Global Optimization of the Matching Section and Full Remote Alignment

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Summary

- Full Remote Alignment
  - Present baseline and new proposal
  - Alignment strategy and required stroke
  - Advantages
  - New possibilities for full Matching Section Optimization

- Matching Section Optimization
  - The magnet system simplifications
  - The QRL-QXL optimization
  - The Cold Powering
  - The Warm Powering

- Conclusions
A little bit of history

- The original idea to investigate the possible benefits of a larger than foreseen deployment of the Remote Alignment capabilities came in April 2017.
- First study and proposal was presented January 2018 and the full study in November 2018 with final approval with all budget implications in February 2019.
- The analysis was performed on Optics 1.3 and the first Optics making use of the Full Remote Alignment Deployment was Optics 1.4.
- Presently we are at optics 1.5 that add some other optimization not linked to the alignment.
Full Remote Alignment and Matching Section Optimization

Objective

Reduce dose to alignment team

Cope with Experiment vs. machine misalignment in RUN IV after the machine and experiment installation completion

Yearly correct ground motion drift without man intervention in the machine

Provide tool to eliminate or at least minimize the residual alignment error using beam as reference

Cope with unexpected source of misalignment avoiding losses in performance of physics time

By products

Gain aperture margin in various equipment

Matching Section Optimization

Reduce the requirement on the Matching Section orbit Corrector System

Mitigate spurious orbit deviations in the triplet (simplifying non linear corrections)
IP1 and IP5 HL-LHC

Synoptic of adjustment system only

Old Baseline vs Full Remote Alignment on optics 1.3

- Motorized adjustment system, remotely controlled: adjustment during run, from CCC
- Manual adjustment system: adjustment during LS,YETS,TS, personnel in the tunnel, access in front of element (special for TAXS)
- Remote alignment compatible

Full Remote Alignment applied to optics 1.3 before all modifications
## Possible alignment strategies with fully remote alignment

<table>
<thead>
<tr>
<th>Machine conditions</th>
<th>Scheme 2: During TS Larger than 2.5 mm</th>
<th>Scheme 3: During YETS</th>
<th>Scheme 4: During LS 2 year RP cool down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine operating conditions</td>
<td>Magnet cold but empty during movement</td>
<td>Magnet cold but empty during movement</td>
<td>Warm</td>
</tr>
<tr>
<td>Max stroke</td>
<td>±10 mm (jack excursion other limits apply)</td>
<td>±10 mm (jack excursion other limits apply)</td>
<td>more</td>
</tr>
<tr>
<td>Time required per IP side Q1 to Q5</td>
<td>60 min No access</td>
<td>60 min No access</td>
<td></td>
</tr>
<tr>
<td>Time required per IP side Q1 to D1</td>
<td>2(L)+2(R) days Access for int. components. De-interconnection of the RF guides (from time point of view this fits into a TS)</td>
<td>2(L)+2(R) days Access for int. components. De-interconnection of the RF guides (from time point of view this fits into a TS)</td>
<td></td>
</tr>
<tr>
<td>Time required per IP side Q1 to Q6</td>
<td>CD: &gt;12 mSv</td>
<td>CD: 2.8 mSv</td>
<td>CD: 0.3 mSv</td>
</tr>
<tr>
<td>Time required per IP side Q1 to Q6</td>
<td>2 TS TS1: measure Between TS1 and TS2 compute TS2 realign</td>
<td>Measurement, computation and re-alignment in the YETS</td>
<td></td>
</tr>
<tr>
<td>CD: &gt;13 mSv</td>
<td>CD: 3.2 mSv</td>
<td>CD: 0.4 mSv</td>
<td></td>
</tr>
</tbody>
</table>
The needed stroke

The Survey team has linked the experiment cavern movement with the ones of the LSS

- For the vertical plane via the deep references (GITL) that are in machine tunnel for ATLAS and CMS
- For the radial plane via the GISB references points that are in the UPS survey galleries

<table>
<thead>
<tr>
<th></th>
<th>Δz [mm/y]</th>
<th>Δr [mm/y]</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP1</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>IP5</td>
<td>0.2</td>
<td>0.2</td>
<td>Δz 0.7 mm/y locally at 150 m from IP where the “new” LHC civil engineering join the LEP tunnel</td>
</tr>
</tbody>
</table>

The proposed value of ±2.5 mm allow covering the movements from LS to LS with a safety factor at least 2 (vs. 0.3 mm) avoiding major realignment intervention during other time slots.

Yearly changes shall be much smaller in the range of 0.2/0.3 mm

This meets the requirement of the experiment that asks for the possibility to compensate +/-2 mm of IP shift and fits with the experimental vacuum system design and capability

In addition at LS3 partial overcompensation in the vertical plane (even in the assembly position of the inner tracker as proposed by CMS) could be applied on the base of the measurement that will be taken during LHC RUN III, allowing to factorize in possible impact of the HL-LHC excavation that will have been completed in LS2.
Orbit corrector strength requirements and aperture without and with remote alignment

Baseline

FRA

Increased corrector margin here applied already to reduce set of correctors

Right Point 5, H crossing.

**Crossing:** ±295 μrad

**Separation:** ±0.75 mm

**IP Offset:** ±2.0 mm

**Luminosity scan:** ±100 μm

**Crab knobs:** ±1-0.5 mm (baseline only)

**Imperfection (2σ):** from uniform distribution of mainly ±0.5 mm quad. Alignment and 0.5 mrad / 20 units dipole errors.

**FRA:**
- orbit bumps reduced at the crab cavities
- IP offset performed by alignment
- Limited crab beam adjustment still possible

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>FRA</th>
<th>Base</th>
<th>FRA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Round β*=15 cm</td>
<td>Flat β*=7.5 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAXS</td>
<td>16.3</td>
<td>16.3</td>
<td>14.0</td>
<td>14.0</td>
</tr>
<tr>
<td>IT</td>
<td>12.0</td>
<td>13.1</td>
<td>11.8</td>
<td>12.7</td>
</tr>
<tr>
<td>TAXN</td>
<td>15.4</td>
<td>17.3</td>
<td>12.4</td>
<td>13.9</td>
</tr>
<tr>
<td>D2</td>
<td>15.5</td>
<td>18.6</td>
<td>12.9</td>
<td>14.7</td>
</tr>
<tr>
<td>Q4</td>
<td>14.5</td>
<td>18.3</td>
<td>10.4</td>
<td>13.0</td>
</tr>
<tr>
<td>Q5</td>
<td>24.8</td>
<td>28.2</td>
<td>17.6</td>
<td>19.9</td>
</tr>
<tr>
<td>Q6</td>
<td>25.5</td>
<td>25.9</td>
<td>18.0</td>
<td>19.3</td>
</tr>
</tbody>
</table>

Courtesy R. De Maria
The Matching Section Optimization

By products

Gain aperture margin in various equipment

Matching Section Optimization

Reduce the requirement on the Matching Section orbit Corrector System

Opportunities

Re-use present LHC Q4 and Q5 at 4.5 K

Re-optimize the cryogenic distribution reviewing the limits between QRL and QXL

Review the capacity of the foreseen cryo plants at P1 and P5 (and also P4 sect 4-5)

Reduce the number of circuits for the correctors, leading to a reduction of the number of associated Power Converters

Limit the modifications to the DSL: the superconducting link presently feeding the Matching Section from Q6 till D2

Relax the design requirements on the TCLX and TCTX, reduce aperture TAXN for improved protection

FRA
### Layout changes

<table>
<thead>
<tr>
<th></th>
<th>Round</th>
<th>Flat</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAXS</td>
<td>16.3</td>
<td>14.0</td>
</tr>
<tr>
<td>Q1</td>
<td>17.4</td>
<td>15.9</td>
</tr>
<tr>
<td>Q23</td>
<td>13.1</td>
<td>12.7</td>
</tr>
<tr>
<td>D1</td>
<td>13.9</td>
<td>13.0</td>
</tr>
<tr>
<td>TAXN</td>
<td>18.0</td>
<td>14.0</td>
</tr>
<tr>
<td>D2</td>
<td>19.5</td>
<td>15.0</td>
</tr>
<tr>
<td>CRABS</td>
<td>28.3</td>
<td>20.1</td>
</tr>
<tr>
<td>Q4 Mask</td>
<td>19.3</td>
<td>13.6</td>
</tr>
<tr>
<td>Q5 Mask</td>
<td>21.0</td>
<td>14.9</td>
</tr>
<tr>
<td>Q6 Mask</td>
<td>26.5</td>
<td>18.9</td>
</tr>
</tbody>
</table>

### Changes in optics 1.4 with respect to the optics 1.3:
- **Q4**: reusing existing LHC Q4 cold mass (3 correctors instead of 4), no need of 1.9 K.
- **Q5**: reusing existing LHC Q5 cold mass (1 corrector instead of 3), no need of 1.9 K.
- Full deployment of remote alignment system to be used with safe beam.
Fulfilling Q4 Optics requirements

- Q4L1 & 5
  - MQY
  - MCBYV
  - MCBYH
  - MCBYV
  - MCBYH
  - MCBYV
  - MCBYH
- Q4R1 & 5
  - MQY
  - MCBYV
  - MCBYH
  - MCBYV
  - MCBYH
  - MCBYV
  - MCBYH
  - MCBYV

-Allowing to have level gauges and Temp sensors in the highest side

HL-LHC Project

Courtesy H. Prin

**HL – LHC integration team:** dreams that shape the reality
From D2 – Q4 (LHC) to Q4 (HL-LHC)

LHC

HL-LHC

Courtesy D. Duarte

HL – LHC integration team: dreams that shape the reality
Cooling capacity: is it enough?

Refrigerator Assessment

*Results based on model v.3, for existing LHC refrigerators only*

**LHC**

- Refrigerators (LHC, incl. RF leads)
  - Equivalent Capacity @ 4.5K (kW)
  - Margin (local available)
  - Margin (based for distribution)

**HL-LHC**

- Refrigerators (HL-LHC, Alternative2)
  - Equivalent Capacity @ 4.5K (kW)
  - Margin (local available)
  - Margin (based for distribution)

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Cooling capacity for SAM’s & DFBL to come from main sector Refrigerators (~0.5kW_eq@4.5K)

- Cooling capacity margins will be aligned on other sectors (5-6 higher as no IT nor RF)

No “weak point/sector” created with this alternative
QRL / QXL optimisation in Right of 5

1. Translation of present QRL modules between Q4 and Q5
2. We leave QRLWZ and Q6 service module in place
3. New QXL-QRL Junction Module (11.4 m to be further optimised to avoid interference with CC2 area)
4. New QXL
5. Adaptation pipe elements
6. Pipe element adaptation
7. New modules Q4 jumper
8. Jumper extension

Present LHC machine and QRL layout

Courtesy J. Metselaar, M. Sisti and WP9 team
## Warm powering simplification

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Optimized approach</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Q4</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadrupole</td>
<td>MQY</td>
<td>MQY</td>
</tr>
<tr>
<td></td>
<td>1X HCRPHRA R2E-LHC4-6-8kA+08V</td>
<td>1 X HCRPHRA R2E-LHC4-6-8kA+08V</td>
</tr>
<tr>
<td>Correctors</td>
<td>8 MCBY</td>
<td>6 MCBY</td>
</tr>
<tr>
<td></td>
<td>8 X HCRPLBC R2E-HL-LHC120A-10V</td>
<td>6 X HCRPLBC R2E-HL-LHC120A-10V</td>
</tr>
<tr>
<td><strong>Q5</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadrupole</td>
<td>MQY</td>
<td>MQML</td>
</tr>
<tr>
<td></td>
<td>1 X HCRPHSB R2E-LHC4-6-8kA+08V</td>
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<td>Correctors</td>
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<td>2 MCBC</td>
</tr>
<tr>
<td></td>
<td>6 X HCRPLBC R2E-HL-LHC120A-10V</td>
<td>2 X HCRPLBC R2E-HL-LHC120A-10V</td>
</tr>
<tr>
<td><strong>Q6</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadrupole</td>
<td>MQML</td>
<td>MQML</td>
</tr>
<tr>
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</tr>
</tbody>
</table>

*Former courtesy M. Martino*
DSL optimisation in Right of 5

Present LHC machine and QRL layout

Cut and remove (11.93m)

HL-LHC Matching Section Optimization layout

LHCDSLE_00

LHC Layout DSLE

HL-LHC Layout DSLE

Courtesy S. Claudet, A. Perin and WP6A

HL – LHC integration team: dreams that shape the reality
Conclusions

- The Full Remote Alignment
  - It is beneficial to reduce radiation to personnel
  - It increases the window for machine optimization (larger margin in aperture margin and lower $\beta^*$ reach)
  - It releases the pressure on orbit corrector system
  - It provides higher machine flexibility and it reduces the reaction time
  - It opened the possibility to re-optimize the Matching Section

- The Matching Section was re-optimized
  - The new configuration reduces the amount of work to be performed and the extension of the LHC machine modifications
  - It simplifies the design of few elements as i.e. the collimators

- The combination of the two actions made possible significant budget savings of few MCHF