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33 CM ATS OPTICS FOR LHC

Abstract

This note summarises the key objectives and procedures of the fourth ATS MD (MD 1257) which should take place on Saturday 29/10/2016.

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1. INTRODUCTION, MOTIVATIONS AND OPTICS READYNESS

The Achromatic Telescopic Squeezing (ATS) scheme [1] offers new techniques to deliver unprecedentedly small beam spot size at the interaction points of the ATLAS and CMS experiments (β^*), while perfectly controlling the chromatic properties of the corresponding optics (linear and non-linear chromaticity, off–momentum beta-beating, spurious dispersion from X-angle). This scheme is a keystone of the HL-LHC project which heavily relies on a β^* as small as 10-15 cm at IP1 and IP5. This aggressive parameter choice then fully determined the main hardware directions taken by the project, such as a very large coil aperture for the new inner triplets (150 mm), but also for most of the components of the new LSS1 and LSS5, in order to offer enough aperture for the beam at such a low β^* and corresponding increase of the crossing angle (up to 600-750 μrad). The ATS also justified the implementation of crab-cavities in order to efficiently transform this very small β^* into luminosity production.

The first series of ATS MDs were achieved with pilot beams during the LHC Run I (2011/2012), validating most of the basic principles of the scheme, in particular the very specific chromatic properties of these optics and the telescopic squeezing techniques which were used to push beta* down to 12 +/- 2 cm at IP1 and IP5 during the last MD bloc of Run I [2]. On the other hand, all the ATS optics developped so far (for LHC and HL-LHC) present the same pathology, which is an unfortunate phase advance very close to 90 degrees between the extraction kickers of IR6 (MKD) and several tertiary collimators (TCT) and inner triplets (IT) in the low-beta insertions IR1 and IR5. This clear limitation prevented to deploy ATS optics for the LHC operation proper [3], and therefore, till now, to gain real experience and confidence with such optics at high intensity, which is mandatory to complete their full validation for the HL-LHC.

Very recently, a new generation of ATS optics has then been deployed to bring a definite cure to the above mentionned problem, offering phase advances close to optimal (within about 30 degrees) between the MKDs and TCTs, for both beams and both IR1 and IR5 [4]. A new LHC hypercycle was made available in LSA including the so-called pre-squeeze (β^* =40 cm at IP1 and IP5), and the telescopic squeeze (β^* =10 cm at IP1 and IP5). While the first part of the ATS has been fully tested with probes and a few nominal bunches (<3E11) in MD blocks 1 and 3 [5,6], respectively, the telecopic squeeze was played with probes in MD block 4 [7], confirming the workingnes of the mechanics, of the overall ATS concept, but also the possibility of state-of-the-art optics correction for telescopic optics.

2. OVERALL OBJECTIVE & STRATEGY FOR THE ATS MD'S IN LHC RUN II

2.1 MAIN OBJECTIVE (HL-LHC)

The main objective of the ATS MDs is to gain experience and confidence with these new type of optics in view of the HL-LHC operation: in particular, (re-)validate the basic principles of the scheme at 6.5 TeV, demonstrate state-of-the-art optics correction in various operation modes (injection, pre-squeeze, telescopic squeeze) and fully exclude unforeseen intensity effects, where it is already known that the ATS optics will have some impact, positive in some cases but also negative in others.

2.2 BY PRODUCTS (LHC)

ATS optics also open new possibilities of optics manipulation for the LHC itself, such as

- the "proper" production (i.e. achromatic and with "decent" squeeze duration) of flat optics with quite small β^* (20-25 cm) in the plane perpendicular to the crossing plane. Flat optics are possibly competitive in terms of performance w.r.t. to more standard (round) collision optics.

- the "proper" production of optics with very large β^* (> 1-2 km)
- the production of telescopic collision optics (flat or round), starting from a "downgraded" pre-squeezed optics but reaching the same collision β^* at the end of the telescopic squeeze, in order to generate ideal phasing configurations and beta functions at the landau Octupoles for an appropriate compensation of the octupole part of the long-range beam-beam interactions. The motivation in this case is a net reduction of the crossing angle (to mitigate the luminosity loss factor), maybe down to 7.5-8 σ (TBC), and then also β^*, to "double-gain" in performance.
- the production of even more exotic optics which are fully out of reach using the standard squeeze techniques, as e.g. collision optics with a kind of second IP at Q6 for TOTEM like experiments requesting large normalised dispersion in this area.

2.3 RUN II OBJECTIVES: 2016 AND 2017-2018

Combining the long-term perspectives with the possible immediate (short term) utilization of ATS optics, brought the emergence of the idea to make ATS optics operational for running the LHC in 2017, with therefore the necessity to fully validate in 2016 the pre-squeezed part of the ATS scheme. With this part of the ATS scheme already used in routine operation, the next step will be to identify the most promising telescopic optics to further boost the LHC performance for Run III, and then use MD sessions in 2017-2018 to validate this optics choice, including some intensity ramp up.

2.4 GOAL FOR THIS MD BLOCK5, MACHINE CONDITIONS AND BEAM PROCESS

With (i) the excellent behaviour of the telescopic squeeze down to β^*=10 cm, as observed with probes at the previous ATS MD in block4 [7], and (ii) the encouraging (but not yet fully conclusive) loss maps and asynchronous dump results obtained at 40 cm in block3 [6], this fourth and last 2016 ATS MD will aim to demonstrate the telescopic squeeze down to β^*=33 cm. Key objectives will be to establish and optimize collision at all IP's, performing loss maps and asynchronous dumps (with different TCT settings, see Tab. 3), and get first estimates of the triplet aperture with this optics.
An ad hoc activity will also be to scan the horizontal and vertical IP15 phases with a dedicated knob (knowing that theses phases are quite different between beam1 and beam2) and check whether beam life time could be improved accordingly. The idea is indeed to propose this moderately telescopic optics as a possible candidate to restart the machine in 2017, straightaway or after a first "re-training" period using the ATS pre-squeezed optics at β^*=40 cm.

The standard loss map filling scheme **Single_7b_1_1_1_5ncPilots2cNom** will be used with two colliding nominals and up to 10 non-colliding probes (<3E11). The ATS hyper-cycle will be played down to β^*=33 cm, i.e. basically the three beam processes, **RAMP-SQUEEZE-6.5TeV-ATS-3m-2016_V1**, **SQUEEZE-6.5TeV-ATS-3m-40cm-2016_V1** and **SQUEEZE-TELE-6.5TeV-ATS-40cm-33cm-2016_V1.**

The tunes will be kept to their injection values (62.31/60.28) all along down to 33 cm, before being trimmed to their collision values in a very short dedicated beam-process before putting the two beams into collision. The crossing bumps will be ON, in particular decreasing from ± 170 μrad down to +/- 140 μrad in IR1/5 from the end of ramp to the end of the pre-squeeze, and then kept constant during the telescopic squeeze segment from β^*=40 cm down to β^*=33 cm.

The collimator (IR3/6/7) and TCT settings will correspond to the one established and analysed in block 3 [8,9,10], with the only exception that the NSigma function of the TCT in IR1 and IR5 will be slightly enlarged to 9.7 σ for the last two matched points of the pre-squeeze (45 cm and 40 cm). This additional opening of the TCTs by 0.7 σ has been fine-tuned taking into account the gain by about 1.2 σ for the triplet aperture, coming from the X-angle reduction from 185 μrad to 140 μrad at β^*=40 cm. Keeping then constant the absolute position of the TCTs for the telescopic segment will ensure to arrive at β^*=33 cm with normalised settings at $9.7 \times (33/40)^{1/2} = 8.8\ \sigma$., i.e. with quasi-nominal conditions for the overall hierarchy.

Table 1: Basic beam and machine parameters during the MD

Beams required [1, 2, 1&2]	1&2
Beam energy	Injection 450 GeV, combined ramp & squeeze, 6.5 TeV, pre-squeeze to 40cm (140 μrad), tele-squeeze to 33 cm (140 μrad)
Bunch intensity [#p, #ions]	Max 3.0E11
Number of bunches	Single_7b_1_1_1_5ncPilots2cNom (at most 2 colliding nominal + xx probes, to not exceed 3E11)
Transv. emittance [m rad]	As small as possible < 2 μrad
Bunch length [ns @ 4s]	Not relevant
Optics change [yes/no]	Yes (ATS optics with X-bumps on).
Orbit change [yes/no]	Yes (ATS optics with X-bumps on)
Interlocks [yes/no]	No change w.r.t. nominal (as much as possible)
Collimation and MP change [yes/no]	Yes but **<u>Quasi-nominal</u> (see Tab. 2)**
RF system change [yes/no]	Yes (same voltage but new momentum compaction)
Feedback changes [yes/no]	Yes (new ADT settings for the new IR4 optics as established in MD1 for the injection and presqueezed optics, and MD4 for the telescopic part)

Table 2: Collimator and MP settings

Collimator	Comparison of settings w.r.t. nominal
TDI-TCLI's	**No change** (both in mm and sigma) except relaxed settings for TCLIB (8.3 σ)
TCDQ	**No change** for absolute position in mm (very slight reduction in sigma due to the optics change at 40 cm, more and more pronounced with the telescopic squeeze)
TCSP	**From MD3:** New functions for the center, nominal Nsigma functions (8.3 σ)
IR3/IR7	**No change** for absolute position in mm
TCTs in IR2/8	**From MD3:** New functions for the center, nominal Nsigma functions vs. β^*
TCTs in IR1/5	**From MD3 (almost):** New fonctions for the center (down to 40 cm and kept constant from 40 cm to 33 cm). Nominal Nsigma functions vs. β^* almost all along, but set to 9.7 σ for the last two matched points of the pre-squeeze (45 cm and 40 cm), then kept constant in mm down to 33 cm.

3. KEY STEPS TO BE TAKEN DURING THE MD

One shift of 11 h is foreseen for ATS activities in the MD5 schedule. The synthetic description of the planned activities is described in Tab. 3, with time estimate for each step. Two fills are foreseen each of them ending up with measurement of TCT losses following an asynchronous dump, the first one with TCT settings at 9 sigma's, and the second with TCT settings at 7 sigma's.

Table 3: Key steps with time estimate

Activity (and comments)	Time estimate [h]
Recycling the machine from 6.5 TeV to new injection settings before MD start	*(2.0)*
Fill # 1 with 10 non-colliding probes for IT aperture measurement	
Machine conditions: "quasi-nominal collimator settings" (see Tab. 2), Crossing bumps at all IPs, QFB matrix pointing to tele-knob, octupole OFF, ADT for injection oscillation only - Injection, ramp, pre- and tele-squeeze down to 33 cm (140 μrad @ IP1/5) → 1.5 h - IT aperture measurement → 2.5 h - Intensity scraping (5E10), de-bunching, and asynchronous dump with TCT@ 9.0 σ → 0.5h	**4.5**
Ramp down and refill	**1.0**
Fill # 2 with Single_7b_1_1_1_5ncPilots2cNom (2 nominals + pilots <3.0E11)	
- **Machine conditions**: as above, except octupole ON and ADT ON. - Injection, ramp, pre- and tele-squeeze down to 33 cm (140 μrad @ IP1/5) → 1.0 h - Ref. orbit at 33 cm → 0.5 h - TCT and TCSP center measurement → 0.25 h - Loss maps (beam separated, ADT gated on pilot bunches only) → 0.5 h - Finding collisions → 1.0 h - TCT and TCSP center: measurement and incorporation → 0.25 h - IP15 phase scan (in collision ?, max +/- 0.1 × 2 π in H plane) → 1.5 h - Loss maps (parallel separation collapsed) on- and off- momentum → 1.0 h - Intensity scraping (5E10), de-bunching, and asynchronous dump with TCT@ 7.0 σ → 0.5h	**6.5**
Contingency	**--1.0**
Total	**11.0**

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