ATS optics

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- **Optics status**
- **MD results**
- **MD Plans for 2017/2018**
- **Conclusions**

Pre-squeezed optics readiness & plan

✓ Done

- **Injection optics** (β^*=11/10/11/10 m, δz^*= ± 2/3.5/2/3.5 mm, θ_c = ± 170 μrad)
- **Pre-squeezed optics** (β^*=0.4/10/3/0.4 m, δz^*= ± 0.55/1.0/0.55/1.0 mm, θ_c = ± 140/200/140/250 μrad)
- **Optics transition for IR1 & 5** (optics and crossing knobs) combined with the ramp down to β^*=3 m
- **Optics transition for IR8** (β^*=10 m → 3 m and 222 T/m → 205 T/m) combined with the ramp
- **Optics transition for IR2** (222 T/m → 205 T/m at cst β^*=10 m) combined with the ramp
- **Functions for the lattice sextupoles** (Q’, Q’’ and off-momentum beta-beat correction)
- **IP knobs and Functions for the arc orbit correctors** (spurious dispersion correction)
- **Standard knobs** (Q, Q’, coupling), **spool/MQT settings**, and others (“nominal” IT & MQSX trims from OMC team, COD at injection, RF, ULO bump, …)

✓ To be done (by order of priority)

- **<u>Pre-squeeze toward a re-optimized 40 cm optics for AFP/TOTEM:</u>** the 40 cm snapshot exists, is found to be comparable to the 2016 optics for AFP, a bit unfavorable for CT-PPS)
- IR2 standard squeeze for ions (snapshot at 50 cm exists)
- VdM optics and un-squeeze sequence
- Desqueeze sequence to 90 m (snapshot at 90 m exists)

Compatibility with AFP (and CT-PPS)

No.	β^*	name	θ_C	$\xi^{205.217}_{min,15\sigma}$	$\xi^{217.302}_{min,15\sigma}$	min. mass
1 – 3	0.4	standard	-140, -185, -200	0.03	0.02	**390**
4 – 6		dev2	-140, -170, -200	0.025	0.015	**325**
7 – 9		ATS	-140, -170, -200	0.04	0.02 5	**520**
10 – 12		ATS new	-140, -170, -200	0.03	0.02	**390**
A	0.33	standard	170	0.03	0.02	**390**
B		dev2	170	0.025	0.015	**325**
C		ATS	170	0.04	0.03	**520**
D		ATS new	170	0.03	0.02	**390**

First results from M. Trzebinski (AFP)

→ The present ATS (Q6 @ 25 T/m) is not favorable: 35% increase in min. mass w.r.t. 2016

→ The new version (Q6 @ 12.5 T/m) is identical in this aspect to the 2016 nominal optics, but still 20% worst than the new nominal optics (“dev2”)

→ Further improvement (~10% not more !!) could be TOTEM bump for both optics types

Telescopic Optics readiness &plan

✓ Done (round optics)

- Telescopic squeeze for IR1 and IR5 type 44 (round optics) from 40 cm down to 10 cm round optics, with IP knobs for IR2 & IR8 and lattice sextupoles, **in particular 33 cm**
- ATS Knobs (Q, Q’, coupling, spurious dispersion)

✓ To be done (mainly flat optics)

- Telescopic squeeze for IR1 and 5 type 25 and 52 (60/20 -- 60/15 cm flat optics for LHC, 40/10 cm for HL-LHC)
- …

Further optimization steps for squeeze time

Present Combined Ramp & Squeeze (19 optics)

Matched Pt	Time (s)	Parab. fr.	Optics Name	Energy (GeV)
1	0	0.05	R2016ats_A11mC11mA10mL10m	450
2	30	0.05	R2016ats_A11mC11mA10mL10m	459
3	60	0.05	R2016ats_A11mC11mA10mL10m	485
4	120	0.05	R2016ats_A11mC11mA10mL10m	594
5	200	0.05	R2016ats_A11mC11mA10mL10m	845
6	300	0.05	R2016ats_A11mC11mA10mL10m	1323
7	400	0.05	R2016ats_A11mC11mA10mL10m	1879
8	490	0.05	R2016ats_A11mC11mA10mL10m	**2412**
9	565	0.12	R2016ats_A970C970A10mL970	2852
10	620	0.1	R2016ats_A920C920A10mL920	3176
11	670	0.1	R2016ats_A850C850A10mL850	3454
12	720	0.1	R2016ats_A760C760A10mL760	3755
13	780	0.1	R2016ats_A650C650A10mL650	4102
14	860	0.12	R2016ats_A550C550A10mL550	4565
15	935	0.12	R2016ats_A460C460A10mL460	4985
16	985	0.15	R2016ats_A380C380A10mL380	5284
17	1040	0.25	R2016ats_A320C320A10mL320	5608
18	1110	0.24	R2016ats_A300C300A10mL300	**6002**
19	1210	0.05	R2016ats_A300C300A10mL300	6500

Present pre-squeeze (3m → 40 cm) in 470 s

Matched Pt	Time (s)	Parab. fr.	Optics Name
1	0	0	R2016ats_A300C300A10mL300
2	44	0.227273	R2016ats_A220C220A10mL300
3	94	0.2	R2016ats_A160C160A10mL300
4	148	0.277778	R2016ats_A120C120A10mL300
5	206	0.258621	R2016ats_A90C90A10mL300
6	269	0.238095	R2016ats_A70C70A10mL300
7	341	0.208333	R2016ats_A55C55A10mL300
8	413	0.18386	R2016ats_A45C45A10mL300
9	470	0.175439	R2016ats_A40C40A10mL300

→ The first 206 s of the pre-squeeze from 3 m to 90 cm can be easily combined in the ramp.

Further optimization steps for squeeze time

Present pre-squeeze (3m → 40 cm) in 470 s

Matched Pt	Time (s)	Parab. fr.	Optics Name
1	0	0	R2016ats_A300C300A10mL300
2	44	0.227273	R2016ats_A220C220A10mL300
3	94	0.2	R2016ats_A160C160A10mL300
4	148	0.277778	R2016ats_A120C120A10mL300
5	206	0.258621	R2016ats_A90C90A10mL300
6	269	0.238095	R2016ats_A70C70A10mL300
7	341	0.208333	R2016ats_A55C55A10mL300
8	413	0.18386	R2016ats_A45C45A10mL300
9	470	0.175439	R2016ats_A40C40A10mL300

Present tele-squeeze (40 cm → 10 cm) in 804 s

Optic Name	Time
R2016ats_A40C40A10mL300	0
R2016ats_A37C37A10mL300	90
R2016ats_A33C33A10mL300	178
R2016ats_A27C27A10mL300	258
R2016ats_A21C21A10mL300	346
R2016ats_A17C17A10mL300	452
R2016ats_A14C14A10mL300	569
R2016ats_A12C12A10mL300	676
R2016ats_A10C10A10mL300	804

→ The telescopic squeeze to 33 cm takes 178 s. Eventually it can be swallowed in the pre-squeeze itself from 90 cm to 40 cm

→ about **4 min (264 s) is within reach for the squeeze at flat top!**

BUT

1) 200 s more may be required for forward physics re-optimised optics (Q6 @ 300A instead than 600 A)

2) And again 200 s more, eventually for a TOTEM bump !

Highlights from ATS MDs

- ✓ About 50 h beam time given to ATS in bloc 1/3/4/5
- ✓ Two types of ATS MD
  1. Optics related with probes beams:
     @ 40 cm (MD1) and 10 cm(MD4)
  2. Collimation related with nominal:
     @ 40 cm(MD2) and 33 cm(MD5)
- ✓ Main results
  1. The " LSA mechanics" and ATS principles are demonstrated down to 10 cm
  2. The OMC tools and techniques are also working for ATS optics,
  3. So far all LHC accelerator systems seems well-behaved with ATS optics: collimation, ADT, RF, BI, LBDS,…
- ✓ MD note in preparation

CERN-ATS-Note-2016-xxx MD
September 2016
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ATS MDs in 2016

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Keywords: LHC and HL-LHC optics, ATS Scheme

Summary

This note presents a summary of the ATS activities which took place in 2016, where a new generation of ATS pre-squeezed and telescopic optics was successfully commissioned, namely: (i) down to a β^* of 10 cm with probe beams, and (ii) with more emphasis at intermediate β^* values of 40 cm or 33 cm where collisions were established with nominal bunches, the triplet aperture was measured and collimation related activities with pre-squeezed or moderately telescopic ATS optics were conducted.

1 Introduction and motivations

1.1 General context

The Achromatic Telescopic Squeezing (ATS) scheme is a novel optics concept enabling the matching of ultra-low β^* while correcting the chromatic aberrations induced by the inner triplet [1]. This scheme is essentially based on a two-stage telescopic squeeze. In a first phase, a so-called pre-squeeze is achieved by using exclusively, as usual, the matching quadrupoles of the high luminosity insertions IR1 and IR5. In a second phase, the squeeze continues by acting only on the insertions located on either side of IR1 and IR5 (i.e. IR8/2 for the telescopic squeeze of IR1, and IR4/6 for IR5). As a result, sizable β-beating bumps are induced in the four sectors on either side of IP1 and IP5. These waves of β-beating are then also necessary in order to boost, at constant strength, the efficiency of the chromatic correction performed by the lattice sextupoles located in the sectors 81, 12, 45 and 56. In principle the first and second phases can be exchanged, interleaved or even be run in parallel (e.g. to further gain in squeeze time), as soon as the first phase has pushed β^* below a transition β^* of the order of 2 m.

The ATS scheme forms the keystone of the HL-LHC project and its complete validation at high

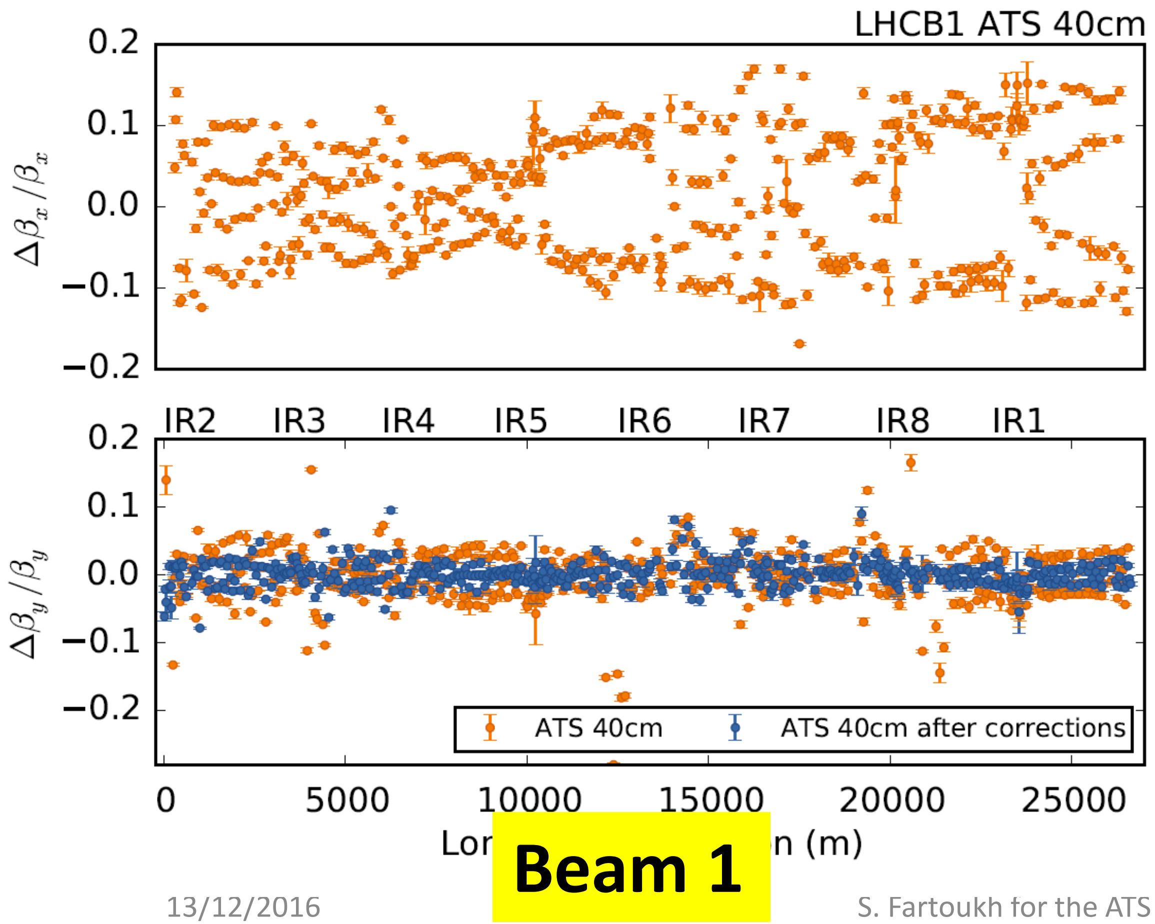
1

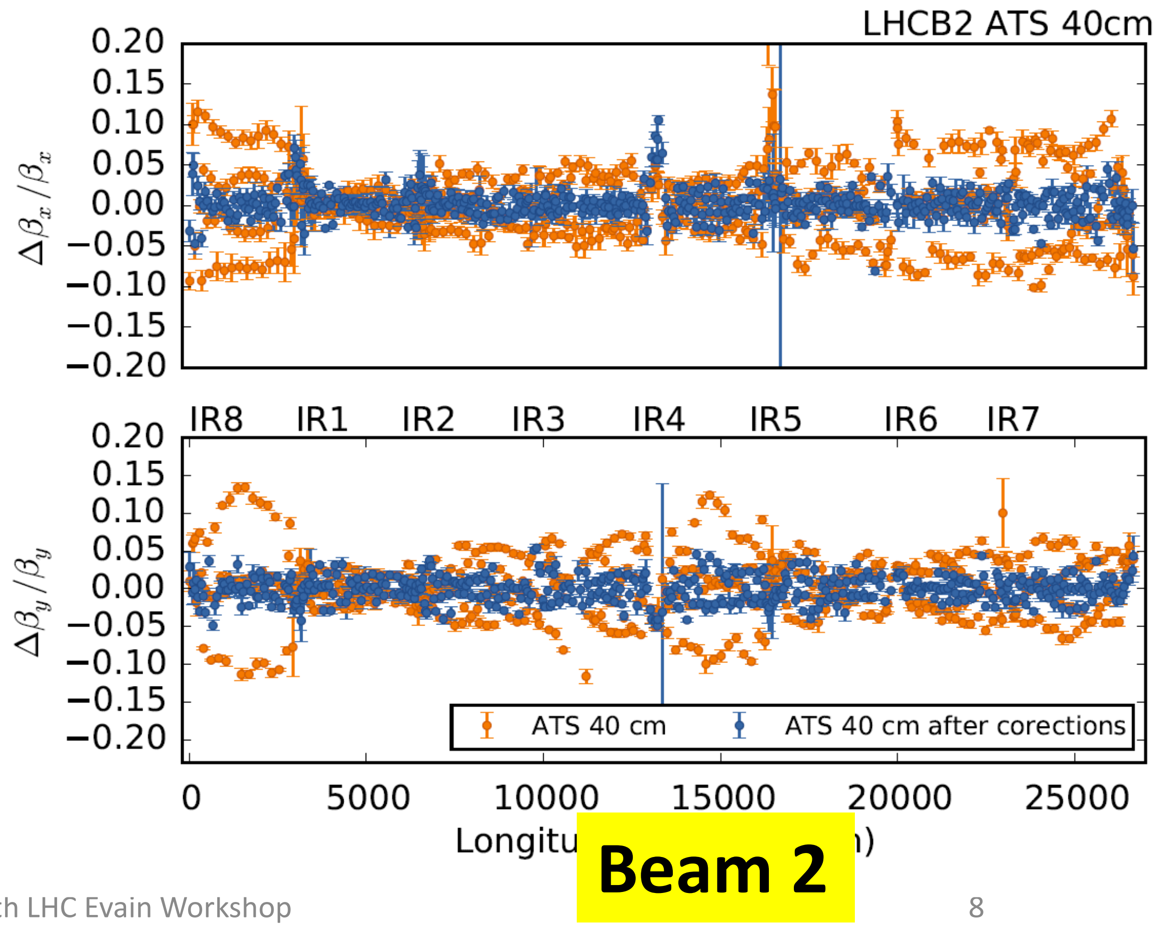
Some illustrations

Optic Name	Time
R2016ats_A40C40A10mL300	0
R2016ats_A37C37A10mL300	90
R2016ats_A33C33A10mL300	178
R2016ats_A27C27A10mL300	258
R2016ats_A21C21A10mL300	346
R2016ats_A17C17A10mL300	452
R2016ats_A14C14A10mL300	569
R2016ats_A12C12A10mL300	676
R2016ats_A10C10A10mL300	804

- **Measurement and correction at 40 cm**

(the AC-dipole was not working for B1H to re-measure after correction)



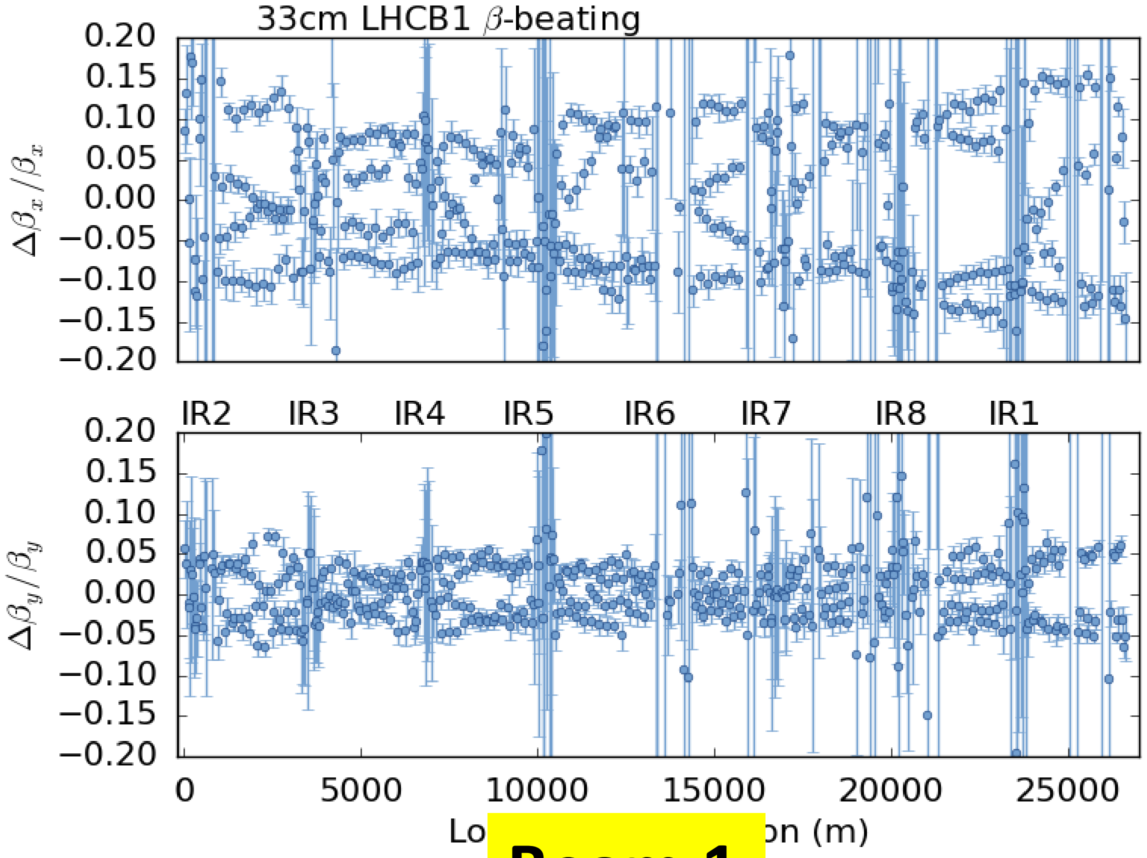


Some illustrations

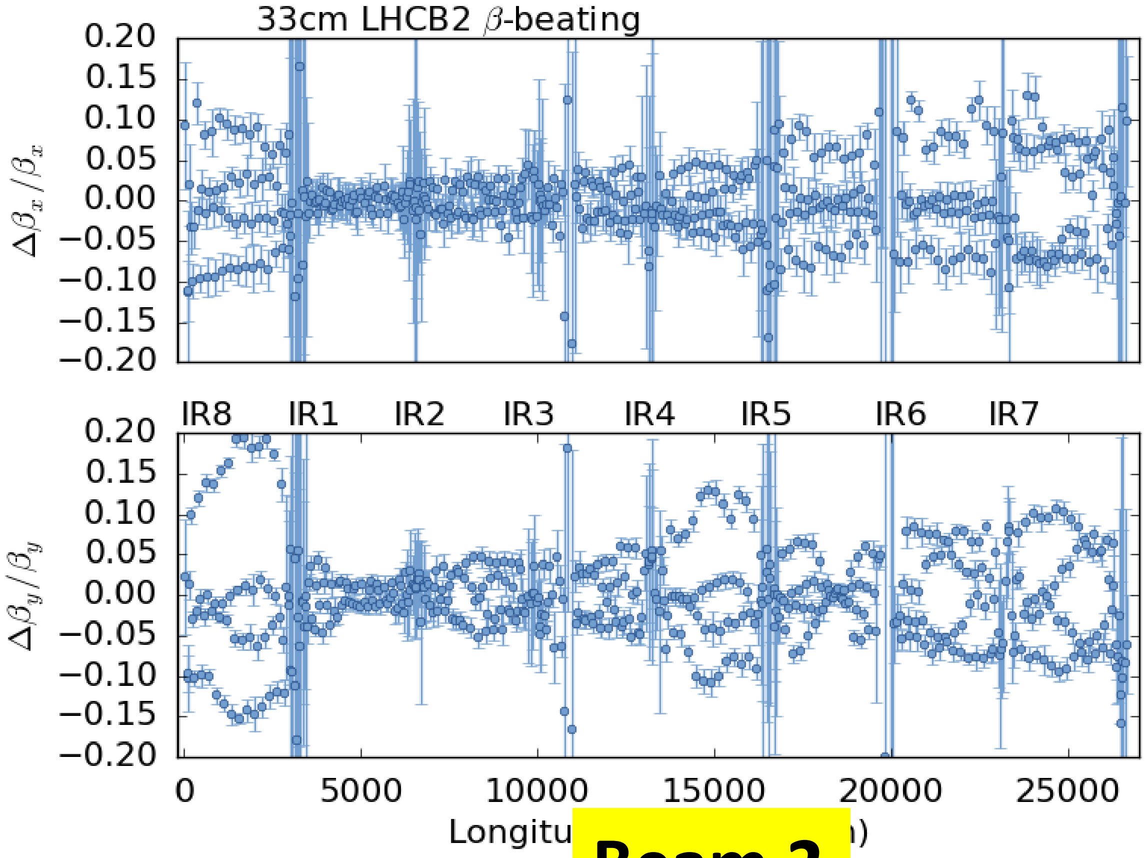
- **Measurement at 33 cm**

→ 15-20% β-beat (left uncorrected)

Optic Name	Time
R2016ats_A40C40A10mL300	0
R2016ats_A37C37A10mL300	90
R2016ats_A33C33A10mL300	178
R2016ats_A27C27A10mL300	258
R2016ats_A21C21A10mL300	346
R2016ats_A17C17A10mL300	452
R2016ats_A14C14A10mL300	569
R2016ats_A12C12A10mL300	676
R2016ats_A10C10A10mL300	804



Beam 1

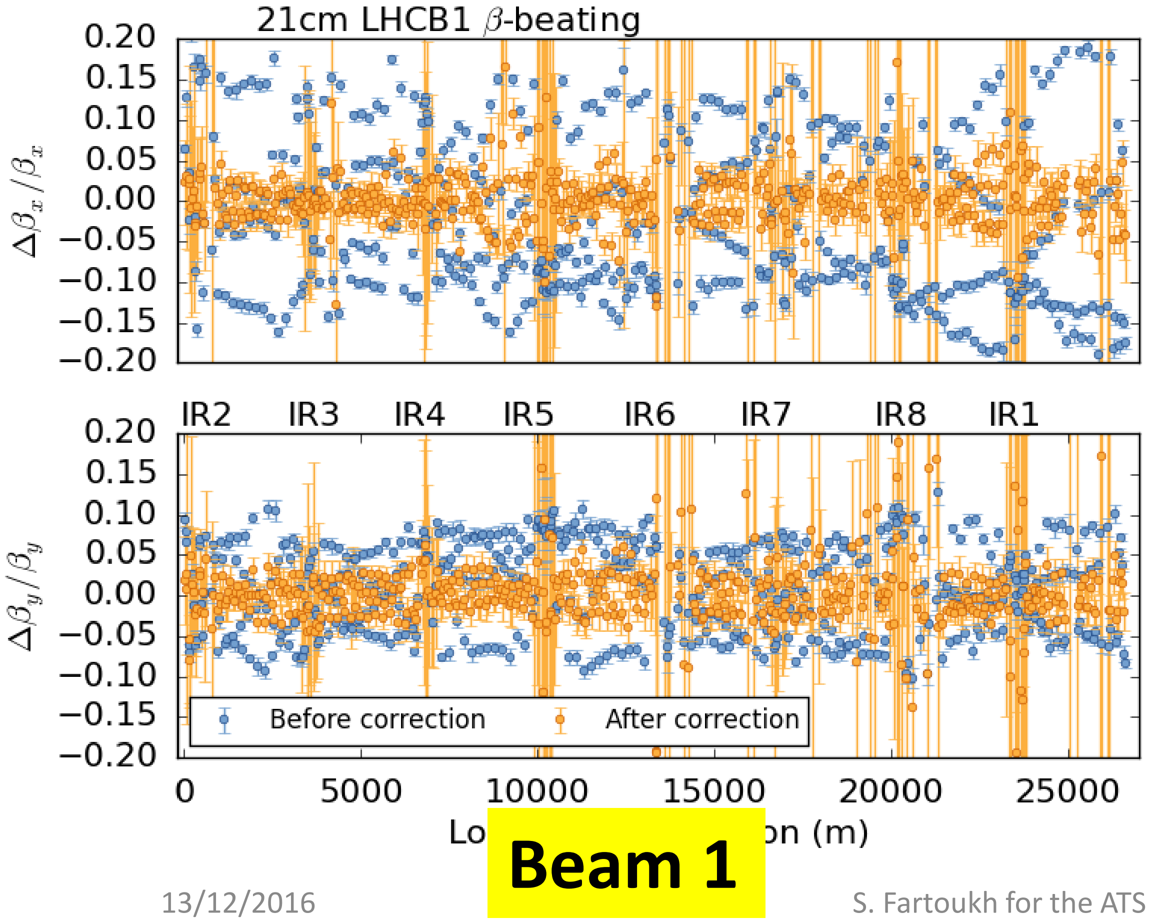


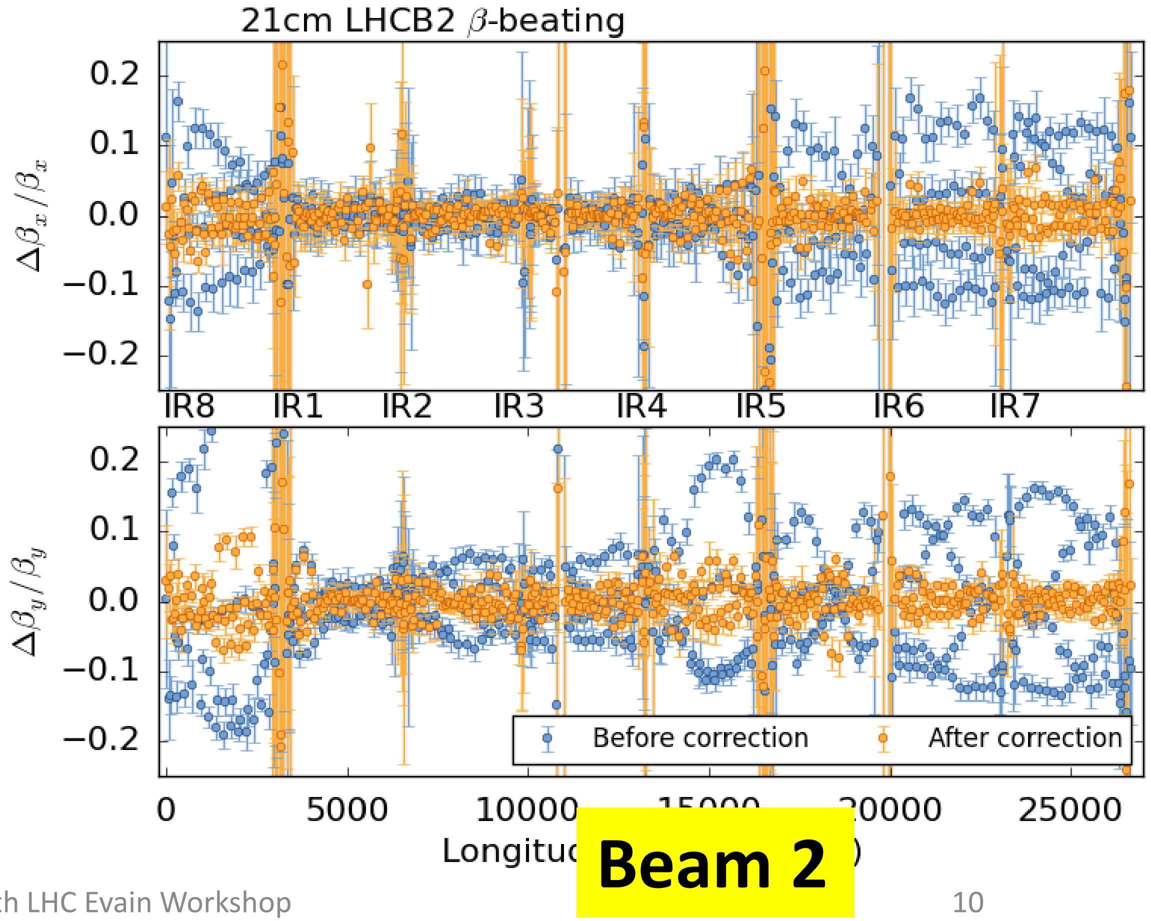
Beam 2

Some illustrations

- **Measurement and correction at 21 cm** →

Optic Name	Time
R2016ats_A40C40A10mL300	0
R2016ats_A37C37A10mL300	90
R2016ats_A33C33A10mL300	178
R2016ats_A27C27A10mL300	258
R2016ats_A21C21A10mL300	346
R2016ats_A17C17A10mL300	452
R2016ats_A14C14A10mL300	569
R2016ats_A12C12A10mL300	676
R2016ats_A10C10A10mL300	804

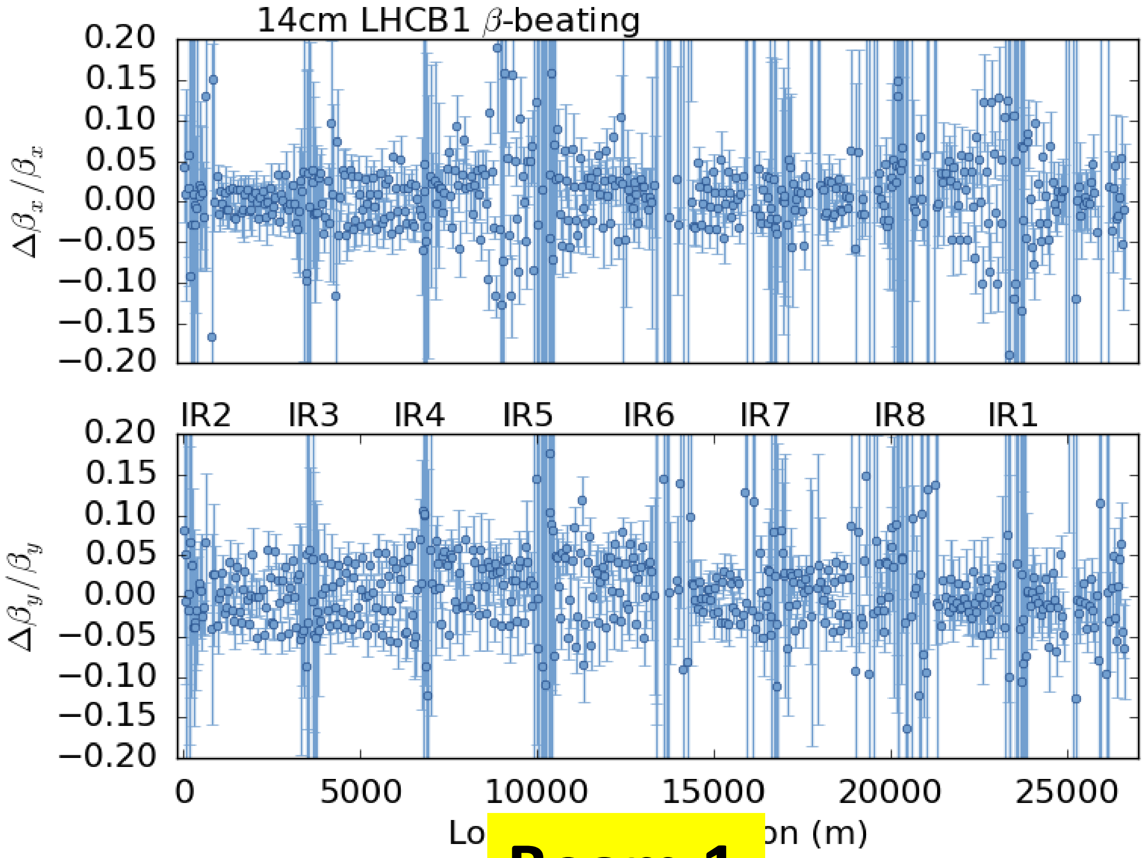




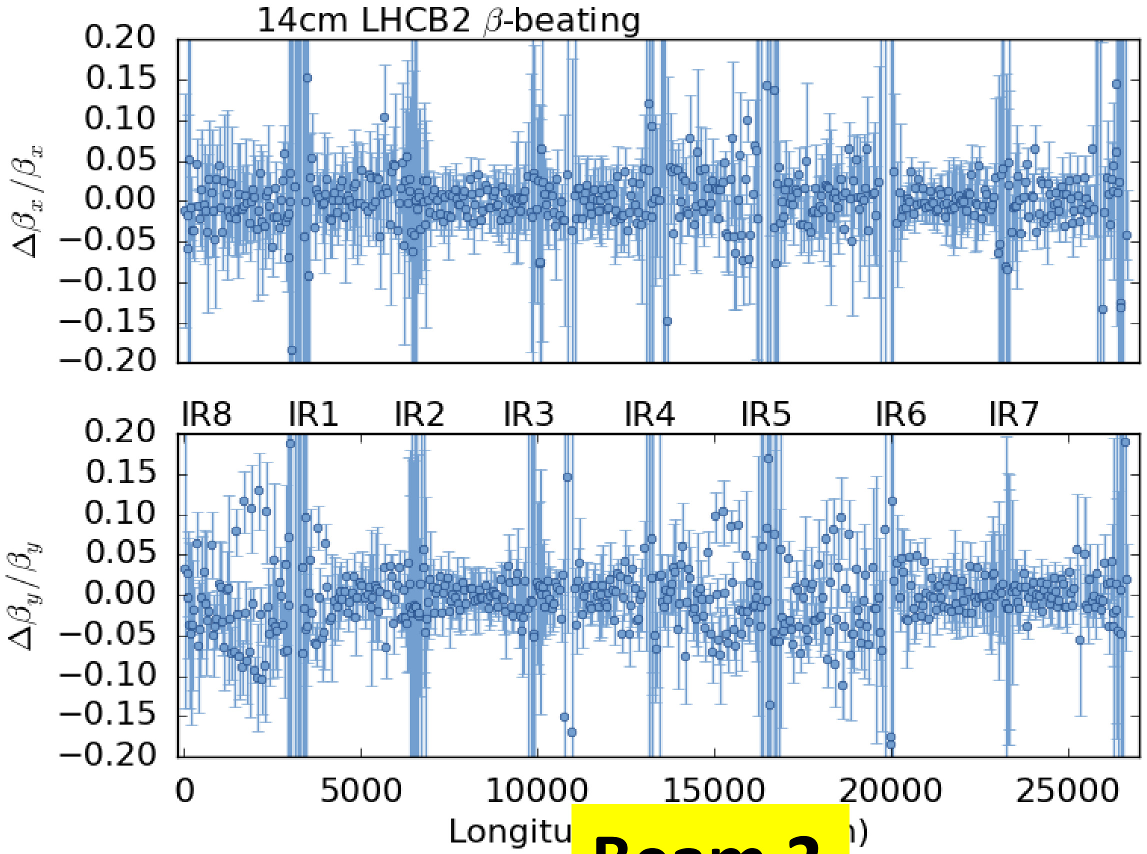
Some illustrations

Optic Name	Time
R2016ats_A40C40A10mL300	0
R2016ats_A37C37A10mL300	90
R2016ats_A33C33A10mL300	178
R2016ats_A27C27A10mL300	258
R2016ats_A21C21A10mL300	346
R2016ats_A17C17A10mL300	452
R2016ats_A14C14A10mL300	569
R2016ats_A12C12A10mL300	676
R2016ats_A10C10A10mL300	804

- **Measurement at 14 cm**



Beam 1

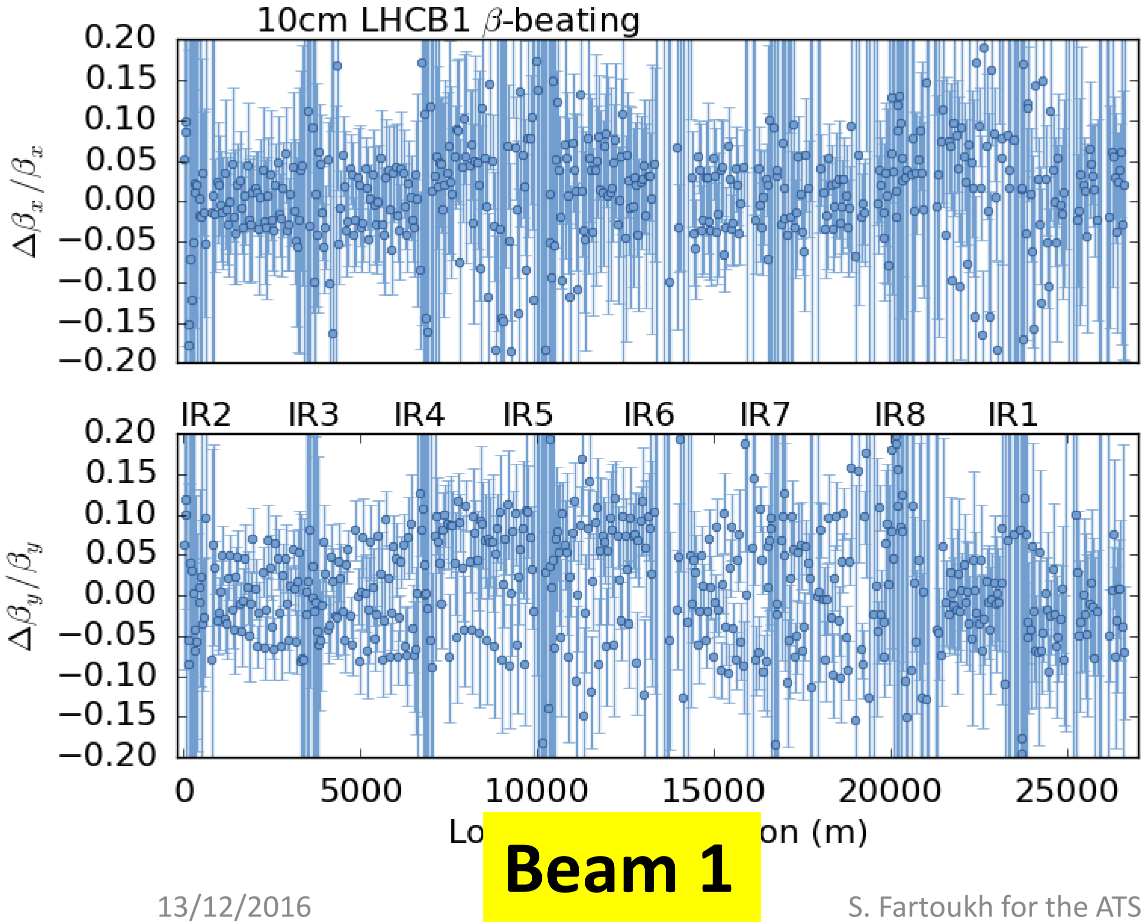


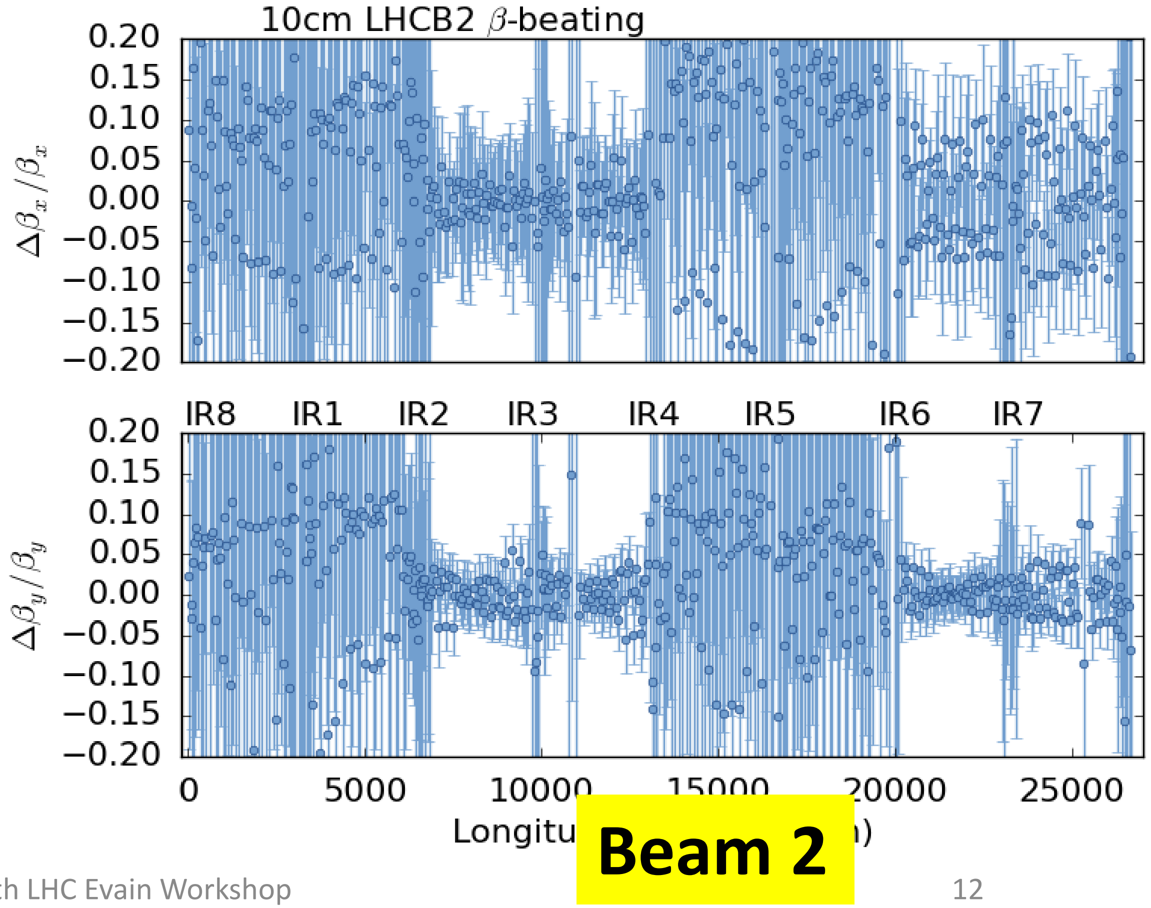
Beam 2

Some illustrations

- **Measurement at 10 cm**

Optic Name	Time
R2016ats_A40C40A10mL300	0
R2016ats_A37C37A10mL300	90
R2016ats_A33C33A10mL300	178
R2016ats_A27C27A10mL300	258
R2016ats_A21C21A10mL300	346
R2016ats_A17C17A10mL300	452
R2016ats_A14C14A10mL300	569
R2016ats_A12C12A10mL300	676
R2016ats_A10C10A10mL300	804





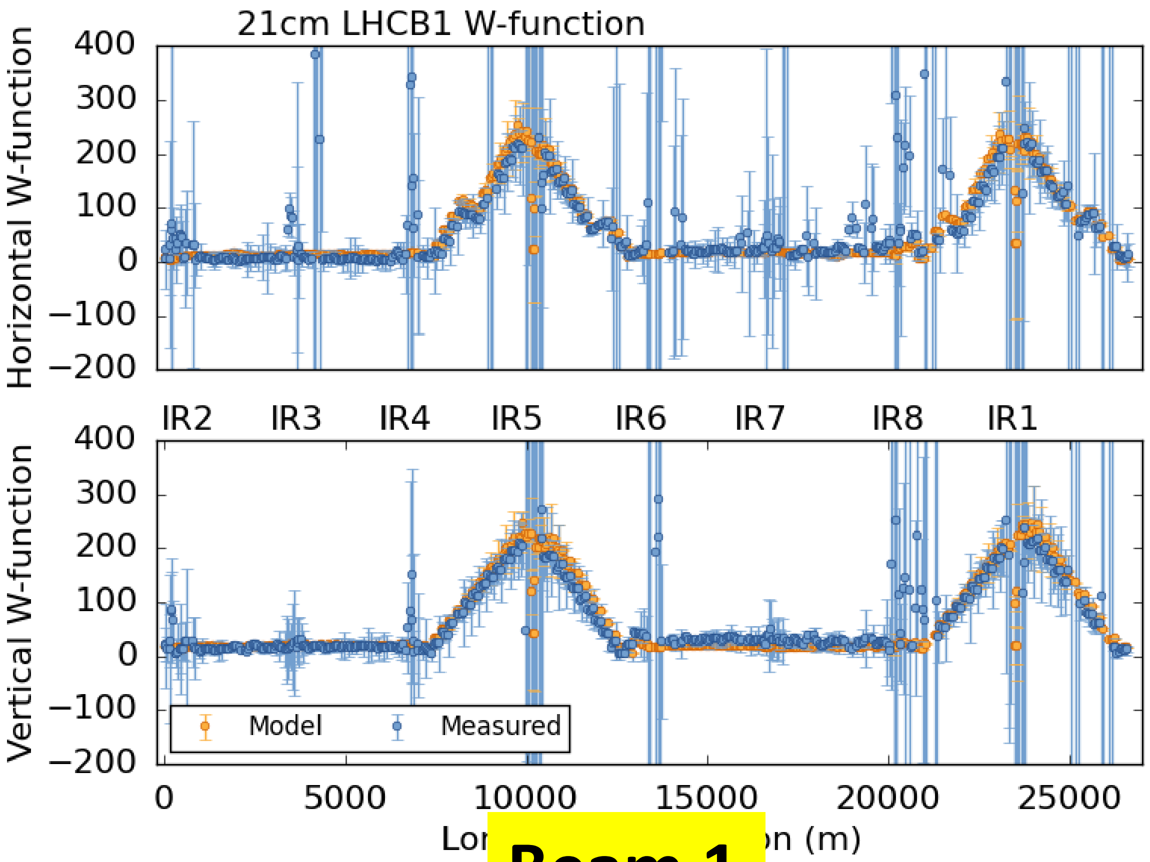
Some illustrations

- **At β^*=21 cm**

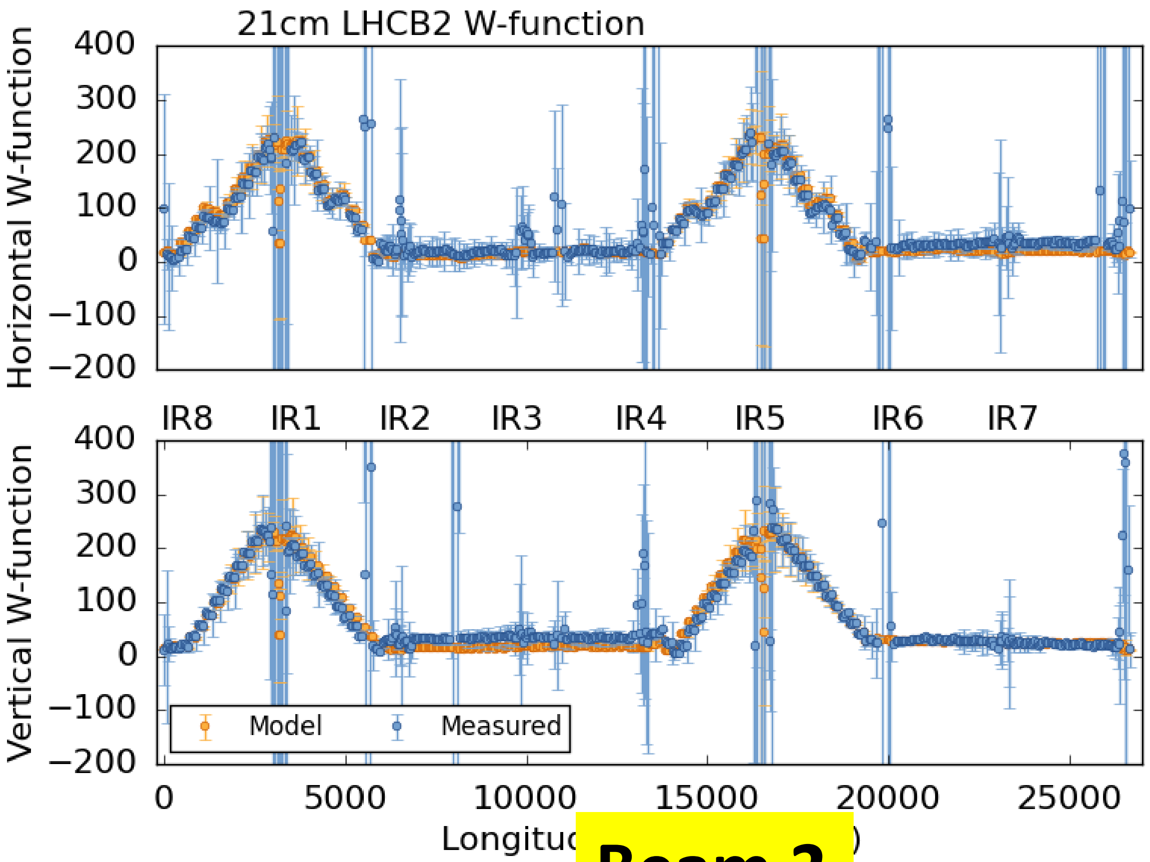
The off momentum β-beating is as expected:

one sector of sextupoles compensating one triplet

Optic Name	Time
R2016ats_A40C40A10mL300	0
R2016ats_A37C37A10mL300	90
R2016ats_A33C33A10mL300	178
R2016ats_A27C27A10mL300	258
R2016ats_A21C21A10mL300	346
R2016ats_A17C17A10mL300	452
R2016ats_A14C14A10mL300	569
R2016ats_A12C12A10mL300	676
R2016ats_A10C10A10mL300	804



Beam 1



Beam 2

Some illustrations

- **At β^*=10 cm**

Dispersion of Max 1.5-2 m in the triplets
.. but for a β_{max} of 24 km !

Optic Name	Time
R2016ats_A40C40A10mL300	0
R2016ats_A37C37A10mL300	90
R2016ats_A33C33A10mL300	178
R2016ats_A27C27A10mL300	258
R2016ats_A21C21A10mL300	346
R2016ats_A17C17A10mL300	452
R2016ats_A14C14A10mL300	569
R2016ats_A12C12A10mL300	676
R2016ats_A10C10A10mL300	804

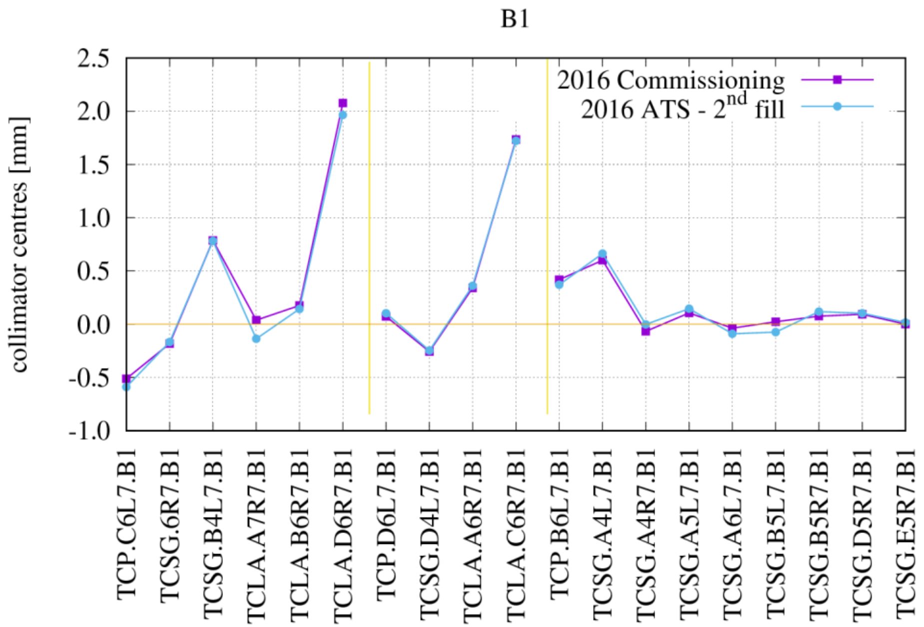
Beam 1

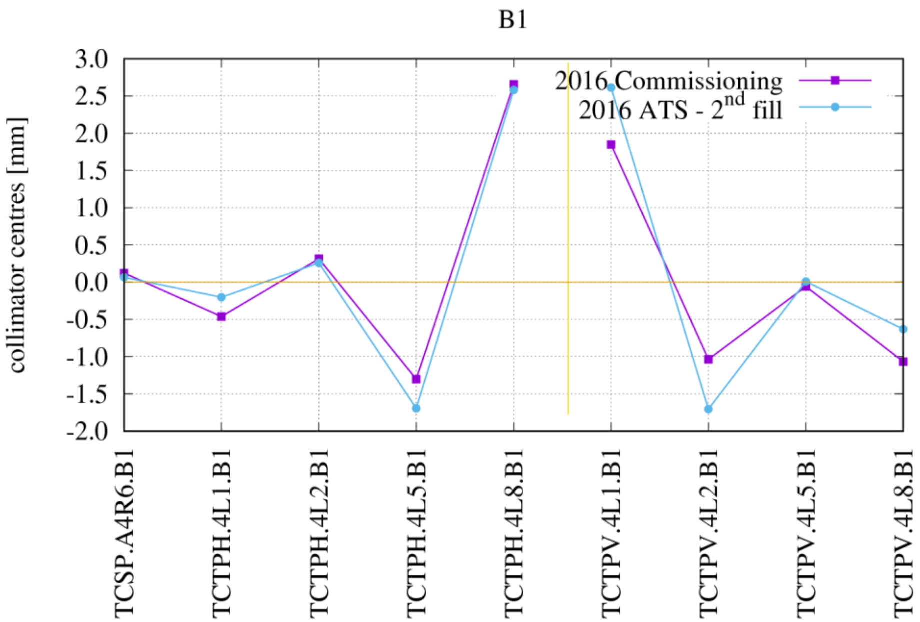
Beam 2

Some illustrations

More details in Alessio's presentation at the [LHC Collimation Working Group #208]

- **TCT & IR7 collimator re-alignment @ 40 cm**





IR7 collimator centres (beam1):
ATS (collision) vs. 2016 commissioning (FT)

TCT centres (beam 1):
ATS (collision) vs. 2016 commissioning
→ Some differences, but the optics are different !!

All together looks more than reasonable !

Some illustrations

- **IT aperture @ 33 cm with +/- 140 μrad half crossing angle**

(with "not fully-optimized" 21 cm β–beating correction knob)

	Aperture [σ]	Bottleneck
B1H	**9.7**	**Q3L1/Q3R5**
B1V	**9.7**	**Q3L1**
B2H	**12.6**	**Q2R5**
B2V	**9.8**	**Q3R1**

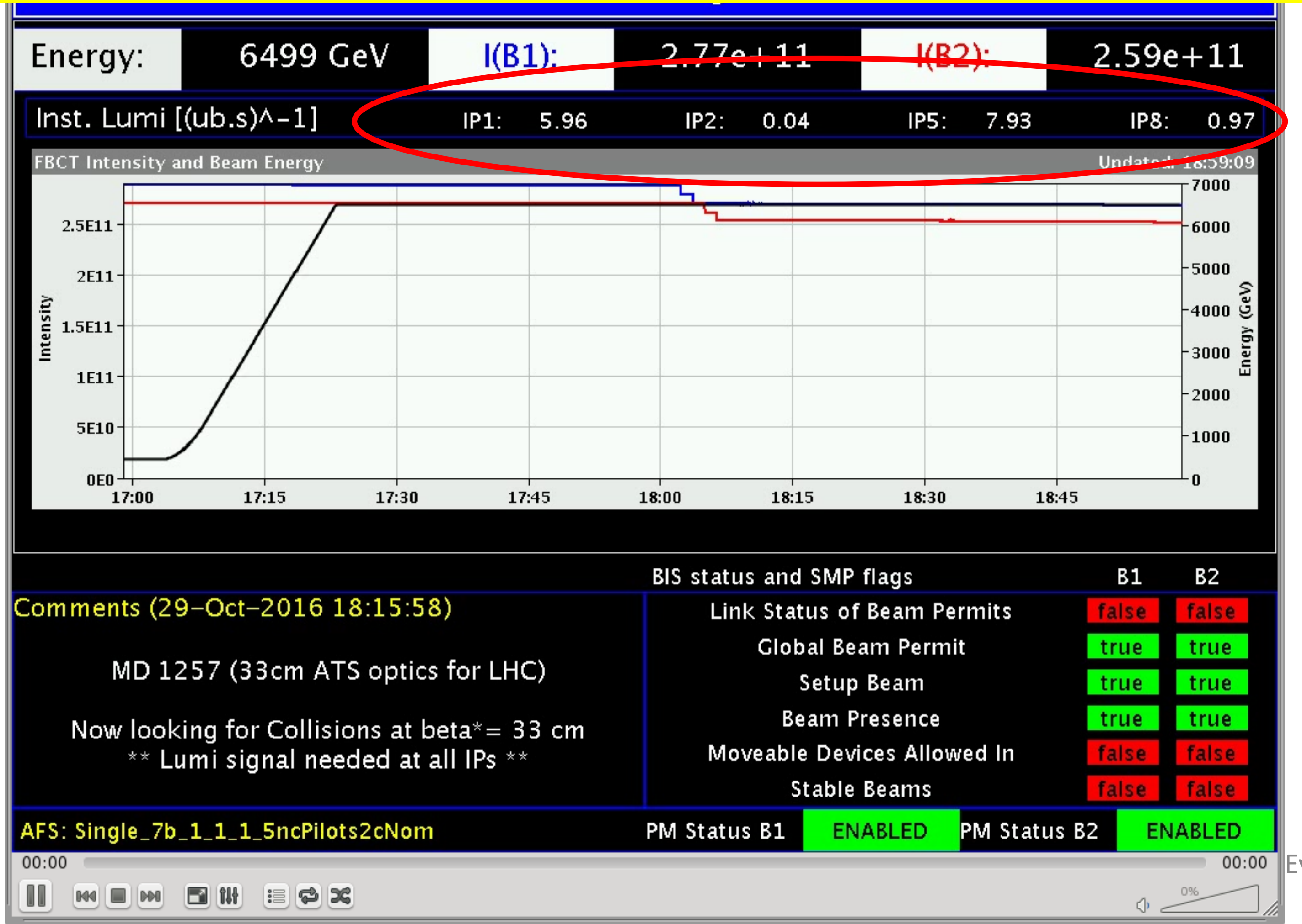
Within reach for 2017, tightening a little bit further the collimation hierarchy !!
(assuming X-angle OK for beam-beam: 9.0 σ @ β^*=33 cm, γε=2.2 μm & 6.5TeV)

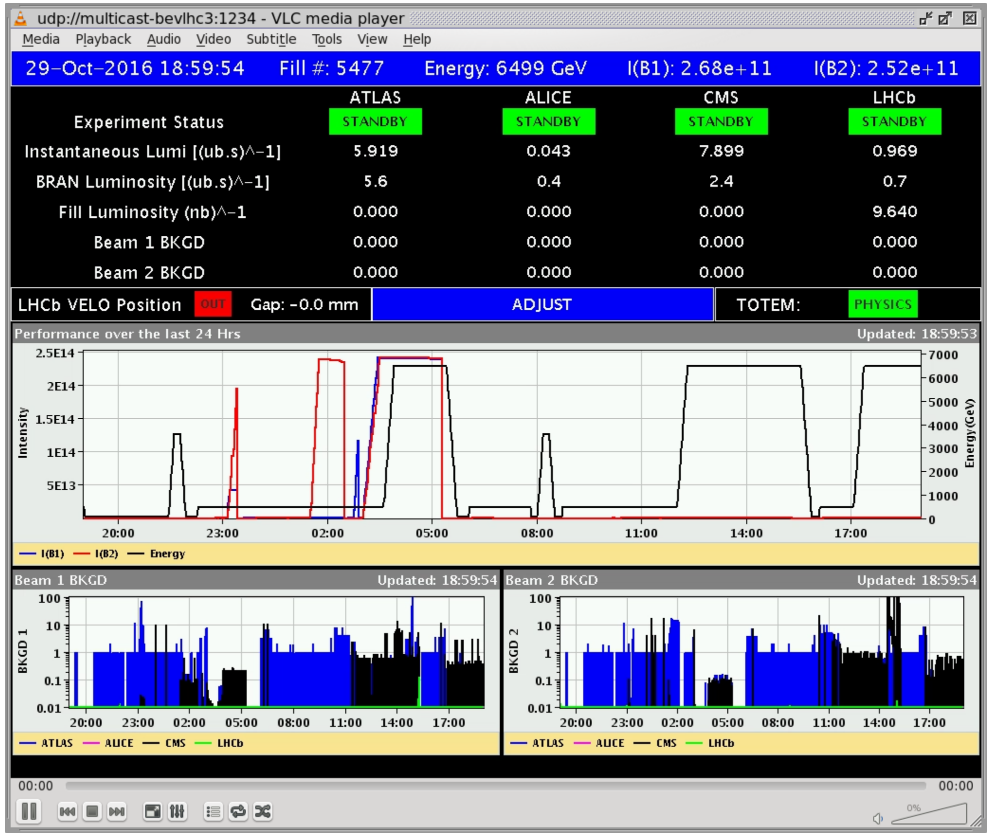
Some illustrations

- **Collision at 33 cm (140 μrad)**

→ "Single bunch lumi" recorded to 6E30 and 8E30 in ATLAS and CMS

(the lumi published by Alice was not correct)

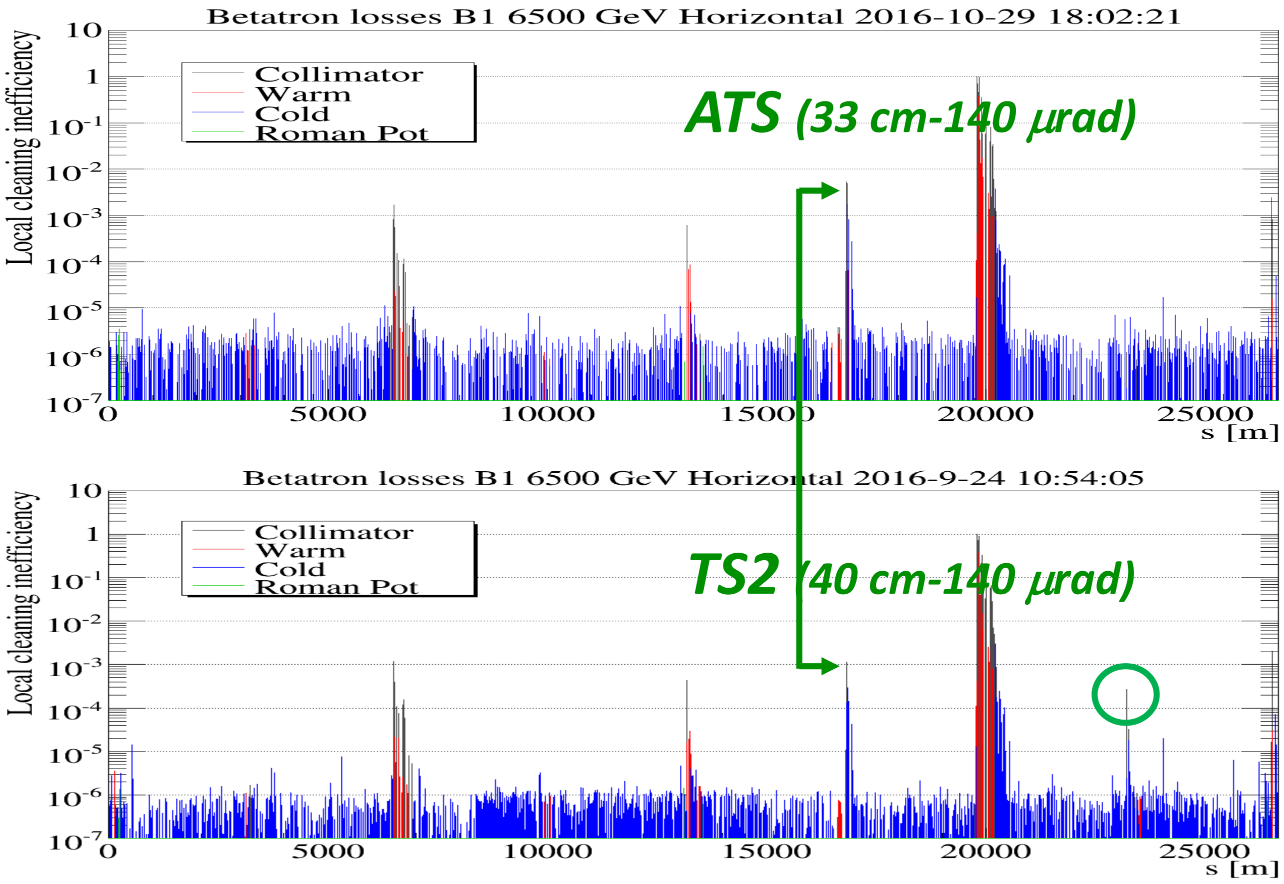




Some illustrations

More details in Daniele's presentation at the [LHC Collimation Working Group #211]

- **Loss maps @ 33 cm**



Case	ATS 0 Hz (separated)	ATS 0 Hz (collision)	ATS +30Hz (collision)	ATS -30 Hz (collision)
B1H	2.3e-4	2.2e-4	2.3e-4	1.4e-4
B1V	1.2e-4	1.1e-4	0.9e-4	No data
B2H	2.5e-4	2.6e-4	2.6e-4	2.5e-4
B2V	2.0e-4	1.6e-4	2.1e-4	No data

Very good inefficiency, beam separated or in collision, on-momentum or off-momentum ($\delta \sim \pm 2.5 \times 10^{-4}$)

Some feature or "non-feature" w.r.t. nominal optics:

- **As expected more losses in IR6**
- **Spike at Q10.R8 still not showing up**

ATS Dev. & MD plan for2017/2018

- Development and experimental validation of **flat telescopic optics** (and possibly synergy with BB wire MD)

→ ultimately 60/15 cm starting from 60 cm pre-squeezed optics

- Experimental study of **LR beam-beam compensation with octupoles and telescopic optics** (and HL-LHC running scenario with MO<0)

→ e.g. 30/30 cm starting from 90 cm pre-squeezed optics, or using the above flat optics.

Outlook

- A very prolific year for the ATS
- Some ''details'' are still missing, e.g.
  - Good TCT-MKD phase, but full demonstration of TCT losses with asynchronous dumps would have been even more convincing
  - ATS Optics re-optimization (and test) for the forward physics experiments (AFP, CT-PPS), if requested ?
- **But roughly speaking, the main pieces are there to take a decision for ATS implementation in the LHC,**

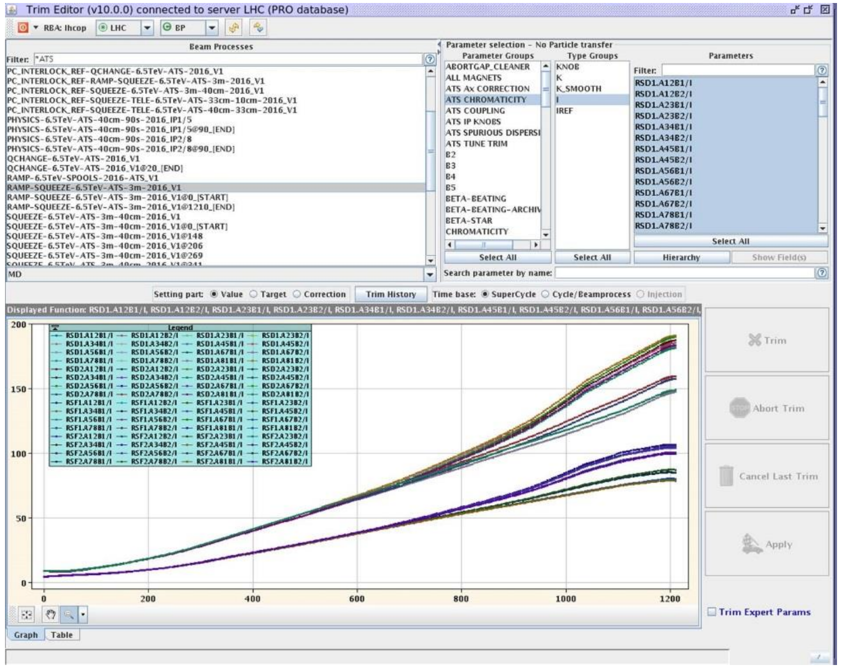
1) **Continuing to push β^* in the LHC, round or flat, … in a "telescopic manner"**
2) **And validate asap the HL-LHC HW choices driven by small β^***

Reserve

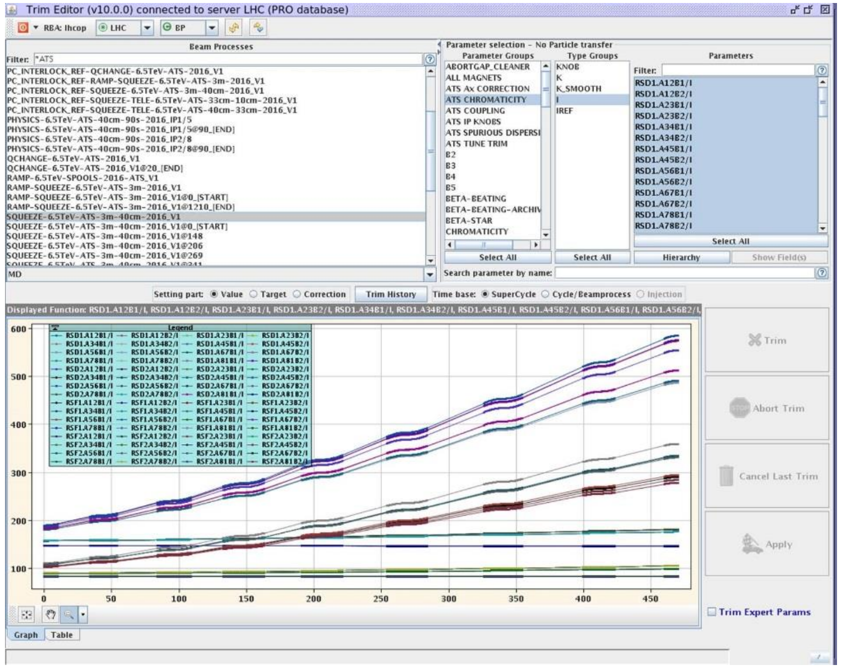
The 10 cm ATS MD

- **The telescopic part is played at (nearly) constant sextupole settings**

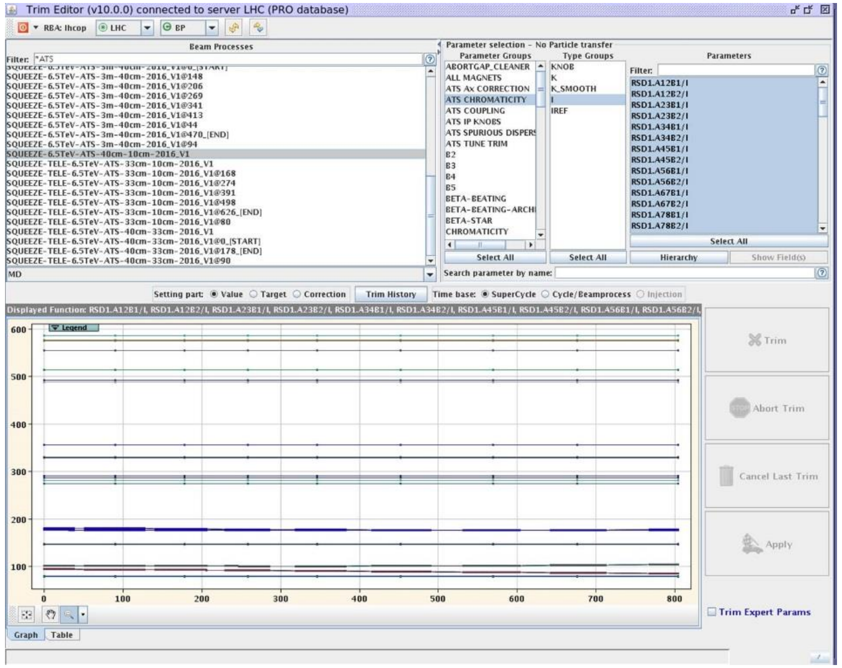
Optic Name	Time
R2016ats_A40C40A10mL300	0
R2016ats_A37C37A10mL300	90
R2016ats_A33C33A10mL300	178
R2016ats_A27C27A10mL300	258
R2016ats_A21C21A10mL300	346
R2016ats_A17C17A10mL300	452
R2016ats_A14C14A10mL300	569
R2016ats_A12C12A10mL300	676
R2016ats_A10C10A10mL300	804



Combined ramp & squeeze (3m) of the 32 sextupole families

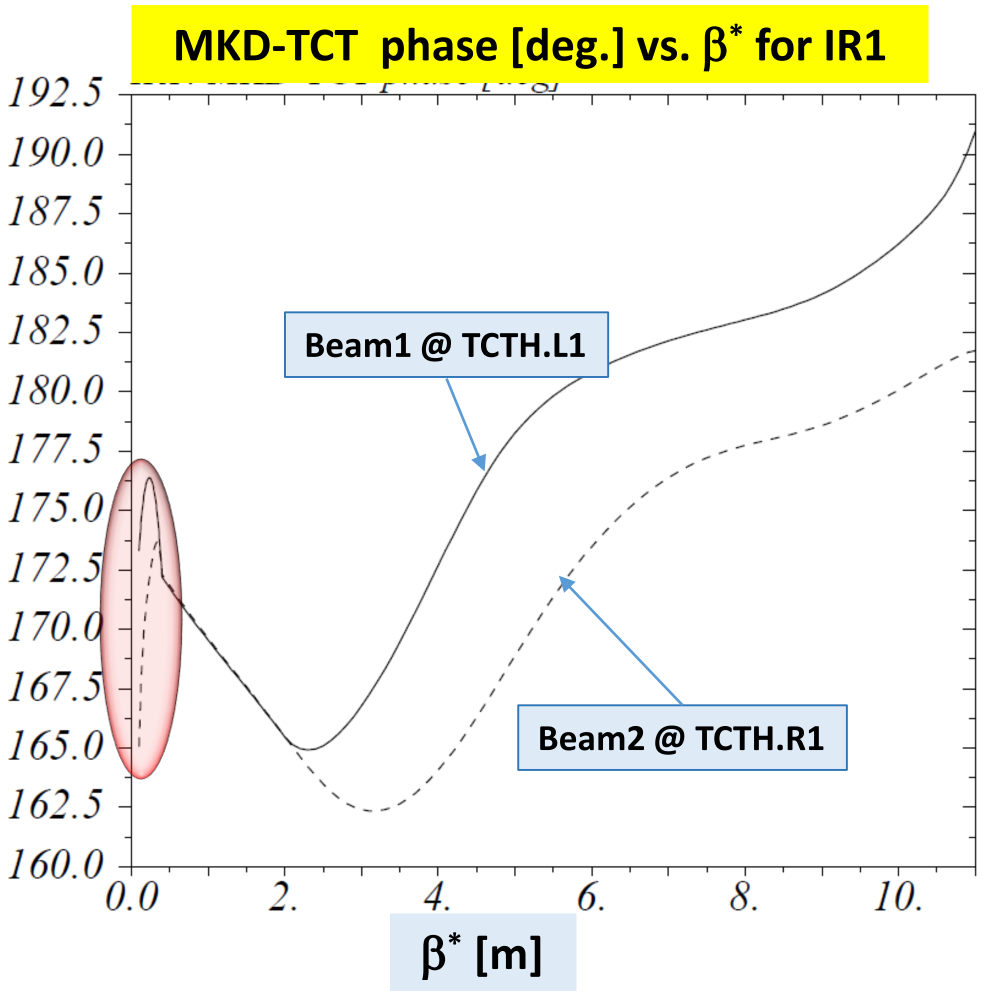


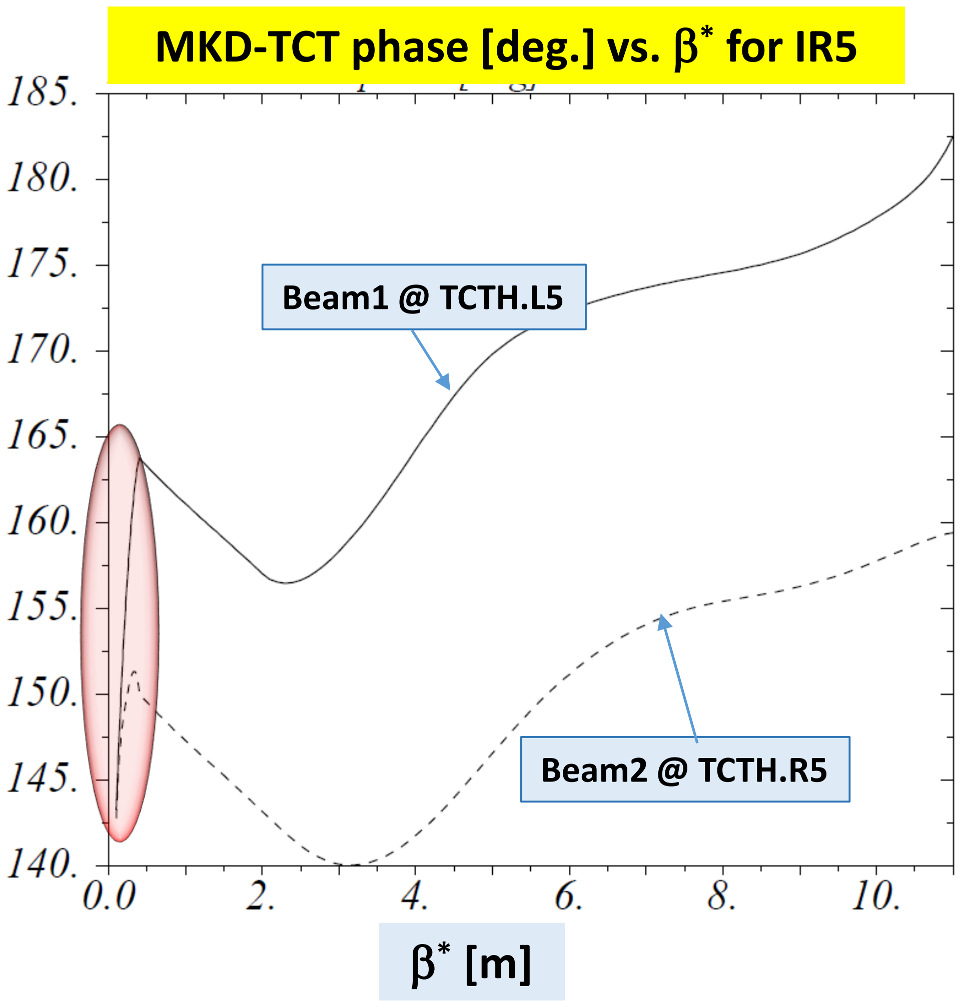
Pre-squeeze(3m → 40 cm): Only 25% of the circuits are moving (at quadruple dI/dt)



Tele-squeeze (40 cm → 10 cm) at constant sextupole

MKD-TCT phases





→ Some degradation (10-20 degrees) observed during the telescopic squeeze
→ The worst case are IR5-beam1 & beam2 in the end of the telescopic squeeze, but still beyond 50 degrees from the worst case