Update of LHCb at High Luminosity

R. De Maria

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<table>
<thead>
<tr>
<th></th>
<th>Run II</th>
<th>Run III</th>
<th>Run IV</th>
<th>Run V-VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration [years]</td>
<td>3.5</td>
<td>3</td>
<td>3.5</td>
<td>5</td>
</tr>
<tr>
<td>L ( [10^{32} \text{ cm}^{-2}\text{s}^{-1}] )</td>
<td>4</td>
<td>&lt;20</td>
<td>20</td>
<td>100-200</td>
</tr>
<tr>
<td>Int. L [fb(^{-1})]</td>
<td>(\sim 8)(^1)</td>
<td>?(^3)</td>
<td>50(^2)</td>
<td>300(^2)</td>
</tr>
<tr>
<td>Ppb ([10^{11}])</td>
<td>1.1</td>
<td>1.1→2.2</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Bunches in IP8</td>
<td>2036→2378</td>
<td>2572 or 2378</td>
<td>2572 or 2378</td>
<td>2572 or 2378</td>
</tr>
<tr>
<td>Emit ([\mu m/\gamma])</td>
<td>2.8</td>
<td>2.8→2.1</td>
<td>2.1 or 1.7</td>
<td>2.1 or 1.7</td>
</tr>
</tbody>
</table>

1) Assuming 5.8 fb\(^{-1}\), 2 fb\(^{-1}\) in 2016 with 4 \(10^{32} \text{ cm}^{-2}\text{s}^{-1}\) and 2036 bunches, extrapolating to 2378 bunches and same efficiency.
2) target.
3) Scaling in Run IV gives 35 fb\(^{-1}\), then target in Run III does not need strictly need higher levelled luminosity.
Peak and Integrated luminosity

Large impact of spectrometer polarity on luminosity.
Difficult to reach the final target of 300 fb$^{-1}$, unless extending the target of Run IV beyond 50 fb$^{-1}$.

Estimates for 2.5 μm/γ and 2378 colliding bunches based on scalings from a 250 fb$^{-1}$ fill for ATLAS and CMS.
Aperture and crossing angle

- Horizontal crossing aperture limited by TCDDM (Beam 2) then triplet
- Vertical crossing aperture limited by triplet
- Crossing angle limited by orbit corrector strength to 310 µrad (with 20 µrad margin and repaired MCBY)
- Protected aperture 14.6 σ (best aperture for worst phase advance from MKD)

Maximum crossing angle without or (*) with new TCDDM

<table>
<thead>
<tr>
<th>β* [m]</th>
<th>H* [µrad]</th>
<th>H [µrad]</th>
<th>V [µrad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>±220</td>
<td>±165</td>
<td>±115</td>
</tr>
<tr>
<td>1.4</td>
<td>±270</td>
<td>±220</td>
<td>±160</td>
</tr>
<tr>
<td>2</td>
<td>±310</td>
<td>±265</td>
<td>±205</td>
</tr>
<tr>
<td>3</td>
<td>±310</td>
<td>±310</td>
<td>±250</td>
</tr>
</tbody>
</table>
Ramp and squeeze

Present ramp and squeeze:

- **H Crossing**  -170 µrad → -250 µrad [0.45 → 7TeV]
- **V Separation**  -3.5 mm → -1 mm [2 → 7TeV]
- **V Angle offset**  -40 µrad → 0 [2 → 7TeV]
- **β**  10 m → 3 m [2 → 7TeV]

Most of the LR above 30σ, Minimum is still about 20σ
Ramp and squeeze

Pushed case $\beta^*=1$, ramp and squeeze:

- H Crossing: $-170 \mu\text{rad} \rightarrow -220 \mu\text{rad}$ [0.45 → 7TeV]
- V Separation: $-3.5 \text{ mm} \rightarrow -1 \text{ mm}$ [2 → 7TeV]
- V Angle offset: $-40 \mu\text{rad} \rightarrow 0$ [2 → 7TeV]
- $\beta^*$: $10 \text{ m} \rightarrow 1 \text{ m}$ [2 → 7TeV]

All LR in between 12 and 18 $\sigma$
Ramp and squeeze

Pushed case $\beta^* = 1$, ramp and squeeze:

- **H Crossing**: $-170 \, \mu\text{rad} \rightarrow -220 \, \mu\text{rad} \ [0.45 \rightarrow \ 7\text{TeV}]$
- **V Separation**: $-3.5 \, \text{mm} \rightarrow -1 \, \text{mm} \ [2 \rightarrow \ 7\text{TeV}]$
- **V Angle offset**: $-40 \, \mu\text{rad} \rightarrow 0 \ [2 \rightarrow \ 7\text{TeV}]$
- **$\beta^*$**: $10 \, \text{m} \rightarrow 1 \, \text{m} \ [2 \rightarrow \ 7\text{TeV}]$

All LR in above 16 $\sigma$

Good polarity

[Graph showing energy vs. separation with different lines for different values of LR, indicating good polarity.]
Ramp and squeeze

Vertical crossing $\beta^*=1$, ramp and squeeze:

- **Crossing**: $-170 \, \mu\text{rad} \rightarrow -115 \, \mu\text{rad}$
- **Separation**: $-3.5 \, \text{mm} \rightarrow -0.5 \, \text{mm} [2\rightarrow 7 \, \text{TeV}]$
- **Crossing plane**: $0 \rightarrow 90^\circ [\text{from 2\rightarrow 7 \, TeV}]$
- **V Angle offset**: $-40 \, \mu\text{rad} \rightarrow 0 [\text{from 2\rightarrow 7 \, TeV}]$
- **$\beta^*$**: $10 \, \text{m} \rightarrow 1 \, \text{m} [\text{from 2\rightarrow 7 \, TeV}]$

Previous case required exchange of TCDDM, however now all LR around $10 \, \sigma$. 
Ramp and squeeze

Vertical crossing $\beta^*=1.4$, ramp and squeeze:

- Crossing: $-170 \mu\text{rad} \rightarrow -160 \mu\text{rad}$
- Separation: $-3.5 \text{ mm} \rightarrow -0.5 \text{ mm} [2\rightarrow 7 \text{ TeV}]$
- Crossing plane: $0 \rightarrow 90^\circ [\text{from } 2\rightarrow 7 \text{ TeV}]$
- V Angle offset: $-40 \mu\text{rad} \rightarrow 0 [\text{from } 2\rightarrow 7 \text{ TeV}]$
- $\beta^*$: $10 \text{ m} \rightarrow 1.4 \text{ m} [\text{from } 2\rightarrow 7 \text{ TeV}]$

Increasing to $\beta^*=1.4$, put LR to about 14 $\sigma$.

Overall vertical crossing does not seem too advantageous.

However one needs to solve the TCDDM problem.
Ramp and squeeze

Pushed case $\beta^*=1.4$, ramp and squeeze:

- **H Crossing**   
  -170 $\mu$rad $\rightarrow$ -270 $\mu$rad [0.45 $\rightarrow$ 7TeV]

- **V Separation**   
  -3.5 mm $\rightarrow$ -1 mm [2 $\rightarrow$ 7TeV]

- **V Angle offset**  
  -40 $\mu$rad $\rightarrow$ 0 [2 $\rightarrow$ 7TeV]

- $\beta^*$   
  10 m $\rightarrow$ 1.4 m [2 $\rightarrow$ 7TeV]

Most LR above 22 $\sigma$. Assuming new TCDDM.
Ramp and squeeze

Pushed case $\beta^*=1.4$, ramp and squeeze:

- **H Crossing**  -170 $\mu$rad $\rightarrow$ -220 $\mu$rad [0.45 $\rightarrow$ 7TeV]
- **V Separation** -3.5 mm $\rightarrow$ -1 mm [2 $\rightarrow$ 7TeV]
- **V Angle offset** -40 $\mu$rad $\rightarrow$ 0 [2 $\rightarrow$ 7TeV]
- **$\beta^*$** 10 m $\rightarrow$ 1.4 m [2 $\rightarrow$ 7TeV]

Most LR above 19 $\sigma$.
With present TCDDM.

One could look at flat beams for higher luminosity
Back-up
Luminosity scenarios

Scenario with large \(2.7 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}\) IP8 virtual luminosity

Small impact on Atlas/CMS
HL-LHC Targets

HL-LHC: mid 2026 to end 2039 after LS4

- Reach ≥ 3000 fb\(^{-1}\) by
  - Maximize availability, levelled luminosity per bunch, number of bunches, bunch population, brightness.
  - Crab-cavities to alleviate geometric reduction factor to small $\beta^*$ and long bunches and pile-up density.

After LS4, proton physics days increase from standard 160 days to 200 and after LS5 to 220
## Injector Brightness and LHC Filling Schemes

<table>
<thead>
<tr>
<th>Production scheme</th>
<th>ppb $[10^{11}]$</th>
<th>$\varepsilon$ [$\mu$m]</th>
<th>Inj.</th>
<th>BPI</th>
<th>Colliding 1,5/2/8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard</strong></td>
<td>1.3→2.3</td>
<td>2.8→2.1</td>
<td>13</td>
<td>288</td>
<td>2748/2494/2572</td>
</tr>
<tr>
<td><strong>BCMS</strong></td>
<td>1.3→2.3</td>
<td>2.5→1.7</td>
<td>20</td>
<td>144</td>
<td>2544/2205/2308</td>
</tr>
<tr>
<td><strong>8b+4e STD</strong></td>
<td>1.6→2.5</td>
<td>2.4→2.1</td>
<td>13</td>
<td>144</td>
<td>1960/1163/1806*</td>
</tr>
<tr>
<td><strong>8b+4e BCMS</strong></td>
<td>1.6→2.5</td>
<td>1.2→1.8</td>
<td>20</td>
<td>96</td>
<td>1696/1470/1538*</td>
</tr>
<tr>
<td><strong>80b</strong></td>
<td>1.3→2.3</td>
<td>1.3→2.1</td>
<td>14</td>
<td>240</td>
<td>2732/2476/2549</td>
</tr>
<tr>
<td><strong>50 ns</strong></td>
<td>1.8</td>
<td>1.8</td>
<td>13</td>
<td>144</td>
<td>1374/1247/1286</td>
</tr>
<tr>
<td><strong>Single</strong></td>
<td>&gt;3.0</td>
<td>&gt;1.5</td>
<td>n/a</td>
<td>1</td>
<td>n/a</td>
</tr>
</tbody>
</table>

**Run II → HL-LHC**

*scaling

New scheme thanks to 200 ns rise time, BCMS very close to standard for IP1/5. 288bpi BCMS and 320bpi 80b cannot be tested in Run II due to transfer line limitations.

Will always short non-colliding train be needed, can they at least collide?

H. Bartosik, G. Iadarola, X. Buffat, C. Schwick
Velo upgrade references

2013, Velo TDR
LHCb Tracker Upgrade TDR
20/7/2014, Velo Approval

M. Giovannozzi, Velo aperture, 9th TREX
5/11/2015
R. Appleby et al, VELO aperture considerations for the LHCb Upgrade, CERN-ATS-Note-2012-101

Neglects crossing angle effects, assume levelling but also 1.7 \(10^{11}\) for run III

<table>
<thead>
<tr>
<th></th>
<th>Nominal</th>
<th>Post LS2</th>
<th>HL-LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25 ns</td>
<td>50 ns</td>
<td>25 ns</td>
</tr>
<tr>
<td>(N / 10^{11}p)</td>
<td>1.15</td>
<td>1.6</td>
<td>1.7</td>
</tr>
<tr>
<td>(\epsilon_n / \mu m)</td>
<td>3.75</td>
<td>2.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Table 1: Overview of global upgrade settings for simulation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>7 TeV</td>
</tr>
<tr>
<td>Number of bunches colliding at IPS</td>
<td>2400</td>
</tr>
<tr>
<td>Bunch z RMS</td>
<td>90 mm</td>
</tr>
<tr>
<td>Half angle horizontal</td>
<td>135 (\mu)rad</td>
</tr>
<tr>
<td>Half angle vertical</td>
<td>120 (\mu)rad</td>
</tr>
<tr>
<td>Luminosity</td>
<td>(2 \times 10^{33}) (\text{cm}^{-2}) (\text{s}^{-1})</td>
</tr>
<tr>
<td>Bunch charge</td>
<td>1.2 (\times 10^{11}) protons</td>
</tr>
<tr>
<td>(\nu) (# interactions per crossing)</td>
<td>7.6 (for (\sigma_{\text{tot}} = 102.5) mb)</td>
</tr>
<tr>
<td>(\mu) (# visible interactions per crossing)</td>
<td>5.2 (for (\sigma_{\text{vis}} = 70.6) mb)</td>
</tr>
<tr>
<td>Bunch (x,y) RMS</td>
<td>37.70 (\mu)m</td>
</tr>
<tr>
<td>(z) RMS luminous region</td>
<td>(\sigma_{\text{hmsi}})</td>
</tr>
</tbody>
</table>