IR2 optics modification for an improved performance of the ALICE fixed-target layout

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Acknowledgments:

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Halo particles are intercepted and disposed by the collimation system.

Part of the secondary halo is intercepted by the crystal and deflected towards the target.

Local absorbers capture additional losses coming from the crystal+target assembly.

Parasitic operation means that fixed-target collisions occur in parallel to beam-beam collisions.

Parasitic operation of fixed target experiment is possible only if new loss spikes stay within acceptable limits (e.g. not larger than usual losses).

The setup is optimized to provide a maximum flux of protons on target (PoT) that can be handled by the detector acquisition system.
More than a factor of 4 of difference!
Space constraints

<table>
<thead>
<tr>
<th>s [m]</th>
<th>3217m “best”</th>
<th>3259m “original”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δμ (TCP.D) [deg]</td>
<td>144</td>
<td>168</td>
</tr>
<tr>
<td>PoC [1e-3]</td>
<td>2.5</td>
<td>0.6</td>
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More than a factor of 4 of difference!
Interaction with a primary collimator

\[ \sqrt{\left\langle \theta_P^2 \right\rangle} = \frac{13.6}{cp[\text{MeV}]} \sqrt{\frac{s}{\chi_0}} \left( 1 + 0.038 \cdot \left( \frac{s}{\chi_0} \right) \right) \]

\( \chi_0 \): radiation length

Molière's multiple-scattering theory: scattered particles gain a transverse RMS kick.

\[ \xi_{\beta} = n_1 \sin(\phi_z) \]
\[ \xi'_{\beta} = n_1 \cos(\phi_z) \]

Change of amplitude and phase:

\[ n_k = \sqrt{n_1^2 + \Delta \theta^2 \cdot \frac{\beta}{\varepsilon}} \]
\[ \Delta \phi = -\text{sgn}(\Delta \theta) \cdot \arccos \left( \frac{n_k}{n_1} \right) \]
Effect of scattering

- Scattering angle transforms into the maximum amplitude growth at the location where the phase advance is $90^\circ \pm \Delta \phi$.

- Such a phase advance is desired between the primary vertical collimator (TCP.D) and the crystal.

- Phase advance close to $0^\circ$ or $180^\circ$ is not favorable.

- Phase advance can be modified by changing the $\beta$ function.
Shift of phase at the crystal by changing the $\beta^*$
Comparison with ion optics
simulation settings

- Only one IR2 optics scenario available for HL-LHC v1.5
- RunII ion optics scenarios used for comparison with my modifications
  - /afs/cern.ch/eng/lhc/optics/runII/2018/ION
  - Only optics, no SixTrack studies.
- Ion optics changes globally (all IRs)
- My changes concern IR2 only.
\( \beta^* = 10\text{m} \) and \( 9.2\text{m} \)

Qualitatively very similar effect
\[ \beta^* = 10\text{m and } 8.5\text{m} \]

Ion optics 2018

HL-LHC v1.5 with my changes

Qualitatively very similar effect
\( \beta^* = 10 \text{m and } 7.6 \text{m} \)

**Ion optics 2018**

**HL-LHC v1.5 with my changes**

Qualitatively very similar effect
$$\beta^* = 10\text{m and 6.7m}$$

Ion optics 2018

HL-LHC v1.5 with my changes

Qualitatively very similar effect
Summary of ion optics review

- 2018 ion optics was analyzed for several IP2 $\beta^*$ values.
- A very similar effect is observed as for manual changes of HL-LHC optics.
- Lower $\beta^*$ values cause a change of phase advance in a favorable way.
- Optics at the region of concern is rather flexible and required modifications should be easy to be implemented.
- This is only a verification of concept. Final optics matching requires a support from optics experts.
IR2 optics modification

- $\beta^*$ constant, only a shift of phase

Simulation settings

- HL-LHC v1.5 optics
- $\beta^* = 10$ m and 7 m
- Coll settings:
  - $n_\sigma (TCP_{IR7}) = 6.7$,
  - $n_\sigma (CRY_{IR2}) = [7.3, 7.5, 7.9]$,
  - $n_\sigma (TCS_{IR7}) = 9.1$,
  - $n_\sigma (TCLA_{IR7}) = 12.7$
- Annular beam halo:
  - DIST_TYPE 3
  - DIST_PARAM 0 0 6.7 0.01 1.129e-4 75.5
- 2.1M particles, 300 turns
\[ \beta^* = 10m, \text{ a shift of phase} \]
$\beta^* = 10\text{m},$ a shift of phase

Ion optics 2018

HL-LHC v1.5
Optimum phase
Loss map comparison

- No extra losses.
- Significantly more protons on the crystal and target.
- Original location is nearly at the worst phase (180deg) for the default optics.
- Phase shift by ~65deg allows to increase the system performance significantly.
- The maximum PoC seems to be independent on the value of $\beta$.
  (no need to change $\beta^*$).
- Such a phase shift should be easy to be implemented into the operational optics.
  However, a support from optics experts is required.
Assets of having the crystal at s=3259m

- Good space availability for the crystal installation.
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Assets of having the crystal at $s=3259\text{m}$

- Good space availability for the crystal installation.
- A single crystal (200μrad) can cover both ALICE polarities. A movable target is then needed.
Assets of having the crystal at $s=3259\text{m}$

- Good space availability for the crystal installation.
- A single crystal (200µrad) can cover both ALICE polarities. A movable target is then needed.
- About a factor of 2 increase of protons on target (PoT) when the crystal is at the optimal phase – comparing to crystal at $s=3217\text{m}$ at default optics.
Extra slides
$\beta^* = 7\text{ m}, \text{ a shift of phase}$

Optimum phase
Loss map comparison

- No evident difference
- Crystal angular orientation not optimized for $b^*=7.5m$ case
PoC summary table

<table>
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<tr>
<th>β* y [m]</th>
<th>10 org</th>
<th>10 org</th>
<th>10 mod</th>
<th>9</th>
<th>8</th>
<th>7</th>
<th>6</th>
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Observations (not yet conclusions):

- Small change of optics allows to recover the PoC performance.
- I will search for some further improvement by locally modifying μ and β
\( \beta^* = 10 \text{m} \)
$\beta^* = 9\text{m}$

$\Delta \mu_y(TCP.D \rightarrow CRY) = 145\text{ deg}$
$\beta^* = 8 \text{m}$
$\beta^* = 7 \text{ m}$

$\Delta \mu_y(TCP, D \rightarrow CRY) = 129 \text{ deg}$
\[ \beta^* = 6 \text{m} \]
$\beta^* = 5\text{m}$

$\Delta \mu_y(TCP. D \rightarrow CRY) = 126\text{ deg}$
PoC (s=3217)