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

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Chamonix Talk outlines, TCC, 21/12/2017

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- ATS MD's in 2016/2017 (round & flat optics)
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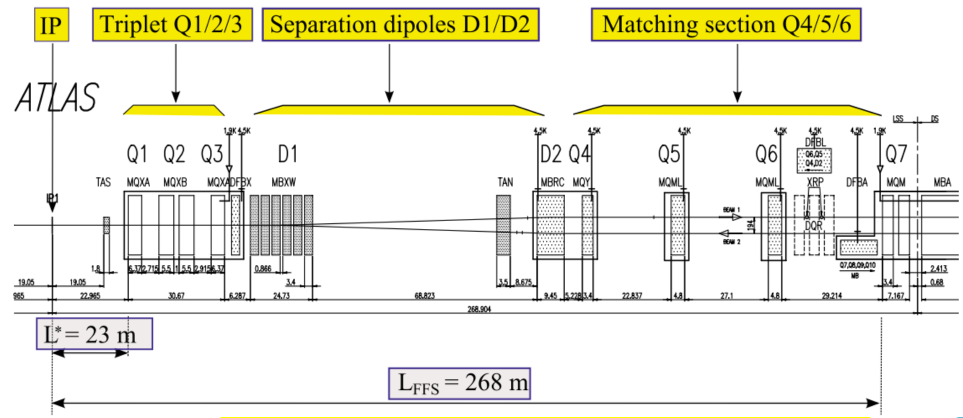
Recap: ATS principle, by products, MDs in Run I

The ATS scheme is the most cost-effective, if not the only way, to reach the targeted HL-LHC β^* 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**:

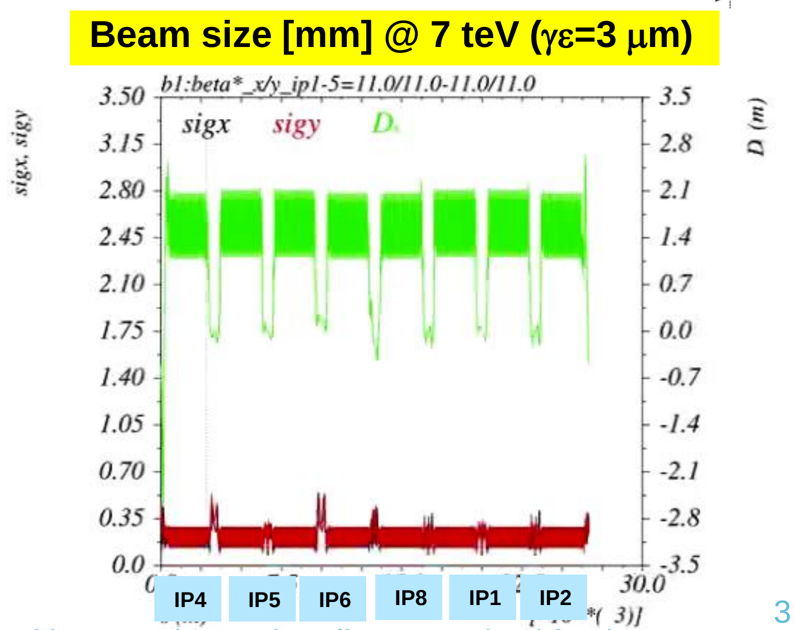
→ acting on the matching quads of IR1 and IR5 with new matching constraints on the left/right IR phase,

→ till reaching some limits on matching quads (or sextupoles)

2. A further reduction of β^*, **the Tele-Squeeze**:

→ acting only IR2/8 for squeezing IR1 and IR4/6 for IR5,

→ inducing **β-beating bumps in s81/12/45/56 to boost the sextupole efficiency, but also the octupoles (see later).**



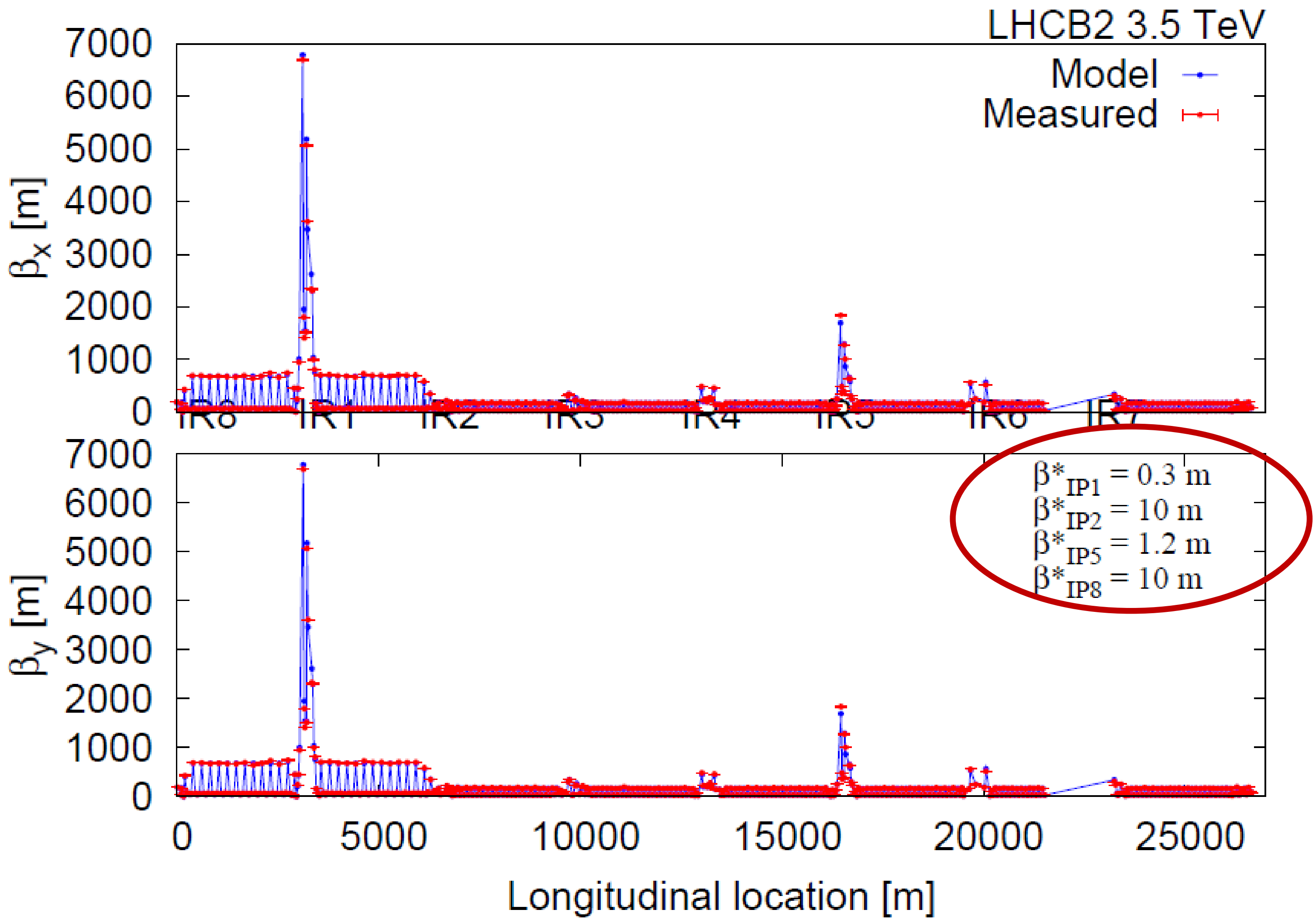
S. Fartoukh, ATS Chamonix Talk summarized for the TCC

Recap: ATS principle, by products, MDs in Run I

- **By-products coming from the (controlled) β-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: β_{MS} □1/β^*
    → no β* limits from Q' correct-ability
  - Very clean compensation of chromatic aberrations, such as off-momentum β-beating, non-linear chromaticity, spurious dispersion from crossing angle
    → 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: ΔQ_{spread} □ $(\beta_{MO})^2$ □1/β^{*2}
    → More Landau damping to cope with impedance/intensity increase,
    → Using the octupoles in SB for BBLR mitigation → X-angle reach

First demonstration with beam in 2011 (.. already with 30 cm β^* !)

→ Telescopic principle (×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 β^*** (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**

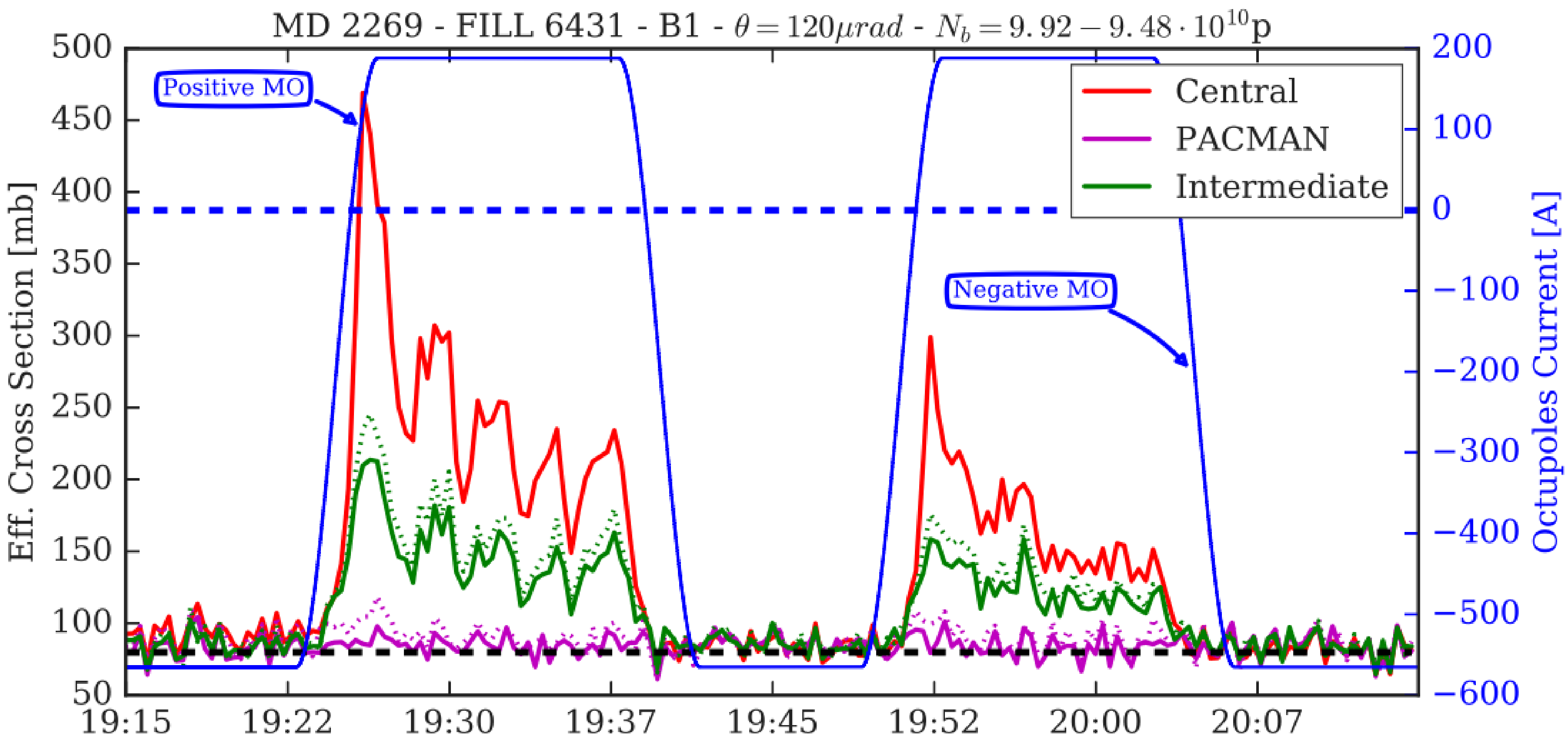
→ **ATS MD's in Run II** (2016-17-..18) developed a new version of the ATS optics (optimized for machine protection aspects) **on 3 fronts**

1. **Round telescopic optics** with pushed pre-squeezed β^* (40 cm), limiting the *high intensity tests to "small" tele-index*
   → **for LHC** (r_{tele} ~ 4/3 @ β^* ~ 30 cm)
2. **Round telescopic optics** with larger pre-squeezed β^* (1 m), enabling *high intensity tests @ large tele-index*
   → **for (HL-)LHC** (r_{tele}~ 3 @ β^* ~ 30 cm)
3. **Flat optics** (just started) → **for (HL-)LHC**

- **Tele index of 3 @ β^*=35 cm (tele-squeeze from 1 m)**

→ First demonstration of BBLR mitigation with octupole (MO)

$$\sigma_{\text{eff}_i} \stackrel{\text{def}}{=} \frac{dN_i/dt}{\mathcal{L}_i}$$



Courtesy of A. Poyet, G. Sterbini, and Beam-Beam team

2017 ATS LHC Optics vs. 2016: check-up after 1 year

- **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 ≥ 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

Target currents **<u>(w/o margin)</u>** for various cases	LHC: round optics (20 cm) Telescope (x2Hx2V)	HL-LHC: round optics with Telescope (x4Hx4V)	LHC: Flat optics (15/60 cm) Telescope (x3-4Hx1V)	HL-LHC Flat optics with Telescope (x5Hx2V)
Q5.L6b1	< 3610 A	~ 3800 A	~3700-3800 A	**~ 3900 A**
Q5.L6b2	< 3610 A	~ 3700 A	<3610 A	~ 3700 A

→ 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