Strategy for the First Two Months of the 2015 Beam Commissioning

S. Redaelli, BE-ABP

with G. Arduini, M. Giovannozzi, M. Lamont, R. Tomás, J. Wenninger

Acknowledgements: Colleagues in OP-LHC, ABP-HSS, ABP-HSC, collimation.
Outline

☑ Introduction
☑ Lessons from Run I
☑ Run II requirements
☑ New decision points
☑ Conclusions
Introduction

2015 LHC commissioning phases

- **Preparation - no beam**
  - First turn

- **Commissioning**
  - **First stable beams**
  - Scrubbing (x2)
  - ~2800 bunches!

- **Intensity ramp-up (50ns, then 25ns)**

- **Stable physics**
  - “Well-prepared” change of $\beta^*$ (inc. mini ramp-up)

- **Stable physics at smaller $\beta^*$**

Machine mode where all experiments are allowed to be completely switched ON.

Intensity ramp-up is done by increasing the number of bunches, keeping the same machine configuration ($\beta^*$, orbit, IR bumps, ...)

Essentially, the beam commissioning of all systems must be **completed**, including **machine protection** (MP) validation.

Since the MP validation is lengthly, changes of machine configuration done after would be **very costly** in term of time!
Goals of initial beam commissioning

What must be done before the first physics with 2-3 bunches:

☑ Establish the key beam commissioning steps

*First threading, beam capture, orbit and optics corrections, IR bumps, aperture, polarities, energy ramp, betatron squeeze, collisions, ....*

☑ Commission with beam the key accelerator systems

*Feedback systems, collimation, RF, injection, dump, diagnostics, ...*  
*Remark: need to take into account the LS1 system changes!*

☑ Execute relevant machine protection commissioning

*We want all MP-related systems in their final configs by the first stBeam!*  
*Complete beam validation of the given machine configuration.*  
*Remark: changes during might become very time consuming.*

☑ Validate by measurements the machine configuration

*The challenges of the Run II require new measurements compared to the standard commissioning of previous years!*

☑ Prepare the scheduled $\beta^*$ change planned for later in 2015.

*What can be done to speed up the optics re-commissioning?*
Goals of initial beam commissioning

What must be done before the first physics with 2-3 bunches:

- **Establish the key beam commissioning steps**
  
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- **Commission with beam the key accelerator systems**
  
  *Feedback systems, collimation, RF, injection, dump, ...*

  **Remark:** need to take into account the LS1 system changes!

- **Execute relevant machine protection commissioning**
  
  *We want all MP-related systems in their final configs by the first stBeam!*  
  
  Complete beam **validation** of the given machine configuration.  
  
  **Remark:** changes during might become very time consuming.

- **Validate by measurements the machine configuration**
  
  *The challenges of the Run II require new measurements compared to the standard commissioning of previous years!*  
  
  Give for “granted” and not presented in detail here

- **Prepare the scheduled $\beta^*$ change planned for later in 2015.**
  
  What can be done to speed up the optics re-commissioning?

Talk B. Salvachua
Baseline 2015 schedule

Initial commissioning: 2 months foreseen
### Initial commissioning: target parameters

*Disscussed in detail this morning, picked from R. Bruce’s slides*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value @ injection</th>
<th>Value @ collision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy [TeV]</td>
<td>0.45</td>
<td>6.5</td>
</tr>
<tr>
<td>$\beta^*$ (1/2/5/8) [m]</td>
<td>11 / 10 / 11 / 10</td>
<td>0.8 / 10 / 0.8 / 3</td>
</tr>
<tr>
<td>Half X-angle (1/2/5/8) [\mu rad]</td>
<td>-170 / 170 / 170 / 170</td>
<td>-145* / 120 / 145* / -250</td>
</tr>
<tr>
<td>Tunes (H/V)</td>
<td>64.28 / 59.31</td>
<td>64.31 / 59.32</td>
</tr>
<tr>
<td>Separation (1/2/5/8) [mm]</td>
<td>2 / 2 / 2 / 3.5</td>
<td>0.55 / 0.55 / 0.55 / 0.55</td>
</tr>
<tr>
<td>Emittance (BCMS/standard) [\mu m]</td>
<td>$\geq$ 1.3 / $\geq$ 2.4</td>
<td>$\geq$ 1.7 / $\geq$ 2.7**</td>
</tr>
<tr>
<td>Bunch intensity [p]</td>
<td>$\leq$ 1.3e11</td>
<td>$\leq$ 1.2e11***</td>
</tr>
<tr>
<td>4 $\sigma$ bunch length [ns]</td>
<td>1.2</td>
<td>1.25</td>
</tr>
<tr>
<td>Collimator settings</td>
<td>2012 (nominal)</td>
<td>2012 mm kept****</td>
</tr>
</tbody>
</table>

* Corresponding to 11 $\sigma$ beam-beam separation. Room for increased angle if needed

** Assuming blowup from IBS only (M. Kuhn, Evian14). Much worse if scrubbing not successful (talk G. Iadarola)

*** Assuming 95% transmission

**** Room for increased margins for machine protection and impedance if needed
Outline

- Introduction
- Lessons from Run I
- Run II requirements
- New decision points
- Conclusions
Baseline established in Jan. 2008

<table>
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<tr>
<th>Activity</th>
<th>Rings</th>
<th>Beam Time [day]</th>
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<tbody>
<tr>
<td>1 Injection and first turn</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2 Circulating beam</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3 450 GeV – initial commissioning</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>4 450 GeV – detailed optics studies</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>5 450 GeV increase intensity</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>6 450 GeV - two beams</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7 450 GeV - collisions</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>8a Ramp - single beam</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>8b Ramp - both beams</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>9 7 TeV – top energy checks</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>10a Top energy collisions</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL TO FIRST COLLISIONS at 7 TeV (1.1x10^{32}cm^{-2}s^{-1})</strong></td>
<td><strong>30</strong></td>
<td><strong>30</strong></td>
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Foreseen frequent changes of optics in the year; ramp-up by bunch intensity and not number of bunches; a few big steps in Nb; ramp comm. for individual beams; ...

Planned first physics with 156 on 156 after 30 days of beam commissioning...

Feedback for Run I commissioning experience:
Awareness of collateral damage; need to avoid quenches in Run I;
Many operational details relevant for commissioning (e.g., bunch intensity for BI);
Validation of machine configuration is lengthy (collimation setup + loss maps);
Steps in intensity and speed of ramp-up determined by machine protection.
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- Validation of machine configuration is lengthy (collimation setup + loss maps);
- Steps in intensity and speed of ramp-up determined by machine protection.

Clearly, the commissioning baseline for 2015 relies on the mature experience of 2012.

Planned first physics with 156 on 156 after 30 days of beam commissioning...

Foreseen frequent changes of optics in the year; ramp-up by bunch intensity and not number of bunches; a few big steps in Nb; ramp comm. for individual beams; ...

S. Redaelli, Cham2014, 23-09-2014
Achieved “ultimate” machine parameters in record time, then optimized bunch intensity and $\varepsilon$. Same $\beta^*=60\text{cm}$ throughout 2012.

Intensity ramp up:
- Increase number of bunches,
- then push bunch intensity.
Followed by a re-commissioning of the optics ($\beta^*=1.5\text{m} \rightarrow 1.0\text{m}$).
2012 commissioning

- First turn
- Both beams at 4 TeV
- Squeeze: crossing and sep bumps
- Ramp with nominal bunches
- Collimator setup after squeeze
- First Stable Beams
- Both beams squeezed to 60cm
- Both beams at 4 TeV
- Squeeze: crossing and sep bumps
- Ramp with nominal bunches
- Collimator setup after squeeze
- First Stable Beams
- Interleaved: BI, ADT, collimation, FiDeL, RF, blow-up, k-mod., ...
- Full validation for stable beams
- 1380 bunches
- 1092 bunches
- 840 bunches
- 624 bunches
- 264 bunches
- 264 bunches
- 1.5 \times 10^{11} \text{ p/b}
- 18/04
- 14/04
- 12/04
- 10/04
- 08/04
- 05/04
- 31/03
- 24/03
- 22/03
- 18/03
- 16/03
- 14/03
- Time
2012 commissioning

First turn
- Both beams at 4 TeV
- Squeeze: crossing and sep bumps
- Ramp with nominal bunches
- Collimator setup after squeeze

First Stable Beams
- 264 bunches $I = 1.5 \times 10^{11} \text{ p/b}$
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Both beams squeezed to 60cm

Both beams at 4 TeV

Squeeze: crossing and sep bumps

Ramp with nominal bunches

Collimator setup after squeeze

2 days

Beam intensity
- 264b
- 624b
- 840b
- 1092b
- 1380b

UTC TIME
Feedback from 2012 commissioning

(Among the many ingredients...)
Excellent performance and knowledge of accelerator systems and of the machine (stability, reproducibility, ...).
A careful choice of parameter set, with reasonable risks (and some luck?)
Rather “small” steps in $\beta^*$ from one year to the other, based on solid knowledge of optics and machine aperture.

Important aspects for the rapid initial commissioning in 2012:
- Commissioning effort was focused on high-intensity proton operation!
- Minimum (no?) hardware changes to cope with, compared to 2011.
- Working in the assumption that few nominal bunches at top energy were SAFE.

This is not the case for the re-commissioning in 2015!
We should expect a longer setup phase.
MP implications on commissioning

- New damage limits proposed in line with updated accident scenarios (Annecy ‘13):
  - Onset of plastic damage: $5 \times 10^9$ p
  - Limit for fragment ejection: $2 \times 10^{10}$ p
  - Limit of 5th axis compensation (with fragment ejection): $1 \times 10^{11}$ p

Inermet 180, 72 bunches

Tertiary collimator that protects the inner triplet

7 TeV equiv. inferred from HRM beams

Test 1 (1 LHC bunch @ 7TeV)
Test 2 (Onset of Damage)
Test 3 (72 SPS bunches)
MP implications on commissioning

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  - Onset of plastic damage: $5 \times 10^9$ p
  - Limit for fragment ejection: $2 \times 10^{10}$ p
  - Limit of for 5th axis compensation (w)

Several new constraints in 2015:
- Protection settings for first ramp and for setup at top energy;
- Definitions for safe setup conditions and impact on validation procedures;
- Details of intensity ramp-up plan

No issue experienced in Run I, but might need to revise this in light of the problem with 5th axis.

7 TeV equiv. inferred from HRM beams

Tertiary collimator that protects the inner triplet

We should expect a reduced commissioning efficiency. Details have to be sorted out for the different commissioning steps.

A. Bertarelli et al.
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2015 commissioning requirements (i)

- **New operational challenges** (obviously...)
  - See complete overview in Mike’s slides this morning

- **Experiments’s requests**
  - Special runs now needed early on
    (implying the early commission of more optics):
    - Dedicated optics setup for VdM scans (de-squeeze).
    - Low-luminosity data taking for LHCf.
  - Alignment and setup of more Roman pots following TOTEM upgrade requested as part of the collimation setup.

- **Injection and dump systems** (see talk by W. Bartmann)
  - Validation of new hardware “gap” interlocks (in the beam energy tracking system);
  - New hardware of the injection (TDI) and dump (TCDQ) protection;
  - Repeat measurements only done at the beginning of Run I:
    - detailed aperture;
    - kicker waveforms;
  - Request for specific checks of TDI heating.
2015 commissioning requirements (ii)

☑ Collimation

- **New hardware with BPMs**: dedicated tests must be foreseen at injection and top energy [18 new collimators with BPMs]
- Verification of new IR layouts with TCL collimators [8 new devices];
- Improve / optimize validation procedures:
  Need to re-establish safe loss maps procedures at top energy;
  Plan to test methods for more efficient off-momentum loss maps.

☑ Beam instrumentation (detailed discussions at Evian)

- Beam size measurements;
- BLM system: new lower-sensitivity monitors in IR2/8;
- New threshold setup;
- New instruments for interlock purposes;
- New “DOROS” BPM’s, in addition to the ones in collimators.

☑ Main RF system and transfer damper (ADT)

- Many new features / hardware changes;
- Measurements on bunch length and longitudinal profile.

☑ Can we fit all that in 2 months?
Preliminary break-down of steps

Recap. of key “standard” activities, from Run I:
- Threading, capture, initial BI
- Initial orbit and optics, more BI, polarities, etc.
- System commissioning: feedback systems, collimation, RF, injection, LBDS, detailed BI, ...
- Optics measured and corrected. Aperture.
- Flat orbit setup followed by IR bump commissioning.
- Squeeze. Steps followed by continuous functions.
- Re-iterate on orbit, optics, aperture, ...
- Collisions.
- Machine protection and validation.

In reality, blocks are **interleaved** with each other!
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- Threading, capture, initial BI
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Detailed work ongoing to collect beam requests and allocate time for each step...

Recent figures indicate 45 (net) days until first stable beams (J. Wenninger)
It start getting tight...
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Key “decision points”

- **IR aperture at injection (bumps):** first check of beta* reach, De-tuning versus amplitude and detailed MCO/MDO setting.
- **Finalize strategy for combined ramp and squeeze**
  - With nominal bunches at top energy:
  - Clean measurements of Q’ and effect of octupoles
  - Single-beam stability limits (check point for BCMS bunches?)
  - Collimator impedance → confirm simulations/new settings
- **Optics measurements and corrections down to 40 cm**
  - Dedicated “local” IR optics / orbit corrections
- **IR aperture measurements for final beta* validation**

Final decision on machine configurations, before ramp-up (changes are very time costly after this point).

Only during intensity ramp-up (no details in this talk):
- ecloud → several dedicated discussions
- beam-beam - iteration on crossing angles
- two-beam effects and octupoles
- monitoring of machine stability and UFO’s

These steps were not part of the 2012 commissioning!
Early local triplet measurements at injection can provide the first feedback on the aperture reproducibility after LS1: crucial for first iteration on $\beta^*$ choice for 2015!

- Was only done in 2009, but recent analysis indicated that it can give a good feeling of beta* after squeeze!

Rigorous aperture checks will then follow at top energy with squeezed beam, for final parameter validation (and potentially at smaller $\beta^*$).

- Techniques for safe measures at top energy well established.
- Might take longer than in the due to new MP constraints!

Example from 2009 - later confirmed by aperture at top energy.
Collimation and impedance

- Monitor regularly the performance: cleaning, machine stability, loss spikes.
  - More frequent loss maps at startup?

- Assess by beam measurements the simulations of collimation impedance
  - Tune-shift measurements versus collimator settings

- Compare different collimator settings
  - “mm-kept”, “2 real sigma retraction”, “nominal settings”
  - Pre-collision settings during the squeeze

- Assess single bunch stability limit (input from E. Métral)
  - Cleaner measurements for different $Q'$ and octupole settings;
  - $Q'$ reproducibility (measure in different ramps);
  - Rise-time of instability for different settings;
  - Review the interest in BCMS beams then?
Collimation and impedance

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  - More frequent loss maps at startup?

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  - Cleaner measurements for different $Q'$ and octupole settings;
  - $Q'$ reproducibility (mirroring stud of S. Redaelli)
  - Rise-time of instability
  - Review the interest in BCMS beams then?

On-going effort to establish a measurement plan: what can we learn initially with single bunches?
Conclusions

- We had the machine under good control in Run I
  The fast and safe commissioning in 2012 and 2011 was recalled. This provides a mature basis for the re-commissioning of Run II!

- The strategy for the startup in 2015 was reviewed
  Focus on the initial commissioning, aimed at re-establishing in safe conditions collisions in all experiment at 6.5 TeV, before intensity ramp.

- Several challenges for 2015 and new needs were reviewed
  New operational challenges and demanding requests from the experiments;
  Several changes of key accelerator systems;
  The impact of machine protection aspects should not be underestimated.

- Additional “decision points” have been identified to assess the machine configuration choices for 2015
  Experience in 2012 showed that several key measurements must be done earlier in order to prepare well the commissioning

- Can we achieve all what is needed in two months?
  Probably feasible if all goes well, but it seems quite challenging;
  We are working on a consistent commissioning plan...