HL-LHC Aperture Update

R. De Maria

Thanks to G. Arduini, S. Fartoukh, C. Garion, M. Giovannozzi
# Beam screen update

<table>
<thead>
<tr>
<th></th>
<th>HV gap [mm]</th>
<th>45 gap [mm]</th>
<th>Mech Tol [mm]</th>
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<tr>
<td>Q1</td>
<td>102</td>
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<td>Q2-3/D1</td>
<td>122</td>
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</tr>
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<td>D2</td>
<td>87</td>
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<tr>
<td>Q4</td>
<td>73.8</td>
<td>72.8</td>
<td>3</td>
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</table>

|       | old | new | old | new | old | new |

C. Garion update

All quantities are in diameter.

The mechanical tolerances consider worst case: negative vertical shift and negative vertical shape restriction.

Mech. tolerances for D2/Q4 not provided. Kept 3 mm.

Comments
- Triplet: Impact 5% aperture loss in Q2-3 -> 10% $\beta^*$ loss
- Q4: 45 gap is the bottleneck in certain scenarios
- Q4: depending on the pre-squeeze optics rectellipse may be more optimal for both flat optics
## Survey-fiducialization tolerances

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<th>Ground motion</th>
<th>Fiducialization</th>
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<td>(r) [mm]</td>
<td>(h) [mm]</td>
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<td>TAXS (*)</td>
<td>2.0</td>
<td>0</td>
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<tr>
<td>Triplets</td>
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<td>0</td>
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<tr>
<td>BPMs</td>
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<tr>
<td>TAXN (*)</td>
<td>0.84</td>
<td>0.36</td>
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<tr>
<td>D1</td>
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<td>0.36</td>
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<tr>
<td>D2/Q4/Q5</td>
<td>0.84</td>
<td>0.36</td>
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</table>

Value derived from J. Jeanneret, LHC rep 1007 but to be validated by survey, WP3, WP8(*) teams
Beam tolerances have been re-defined by:

- taking into account LHC Run I positive experience
- adding safety margins based on possible unknowns.

For collimation:

- magnet protected by TCT: $\geq 12\,\sigma$
- magnet not protected by TCT: $17\,\sigma$ or possibly less pending dedicated studies (R. Bruce).

<table>
<thead>
<tr>
<th>Beam Tolerance</th>
<th>LHC Design</th>
<th>LHC 2012-6 Coll.</th>
<th>HL-LHC Inj./Coll.</th>
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<tr>
<td>Emittance [µm] (normalization only)</td>
<td>3.75</td>
<td>3.5</td>
<td>3.5</td>
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<tr>
<td>$\beta$-beating [%]</td>
<td>20</td>
<td>5</td>
<td>10/20</td>
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<tr>
<td>Orbit error [mm]</td>
<td>4</td>
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<td>Spurious Disp. [%]</td>
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<td>10</td>
<td>14/10</td>
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<tr>
<td>Energy error [$10^{-3}$]</td>
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<td>0.1</td>
<td>0.6/0.2</td>
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<tr>
<td>Target aperture with TCT (w/o TCT) [σ]</td>
<td>8.4</td>
<td>9.5$^{(1)}$</td>
<td>9/12(17$^{(2)}$)</td>
</tr>
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$^{(1)}$ With good MKD-TCT phase advance.

$^{(2)}$ or possibly less pending dedicated studies.

R. Bruce et al.
## Aperture and knobs effects V1.2

<table>
<thead>
<tr>
<th>Aperture</th>
<th>Beam Type</th>
<th>H,V^2full gaps</th>
<th>Sep. knob</th>
<th>Crossing Knob</th>
<th>Crab shift knob</th>
<th>Crab slope knob</th>
<th>Offset knob</th>
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<td>Circle</td>
<td>60, 60 [mm]</td>
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<td>Octagon</td>
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<td>RectEllipse</td>
<td>57.8, 48 [mm]</td>
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<td>0.0 [mm]</td>
<td>2.1 [mm]</td>
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</table>

1 Either Beam screen or beam pipe;

2 Mechanical tolerances already removed. Rectellipse types are exchanges the H,V orientation depending on the polarity.
Aperture update

Adding tolerances one by one in the next tables:

- Bare: no mechanical tolerances, perfect beam, perfect alignment
- Mech: mechanical tolerances in beam screen, perfect beam, perfect alignment
- Beam: mechanical tolerances in beam screen, imperfect beam (including triplet misalignments in orbit budget), perfect crab and perfect IP alignment
- Crab: mechanical tolerances in beam screen, imperfect beam (including triplet misalignments in orbit budget), crab misalignment, perfect IP alignment
- Offset: mechanical tolerances in beam screen, imperfect beam (including triplet misalignments in orbit budget), crab misalignment, IP misalignment
### Aperture Round

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\[ \beta = 15 \text{cm} \]
\[ \Theta_c = \pm 295 \mu \text{rad} \]
\[ d_{sep} = \pm 2 \text{mm} \]
Aperture Flat

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</table>

\[ \beta=30/75\,\text{cm} \]
\[ \Theta_c=\pm245\,\mu\text{rad} \]
\[ d_{\text{sep}}=\pm0.75\,\text{mm} \]
Bare aperture 12 sigma (round)

No beam and orbit tolerances included!
Bare aperture 12 sigma (flat)
Backup
Nominal values are defined by:

**Cold Bore:**
1. The coil inner radius at 1.9 K is 74.350 mm [P. Ferracin]
   a. The insulated cable inner radius position at room temperature, with no stress, is 75 mm.
   b. The deformation due to pre-load and cool-down is 0.400 mm
   c. Quench heaters and insulation: 0.1 mm + 0.15
2. Gap coil/insulated cold bore at 1.9 K: 1.5 mm [R. Van Weelderen]
3. Cold bore insulation: 0.2 mm [P. Ferracin]
4. Tolerance on the cold bore thickness: 0/+0.5 mm

→ Nominal cold bore outer radius at 1.9 K: 72.15 mm
→ Nominal cold bore outer radius at room temperature: 72.35 mm

→ Nominal cold bore inner radius (thickness 4 mm for Q1 to D1) at room temperature: 68.35 mm

Present specification based on a machined long circular tube: (Input’s from Manufacture de forage, tbc)
- Inner diameter: 136.7 mm, tolerance: 0/+0.1
- Thickness: 4 mm, tolerance 0/+0.5
- Straightness: 0.3 mm/m

**Beam screen:**
1. Gap w.r.t cold bore: 1.5 mm
2. Shielding thickness Q1: 16mm, Q2-D1: 6 mm
3. Beam screen wall thickness: 1mm
## Summary table

<table>
<thead>
<tr>
<th></th>
<th>Cold bore</th>
<th>Beam screen</th>
<th></th>
<th></th>
<th></th>
<th>Cooling tube Nb * OD * thickness</th>
<th>Shielding maximum height</th>
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<tr>
<td></td>
<td>Inner diameter</td>
<td>Thickness</td>
<td>Nominal aperture* H(V); +/-45 °</td>
<td>Vertical tolerance</td>
<td>Horizontal tolerance</td>
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<td></td>
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<tr>
<td></td>
<td></td>
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<td>Shape</td>
<td>Positioning**</td>
<td>Shape</td>
<td>Positioning**</td>
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<td>86; 77</td>
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<td>Q4</td>
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<td>72.8; 62.8</td>
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</tbody>
</table>

* Cu layer thickness, thermal contraction, self weight deformation not accounted (see slide 2)

** 1 additional support, 0.25 mm radial clearance between the support and the cold bore.