Commissioning of the 90 m Totem Optics

• Introduction: scenario; $\beta$, phase advance, tune

• Compatibility of early physics and Totem 90 m optics
  • need for global tune compensation of “un-squeeze”
  • aperture, $\beta$-beating
  • smooth “un-squeeze” to 90 m

• Conclusion

based on work and discussions within LCU, LHCCWG & LTC
Scenario: early physics and Totem 90 m optics

Earlier physics operation:
- injection; optics with $\beta^* = 11$ m in IR1/5, no crossing angle
- injection of limited number of bunches (43 to 156) and intensities $\sim 5 \times 10^{10}$ / bunch
- ramp with same $\beta^* = 11$ m in IR1/5
- prepare for physics
  - normally: increase Luminosity by local squeeze from 11 m down to 2 m in both IR1/5
  - here: local squeeze in IR1 to 2 m + “un-squeeze” in IR5 to 90 m $\beta^*$
    with phase advance of $\Delta\mu_y = 0.25$ (90°), $\Delta\mu_x = 0.50$ (180°) for outgoing beam between IR5 and roman pot at 220 m from IP (between Q5 and Q6).

What happens in the squeeze and un-squeeze and how does it compare?
the main changes in tune (phase advance) and aperture can be derived from optics principles ----->
The $\beta$-function in a field free region has a form of a parabola with

$$\beta(s) = \beta^* + \frac{(s - s_0)^2}{\beta^*}$$

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

$$\Phi(s) = \int \frac{1}{\beta(s)} \, ds$$

Integrated symmetrically around the minimum

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

Contributes 0.5 in tune ($\pi$ in phase) for low $\beta^* < l$
going to 0 for high $\beta^* \gg l$

For the LHC with $l = 26.15$ m from IP to centre of Q1
LHC physics tune

Target physics tunes are \( Q_x = 64.31 \) and \( Q_y = 59.32 \) for both beams in the LHC

individual contributions from arcs and insertions:

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<th>beam2</th>
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Remains constant from end of ramp through the squeeze

IR5 contributes 2.633 in \( Q_x \) and 2.649 in \( Q_y \), both for beam 1 & 2
\( \beta^* = 2 \text{ m physics optics in IR 5} \)

\( \beta_x, \beta_y (m) \)

\( D_x \)

\( s (\text{km}) \)

\( D_{x,y} (m) \)

\( \mu_x = 2.633 ; \mu_y = 2.649 \)
$\beta^* = 90 \text{ m Totem optics}$

 mux = 2.540 ; muy = 2.620 needs extra $\Delta Q_x = 0.093, \Delta Q_y = 0.029$ trim
Aperture of $\beta^* = 2 \, \text{m}$ physics optics in IR 5
well within specs, but already tighter than the $\beta^* = 2 \text{ m} \ $ physics optics
Aperture of 90 m Totem optics at injection

not enough aperture to inject into 90 m optics, “un-squeeze” needed
90 m Totem optics. $\Delta Q_x = 0.093$, $\Delta Q_y = 0.029$ using trim quads $k_{qtd}$, $k_{qtf}$

similar for both beams, shown here for beam 1

maximum excursions in $x$: $-3.5$ to $+2.2\%$

maximum excursions in $y$: $-1.2$ to $+0.6\%$
match “squeeze” from 90 m to 11 m in IR5, left side

In 21 steps, each step with a 10% reduction in $\beta^*$ (90, 81, 73, ... 11 m). Last step shows our normal 11 m strength. Match with 23 variables (quad strength), 19 constraints $\beta$, D..
“squeeze” match from 90 m to 11 m in IR5, right side

kqt13, kq4, kqx, ktqx1, ktqx2 interpolated between start / end
squeezed from 90 m to 11 m

\[ \beta_x, \beta_y \quad D_x, D_y \quad s (m) \]

Momentum offset = 0.00 %

V6.500 initial totem optics 90m MAD-X 3.03.41 13/03/07 20.27.05
Momentum offset = 0.00 %

\[ \beta = 59 \]

MAD-X 3.03.41 13/03/07 20.27.37

\[ x (m), y (m) \]

\[ D_x (m), D_y (m) \]

\[ \beta_x, \beta_y, D_x \]

\( s (m) \)
Momentum offset = 0.00 %

\[ \beta_x \quad \beta_y \quad D_x \]

beta = 53

MAD-X 3.03.41 13/03/07 20.27.47

\[ \text{Momentum offset} = 0.00 \% \]
Momentum offset = 0.00 %
s (m)
beta = 47
MAD-X 3.03.41  13/03/07 20.27.53

![Graph showing beta and D as functions of s](image-url)
beta = 43
MAD-X 3.03.41 13/03/07 20.27.59

Momentum offset = 0.00 %

s (m)

beta = 43

Dx (m), Dy (m)

s (m)

Momentum offset = 0.00 %
Momentum offset = 0.00 %

beta = 38

MAD-X 3.03.41 13/03/07 20.28.07

Dx (m), Dy (m)

x (m), y (m)
Momentum offset = 0.00 %
s (m)

beta = 25

MAD-X 3.03.41 13/03/07 20.28.34

0.0
200.
400.
600.
800.
1000.
1200.
1400.
1600.

beta = 25

MAD-X 3.03.41 13/03/07 20.28.34

0.0
200.
400.
600.
800.
1000.
1200.
1400.
1600.

Dx (m), Dy (m)
Momentum offset = 0.00 %

$\beta = 11$

MAD-X 3.03.41 13/03/07 20.29.20

$x (m), y (m)$

-0.5
0.0
0.5
1.0
1.5
2.0
2.5

$D_x (m), D_y (m)$

$x$ $y$ $D_x$
Momentum offset = 0.00 %

ir5 inj. optics, this is the target

MAD-X 3.03.41 13/03/07 20.29.21

\[ \beta_x, \beta_y, D_x \]

\[ x, y \]

\[ \beta (m), \beta (m) \]

\[ \alpha \]
Conclusion

Based on the optics / aperture arguments presented:  
the “un-squeeze” from our standard 11 m injection&ramp optics to the  
90 m Totem optics in IP 5 looks feasible.

One known issue:  
The “un-squeeze” is not completely local: the global tune is reduced;  
this is correctable by a global tune adjust within the nominal tuning range  
and not expected to be critical: to be verified in early operation or MD

Commissioning time

Hard to predict for a new machine of the size and complexity of the LHC  
Probably similar to the time needed to commission the squeeze down to 2 m
Backup Slides
Outlook V6.501

Phase advances were kept fixed between optics versions V6.5 and V6.500

To allow for a more general optimisation, they were allowed to change for V6.501, mux increased in various places: IR2, IR7 can be expected to rather facilitate the integration of the early Totem 90 m optics.

### LHCVERSION V6.500

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### LHCVERSION V6.501

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</table>
ΔQx = 0.093, ΔQy = 0.029 adjust required for Totem 90 m
same for b1, b2: use main quads to adjust tune kqd, kqf

- Maximum excursions in x within ±1%
- Maximum excursions in y within ±0.8%