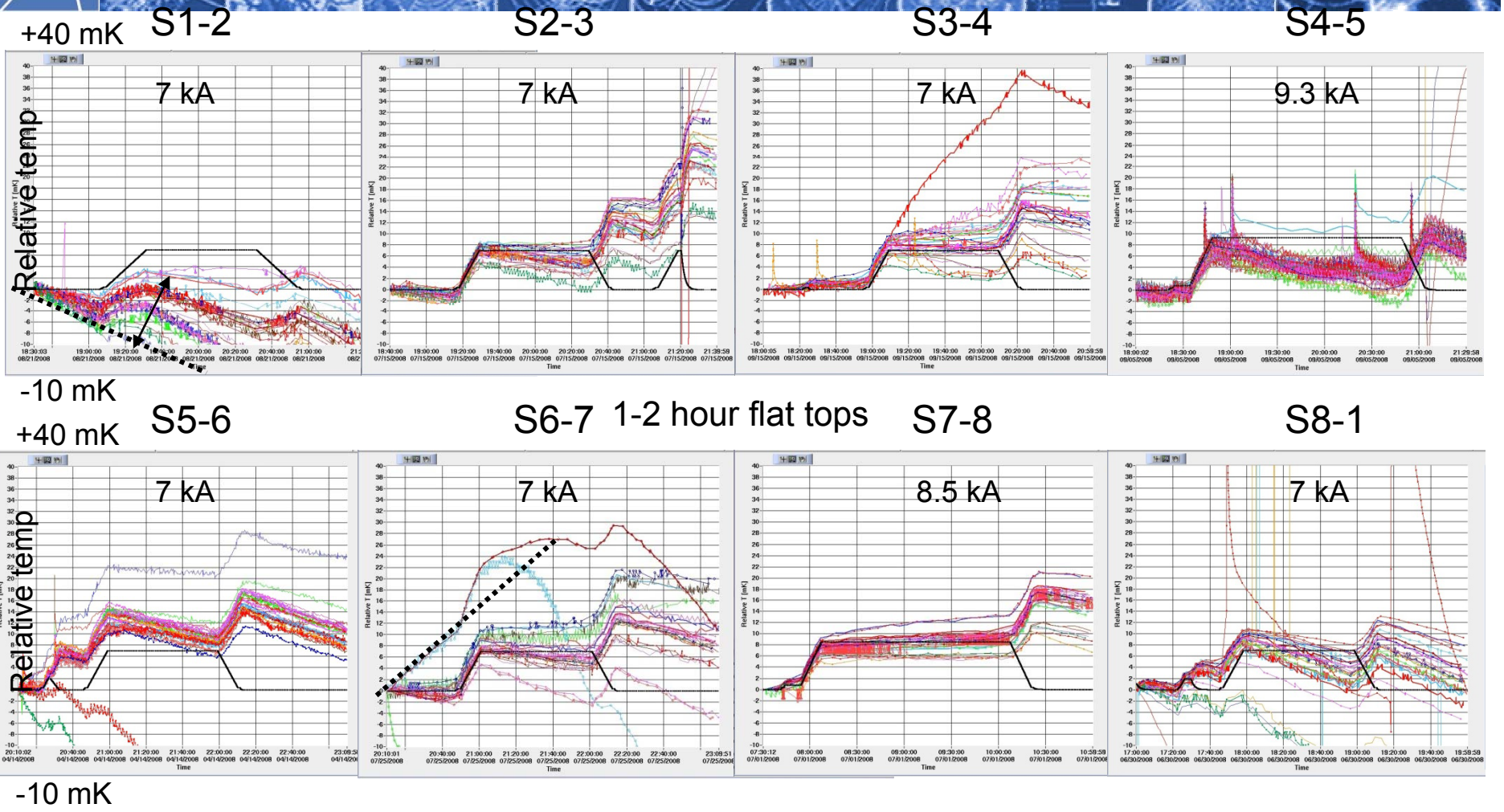
- Pre-detection of Poor splices in untested sectors
  - Analysis of SM18 data + calorimetry at 7kA
  - Early running of S23 and S45 (weekend calorimetric run in April/May??) →
- QPS fully operational☺
- QPS in event of trip of UPS ☺
- Pressure valves in DFBs and inner triplets
- Quench Protection during magnet ramp down ☺
- Protect RF and injection kickers (vacuum valves)
- Water cooled cables
- Anomalies in electric circuits (K-H. Mess)
- Xray machine available Aug/Set ?sooner
- Undulator (left of point 4) availability and necessity

Verification from SM18 data on magnet 2334



- Data from SM18 acquired during the cold tests confirms an inter-pole splice of 105 nOhm in magnet 2334 (B16R1)

All sectors quick comparison



All the current plateaux scrutinized for suspect temperature increase

Unstable conditions and dynamic temperature control prevent accurate calculations.

Precautions before Running with Beam

- Pre-detection of Poor splices in untested sectors
  - Analysis of SM18 data + calorimetry at 7kA
  - Early running of S23 and S45 (weekend calorimetric run in April/May??) →
- QPS fully operational☺
- QPS in event of trip of UPS ☺
- Pressure valves in DFBs and inner triplets
- Quench Protection during magnet ramp down ☺
- Protect RF and injection kickers (vacuum valves)
- Water cooled cables
- Anomalies in electric circuits (K-H. Mess)
- Xray machine available Aug/Set ?sooner
- Undulator (left of point 4) availability and necessity

QC splices during production

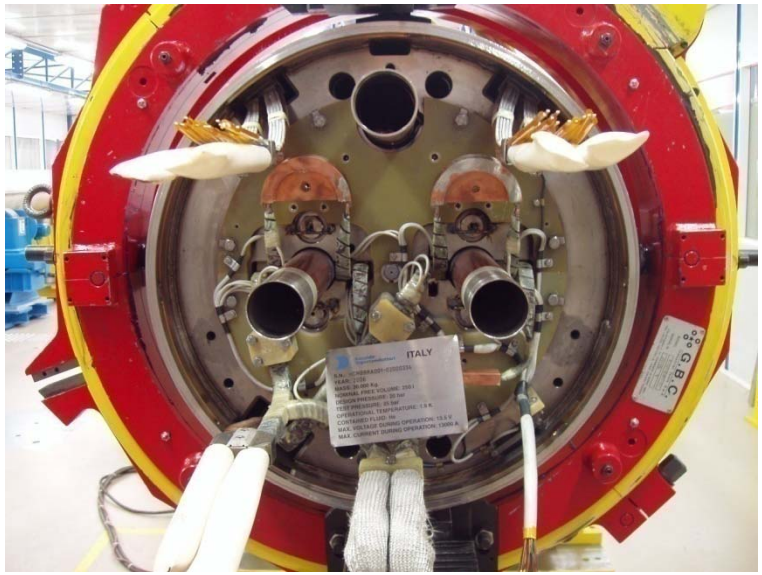
- Visual inspection of each splice by member of QC team prior to soldering operation and after soldering operation (before insulation): take photos NEW
- Dimensional measurement of the finished splice (?): NEW
- Systematic ultrasonic testing of 13 kA splices: NEW →
- Record temperature cycles during soldering of 13 kA splices with separate equipment: NEW.
- Possibly record pressure data?
- Production data analysis and storage
- Weekly audits
- Braze BB vs insulate BB and US weld spools by separate teams
- … and don't be blind to other potential problems …

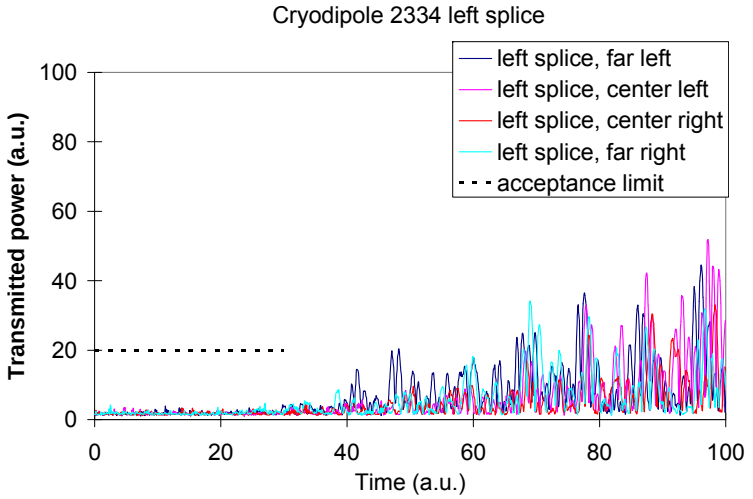
S34 new splices should be perfect!!

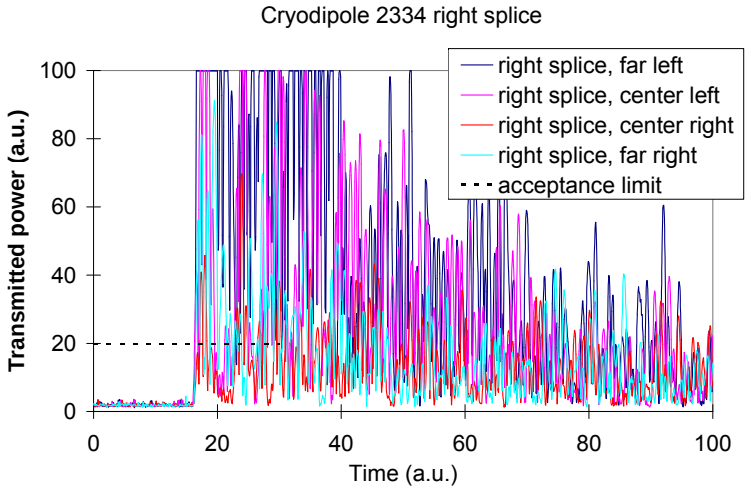
Courtesy C. Scheurlein

Ultra-Sound testing 13 kA splices

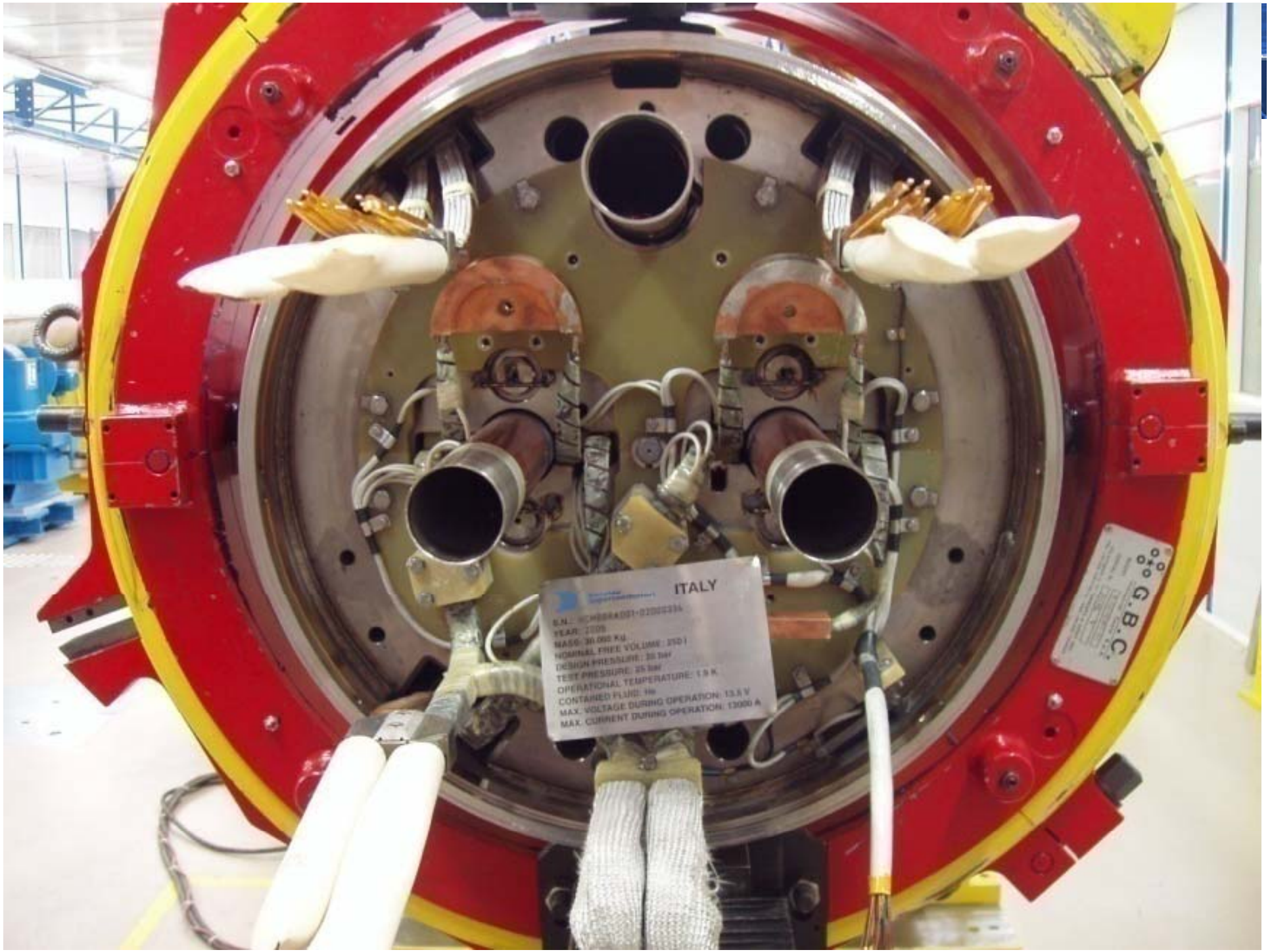
US inspection of defective inter-pole splice in MB 2334 has confirmed the US test to be a very useful QC tool.







Courtesy C. Scheurlein


ITALY
S.N.:
YEAR: 2005
MASS: 30.000 Kg
NOMINAL FREE VOLUME : 350 l
DESIGN PRESSURE: 20 bar
TEST PRESSURE: 25 bar
OPERATIONAL TEMPERATURE: 1.9 K
CONTAINED FLUID: He
MAX. VOLTAGE DURING OPERATION: 13.5 V
MAX. CURRENT DURING OPERATION: 13000 A
G.B.C.

- Pre-detection of Poor splices in untested sectors
  - Analysis of SM18 data + calorimetry at 7kA
  - Early running of S23 and S45 (weekend calorimetric run in April/May??)
- QPS fully operational
- QPS in event of trip of UPS √√☺
- Pressure valves in DFBs and inner triplets ?
- Quench Protection during magnet ramp down √√☺
- Protect RF and injection kickers (vacuum valves) √
- Water cooled cables ?
- Anomalies in electric circuits (K-H. Mess)
- Xray machine available Aug/Set ?sooner
- Undulator (left point 4) availability and necessity ?

Precautions for Running 2

- Long Straight sessions: clarification ?
- Automation of the calorimetry measurements
- Complete set of Omhic measurements of all splices during Power Tests and Cold check-out
- MQM praying hands splices? Change ?

Topics for Discussion/Decisions

- Road Map and Schedule
- Repair Scenarios (two)
- Dipole Field for Operation
  - Training/re-training
- “Precautions for Running”
- Beam Conditions for Physics
- Future Improvements to convert LHC into an “Operational” Machine
- Safety Considerations

Future Improvements

- ARCOM-RAMSES replacement
- MQM praying hands splice to be replaced
- Clamping of busbar splices, development followed by campaign of replacements?
- Spares, spares, spares
- SEU; continuation of protection
- Helium storage
- Improvement in controlled access system
- Vacuum consolidation to reduce collateral damage in case of splice rupture
- Cooling Tower maintenance (LEP/LHC HVAC)
- Use of new xray machine
- Centralised radiation workshop

Topics for Discussion/Decisions

- Road Map and Schedule
- Repair Scenarios (two)
- Dipole Field for Operation
  - Training/re-training
- “Precautions for Running”
- Beam Conditions for Physics
- Future Improvements to convert LHC into an “Operational” Machine
- Safety Considerations

Safety Considerations

- Need safety conditions for access urgently
  - When considering access to service areas during lower current tests, consider the energy in the circuit
- Safety Information Panels needed ?
- Level 3 alarms situation to be looked at by sc
- Emergency Preparedness. We should review the procedures based on the S34 incident
- Cooling Tower maintenance (LEP/LHC HVAC)

Closing Remarks

- The Chamonix yearly retreat is crucial
  - Seeds planted for several collaborations machine-physics groups
- Strong Recommendations
  - Beam physics running during winter 2009-2010
  - Long running period of 11 months is possible
  - Enhanced QPS system fully operations for run
  - 10TeV cm; > 200pb-1 (goodbye to competition)
  - Ions at the end of the proton run
- Future Work-Plan established
  - Preparation for 2009-2010 run (safely and reliably)
  - Longer term to convert LHC into an “operational” machine
- Chamonix 2010 already planned!

Closing Remarks

- Thanks!!!
  - Chairs and scientific secretaries: excellent organisation
  - Speakers: many excellent presentations, not a single poor presentation
  - Colleagues (experts) from other labs/panels
  - LHC detectors (Tech coordinators and Spokespersons)
  - Participants (lively discussions, expert advice)
  - Roger Bailey, Frank Zimmermann, Christian Carli
  - Tjitske!! For everything

Special Thanks to the DG for insisting on Chamonix 2009