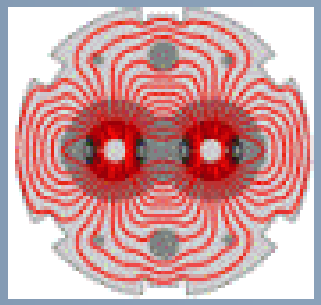
Session Summary - Preconditions for LHC operation at 5 TeV in 2010

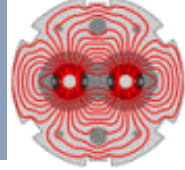


LHC Performance Workshop – Chamonix 2010

Session 1 - 25th January 2010

A.Siemko , M.Zerlauth TE/MPE

Session overview



- Scope and results of hardware commissioning to 3.5 TeV and lessons learnt (M.Solfaroli)
- Enhanced QPS – performance, commissioning at 3.5TeV, outlook towards 5 TeV (R.Denz)
- Do the splices limit us to 5TeV – plans for the 2010 run (M.Koratzinos)
- Lessons Learnt from Beam Commissioning and Early Beam Operation of the Beam Loss Monitors (incl. outlook to 5 TeV) (E.B.Holzer)
- How to safely reach higher energies and intensities? Settings and commissioning of MPS for 5 TeV operation (J.Wenninger)
- What else needs to be done, to reach 5 TeV and beyond? Consolidation and commissioning of essential magnet powering systems (W.Venturini)
- Hardware Commissioning 2010 and beyond (R.Schmidt)

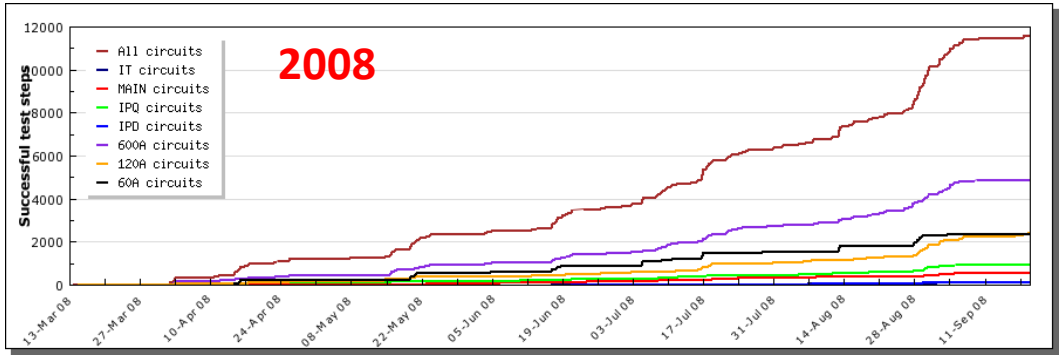
HWC 2009/2010 and beyond

01/04/08
10/09/08

164 days

121*MA (2)
3*MAN (3)

251 shifts

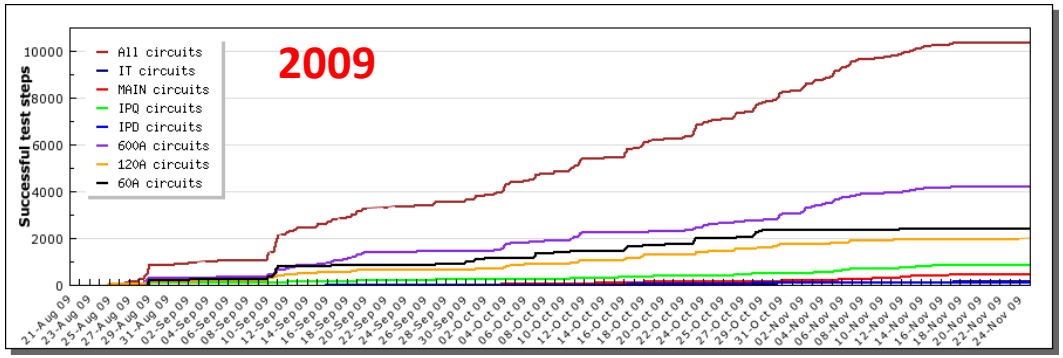


21/08/09
18/11/09

89 days

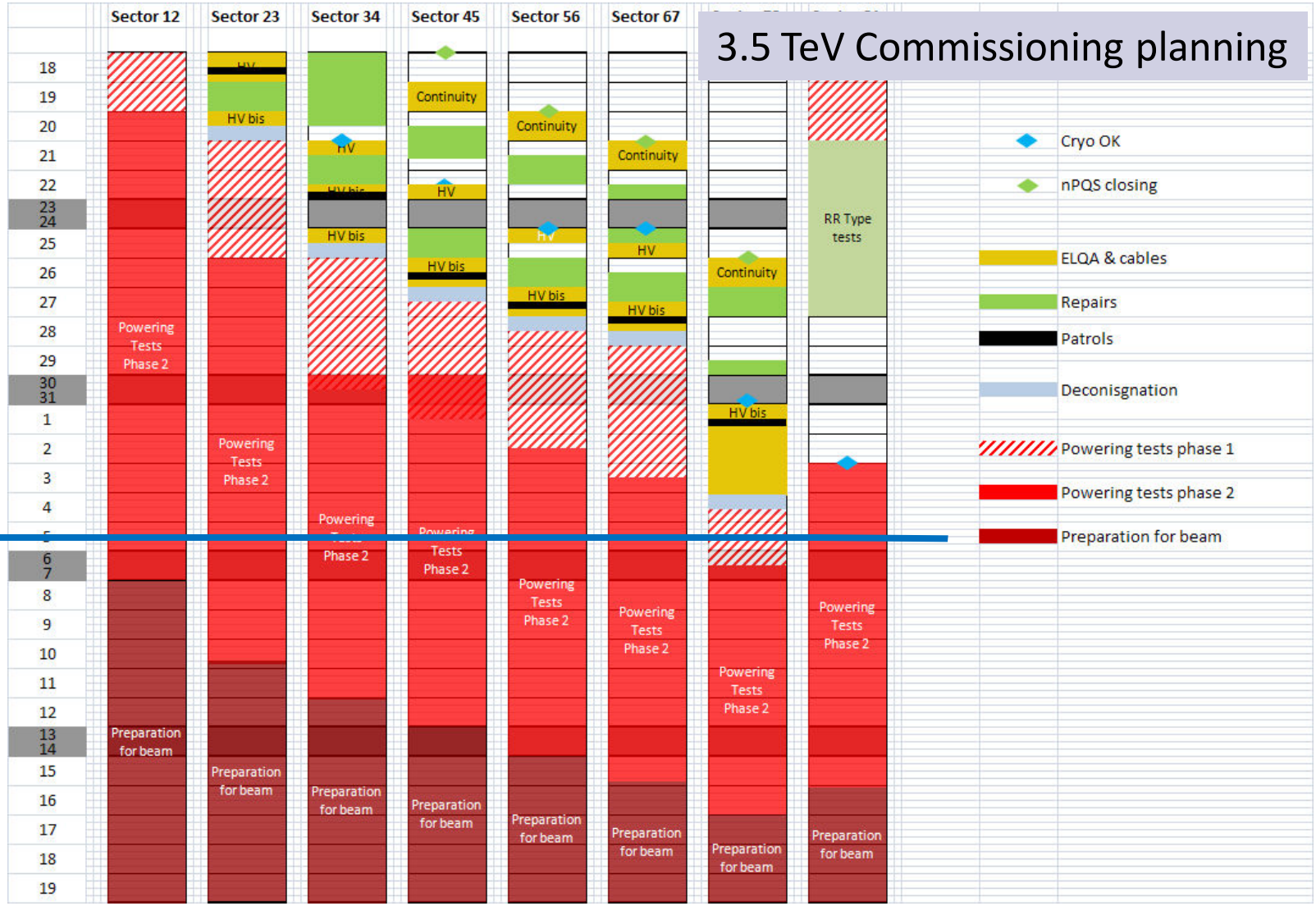
33*MA (2)
52*MAN (3)

222 shifts



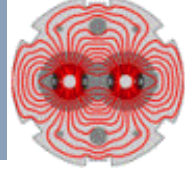
- HWC in 2009 went smooth (total time reduced from 164 to 89 days and 20% less shifts) despite the increase in complexity due to nQPS
- Mainly thanks to increased parallel commissioning (up to 5 sectors in 2009)
- nQPS connector repair finished on schedule and commissioning to 3.5 TeV well underway

HWC 2009/2010 and beyond



Courtesy of K.Foraz

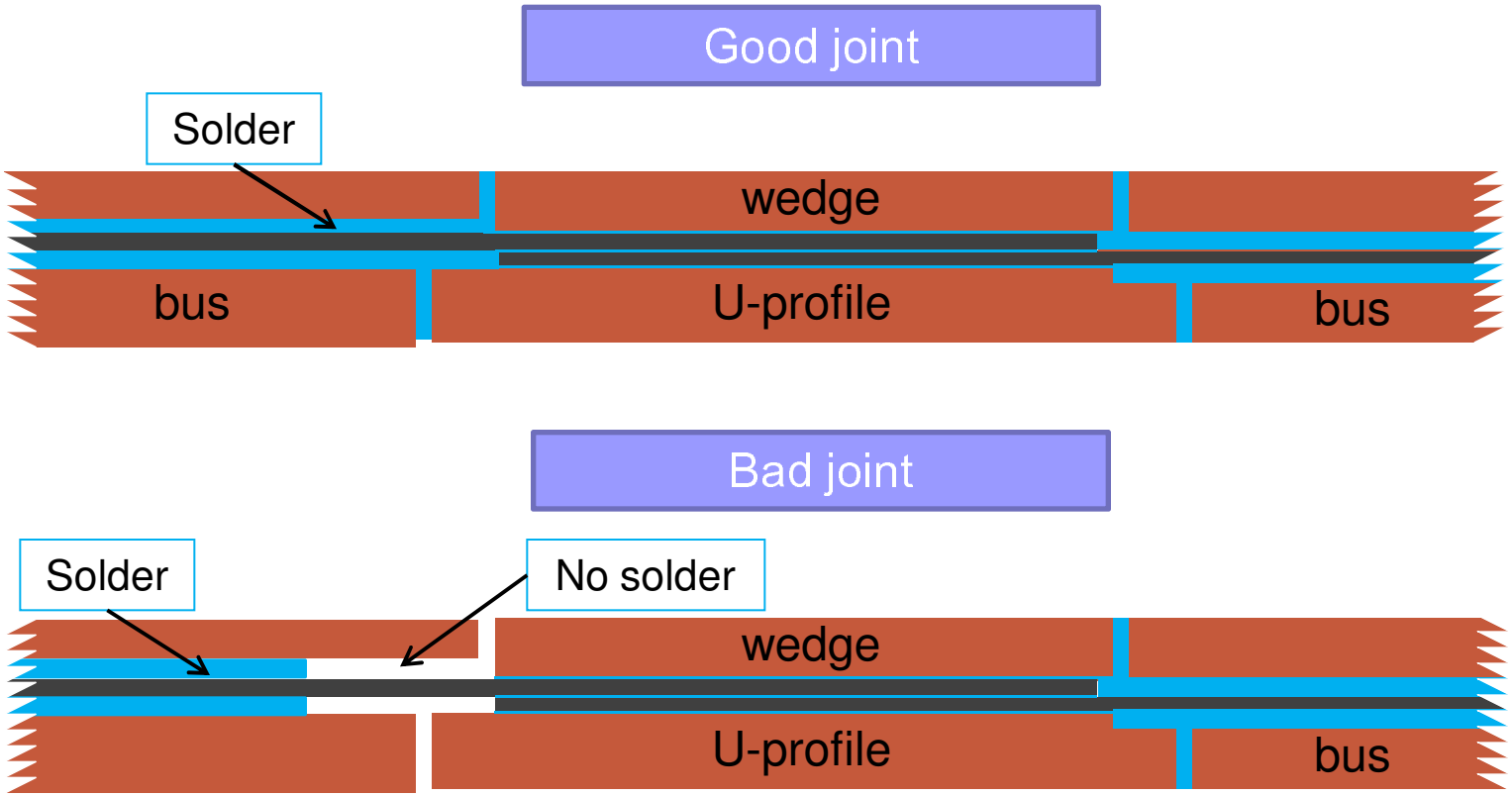
HWC 2009/2010 and beyond



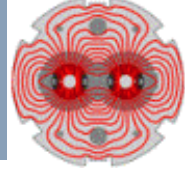
- **For several years, extensive re-commissioning of the super-conducting circuits is to be expected**, after total or partial warm up…
  - adding relief valves, consolidation of splices, commissioning to 5…7 TeV, magnet training, upgrades with radiation tolerant electronics,….
- It is worth to invest time and effort into further optimisation of hardware commissioning with the **long-term goal to commission the machine in 3 weeks**
- **Re-organisation of HWC team proposed for campaigns beyond 2010** to
  - Further optimize the planning/coordination between shut-down coordination and hardware commissioning
  - Increase efficiency by starting preparations for future campaigns with a dedicated team (involving members from OP, MEF, MPE/MP3, EPC, Controls, Cryo, MSC,..)
    - to propose improvements of tools
    - updating of commissioning procedures for future shut-downs/upgrade scenarios

Interconnection splices and resistance at warm

- A copper stabilizer with no continuity coupled to a superconducting cable badly soldered to the stabilizer poses a real problem (A. Verweij)



Interconnect splice resistances



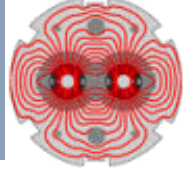
- The nQPS campaign of 2009 gave excellent results for ‘cold’ splices:
  - There is no excess resistance **above 4nΩ** anywhere in the machine
  - The splice resistances found above 2nΩ are:
    1. 2.87±0.1 (RQ circuit, sector 23)
    2. 2.32±0.1 (RB circuit, sector 34)
    3. 2.05±0.5 (RQ circuit, sector 34)
- An excess resistance at cold of 2nΩ:
  - Poses no problems under normal operation.
  - However it might suggest a structural problem or a problem with the soldering procedure which might be more serious
  - **Time evolution** needs to be followed closely
- The excess resistances found are natural candidates to be checked by the new X-ray tomograph

Resistance measurements at warm

A heroic effort was undertaken in 2009 to measure bus bar segment resistances at warm. Measurements were taken **by hand** (100,000 numbers!). Five sectors were measured at warm and the worst splices were opened up and repaired.

Circuit/ Sector	Temperature spread (K)	Excess resistance spread	Highest remaining excess resistance	Excess resistance limit 90%CL
A12 RB	**1.1**	**13**	**37**	**51**
A34 RB	**1.9**	**10**	**35**	**47**
A45 RB	**0.9**	**17**	**53**	**78**
A56 RB	**0.4**	**9**	**20**	**34**
A67 RB	**0.6**	**14**	**31**	**48**

Interconnection splice limitations



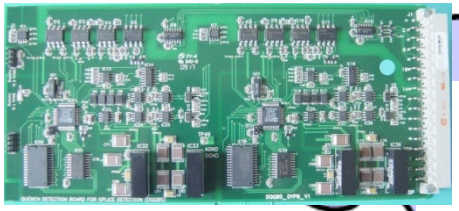
- Superconducting splices measured with excellent accuracy (at cold), copper stabilizer splices are limiting the top energy
  - Worst Cu-Cu-splice measured: **60±1μΩ ,** worst known to exist : **53±15μΩ,** worst estimated to exist : **90μΩ**

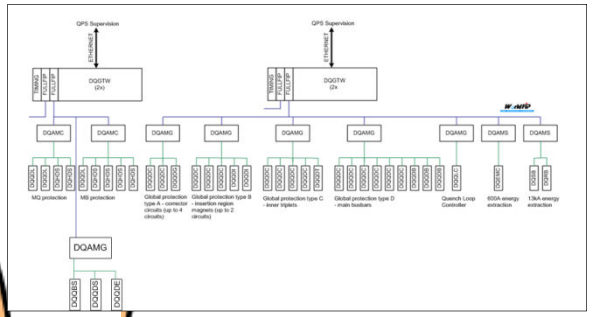
- **Current knowledge of copper stabilizer splices leaves no margin for operation at 3.5TeV**

- **5TeV running is excluded without major repairs**

- Two diagnostic **methods are under development to further increase our knowledge** of interconnection splices and to spot outliers
  - A low current method that can measure the RRR of the busbars
  - A high current method (the Thermal Amplifier) that is sensitive to the worst splices in all bus bar segments

What is enhanced QPS (nQPS)?





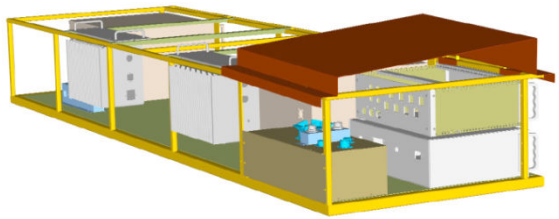
Supervision & data analysis

Splice protection & monitoring

436 crates, 3924 detection boards, 872 power packs
~30000 signals
240 km of cables, 7800 connectors

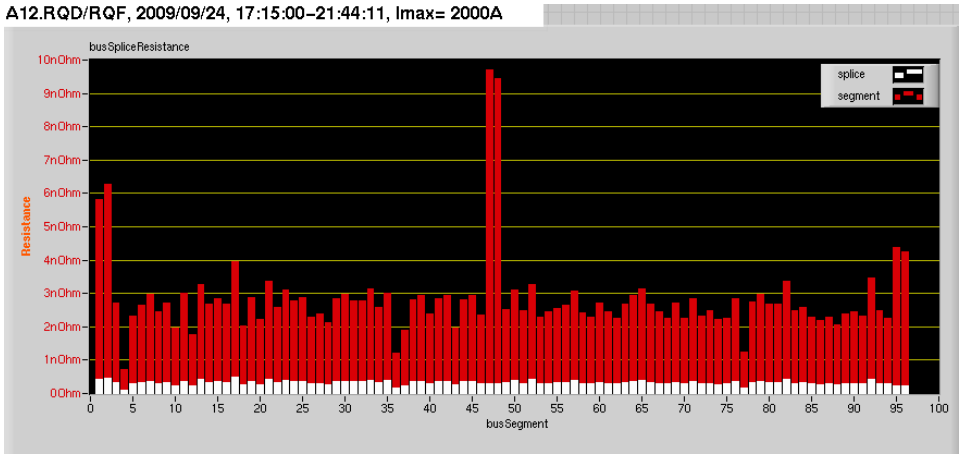
powering

Symmetric qu
detectio

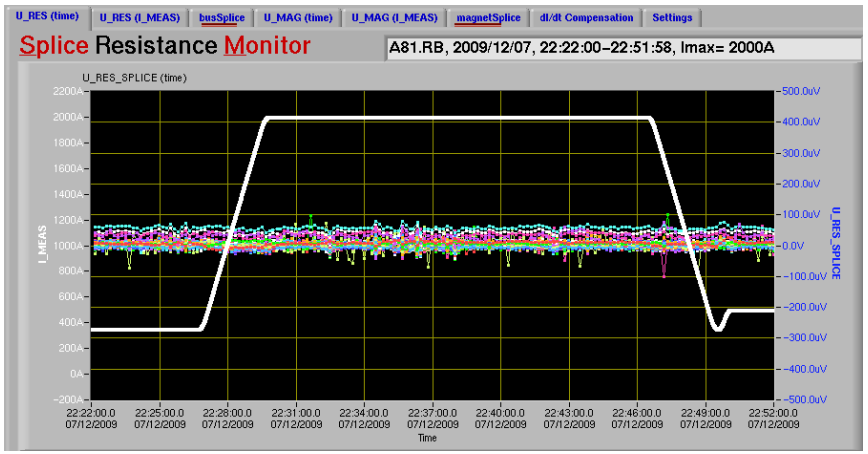


nQPS performance – splice mapping

- Complete mapping of the superconducting interconnection splices in the LHC main circuits for the first time – no bad surprises
- Successful validation of nQPS design
- Final commissioning up to 3.5 TeV of **nQPS** is ongoing – no bad surprises
  - Only **minor additional commissioning to go to 5TeV will be needed**
  - Main constraint with respect to the overall dependability (= reliability + availability + safety) of the QPS system is the large equipment number
  - For **long term need a radiation tolerant/hard MicroFipTM** for whole QPS



First splice mapping at I = 2 kA to qualify splices (~ 400 pW)

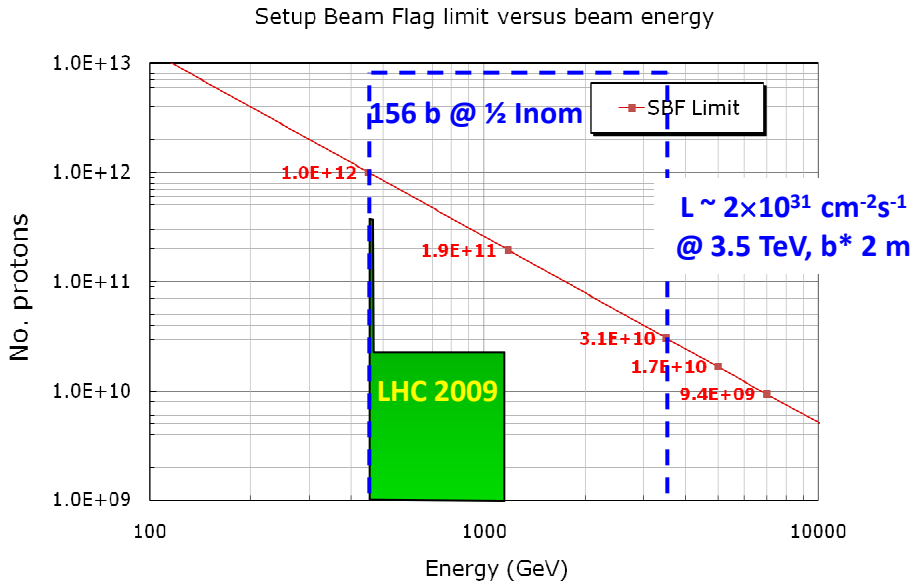


Resistive voltage during ramp and coasting

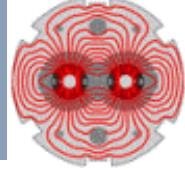
Machine Protection Systems in 2009

- The large majority of interlocks were tested and ACTIVATED !
  - and we could still operate the LHC !
  - and we did not quench with circulating beam – thanks to very good collimation !
  - the *'with so many interlocks it will never work'* scenario did not occur !
- But the beams were modest – compared to design:
  - the maximum stored energy was ~30 kJ – a factor 10'000 to go…
  - no beam made it above the SBF limit.

The 2010 plans imply World record stored energies ~10xTEVATRON to be reached on the time scale of a few months !

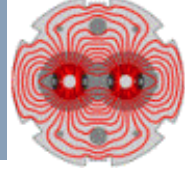


Increasing energy and intensity in 2010



- In **2010 we will operate (highly) unsafe beam**: we may reach sufficient stored energy to shutdown the LHC for some months in case of incident.
- **For unsafe beams, we need a careful machine setup**, a **well established operational cycle**, **good diagnostics** and a **reliable control system**.
- **MPS commissioning to be finished (essentially equivalent for 3.5TeV, 5TeV or 7TeV)**, some part to be repeated (global tests).
  - Collimators and absorbers are critical.
- **Stable operational cycle must be established**, **intensity increase must be gradual** and only after careful analysis of losses
- Machine (MPP) and Magnet (MP3) Protection must work closely together, in particular if we start to quench!
- Great care must be used during MD periods not to jeopardize safety of regular operation
  - Procedures are needed to restore initial machine & settings

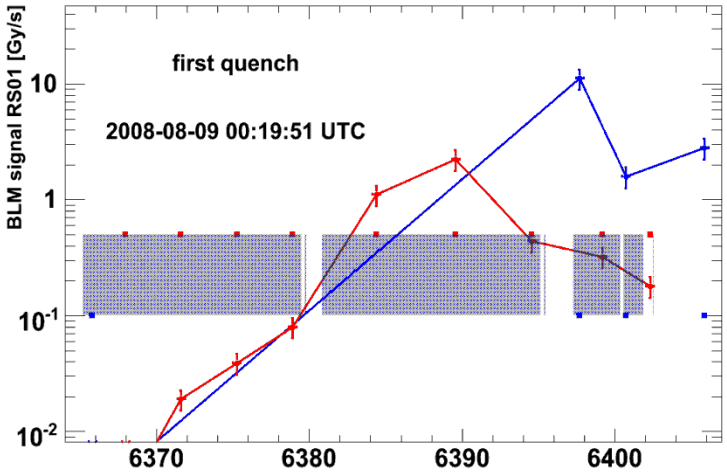
Early Beam Operation of the Beam Loss Monitors



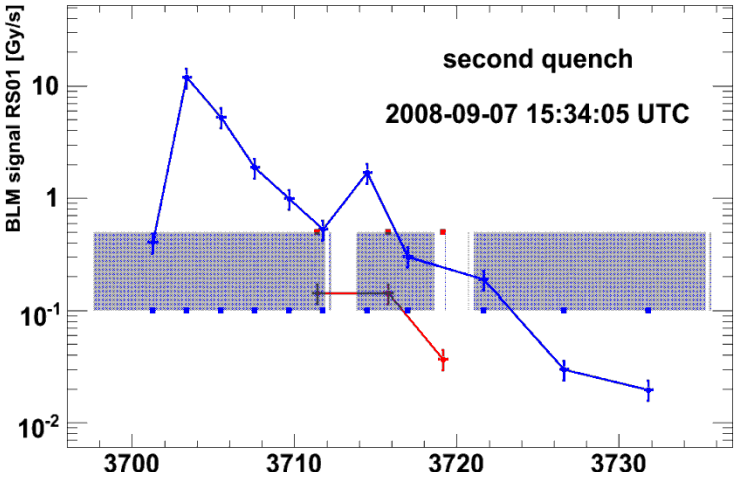
- During 2009 run very satisfying performance, with machine protection functionalities being **phased in**, in order not to compromise the availability during commissioning
- Important step for the BLM system is to go to unsafe beams, and will be crucial to reach full protection level
  - Additional Beam tests in 2010 to determine safe setting of threshold levels and full application of procedures
- Known BLM system limitations and upgrades look compatible with LHC schedule
  - Typically, warm elements should have higher thresholds
  - Certain locations **need** higher thresholds (add capacitor or install new small IC, choose different monitor location, install shielding, etc.)
- **No additional limitation found for energies up to 5 TeV**
- Collimation cleaning looks very promising
  - In 2009 **limitation** seen in **injection losses (injection was not yet optimized)**

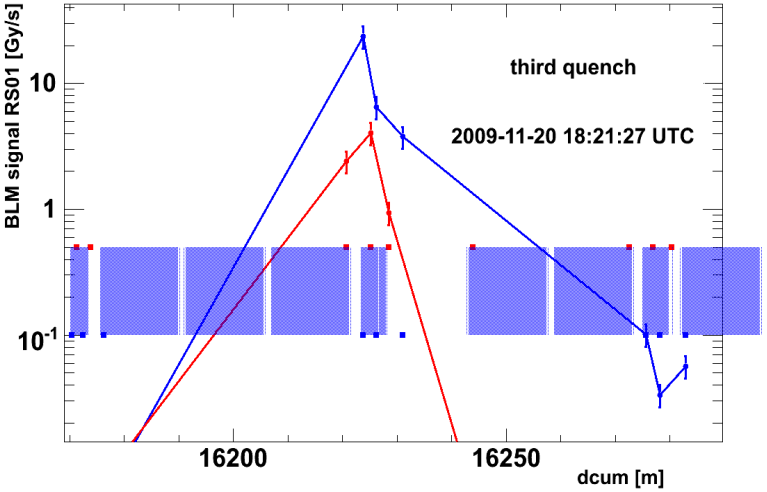
Analysis of first 4 beam induced quenches

analyzed (opposite beam equipped)

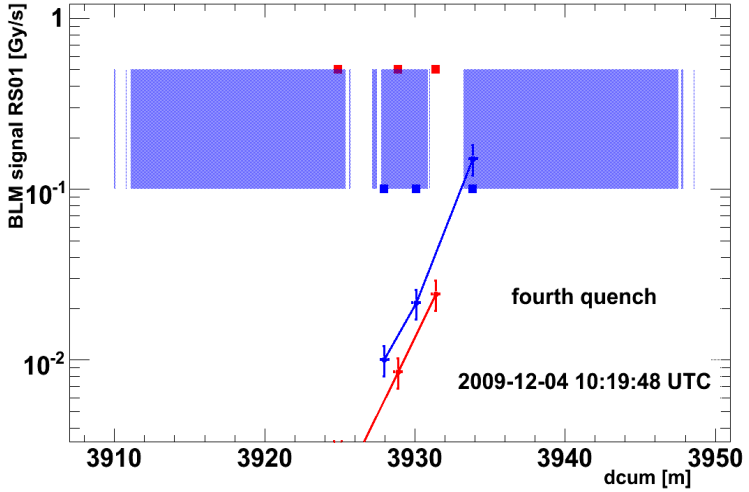


analyzed





highest IC saturation

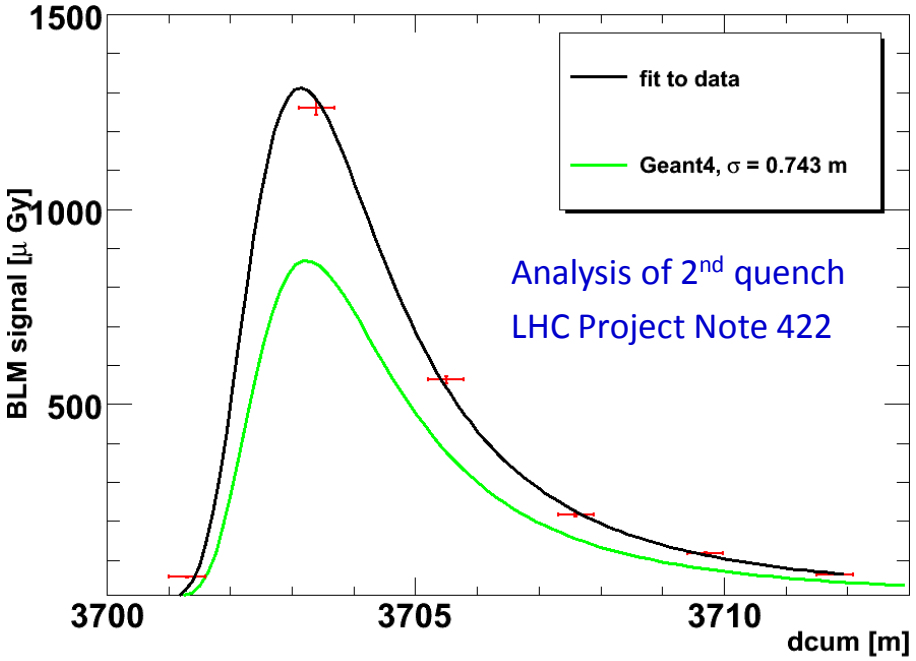


MB not equipped

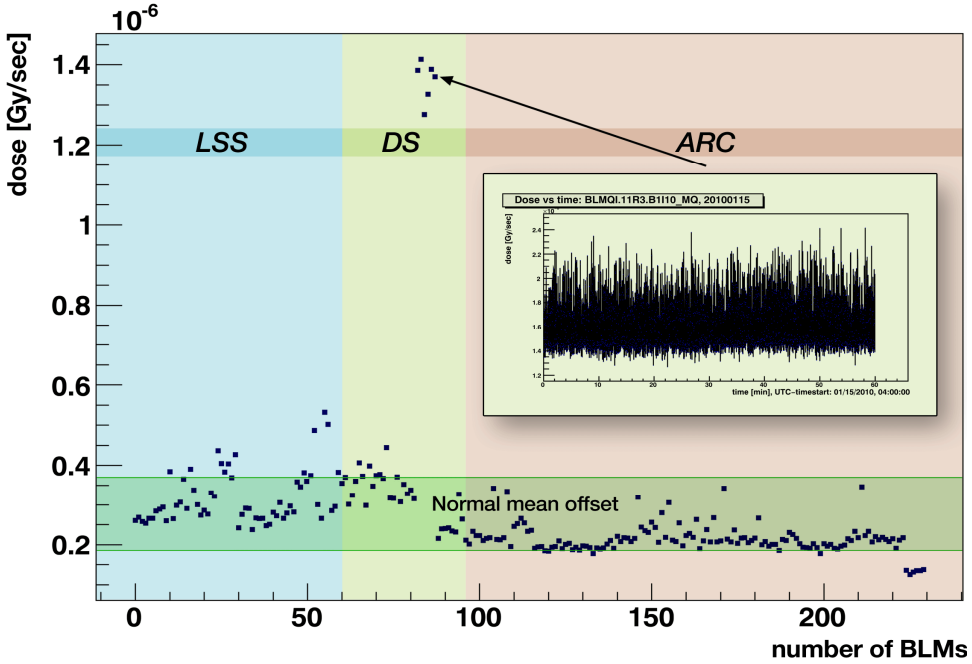
Accuracy of Thresholds vs Noise and offsets

- All quenches so far on main bending magnets (all injected beam). Most likely loss locations with circulating beam are the quadrupoles.
- 2 quenches in 2008 (injected beams): signals in BLMs could be reproduced by GEANT4 simulations to a factor of 1.5

  → thresholds raised by ≈50%



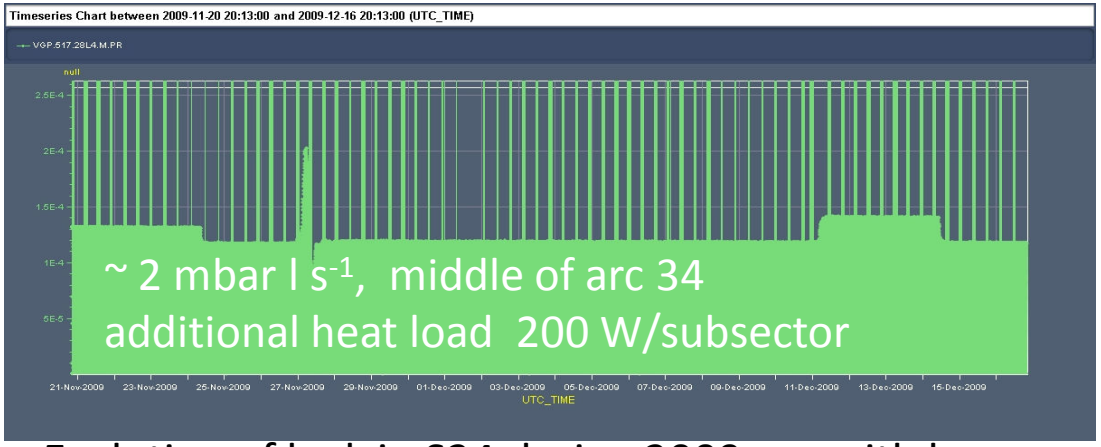
Simulation vs measured losses for MB quench



Example mean offset level right of IP3

Other consolidation work necessary for 5 TeV

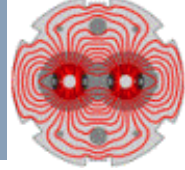
- **Consolidation needed to go from 3.5TeV to 5TeV:**
  - Snubber capacitors + Reduced R_{dump} (τ=68 s for RB, τ=15 s for RQF/D)
  - Replacement of dipole magnet with faulty quench heaters in S12
  - Weak MCBY circuits: prepare fallback solution? (under study)
  - R1Q1 protection
- **Potentially impacting availability (already for 3.5TeV):**
  - Vacuum leak in sector 34
  - Valve consolidation on DFBs
  - MCBX and several other 600 A circuits (0V crossing, QPS calibration,…)



Evolution of leak in S34 during 2009 run with beam

13kA EE system of LHC main circuits

Session 1 – Conclusions



- Smooth HWC in 2009 (50% of 2008 campaign, 20% less shifts)
  - further improvements to be discussed and worked out for future campaigns **to achieve 3 weeks for full LHC commissioning**
- Final commissioning up to 3.5 TeV of **nQPS** is ongoing – no bad surprises
  - Only **minor additional commissioning to go to 5TeV will be needed**
- Known BLM system limitations and upgrades look compatible with LHC schedule - **no additional limitation found for energies up to 5 TeV**
- Large majority of MPS interlocks were tested and activated, no unsafe beam yet in 2009 - **a factor 10'000 in stored energy to go**
- Superconducting splices measured with excellent accuracy (at cold), copper stabilizer splices are limiting the top energy
- **Current knowledge of copper stabilizer splices leaves no margin for operation at 3.5TeV, 5TeV running is excluded without major repairs**
- **Additional consolidation needed before increasing energy above 3.5TeV**
  - snubber capacitors, dump resistors, replacement of MB in S12, weak MCBYs, R1Q1 protection issue, vacuum leak in sector 34, valve consolidation,….