Baseline Machine Parameters and Configuration for 2015

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Thanks for essential input from many colleagues:

R. Bruce, 2014.09.23
Outline

• Challenges and strategy for 2015
• Startup scenario
  – Focus on collimation / aperture, crossing angle, $\beta^*$
• How can we push the performance?
• Summary
Run 1 → Run 2

- Fast Re-commissioning in 2012: quickly back at high luminosity
- Run 2 pre-requisites: Run at increased energy (≤6.5 TeV) and 25 ns bunch spacing
- Apart from higher energy and more bunches, many things changing:
  - LS1 activities and upgrades...
  - At higher energy: more dangerous beams, lower quench limit, higher risk for asynchronous dumps
  - Uncertainties in scaling of 2012 issues with loss spikes and instabilities to higher energy
- Many unknowns! Has to be proven with beam that LHC works as well as in Run 1.
- Start carefully...
Strategy for 2015

- **Startup:**
  - Put focus on *feasibility, stability and ease of commissioning*. Allow comfortable margins for operation and avoid introducing too many untested features at once.
  - Main priority: Get LHC running 25 ns at 6.5 TeV.
  - Where possible, calculate parameters *based on what we know* can be achieved from Run 1 experience.
  - Performance should not be main focus, but we should also not be overly pessimistic.

- **Later in the run**
  - When we know better how the machine behaves at 6.5 TeV through OP experience and MDs, we can *push the performance*. 

2015 proton run outline

50 ns commissioning and scrubbing

50 ns intensity ramp-up + physics run

25 ns commissioning and scrubbing, relaxed

25 ns intensity ramp-up + physics run, relaxed

25 ns commissioning, pushed

25 ns intensity ramp-up + physics run, pushed

Use same parameters as for 25 ns relaxed

Main focus in this talk

Parameters depend on experience with beam

R. Bruce, 2014.09.23
2015 scenario

- Main goal of parameters in this talk: usability with 25 ns
  - Focus on the relaxed startup configuration
  - At 50 ns: use same settings as for 25 ns to save commissioning time
- For simplicity at startup (do not add too many new things!):
  - No combined collide and squeeze (initially)
  - No combined ramp and squeeze (initially)
  - No \( \beta^* \) levelling (initially)
- More details on 2015 strategy: talk J. Wenninger
Overview of machine parameters

- Key parameters influencing luminosity, beam stability and machine protection – should be addressed at injection and in physics
  - Energy
  - Bunch spacing
  - Bunch characteristics: intensity, emittance, bunch length
  - Optics
  - Collimator settings
  - Crossing angle, separation
  - $\beta^*$

M. Solfaroli
E. Meschi
Y. Papaphilippou, A. Butterworth
M. Giovannozzi
This talk
This talk
This talk
Energy and bunch spacing

• **Beam energy:** Baseline target = 6.5 TeV
  - Not really any news since Evian...
  - Further details: talk M. Solfaroli

• **Bunch spacing:** 25 ns
  - Strong request from experiments – lower pileup than 50 ns. The LHC was designed for this!
  - Some complications: e-cloud (talk G. Iadarola), stronger long-range beam-beam ...
Bunch characteristics

• Beam injected in LHC: could optimistically hope for (talk Y. Papaphilippou):
  – Standard: $1.3 \times 10^{11}$ p/bunch, $\varepsilon_n = 2.4$ $\mu$m, 2748 bunches (2736 colliding at IP1/5).
  – BCMS: $1.3 \times 10^{11}$ p/bunch, $\varepsilon_n = 1.3$ $\mu$m, <2604 bunches(<2592 colliding at IP1/5).

• In LHC:
  – Beam stability poses limits on brightness (E. Metral, LMC 3/9/14) – BCMS could be problematic
  – If 95% transmission of intensity => $\sim 1.2 \times 10^{11}$ p/bunch in collision
  – 5-20% emittance increase expected from IBS (M. Kuhn in Evian14) and potentially more from e-cloud if scrubbing not successful (talk G. Iadarola)

• Longitudinal parameters (talk A. Butterworth):
  – Injection: 6 MV RF voltage and 1.2 ns bunch length
  – Top energy: 12 MV RF voltage and 1.25 ns bunch length
Optics

• **Baseline: nominal optics**, possibly modified to match new requirements

• ATS optics: promising option, but still some points to be studied

• Further details: talk M. Giovannozzi
Collimation

• Collimator settings influence performance
  – Cleaning efficiency. Together with lifetime, sets limit for max intensity
  – Impedance. Sets limit for beam stability
  – Aperture: sets limit for $\beta^*$. Main $\beta^*$ limit in Run 1
Aperture limit on $\beta^*$

- Collimation hierarchy determines minimum protected aperture
- As $\beta^*$ is squeezed to achieve a smaller beam size at IP, and higher lumi, beam size increases in triplet => Aperture margin decreases => Limitation on $\beta^*$
Collimator settings at startup

• Evian proposal: 2012 collimator settings in mm (inj. + 6.5TeV)

• Well proven long-term stability of hierarchy and cleaning in 2012
  – MDs: Confident more performing settings could work (2 sigma retraction), but not justified to increase impedance at startup

• Cleaning – verification with final optics pending. A priori no issues, unless very bad surprises in lifetime or quench limit

• Protection:
  – Margins adequate with underlying assumption that orbit and optics correction are not worse than 2012
  – Asynchronous beam dumps more likely at higher energy. Should be prepared!
  – For more relaxed margins at startup: consider adding $1\sigma$ to TCT setting
Collimator settings in physics

<table>
<thead>
<tr>
<th>[σ with ε=3.5μm]</th>
<th>2012 mm kept</th>
<th>2σ retraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP IR7</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>TCSG IR7</td>
<td>8.0</td>
<td>7.5</td>
</tr>
<tr>
<td>TCSG IR6</td>
<td>9.1</td>
<td>8.3</td>
</tr>
<tr>
<td>TCDQ IR6</td>
<td>9.6</td>
<td>8.8</td>
</tr>
<tr>
<td>TCT IR1/5</td>
<td>11.5</td>
<td>10.7</td>
</tr>
<tr>
<td>Protected aperture</td>
<td>13.4</td>
<td>12.3</td>
</tr>
</tbody>
</table>

**Startup**

MP margins to be checked if operating at β* significantly different from 2012
Aperture at 2015 startup

• Need to estimate aperture for calculation of $\beta^*$
• Use \textit{same method for aperture calculation as in 2012}
  – Estimated aperture very close to allowed limit as in 2012. No hidden margin!
• \textbf{Important to measure aperture early on} in commissioning, as in 2012, or even earlier (injection). See talk S. Redaelli
  – If bad surprises: re-evaluate reach in $\beta^*$
Beam-beam separation

- Crossing angle needed to calculate aperture at given $\beta^*$.  
- Need sufficient crossing angle to minimize detrimental effect of parasitic encounters (small dynamic aperture → beam losses).

Talk T. Pieloni in Evian: Baseline of $11 \sigma$ beam-beam separation for nominal beam ($\varepsilon=3.75$ $\mu$m) – driven by intensity of $1.3e11$. Gives sufficient angle in $\mu$rad also for smaller $\varepsilon$.

- Parallel separation: Scaling 2012 value to 6.5 TeV gives $0.55$ mm at 6.5 TeV
Aperture vs $\beta^*$

- With the given assumptions, the limit is at $\beta^* = 65 \text{ cm}, 160 \mu\text{rad}$ (Evian 2014)
Additional margins

• Some uncertainties in the underlying assumptions, e.g.
  – Will orbit and β-beat be as good as in 2012 (assumption for collimation hierarchy)?
  – How do the instabilities / lifetime drops observed in 2012 scale to higher energy and 25 ns?

• With the philosophy that focus at the startup is on feasibility and ease of commissioning, and that we can push performance at a later stage: wise to take some extra margins

• LMC 3/9/2014 : Decision to start at $\beta^*=80$ cm
Margins at $\beta^*=80$ cm

- Going to $\beta^*=80$ cm, $145\mu$rad buys us $\sim2\sigma$ margin
How can the gain in aperture be used?

- Gain in aperture margin
- Gain in MP margin – move out TCTs
- Gain in impedance – move out all collimators
- OR: increase crossing angle and $\beta^*$ – plot doesn’t change
Increased beam-beam separation

- If all margin for beam-beam separation: $15\sigma$ possible at $\beta^*=80$ cm
Use of additional margins

- Not decided yet how the additional $2\sigma$ gain will be used
  - Pending LMC action
- Example 1: maintain beam “challenges” with increased protection.
  - Put all margin on machine protection
- Example 2: splitting $1\sigma$ machine protection + $1\sigma$ beam-beam
  - $1\sigma$ more aperture allows about $2\sigma$ larger beam-beam separation
- Could even be decided/changed during commissioning, when we see where it is most needed
Outline

• Challenges and strategy for the 2015 startup
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• How can we push the performance?
• Summary
How to push performance

• Later, with beam experience, push performance. What to change:
  
  – **Smaller emittance:** Better lumi both through beam size and possibility of smaller crossing angle → $\beta^*$.  
  
  – **Increase bunch intensity:** most beneficial parameter for luminosity.  
  
  – **Tighter collimation hierarchy:** makes smaller $\beta^*$ possible. Tighter cleaning margins (IR7) or tighter MP margins, e.g. through BPM buttons. Limitations: impedance, machine stability, TCT damage limit.  
  
  – **Smaller beam-beam separation:** gains aperture and hence allows smaller $\beta^*$. Possible limitations: Beam stability  
  
  – **Aperture:** should already be close to the limit. Probably not much to gain  
  
  – **Squeeze separation plane $\beta^*$** more than crossing plane (more aperture)  
  
  – **Shorter bunch length:** impacts lumi through reduction factor, but higher pileup
Pushed $\beta^*$ - how low can we go?

- $\beta^* = 65$ cm should be within reach even with rather conservative assumptions (see Evian 2014)
- $\beta^* = 55$ cm likely to be within reach. E.g.:
  - Tighter collimator settings (2\(\sigma\) retraction on the aperture limit), or
  - 10\(\sigma\) beam-beam separation and 2.5 \(\mu\)m emittance
- $\beta^* = 40$ cm possible with optimistic assumptions (Evian 2014) – maybe not for 2015, and not given that we can go there
  - Still commission optics down to 40 cm to be prepared
  - Oval optics, e.g. 40cm/50cm might be easier to reach for aperture and could give slightly better luminosity than 40cm/40cm (depends on bunch length and BB sep.).
- Caveat: Pushed scenario might introduce additional OP complexity, e.g. collide and squeeze
- Final limit can only be determined based on beam studies in 2015
Summary

• **Run 2:** Many things have changed - baseline: 6.5 TeV and 25 ns
  – Start carefully and push performance later.

• For initial 50 ns run, use same settings as for 25 ns

• **Beams** from injectors: Choice between standard and BCMS

• **Collimator settings:** 2012 settings in mm
  – Possibility to increase margins for machine protection or impedance

• **11 σ** beam-beam separation

• **β*=80cm** at startup to allow relaxed margins
  – Push performance later when limits are better known
  – Commission optics down to β*=40 cm
## 2015 baseline parameters (startup)

<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) [μrad]</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) [μm]</td>
<td>≥ 1.3 / ≥ 2.4</td>
<td>≥ 1.7 / ≥ 2.7**</td>
</tr>
<tr>
<td>Bunch intensity [p]</td>
<td>≤ 1.3e11</td>
<td>≤ 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 mm kept</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.

R. Bruce, 2014.09.23
Backup
Collimation and $\beta^*$ in Run 1

- **2010:**
  - **Relaxed start** with large margins for maximum safety:
    Relaxed collimator settings, $\beta^*=3.5\text{m}$

- **2011** *(Evian 2010)*:
  - **New calculation** of collimation margins: $\beta^*=1.5\text{m}$
  - **IR aperture measurements** with squeezed optics:
    $\beta^*=1.0\text{ m}$

- **2012** *(Evian 2011, Chamonix 2012)*:
  - **tight collimator settings**, aperture very close to limit:
    push to $\beta^*=60\text{ cm}$

- Performance evolving with collimation hierarchy and better knowledge of aperture
Aperture in Run 1

- Run 1: IR triplet apertures measured with beam on several occasions – close to ideal design value!
Cleaning in Run 1

- Cleaning working very well and good quench performance
  - Collimation was **not limiting factor** for intensity in Run 1
  - Very stable settings – only **1 full alignment per year**
2015 scenario

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