High-beta optics plans

- introduction, schedule, constraints
- strategy for $\beta^* = 90$ m and $\beta^* = 500$ m
- longer term, studies required for LS1 and beyond

Acknowledgment:
S. Redaelli, G. Müller, J. Wenninger (on-line, commissioning)
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Operations, TOTEM and ALFA teams
Planning and requests 2012

Priority: maximize Luminosity

\[ \text{double } L_{\text{peak}}, \quad \int L dt \geq 15 \text{ fb}^{-1} \]

Baseline: 4 TeV, 50 ns

IP1/5 \( \beta^* = 60 \text{ cm} \) (backup 70 - 90 cm)

ALICE & LHCB \( \beta^* = 3 \text{m} \)

\(~129\) proton running

\(~18+4\) days of MD

\(~8\) days special runs

“to be scheduled”

VdM, Roman Pots and high-\( \beta^* \)

\( \beta^* = 90 \text{ m} \) and 500 m
β-function, phase advance and tune

Relation between phase advance $\Phi(s)$, $\beta(s)$ and tune of the ring $Q = \Phi / 2\pi$

$$\Phi(s) = \int 1 / \beta(s) \, ds$$

Integrated symmetrically around the minimum:

$$\Phi(s) = \int_{s_0-\ell}^{s_0+\ell} \frac{1}{\beta(s)} \, ds = 2 \arctan \left( \frac{\ell}{\beta^*} \right)$$

A low $\beta$ insertion contributes \textbf{0.5 in tune} ($\pi$ in phase)

Where low-$\beta^*$ means $\beta^* \ll \ell$

And \textbf{0} for high-$\beta^*$ $\beta^* \gg \ell$

For the LHC with $\ell = 26.15$ m from IP to centre of Q1

Major tune change in de-squeeze. In triplet mostly between injection and 90 m
90 m optics

shown for IP5 with $\pi$ in $x$ and $\pi/2$ in $y$ to roman pot at 220 m

With current cabling required to have quad strength ratios within $0.5 < b_1/b_2 < 2.0$
500 m optics for 2012, preliminary
shown for IP5 with \( \pi/2 \) in \( y \) to roman pot at 220 m

With current cabling required to have quad strength ratios within \( 0.5 < b1/b2 < 2.0 \)

<table>
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<th>Kq4.15b1</th>
<th>Kq4.15b2</th>
<th>Kg4.15b1</th>
<th>Kg4.15b2</th>
<th>Kg5.15b1</th>
<th>Kg5.15b2</th>
<th>Kg6.15b1</th>
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<th>Kg10.15b1</th>
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<td>Kg10.5b2</td>
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\( \Delta Q_x = 0.212 \quad \Delta Q_y = 0.229 \quad \beta_y = 160.996 \text{ m} @ RP 220 \text{ m} \)

\( \mu_x r_p v b_6 r_5 b_2 = 176^\circ \quad \mu_y r_p v b_6 l_5 b_2 = 90^\circ \quad L_y = 284 \text{ m} \)
The current ratio constraint

\[ 0.5 < \frac{b_1}{b_2} < 2 \]

removed with a 2nd return cable

D. Nisbet LMC 15/4/2009
F. Duval LMC#31 October 2009; cost \( \sim 100 \text{ kCHF} \)
my proposal, do for Q4, Q7, Q8 L/R, LMC#32 10/2009

Installation in LS1: implies to buy cables by June 2012 latest
Aperture at $\beta^* = 90$ m

**beam 1**

4 TeV, ± 2 mm separation

**beam 2**

Aperture at $\beta^* = 90$ m not critical

IP region in shadow of roman pot / Q6 region and arc
Aperture at $\beta^* = 500$ m

At $\beta^* = 500$ m, the aperture limit is moved in to the triplet region close to TAS
Still within the standard specification of $n_1 = 7$

at $\beta^* = 1000$ m  $n_1 \approx 5.2$ with and $n_1 \approx 6.3$ without separation
Basic strategy: keep (re-commission cleanly) the de-squeeze to 90 m (during re-commissioning) and extend it with extra files for higher $\beta^*$, above 90 m all matched for $\Delta\mu_y = 90^\circ$

“Same optics” in IP1 & 5 except for:
match the vertical phase advance to $\Delta\mu_y = 90^\circ$ for TOTEM for RP at 220m, ALFA RP at 240 m parallel separation: IP1 in x, IP5 in y
Preliminary files exist for $\beta^* = 90 - 500$ m, appear to fulfill all constraints, require a bit more smoothing + transfer to control system
Keep ± 2mm separation during de-squeeze
no constraint on $\Delta\mu_x$, naturally just a bit below $\sim 175^\circ$
$L_{y_{\text{eff}}} = \sqrt{\beta^*\beta_{\text{RP}}}$ not constraint, typically $\sim 250 - 300$ m

matching to $\sim 200$ m rather straightforward, 400 m reached with few iterations
500 m and more getting difficult, main reasons:
• control of b1/b2 ratios of in particular Q8, Q7 and Q4 --- remove this in LS1
• parallel separation, kicks up to 113 $\mu$rad, outside the range allowed at 7 TeV, ok @ 4 TeV
• aperture
Getting down to \(-t \approx 6.5 \times 10^{-4} \text{ GeV}^2\) is known to be extremely challenging at LHC energies.

Original ALFA request: \(\beta^* = 2450 \text{ m}, \ Q4 \text{ inverted and } 200 \text{ m injection, } \varepsilon_N = 1 \mu \text{m} \ (7 \text{ TeV})\)

\(-t \approx p^2 \theta^2 \quad \theta = 6.4 \mu \text{rad} \text{ at } 4 \text{ TeV}, \quad \theta = 3.6 \mu \text{rad} \text{ at } 7 \text{ TeV}\)

\(t \propto n_\sigma^2 / \beta^*\) roman pots can be put to 5 \(\sigma\) or less, or \(\sim 2\) times closer than early estimates.

Opens the way to get to the Coulomb region at more practical \(\beta^*\) in the range of

500 m this year and \(\sim 1 \text{ km} \) after LS1 (with cable constraints removed and higher energy)

Estimate for \(E_b = 4 \text{ TeV}, \varepsilon_N = 2 \mu \text{m}, \ \delta \text{gap} = 0.4 \text{ mm}, \ n_\sigma = 5, \) Coulomb region reached at \(b^* = 490 \text{ m}\)
(MD) Subjects in 2012 with beam for high-β*

**General aims**

- define the 2012 high-β physics optics
- explore limits to define the required hardware modifications in LS1 (extra cables) for the high-β program at the design beam energy after LS1

**Tasks (MD-sessions)**

- de-squeeze to $\beta^* \sim 500$ m in IP1&5 + recommission 2012 new energy, modified ramp + squeeze?
- scraping to $\sim 1$ μm normalized emittance at top energy
- injection at 90 m optics in IP1&5 -- to speed up operation with high-beta*
- squeeze with colliding beams
- test Q4 inversion, with injection at 200 m
- longitudinal separation using RF
- maximum $\beta^*$ without extra cables
• Get to $\beta^* \approx 500$ m by de-squeeze in 2012 starting a.s.a.p. 
  approach the interference region by minimizing $n_0$, $t_{\text{min}} \sim n_0^2 / \beta^*$
  with reduced emittance and going closer with RPs to beam
  all bunches same intensity $\sim 3 \times 10^{10}$ $\varepsilon_n < 2 \mu$m
  also test higher intensity and further emittance reduction by scraping

• 2012 also crucial for modifications in LS1, required to fully exploit high-$\beta$ at the
  nominal LHC energy after LS1
  Good potential to reach Coulomb region without Q4 inversion at full energy
  Requires the installation of the missing cables, most important for Q4, Q7, Q8
  (was in principal agreed in LMC 31, 32)
  in LS1, apply to both IP1 & IP5 and left and right of the IPs

  to be efficient: we need at least a rough schedule for the special runs soon
  with several sessions, separated in time
Backup
Separation bump at 500 m

MCBX off – have wrong phase advance for parallel separation at high $\beta$

```plaintext
acbyv4.15b1 := 0.000113450750 *on_sep5 ;
acbcv5.15b1 := -0.000079352759 *on_sep5 ;
acbyv4.r5b1 := 0.000000837063 *on_sep5 ;
acbcv5.r5b1 := 0.000005866063 *on_sep5 ;
acbyv4.15b2 := -0.000000435499 *on_sep5 ;
acbcv6.15b2 := -0.000006223428 *on_sep5 ;
acbyv4.r5b2 := -0.000098589908 *on_sep5 ;
acbcv5.r5b2 := 0.000070288777 *on_sep5 ;
```
de-squeeze 11 m to 90 m in 19 intermediate steps

Constraints were fulfilled and that the spacing between intermediate files during the un-squeeze was adequate.

We found that a sufficiently smooth un-squeeze from 11 to 90 m can be performed using 19 intermediate steps. The evolution of the normalized quadrupole strengths is shown in Fig. 7.

Figure 7: Quadrupole strength evolution during the un-squeeze from 11 to 90 m in IR5. Top is for Beam 1 left and right, and bottom the same for Beam 2.

Figure 8: $\beta^*$-beat during the un-squeeze from 11 to 90 m for Beam 1 (left) and Beam 2 (right) from linear interpolation between match points. We determined the $\beta^*$-beating introduced by the linear interpolation between the steps. The result is that the $\beta^*$-beating from linear interpolation between the 19 match points chosen remains below...