Beam commissioning major phases and planning

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25.11.2021

Based on studies of Run3 WG (https://cds.cern.ch/record/2790409)
Thanks to: S. Fartoukh, J. Wenninger
Outline

2022 LHC commissioning

- Machine check-out
- Beam commissioning
- Scrubbing
  - Intensity ramp-up

Global and machine protection tests

From first turn until first stable beams

Intensity ramp-up to:
- establish operational cycle
- identify and mitigate issues
- identify issues related to stored beam intensity and other beam parameters

Intense period of mostly stable beams to provide large set of data to the experiments
### Planning

**Closure of tunnel and experimental caverns 31st March**

- **2 wks** of MC (interleaved with S23 training)
- **8 wks** of Beam commissioning
- **10 days** of scrubbing
- **5+2 wks** of intensity ramp-up
- ...

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DRAFT LHC Schedule 2022  
For approval at Research Board of 1 December 2021

#### Jan

<table>
<thead>
<tr>
<th>Wk</th>
<th>Jan</th>
<th>Feb</th>
<th>LHC hand-over to BE-OP</th>
<th>Mar</th>
<th>Apr</th>
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<tbody>
<tr>
<td>Mo</td>
<td>Annual Closure</td>
<td>3</td>
<td>12</td>
<td>17</td>
<td>24</td>
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<tr>
<td>Tu</td>
<td></td>
<td>7</td>
<td>14</td>
<td>21</td>
<td>28</td>
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</tr>
<tr>
<td>Su</td>
<td></td>
<td>7</td>
<td>14</td>
<td>21</td>
<td>28</td>
</tr>
</tbody>
</table>

#### May

- **Easter w/e**

#### Sep

- **High $\beta$ setup**
- **TS1 Special Run (LHCf)**
- **Jeune lune**
- **MD 1**
- **V0A program**

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R. Steerenberg
Machine check-out

Machine check-out is meant to ensure that all systems work together in the correct way and communicate with each other as expected!

Checklist to be completed:

- All MP tests to be done
- Powering tests, including global powering
- Individual System Tests
- LBDS BETS MP tests
- ALICE spectrometer fault MP tests
- Vacuum interlock tests
- Collimation system cycles and setup
- Orbit feedback configuration tests
- Sequences dry-run
- Settings check
- ...and many many others!!

See C.Wiesner’s slides
Machine check-out

Due to **limited intensity**, most of the systems were **not or only partially** used/tested for the pilot beam test:

- Injection Quality Check
- Post Mortem
- UFO buster
- BPM-PM issue to be solved
- BRANs
- SFB, SMP,…
- BETS-TCDQ/TDI
- Full setup of inj/dump systems
- Asynchronous dumps
- Lumi server
- PC interlock
- RF blow-up
- …

*Just very few examples...*
Machine check-out

As seen during the beam test, due to the early preparation of the majority of the sectors, many activities can be anticipated

- Seven out of eight sectors will be ready 5 weeks before the MC official start
- **S23** is not included in the BETS configuration -> possibility to perform **BIS-LBDS tests**, while training S23
  - Disabling PIC (vac?) inputs of S23
  - **Strap** of interlock inputs from access system and WIC of IP3/IP7?
- Interleave some **training and MC tests**
- Not an easy operation, but some activities can be done
Prepare the machine for first physics fill, followed by intensity ramp-up:

- **Commission with beam** the key accelerator systems (feedbacks, RF, ADT, injection, dump, collimation, instrumentation,…), with particular emphasis at the LS2 changes
- Test all **Machine Protection** systems and functionalities
- Establish and validate the **machine configuration**
- **Prepare** for later foreseen changes
Additional bonus

**Pre-commissioning of special cycles** (VdM, 90 m, LHCb rotation,…) during beam commissioning proved in the past to be an efficient strategy:

- Rather **easy** commissioning
- Many activities can be done by **OP** (nights filling)
  - First go to bring a pilot to the end of the cycle
  - Feedforward, cleaning after optics, collimation, etc
- Very fast way into the cycle when dedicated period for operation -> **high efficiency**
- Allows to have other options in the pocket to establish collisions, **in case of needs**
- Perform **machine development/operational studies**
Beam and optics parameters for 2022

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value @inj</th>
<th>Value @FT</th>
<th>Value @coll</th>
</tr>
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<tbody>
<tr>
<td><strong>Energy</strong> [TeV]</td>
<td>0.45</td>
<td>6.8</td>
<td>6.8</td>
</tr>
<tr>
<td>$\beta^*$ (1/2/5/8) [m]</td>
<td>11/10/11/10</td>
<td>2/10/2/2</td>
<td>0.6/10/0.6/2 down to 0.3/10/0.3/2</td>
</tr>
<tr>
<td>(half) <strong>Xing</strong> angle [urad] IP1(V)/IP2(V)/IP5(H)/IP8(H)</td>
<td>-170/170/170/-170</td>
<td>-160/200/160/-200</td>
<td></td>
</tr>
<tr>
<td><strong>Sep</strong> (1/2/5/8) [mm]</td>
<td>-2/3.5/-3.5</td>
<td>-0.55/1/0.55/-1</td>
<td></td>
</tr>
<tr>
<td><strong>Tune</strong> (H/V)</td>
<td>.27/.295 (to be checked)</td>
<td>.28/.31</td>
<td>.31/.32</td>
</tr>
<tr>
<td><strong>Emittance</strong> (BCMS standard) [um]</td>
<td>1.3</td>
<td>1.8</td>
<td>1.8 -&gt; 2.5</td>
</tr>
<tr>
<td><strong>Bunch intensity</strong> [p]</td>
<td>1.1E^{11} to start, towards 1.4E^{11} later</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bunch length</strong> [ns]</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>COLL</strong> (TCP/TCSG/TCSP) [σ]</td>
<td>5.7/6.7/7.5</td>
<td>5.0/6.5/7.3</td>
<td>5.0/6.5/7.3</td>
</tr>
</tbody>
</table>
Main decision points

- 450 GeV injection, threading, capture…
- Systems setup (RF, ADT, BI,…)
- Optics

**Nominal bunch setup**
- Nominal orbit and trajectory
- COLL alignment and LMs
- Aperture
- Inj and LBDS validation
- 450 GeV collisions
- More system tests
- Train injection setup

**Optics**
- CRS validation
- Squeeze in steps
- Optics corrections
- Magnetic measurements
- Systems commissioning
- CRS validation with bumps

**Special cycles setup**
- Special cycles setup
- 90 m cycle
- VdM cycle
- Intermediate energy
- Machine development studies
The 2022 cycle

- **Injection @ 450 GeV**
- **CRS to 2m (10m in IP2) and 6.8 TeV**
- **Squeeze to 60 cm (NO squeeze in IP2/IP8)**
- **Collision tunes**
- **Collisions**
- **Levellings**

**LHCb rotation**
The 2022 cycle - CRS

PELP ramp to 6.8 TeV: 1275 sec (vs 1210 sec of 6.5 TeV)

- Most of the **optics changes** in the ramp, with the aim to arrive at flat-top with $\beta^* <= 2\ m$ in IP1/IP5/IP8 (10 m in IP2)
- This **conservative choice** also takes into account some synergies with the configuration to be used for 2023/24
- **Squeeze** starts at 1.7 TeV, already tested in MD in Run2 (earlier starts used in the past)
- $\beta^* = 2m$ is reached at 4.5 TeV to allow space for (future!) optics changes (anti-telescope and/or more squeeze)
- Some additional squeeze could be added
- **More margin** for the “tune change” (.27/.295 -> .28/.31) are available thanks to the new QFB with dynamic reference
The 2022 cycle - squeeze & Q change

SQUEEZE

- A squeeze to $\beta^* = 60$ cm will be performed at the end of the ramp
- **Duration 531 sec**, mainly dominated by the decay time of the Q6 current in IR1 and IR5 (2m-1.5m optics transition time is dominated by RQT13.R1B2)
- **Six intermediate matched points** (155, 133, 118, 104, 89, 71 cm) to minimize the peak $\beta$-beating during optics transition

Q-change

- Tunes are moved from .28/.31 to .31/.32
- **historically** performed at flat-top
- will be performed **before collisions**, offering more margin for coupling and better DA during the squeeze (systematically tested during ATS MD’s in Run2)
The 2022 cycle – collisions+levelings

BP should be **shorter than in Run2** (120 sec), as IP2 and IP5 shifts have been “cured” during LS2

**Luminosity levelling (keep it easy):**
- **Initial reduction** of Xing will not be applied in 2022 to limit complexity
- **$\beta^*$ levelling** from 60cm to 30cm
- **TCT position** will be kept constant in mm during $\beta^*$

**Working point** will have to be adjusted, due to the **large variations of head-on beam-beam tune shift** during $\beta^*$ levelling, (intensity decrease and emittance blow up, bunch length shrinking, optics parameter changes)

The **optimal amount of steps in $\beta^*$ levelling** has to be found once final confirmation that the experiments will take data during the dynamic phases
Intensity ramp-up

**2015**

Double intensity ramp-up (25/50 ns)

**Proposal for 2022:**

3/12-75-300-600-900-1200-1800-2400–2700 (see C.Wiesner’s talk)

Trade between increasing N of bunches and bunch intensity

**Trade between increasing N of bunches and bunch intensity**
Intensity ramp-up & $\beta^*$ levelling

- **Aim** to do the **initial ramp-up on N of bunches** with $\sim 1.1 - 1.2 \times 10^{11}$ p/bunch until full machine, then increase bunch intensity.

- During the ramp-up we should **already exercise $\beta^*$ levelling** extensively, even if at $L < 2 \times 10^{34}$.

- A **strategy** needs to be **agreed upon**, in particular with respect to fill length and $\beta^*$ steps.

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$L = 2 \times 10^{34}$

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- Level at initial luminosity, similar to nominal fill but at lower $L$.
  - **‘long’ ramp-up fills**

- Level at initial luminosity, then fast levelling (to exercise) and dump (whatever the value).
  - **short(er) ramp-up fills**

- Level to a pile-up/lumi target asap, then level / let lumi decay.

- Adjust or SB
Timing

Preliminary detailed planning (with margin for access & problems) indicate 49 days until first stable beams

2015 commissioning was done in 59 days (~8 weeks), but:

- **Energy increase** 4TeV -> 6.5 TeV
- **25 ns** beam setup, after initial commissioning with 50 ns
- Fight with **ULO in 15R8** (investigation and quench recovery)
- Everything had to be commissioned from scratch (**NO beam test** prior to commissioning)

However, more complex cycle wrt 2015 will require longer setup

Everything will have to be redone…What we gained is the confidence in the systems and that NO major problem is present
Conclusions

➢ Even besides the RF finger discovery, the **beam test was extremely useful. However**, the activities done will have to be repeated.

➢ The **operational cycle** for 2022 operation is **designed** (few details still to be finalized), to maximize synergies with the rest of Run3.

➢ **Beam commissioning planning** is being established. Some margin will allow to slot in some fundamental activities for the global success of Run3.

➢ **We are ready** and eager to start again…waiting for the machine. 😊