Summary of Chamonix 09

S. Myers
– 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
Topics for Discussion/Decisions

- Road Map and Schedule
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6 February 2009
• Physics Discovery Potential  \[ D_p \approx \eta_{\text{LHC}}.L_{\text{avg}}.T_{\text{run}}.F(E) \]

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

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

\( L_{\text{avg}} \) is the average luminosity during the physics run

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

• \( T_{\text{run}} \) 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

6 February 2009
From F. Bertinelli’s talk

- no holidays (Easter, May ...): is this realistic?
- ignore experience on delays (e.g. humidity for PAQs, Cu/Sn/Ag pollution of some TIG welds, leaks with W closing ...)
- no (more) extra work (... additional sectors ...)

6 February 2009
Schedule with running in winter months

- Gains 20 weeks of LHC physics (independent of “slip”)

<table>
<thead>
<tr>
<th>Year</th>
<th>2009</th>
<th>2010</th>
</tr>
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<tbody>
<tr>
<td>Baseline</td>
<td>SH SH SH SH SH SH SH SH SH SH SH SH SH SH SH SH SH SH SH SH</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>24 weeks physics possible</td>
</tr>
<tr>
<td>Base'</td>
<td>SH SH SH SH SH SH SH SH SH SH SH SH SH SH SH SH SH SH SH SH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>44 weeks physics possible</td>
<td></td>
</tr>
</tbody>
</table>

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

HIGH price Electricity
Today’s cheapest applicable EDF Tariff

Planned Operation

Today’s Operation

6 February 2009
• **Electrical Costs!!**
  - Assuming Full running through December to February
  - dedicated running of the injectors during winter and
  - reduced cryo power from 8MW to 5MW/sector
  → **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
  • …

6 February 2009
FIRST PROPOSAL

Plan Electricity Provision for Running in Winter 2009-2010
Topics for Discussion/Decisions

- Road Map and Schedule
- Repair Scenarios
- Dipole Field for Operation
  - Training/re-training
- “Precautions for Running”
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- Safety Considerations

6 February 2009
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)

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

LHC should not be operated unless the FULL Quench System is tested and operational (my opinion, but open for discussion)
• Intermediate cool-down & QRL warm-up (Stand Alone)

• Activities
  – Arc
  – LSS

• Flushing & ELQA at warm

• Cool-down

• Powering tests

• Cold check-out
The emptying of sectors 78 & 81 can only occur when the first 2 sectors are cold: i.e sectors 12 & 56

Critical points - Changes
- Gaining 5 wks margin on sector 34
- Sectors 12, 56, 78 & 81 on the critical path

Delay w.r.t current schedule = + 5wks
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
## Schedule Scenarios

### Earlier PH may be possible due to changes in safety constraints and additional shifts for power testing

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

### ALARA

### HIGH price Electricity

### 6 February 2009

Stop here for discussion

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

<table>
<thead>
<tr>
<th>Sector</th>
<th>1st training quench [A]</th>
<th>I_max [A]</th>
<th># training quenches</th>
<th>Starting in:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td># ALS</td>
</tr>
<tr>
<td>1-2</td>
<td>-</td>
<td>9310</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2-3</td>
<td>-</td>
<td>9310</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3-4</td>
<td>-</td>
<td><strong>8715 (bus)</strong></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4-5</td>
<td>9789</td>
<td>10274</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>5-6</td>
<td>10004</td>
<td>11173</td>
<td>27</td>
<td>0</td>
</tr>
<tr>
<td>6-7</td>
<td>-</td>
<td>9310</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7-8</td>
<td>8965</td>
<td>9310</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>8-1</td>
<td>-</td>
<td>9310</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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

6 February 2009
Estimated dipole training to reach 6 and 6.5 TeV

<table>
<thead>
<tr>
<th>Sector</th>
<th>Number of magnets</th>
<th>Number of quenches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ALS</td>
<td>ANS</td>
</tr>
<tr>
<td>1-2</td>
<td>49</td>
<td>96</td>
</tr>
<tr>
<td>2-3</td>
<td>56</td>
<td>60</td>
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<tr>
<td>3-4</td>
<td>56</td>
<td>65</td>
</tr>
<tr>
<td>4-5</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>5-6</td>
<td>28</td>
<td>42</td>
</tr>
<tr>
<td>6-7</td>
<td>57</td>
<td>36</td>
</tr>
<tr>
<td>7-8</td>
<td>54</td>
<td>40</td>
</tr>
<tr>
<td>8-1</td>
<td>64</td>
<td>24</td>
</tr>
<tr>
<td>Total</td>
<td>154</td>
<td>154</td>
</tr>
</tbody>
</table>

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

6 February 2009
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, 
\( I_{\text{max}} = 8.7 \) kA, \( D_{\text{runaway}} \approx 1 \) 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).
This simulation result is critical for our decision and should be independently confirmed.

6 February 2009

Remember 1V previously!
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)

Without losing helium, and powering permit on other powering subsectors

- 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).

6 February 2009
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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
**Shutdown 08-09**

- **Intermediate cool-down & QRL warm-up (Stand Alone)**
  - Activities
    - Arc
    - LSS
  - Flushing & ELQA at warm
- Cool-down
- Powering tests
- Cold check-out
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)

6 February 2009
All sectors quick comparison

<table>
<thead>
<tr>
<th>Sectors</th>
<th>Current (kA)</th>
<th>Temperature (mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1-2</td>
<td>7</td>
<td>+40</td>
</tr>
<tr>
<td>S2-3</td>
<td>7</td>
<td>+40</td>
</tr>
<tr>
<td>S3-4</td>
<td>7</td>
<td>-10</td>
</tr>
<tr>
<td>S4-5</td>
<td>9.3</td>
<td>-10</td>
</tr>
<tr>
<td>S5-6</td>
<td>7</td>
<td>+40</td>
</tr>
<tr>
<td>S6-7</td>
<td>7</td>
<td>-10</td>
</tr>
<tr>
<td>S7-8</td>
<td>8.5</td>
<td>-10</td>
</tr>
<tr>
<td>S8-1</td>
<td>7</td>
<td>+40</td>
</tr>
</tbody>
</table>

6 February 2009

All the current plateaux scrutinized for suspect temperature increase.

Unstable conditions and dynamic temperature control prevent accurate calculations.
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
- **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

6 February 2009
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.

Cryodipole 2334 left splice

Cryodipole 2334 right splice

Transmitted power (a.u.)

Time (a.u.)

- acceptance limit

Courtesy C. Scheurlein

6 February 2009
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- Water cooled cables
- Anomalies in electric circuits (K-H. Mess)
- Xray machine available Aug/Set sooner
- Undulator (left of point 4) availability and necessity
- 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

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6 February 2009
Beam Conditions for Physics

- Machine Protection Tested with beam (testing at 0.5 TeV energy levels)
- 4 TeV “on the way” to 5 TeV (no higher in 2010)
- Intensity limited until QPS symmetric mode is completely tested
- Physics at 5 TeV
- Estimated integrated luminosity
  - during first 100 days of operation.. $\approx 100\text{pb}^{-1}$
  - During next 100 days of operation.. $\approx 200\text{pb}^{-1}$??
- Then towards end of year ions (to be planned in detail soon)
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6 February 2009
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

6 February 2009
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6 February 2009
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)
• Excellent Workshop (My Opinion)
  • Many discussions (focused and unfocused)
  • Networking: colleagues, friends, collaboration seeds planted …
  • Have defined the work programme for the next 12-18 months (to be followed up)
  • Have converged on the schedule (will be finalised early next week)
  • Have defined most likely beam conditions for physics
• 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: making up think twice or 3,4, times)
  • Participants (lively discussions, expert advice)
  • Roger Bailey, Frank Zimmermann, Christian Carli

• Tjitske!! For everything