Crystal collimation LHC MD data analysis

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On behalf of UA9 collaboration and Collimation Team
Special thanks to all MD participants
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LHC MD overview

Preliminary operation
- The test was performed at injection energy with one pilot and one nominal bunch.
- ADT was constantly used to have clear loss signal.
- Crystals aligned as primary collimator (500 μm wrt TCP alignment).
- Fast angular scan was performed to find the channeling orientation.

Fine angular scan
- Scan performed for both crystals at different goniometer speed.
- Performed with complete collimation system at nominal position and with reduced collimator configuration.

Channeled beam scan
- Performed for both crystal scraping with TCSG used as absorber.

Loss map
- With reduced collimator configuration and both crystal in Channeling orientation.
- Reference loss maps were also performed with standard collimation system.
Preliminary operation

✔ For each alignment the linear position was reproduced within 1 mm of tolerance ($\sigma = 1.5$ mm).
✔ Channeling orientation was reproduced within 10 $\mu$rad of tolerance.

Fine angular scan

✔ 3 scans for the horizontal crystal, and 2 scans for the vertical were taken.
✔ Measurements performed on angular scans:
  • Reduction Factor (amorphous losses wrt channeling losses)
  • Bending angle estimation

Channeled beam scan

✔ Measurements performed on angular scans:
  • Extracted beam size
  • Crystals deflection angle
  • Multi-turn Channeling efficiency

Loss map

✔ Collimation cleaning efficiency comparison of the two systems
Horizontal scan

Horizontal Crystal Angular Scan

Reduced collimator config.

Crystal at 5.57 \( \sigma \)
Horizontal scan analysis

Reduced collimator config.

Crystal at 5.57 σ

2nd grade fit function:
- Best CH: 3149 μrad
- Min losses: 2.64 × 10^{-15}

Reduction factor ➔ 31
Vertical scan

Reduced collimator config.

Crystal at 5.43 σ

2nd grade fit function:
- Best CH : 2242 µrad
- Min losses : 3.06×10^{-16}

Reduction factor ➔ to be checked

Maybe too close to BKG value
Under investigation for BKG signal
# Angular Scan Analysis Recap

<table>
<thead>
<tr>
<th>Crystal</th>
<th>Nomial Collimation</th>
<th>Reduced Collimation</th>
<th>$\sigma_{CRY}$</th>
<th>Scan Speed $\mu$rad/s</th>
<th>Best CH $\mu$</th>
<th>Reduction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>x</td>
<td></td>
<td>5.57</td>
<td>0.5</td>
<td>3164</td>
<td>26</td>
</tr>
<tr>
<td>H</td>
<td>x</td>
<td></td>
<td>5.57</td>
<td>0.5</td>
<td>3160</td>
<td>17</td>
</tr>
<tr>
<td>H</td>
<td>x</td>
<td></td>
<td>5.57</td>
<td>1</td>
<td>3149</td>
<td>31</td>
</tr>
<tr>
<td>V</td>
<td>$x^*$</td>
<td></td>
<td>5.43</td>
<td>0.3</td>
<td>2232</td>
<td>np</td>
</tr>
<tr>
<td>V</td>
<td>x</td>
<td></td>
<td>5.43</td>
<td>1</td>
<td>2242</td>
<td>np</td>
</tr>
</tbody>
</table>

* In this case upstream collimators were retracted of 1 mm.
Reduced collimator config.

Crystal at 5.5 $\sigma$ in CH

Evaluation of channled beam size: 436 $\mu$m
Applying the transformation below we obtain the crystal deflection angle

$$\theta_k(s_{col}) = \frac{x(s_{col}) - \sqrt{\beta_{col}/\beta_{cry}} \cdot x_{cry} \cos(\Delta\phi)}{\sqrt{\beta_{cry} \beta_{col} \sin(\Delta\phi)}}$$

60 urad is in agreement with the behaviour of the twin crystal
Normalizing the scraper scan to the amount of losses reached when intercepting the circulating beam we can roughly evaluate $\eta_{\text{CH}}^{\text{multi}}$. 

\[ \chi^2 / \text{ndf} = 1.585 / 33 \]

\[ p_0 = 0.7801 \pm 0.03759 \]
# Angular Scan Recap

<table>
<thead>
<tr>
<th>Crystal</th>
<th>Reduced Collimation</th>
<th>$\sigma_{\text{CRY}}$</th>
<th>Scan Speed</th>
<th>$\sigma_{\text{EB}}$</th>
<th>$\Theta_\mu$</th>
<th>$\Theta_\sigma$</th>
<th>$\eta^{\text{CH multi}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>x</td>
<td>5.5</td>
<td>50 μm / 3 s</td>
<td>436 μm</td>
<td>60.5 μrad</td>
<td>8.14 μrad</td>
<td>78 %</td>
</tr>
<tr>
<td>V</td>
<td>x</td>
<td>5.6</td>
<td>50 μm / 3 s</td>
<td>584 μm</td>
<td>51.7 μrad</td>
<td>11.6 μrad</td>
<td>67 %</td>
</tr>
</tbody>
</table>
Loss maps were taken with both crystal in CH and reduced collimation.

Comparison with reference loss maps, with nominal collimation settings, and simulations is on going.
Preliminary comparisons between beam loss pattern in IR7 and cleaning inefficiency

Very good qualitative agreement between data and simulations, detailed analysis on-going
Conclusions

Achieved Results
✓ So far the analysis confirm the good results we saw in the online procedure.
✓ Estimated crystal angles:
  • Vertical 51.7 against 50 nominal
  • Horizontal 60.5 against 50 nominal
✓ The test of the goniometers is a very important validation of this new hardware.
✓ All the results represent an important benchmark for future tests.

Next goals
☐ Improvement of analysis is possible and it’s on going (trying a better fit function and a better evaluation of multi-turn efficiency)
☐ Cleaning evaluation from the loss maps is as well on going.
☐ Simulations have to be performed to compare the experimental results.
Backup
Vertical extracted beam scraping

Reduced collimator config.

Crystal at 5.5 $\sigma$ in CH
Horizontal deflection angle

Vertical Crystal Scraping

χ² / ndf  6.257e-39 / 97
Constant  3.209e-17 ± 2.39e-20
Mean      -51.71 ± 0.0009101
Sigma     11.62 ± 4.979e-19
Horizontal scan

Horizontal Crystal Angular Scan

Reduced collimator config.

Crystal at 5.6 σ

Reduction factor → 31
Vertical Crystal Angular Scan

Vertical scan

Reduced collimator config.

VR ~ 50 urad

AM

VR ~ 50 urad

CH

Reduction factor $\rightarrow$ 176
Cleaning performance of the system defined as average level of losses in the IR7-DS

Cleaning Comparison

IR7 insertion with present collimation

<table>
<thead>
<tr>
<th>Config. Plane</th>
<th>IR7-DS avr. losses</th>
<th>Gain w.r.t. Std coll.</th>
<th>Gain w.r.t. crystal in AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Std. H</td>
<td>(1.97 ± 0.01) x 10^-5</td>
<td>1.0</td>
<td>(1) 0.34 ± 0.02 - (2) 0.30 ± 0.03</td>
</tr>
<tr>
<td>CH (1) H</td>
<td>(1.46 ± 0.02) x 10^-6</td>
<td>3.5 ± 0.2</td>
<td>39.6 ± 0.6</td>
</tr>
<tr>
<td>CH (2) H</td>
<td>(2.53 ± 0.09) x 10^-6</td>
<td>7.8 ± 0.3</td>
<td>26.2 ± 1.0</td>
</tr>
<tr>
<td>AM (1) H</td>
<td>(5.78 ± 0.02) x 10^-5</td>
<td>0.34 ± 0.02</td>
<td>1.0</td>
</tr>
<tr>
<td>AM (2) H</td>
<td>(6.62 ± 0.07) x 10^-5</td>
<td>0.30 ± 0.03</td>
<td>1.0</td>
</tr>
<tr>
<td>Std. V</td>
<td>(1.89 ± 0.01) x 10^-5</td>
<td>1.0</td>
<td>0.30 ± 0.02</td>
</tr>
<tr>
<td>CH V</td>
<td>(1.56 ± 0.03) x 10^-6</td>
<td>2.1 ± 0.2</td>
<td>40.8 ± 0.8</td>
</tr>
<tr>
<td>AM V</td>
<td>(6.36 ± 0.03) x 10^-5</td>
<td>0.30 ± 0.02</td>
<td>1.0</td>
</tr>
</tbody>
</table>