Achromatic Telescopnic Squeezing (ATS) scheme: principle, by-products and experience with beams

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- ATS MD’s in 2016/2017 (round & flat optics)
- 2017 ATS LHC optics: Check-up after one operational year (2017 vs. 2016)
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Recap: ATS principle, by products, MDs in Run I

The ATS scheme is the most cost-effective, if not the only way, to reach the targeted HL-LHC \( \beta^* \) of 10-15 cm

**Why:** To be focused at the IP, the beam must first be widely expanded in the triplet, something **intrinsically limited by the finite length of the matching section**

**How:** a **squeeze in two steps**

1. An “almost” standard squeeze, **the Pre-squeeze:**
   - acting on the matching quads of IR1 and IR5 with new matching constraints on the left/right IR phase,
   - till reaching some limits on matching quads (or sextupoles)

2. A further reduction of \( \beta^* \), **the Tele-Squeeze:**
   - acting only IR2/8 for squeezing IR1 and IR4/6 for IR5,
   - inducing \( \beta \)-beating bumps in s81/12/45/56 to boost the sextupole efficiency, but also the octupoles (see later).
Recap: ATS principle, by products, MDs in Run I

By-products coming from the (controlled) $\beta$-beating induced in the IR1/5 adjacent arcs, and from the phasing of these arcs w.r.t the triplet

- Q’ correction at constant sextupole strength: $\beta_{MS} \propto 1/\beta^*$
  $\rightarrow$ no $\beta^*$ limits from Q’ correct-ability

- Very clean compensation of chromatic aberrations, such as off-momentum $\beta$-beating, non-linear chromaticity, spurious dispersion from crossing angle
  $\rightarrow$ preservation of off-momentum triplet aperture, IR7 hierarchy preservation over the RF bucket (no degradation of TCP/TCS retraction), control of chromatic tune spread ($Q''$, $Q'''$,..), other exotic effects avoided like strong pacman effect on Q’

- Lattice octupoles boosted at constant strength: $\Delta Q_{\text{spread}} \propto (\beta_{MO})^2 \propto 1/\beta^{*2}$
  $\rightarrow$ More Landau damping to cope with impedance/intensity increase,
  $\rightarrow$ Using the octupoles in SB for BBLR mitigation $\rightarrow$ X-angle reach
First demonstration with beam in 2011 (. . already with 30 cm $\beta^*$ !)
$\rightarrow$ Telescopic principle ($\times 4$) demonstrated in IR1

Thanks to G. Vanbavinckhove & OMC team
Highlights from ATS MD’s in 2016/2017

→ ATS MD’s in Run I (2011-12) demonstrated the basics, down to 10 cm $\beta^*$ (in non-operational machine conditions, e.g. w/o X-angle) with
   (i) low intensity beams and
   (ii) not always with state of the art optics correction

→ ATS MD’s in Run II (2016-17-..18) developed a new version of the ATS optics (optimized for machine protection aspects) on 3 fronts

1. **Round telescopic optics** with pushed pre-squeezed $\beta^*$ (40 cm), limiting the *high intensity tests to “small” tele-index*
   → for LHC ($r_{tele} \sim 4/3 \ @ \ \beta^* \sim 30 \ cm$)

2. **Round telescopic optics** with larger pre-squeezed $\beta^*$ (1 m), enabling *high intensity tests @ large tele-index*
   → for (HL-)LHC ($r_{tele} \sim 3 \ @ \ \beta^* \sim 30 \ cm$)

3. **Flat optics** (just started) → for (HL-)LHC
• Tele index of $3 @ \beta^* = 35 \text{ cm}$ (tele-squeeze from 1 m)

→ First demonstration of BBLR mitigation with octupole (MO)

$\sigma_{\text{eff}_i} \overset{\text{def}}{=} \frac{dN_i/dt}{L_i}$

![Graph showing effective cross section and OCTOPOLES CURRENT with Positive and Negative MO](image)
Optics correct-ability: as excellent as before

Collimation: even improved (not due to the ATS but to the tighter collimator settings)

Luminosity Life time: qualitatively very similar (even slightly improved)

Integrated Performance .. we know: of course not only the 30 cm helped, but at least the ATS did not degrade!

Also take into a account the many other changes:
- New beam types from injector in 2017 (8b4e, 8b4e BCS)
- X-angle change (150 mrad in 2017 vs. 185/140 mrad in 2016)
- X-angle anti-levelling in 2017 with $\geq 4$ steps (150/140/130/120)
- Lumi Levelling with parallel separation
Limitations for future operation and mitigation

- **Operation at 7.0 TeV: magnet strength limitations**
  - None except some RSD circuits @600A++ and Q5.L6

<table>
<thead>
<tr>
<th>Target currents (w/o margin) for various cases</th>
<th>LHC: round optics (20 cm) Telescope (x2Hx2V)</th>
<th>HL-LHC: round optics with Telescope (x4Hx4V)</th>
<th>LHC: Flat optics (15/60 cm) Telescope (x3-4Hx1V)</th>
<th>HL-LHC Flat optics with Telescope (x5Hx2V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q5.L6b1</td>
<td>&lt; 3610 A</td>
<td>~ 3800 A</td>
<td>~3700-3800 A</td>
<td>~ 3900 A</td>
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<tr>
<td>Q5.L6b2</td>
<td>&lt; 3610 A</td>
<td>~ 3700 A</td>
<td>&lt;3610 A</td>
<td>~ 3700 A</td>
</tr>
</tbody>
</table>

- Various options, HW tests requested asap to take decisions

- **Operation with LIU beam and large telescope**
  - The β’s are moving in IR6 (@TCDQ) during the tele-squeeze,
  - The TCDQ gap is limited to 3.6 mm (or larger) at full bunch intensity
  - A definite cure exists (on paper) via
    - (i) an upgrade of the BETS to enable TCDQ movement at flat top (in SB)
    - (ii) a running scenario with combined β* - TCDQ (& TCT) levelling