The 8th Evian Workshop: New optics correction approaches in 2017

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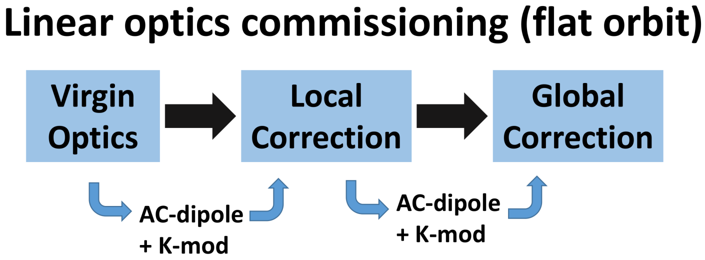
and the **O**ptics **M**easurement and **C**orrection (**OMC**) Team

Commissioning was tough this year...

Major revisions to OMC strategy in 2017

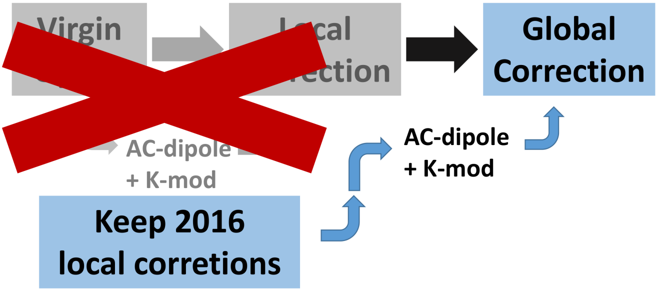
→ Optics commissioning in 2016 was exclusively linear, performed with flat-orbit



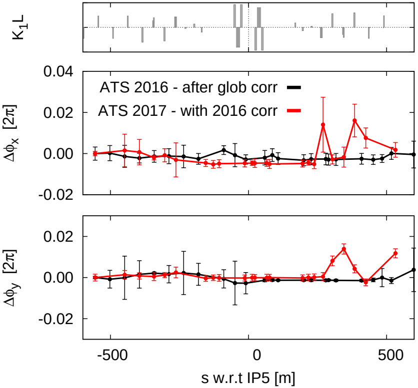
Major revisions to OMC strategy in 2017

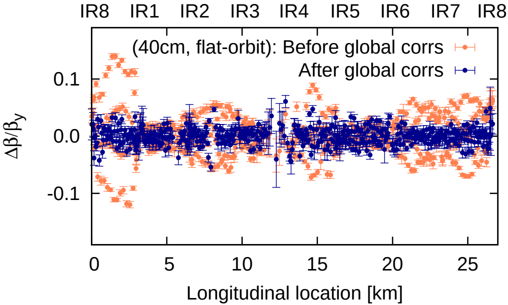
→ 2017 strategy omitted virgin measurement, use local corrs from ATS MD in 2016

Linear optics commissioning (flat orbit)



- **Local correction degraded between 07/2016 → 04/2017**





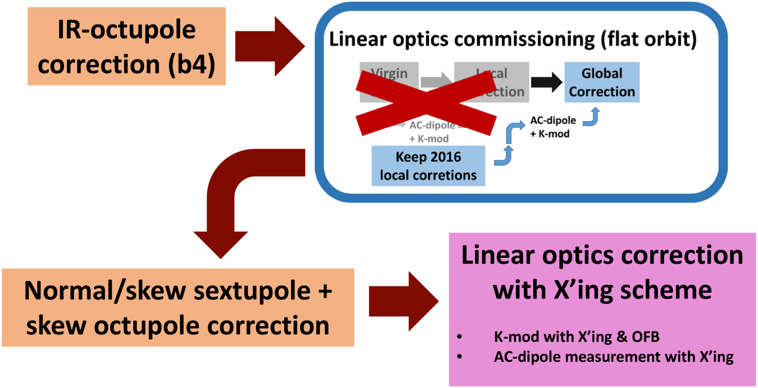
- **Global corr's compensated for local residual in 2017**

- **May be unsustainable if more degradation & β^* reduction**

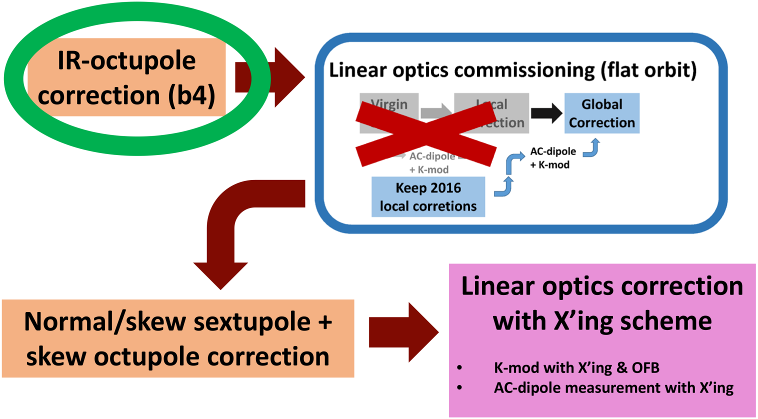
Major revisions to OMC strategy in 2017

→ Core of optics commissioning remains linear correction, but now integrated into a combined linear/nonlinear commissioning

Combined linear & nonlinear optics commissioning

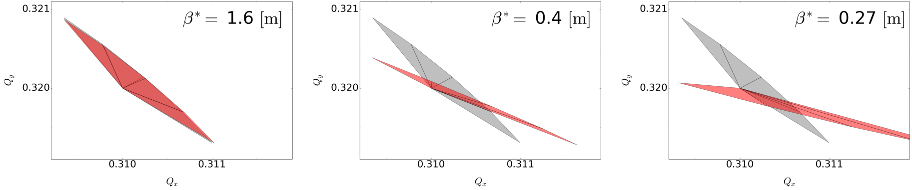


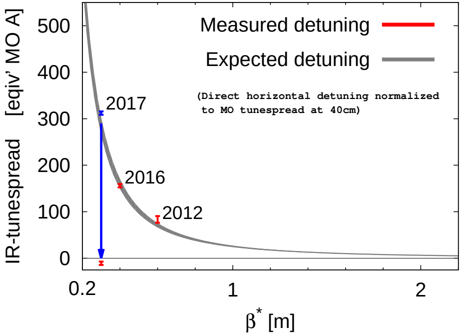
Combined linear & nonlinear optics commissioning



IR-octupole errors distort tune footprint during β^*-squeeze

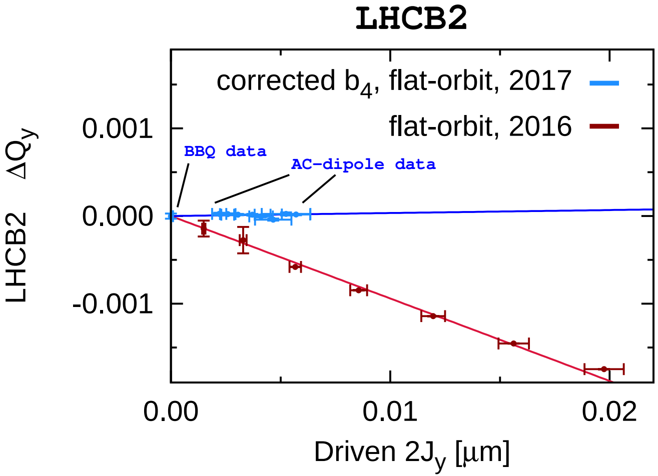
Desired MO footprint, Obtained footprint





- **Reduced stability for given MO**
- $\equiv 150\,\mathrm{A}$ **MO trim between 0.4/0.3m**
- **Dramatic influence on 0.14m lifetime**
  $\rightarrow$ observed to loose 1% of beam in 15 minutes (non-colliding)

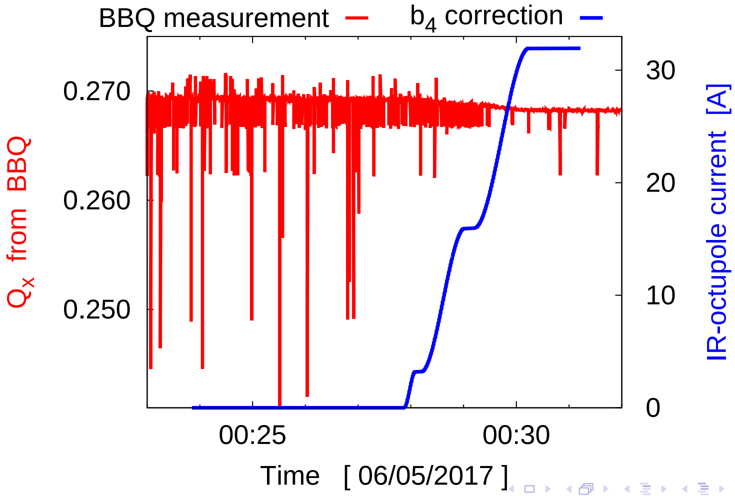
Local correction with MCOX eliminated contribution to tune footprint from normal octupole errors in IR1 & IR5



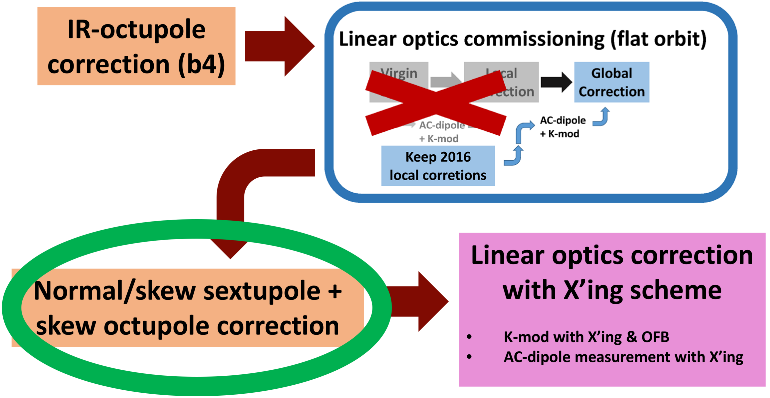
Clear improvement to BBQ upon IR-octupole correction

→ **big reduction to noise in tune measurement**

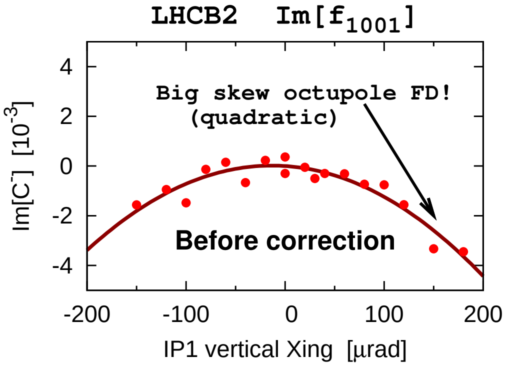
→ **Mandatory to obtain good K-mod at 30cm!**



Combined linear & nonlinear optics commissioning



Corrected feed-down to linear coupling in IR1

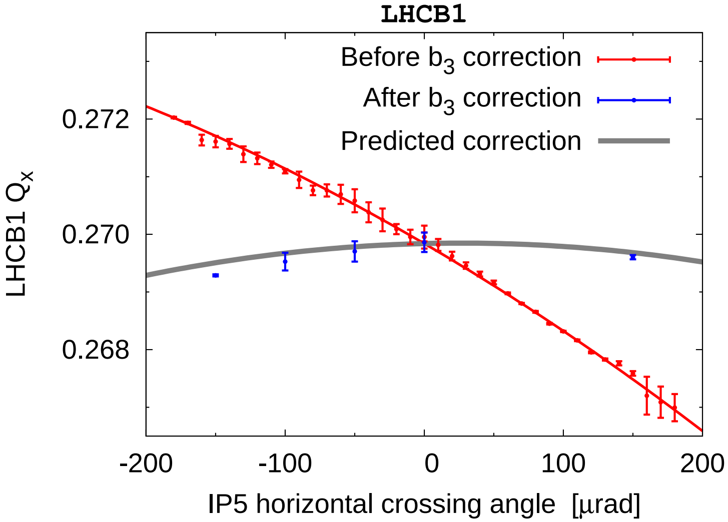


- **Important for instabilities and crossing-angle leveling**

- **Before correction:** $\Delta|C^-|_{0\rightarrow150\mu\text{rad}} = 5 \quad \times 10^{-3}$
- **After correction:** $\Delta|C^-|_{0\rightarrow150\mu\text{rad}} = 1.5 \times 10^{-3}$

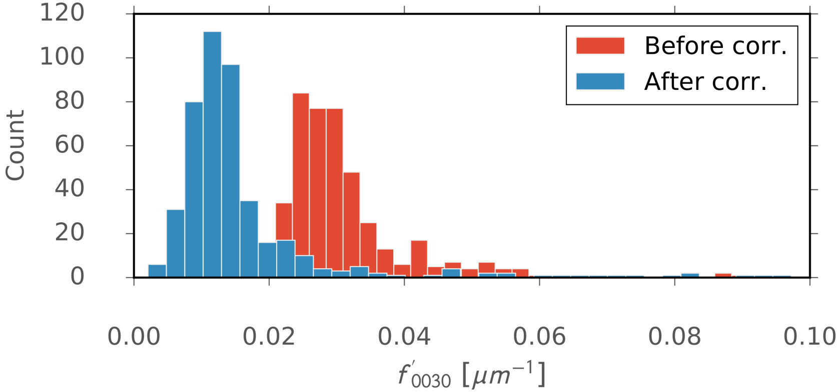
- **No IR5 correction as smaller than IR1 (relevant at smaller β^*)**

Corrected feed-down to tune in IR1 and IR5



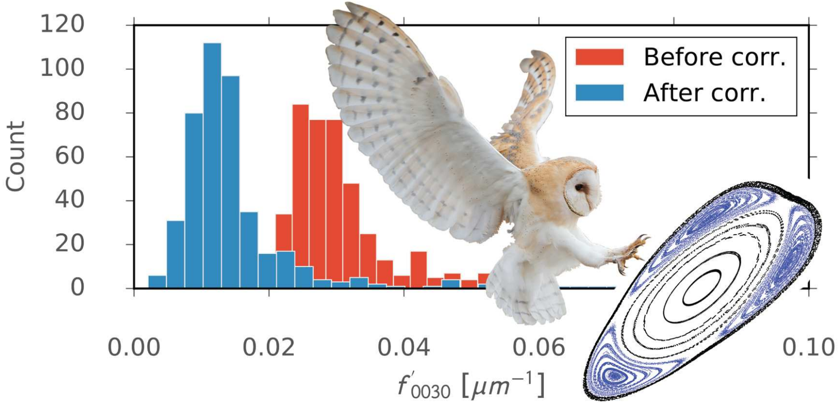
Corrected feed-down to tune in IR1 and IR5

→ reduced strength of $3Q_y$ resonance



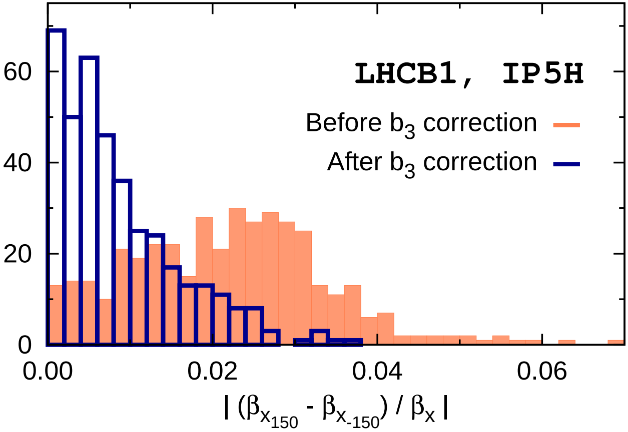
Corrected feed-down to tune in IR1 and IR5

$\rightarrow$ reduced strength of $3Q_y$ resonance



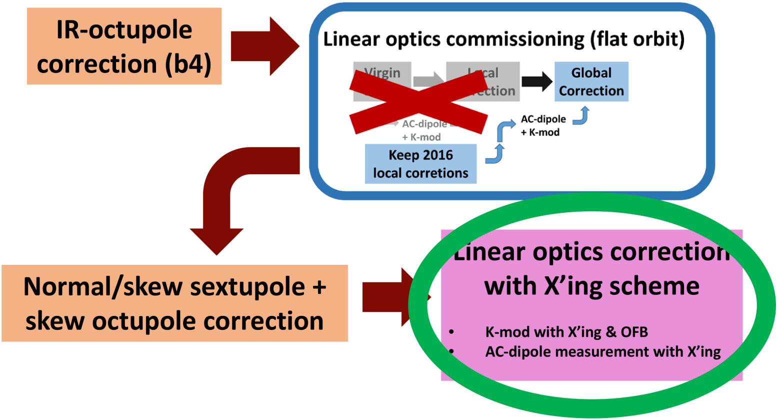
Corrected feed-down to tune in IR1 and IR5

→ **Improved stability of linear optics vs X'ing scheme**

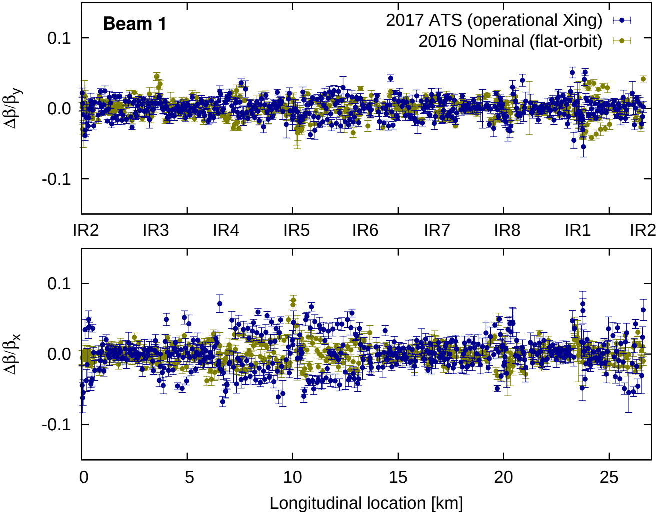


- contribution of nonlinear errors to linear optics quality never previously considered in LHC commissioning

Combined linear & nonlinear optics commissioning



Global correction for nonlinear sources at operation crossing scheme restores comparable optics quality to flat-orbit



Operational configuration now compensated to level previous achieved only for flat-orbit

	2017 ATS (w Xing)		2016 Nominal (flat)	
	Beam 1	Beam 2	Beam 1	Beam 2
$\beta^*_x\|_{\mathrm{IP1}}$	39.8 ± 0.1	39.9 ± 0.1	39.8 ± 0.5	39.8 ± 0.1
$\beta^*_y\|_{\mathrm{IP1}}$	40.8 ± 0.4	40.1 ± 0.1	40.1 ± 0.1	40.1 ± 0.1
$\beta^*_x\|_{\mathrm{IP5}}$	40.3 ± 0.2	40.2 ± 0.1	39.9 ± 0.2	39.5 ± 0.1
$\beta^*_y\|_{\mathrm{IP5}}$	40.2 ± 0.2	39.6 ± 0.1	40.1 ± 0.1	39.6 ± 0.2

$$\frac{L_{\mathrm{IP5}}}{L_{\mathrm{IP1}}} = 1.003 \pm 0.004$$

Similar quality obtained for $\beta^* = 0.3\,\mathrm{m}$

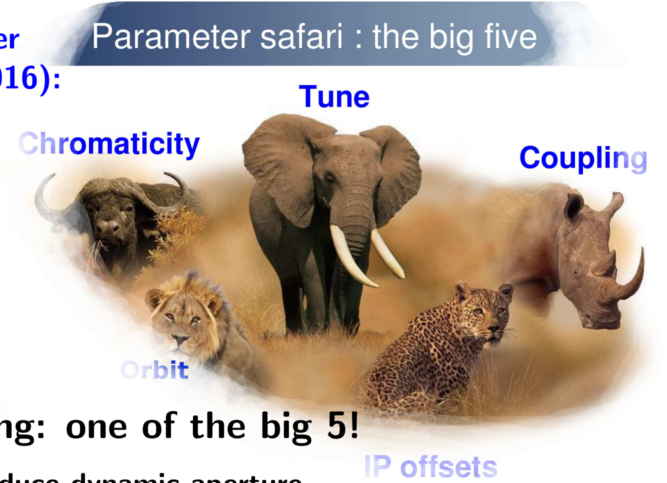
Expansion of OMC activities only possible thanks to rapid and continual development of optics tools

Project	Main Branch Commits in 2017	Lines of code
Python codes	455	127230
Java GUIs	178	38843

- **Integration of new observables & correction techniques**
- **Explore machine learning to improve measurement & correction**
- **A big push towards increased automation of OMC tools**
  → automation of basic tasks: logging, SVD-cleaning & FFT
  → **allows basic global coupling correction to be calculated online**

An operational tool for coupling correction

Jorg's parameter safari (Evian 2016):

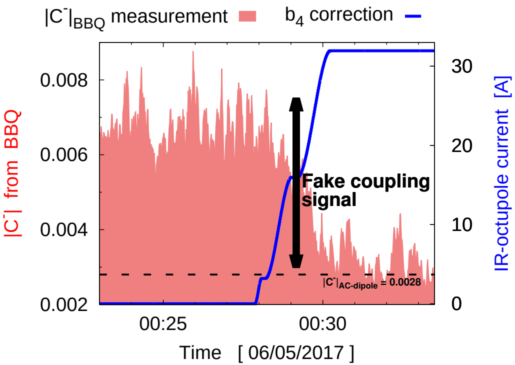


Linear coupling: one of the big 5!

- Observed to reduce dynamic aperture
- Huge influence on nonlinear optics
- Distorts footprint from MO causing loss of Landau damping

Linear coupling: a real operational challenge!

Coupling measurement from BBQ of limited use:



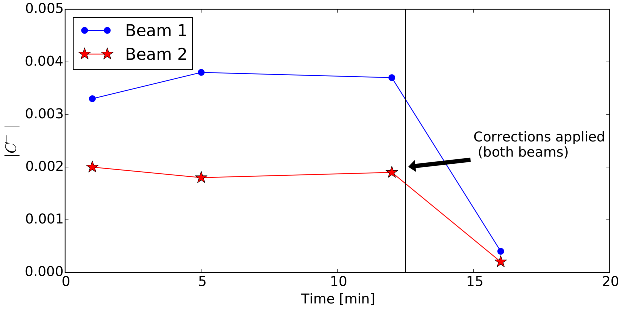
- **No info on $\Re$e and $\Im$m corrs**
- **Gives nonsense measurement with strong octupoles**
- **Doesn't actually measure $|C^-|$**
- Best measurement is AC-dipole $\rightarrow$ Only used with single pilot

Previously there has been no reliable way to monitor & correct linear coupling during regular operation

ADT can now drive forced oscillations of individual bunches

$\longrightarrow$ ADT-AC dipole!

- Used in regular operation $\rightarrow$ **overcome limit of regular AC-dipole**
- Obtain spectral data all around ring $\rightarrow$ **overcome limit of BBQ**
- **Automated OMC methods used to provide online correction for $\Re$e and $\Im$m parts of coupling**



Substantial effort by many groups!

BE Beams Department | Accelerators and Beam Physics

J. Coello de Portugal
E. Fol
L. Malina
T. Persson
P. Skowronski
R. Tomas

BE Beams Department | Controls

M. Hruska

M. Gabriel

BE Beams Department | Operation

M. Hostettler, A. Calia,
K. Fuchsberger,
D. Jacquet, G.H. Hemelsoet

BE Beams Department | Radio-Frequency

D.Valuch

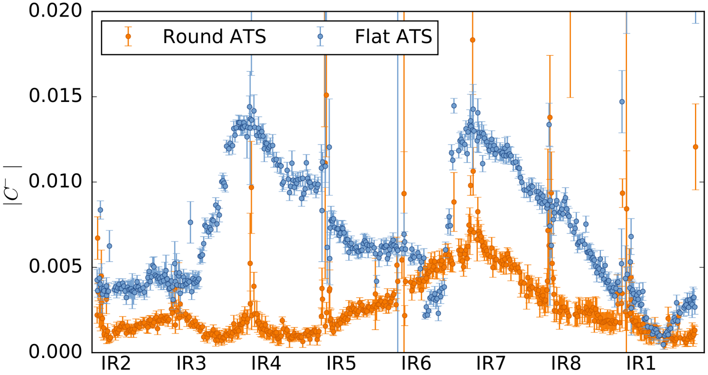
M. Söderén

Non-expert tool deployed in CCC to provide measurement & correction of linear coupling during regular operation

Well on the way to taming linear coupling!

Still not the end of the story for coupling

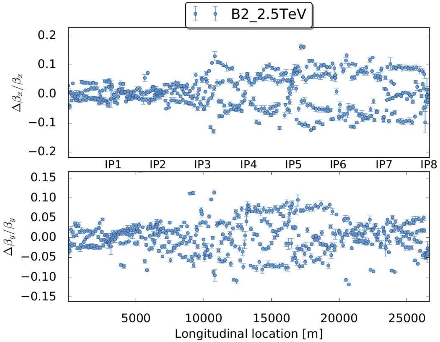
- **Local coupling (requires dedicated measurement with AC-dipole)**



- **Linear coupling from beam-beam**

Changes to strategy for 2018

- **Remove/revisit MCO @ 450 GeV**
  - → correction deteriorated from 2015
  - → Possible gain in spool piece ramp
- **Measurement-based incorporation of optics corr's in RAMP**
  - → 2.5 TeV commissioning showed excellent $\Delta\beta/\beta$ without correction
  - → Injection correction to be trimmed out by 2.5 TeV

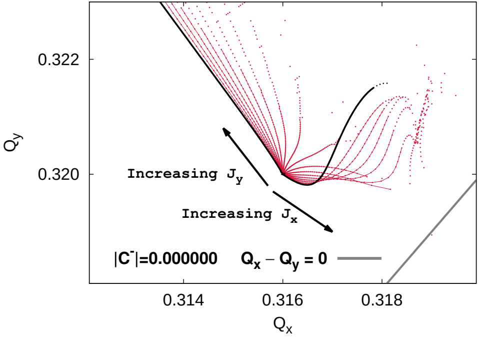


- **Start low-β commissioning with existing local corr's in place: iterate if necessary**
- **Start low-β commissioning with 2017 NL-corrections in place**
  - → online re-validation + coupling feed-down in IR5

Changes to strategy for 2018

Big OMC priority for 2018 is skew octupole compensation in IR1/5

skew octupole (a_4) → rotated normal octupole ($\frac{\pi}{8}$)



- **Skew octupoles distort Q-footprint**

  → $|C^-| + a_4$ gives amplitude detuning like normal octupole

  → $a_4 + b_4$ create amplitude dependent ΔQ_{min}

- **Potential for large impact on instabilities at small ΔQ**

Changes to strategy for 2018

- 1 shift, **Injection & Ramp**
- 0.5 shift, **linear optics through squeeze**
- 1 shift, **linear+nonlinear optics 27cm**
- 3 shift, **linear+nonlinear optics 25cm**
- 0.5 shift, **IR4 K-mod**

Total: 6 shifts

Aperture becomes more critical for linear/nonlinear commissioning at small β^*

Received a lot of support from various groups this year:

→ support from BI to allow BSRT for pilots at 6.5 TeV

→ support from collimation

We will rely on this more & more as β^* decreases

Conclusions

- **At low-β linear and nonlinear optics are intrinsically linked**

  $\longrightarrow$ Can't measure or correct linear optics to desired quality without also compensating nonlinearities

  $\longrightarrow$ Nonlinear optics correction requires good linear optics

- **Nonlinear optics is an operational concern, particularly for instabilities**

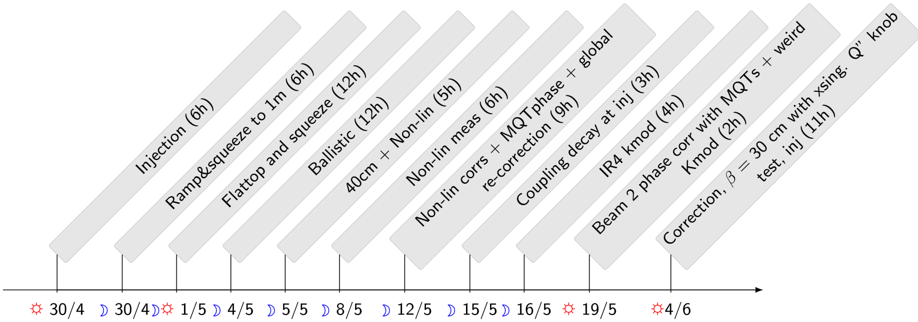
- Changes to OMC strategy & new tools deployed in the control room are delivering meaningful improvements, particularly to:

  linear optics, linear coupling, performance of instrumentation,

  & control of footprint for Landau damping of instabilities

as always, many interesting things to look at in 2018...

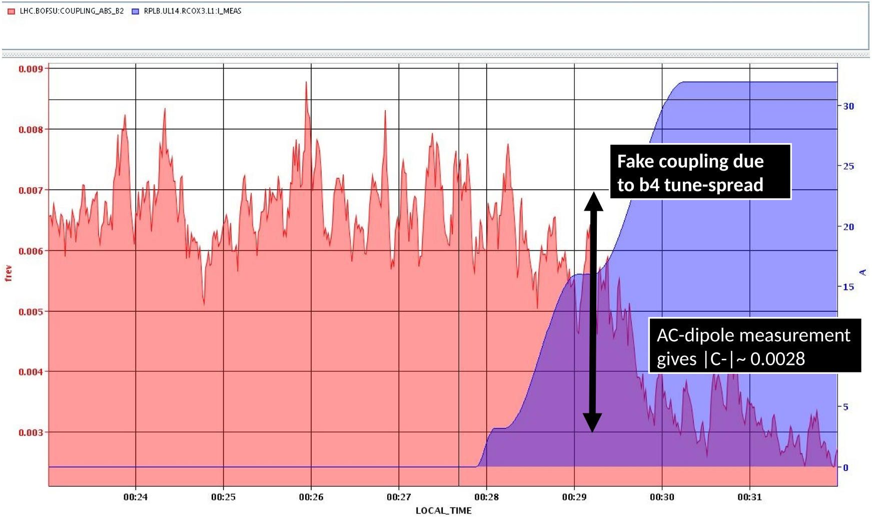
Reserve Slides



- **3 new optics commissioned**
- **11 shifts (3-days, 8-nights)**
- **76 hours of measurements**

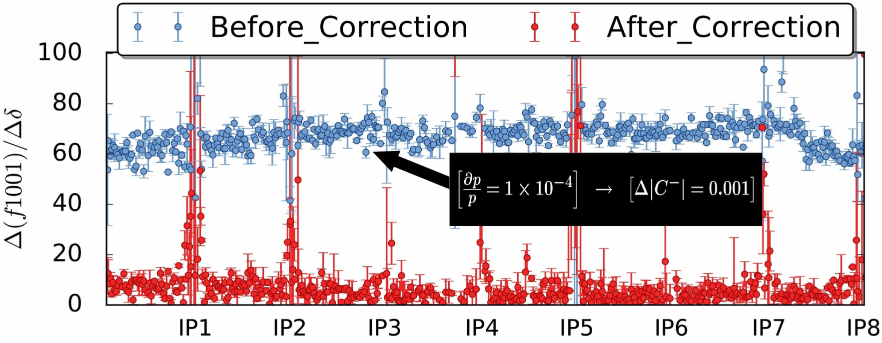
Clear improvement to BBQ upon IR-octupole correction

→ **remove fake coupling signal from BBQ**



Chromatic coupling correction (flat orbit) → change of $|C^-|$ with $\frac{\partial p}{p}$

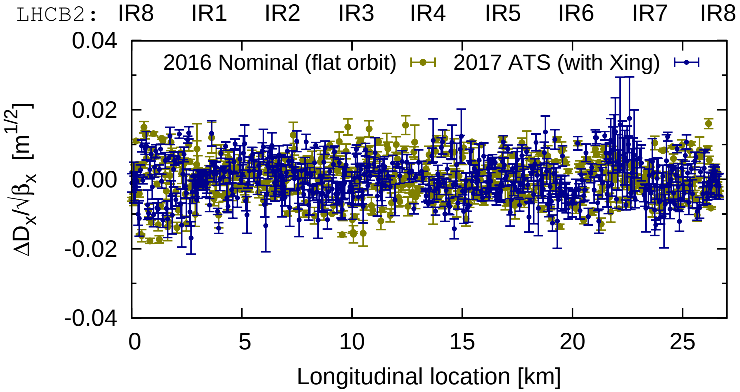
- corrected by skew sextupoles in arc



- Corrections operational for first time in 2017
- Improved control of $|C^-|$ w.r.t radial errors in arcs
  → particularly relevant for Q', Q'' measurements

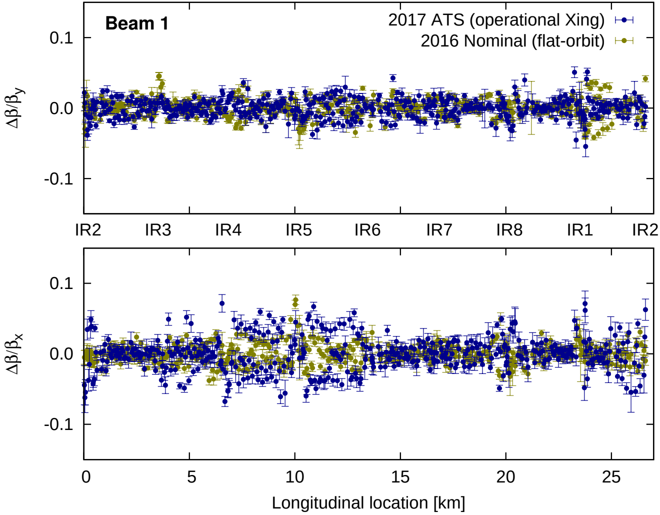
Linear re-optimization: Various updates to procedures & software tools required:

- **First K-modulation with crossing angles and Orbit-Feed-Back**
- **First time correcting beta-beat & dispersion with crossing-scheme**

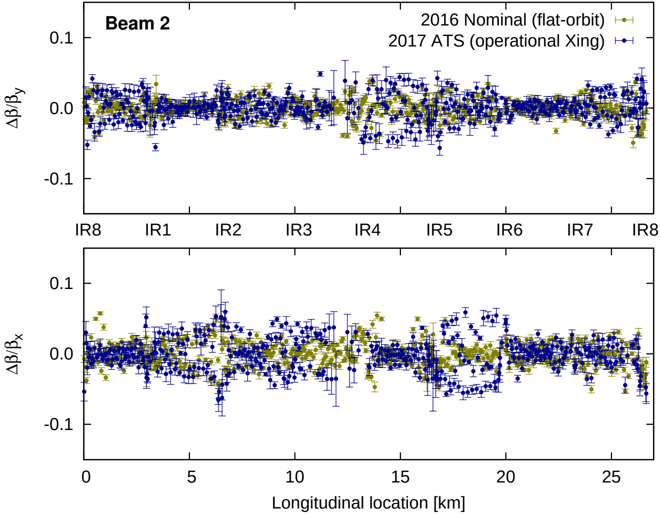


ATS dispersion-beat (with Xing) comparable to 2016 Nominal (flat)

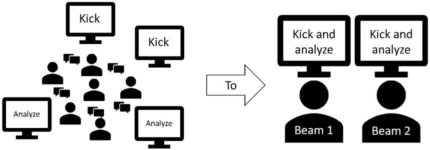
Achieve comparable β-beat for ATS (with Xing) as for 2016 Nominal (flat-orbit)



Achieve comparable β-beat for ATS (with Xing) as for 2016 Nominal (flat-orbit)



- Big steps towards automation of the optics measurements
  - Logging, analysis and coupling measurement of AC-dipole kicks
  - Human intervention only needed for more complex analysis allowing distinction between operational and expert tools



- Constant code performance and quality improvements

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  - Replacement of legacy codes → easy improvements and better maintainability
  - Full optics analysis stack implemented in Python loosening the dependency on Java GUIs also allowing further automation
  - Exploring machine learning techniques