Challenges of optics control for HL-LHC and β^* luminosity levelling

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- ★ β^* levelling challenges (performance, IP1/IP5 imbalance, beam-beam)
- ★ Optics measurement resolution
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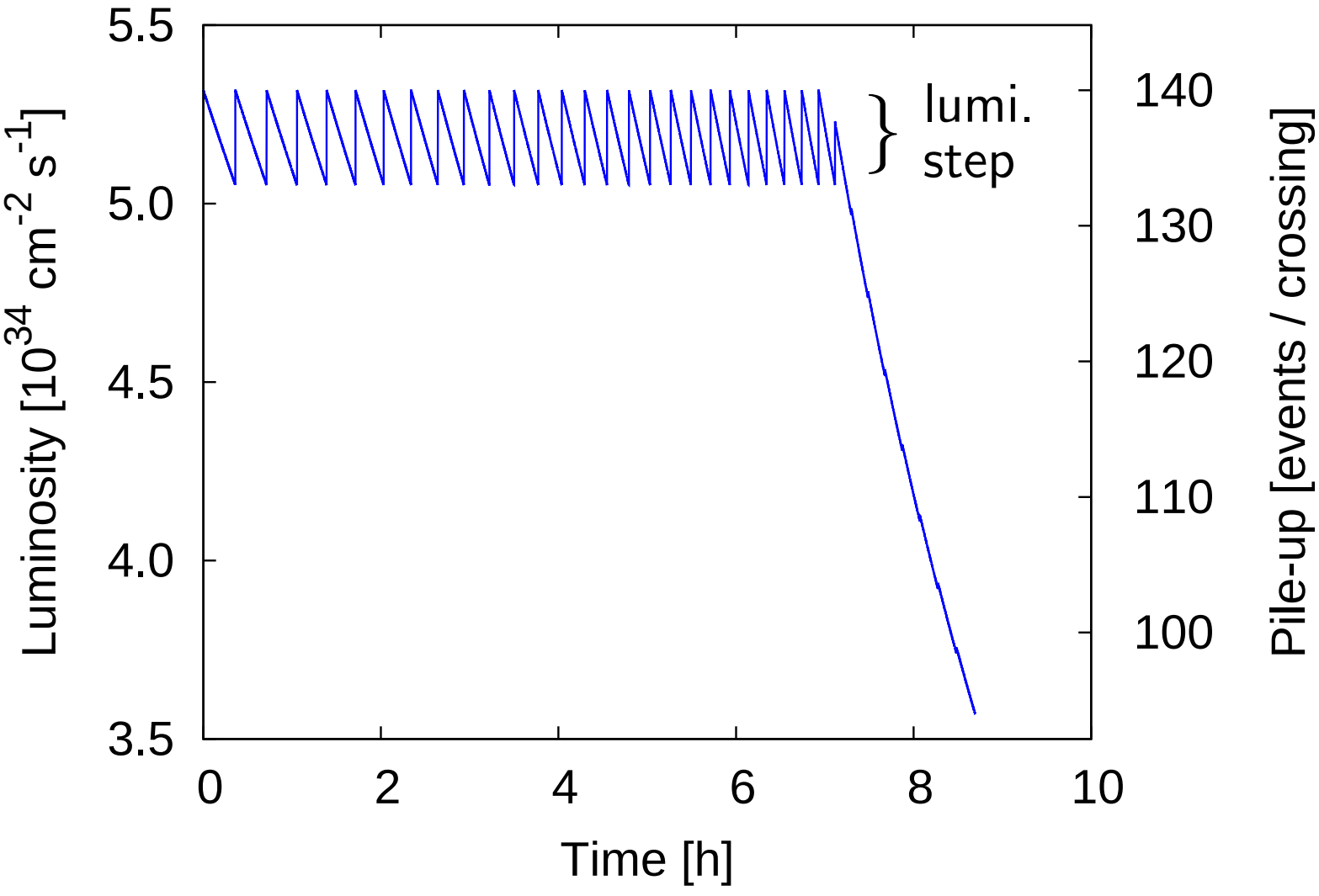
- ★ IR non-linearities

β^* leveling challenges

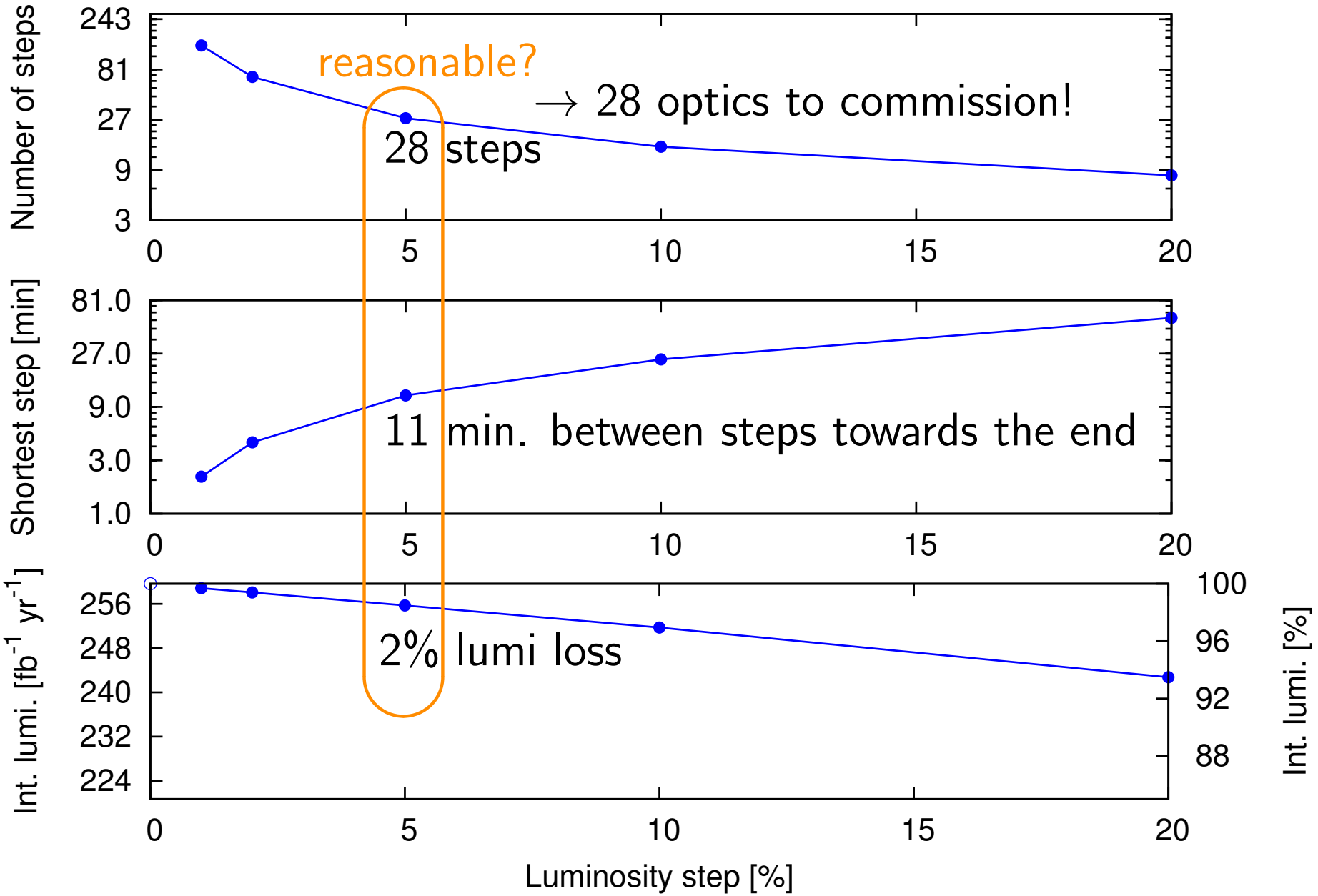
- So far an ideal β^* leveling is assumed
- A step-based β^* leveling is more realistic
- At every step IP offsets require adjustment $\rightarrow$ **penalty per step**
- In 2015 commissioning the β^* range [40,80]cm took **8 shifts** $\rightarrow$ extrapolation to HL-LHC?
- *à la carte* β^* is an even greater challenge

Step-based β^* leveling

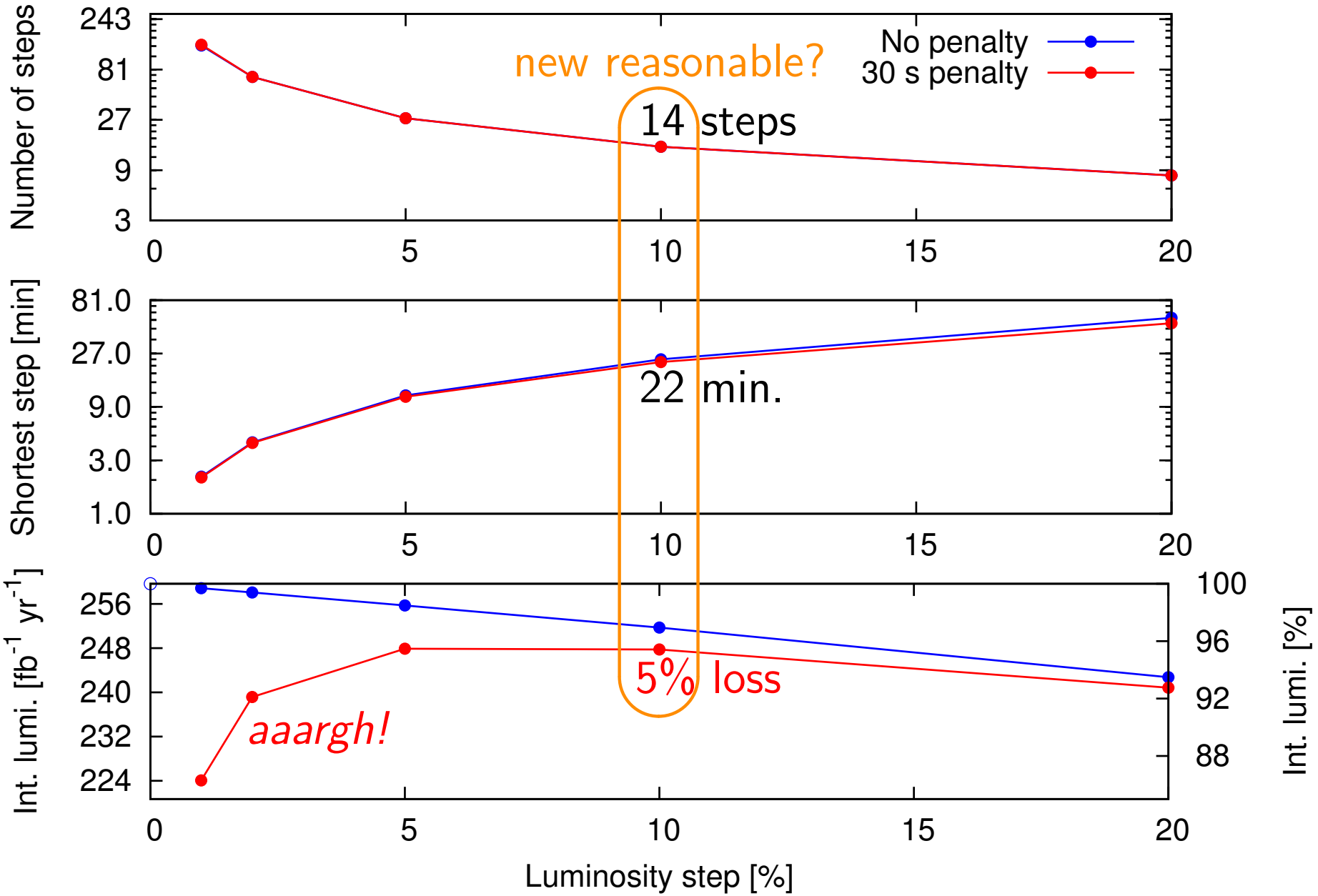


Respecting max pile-up limit causes lumi loss.

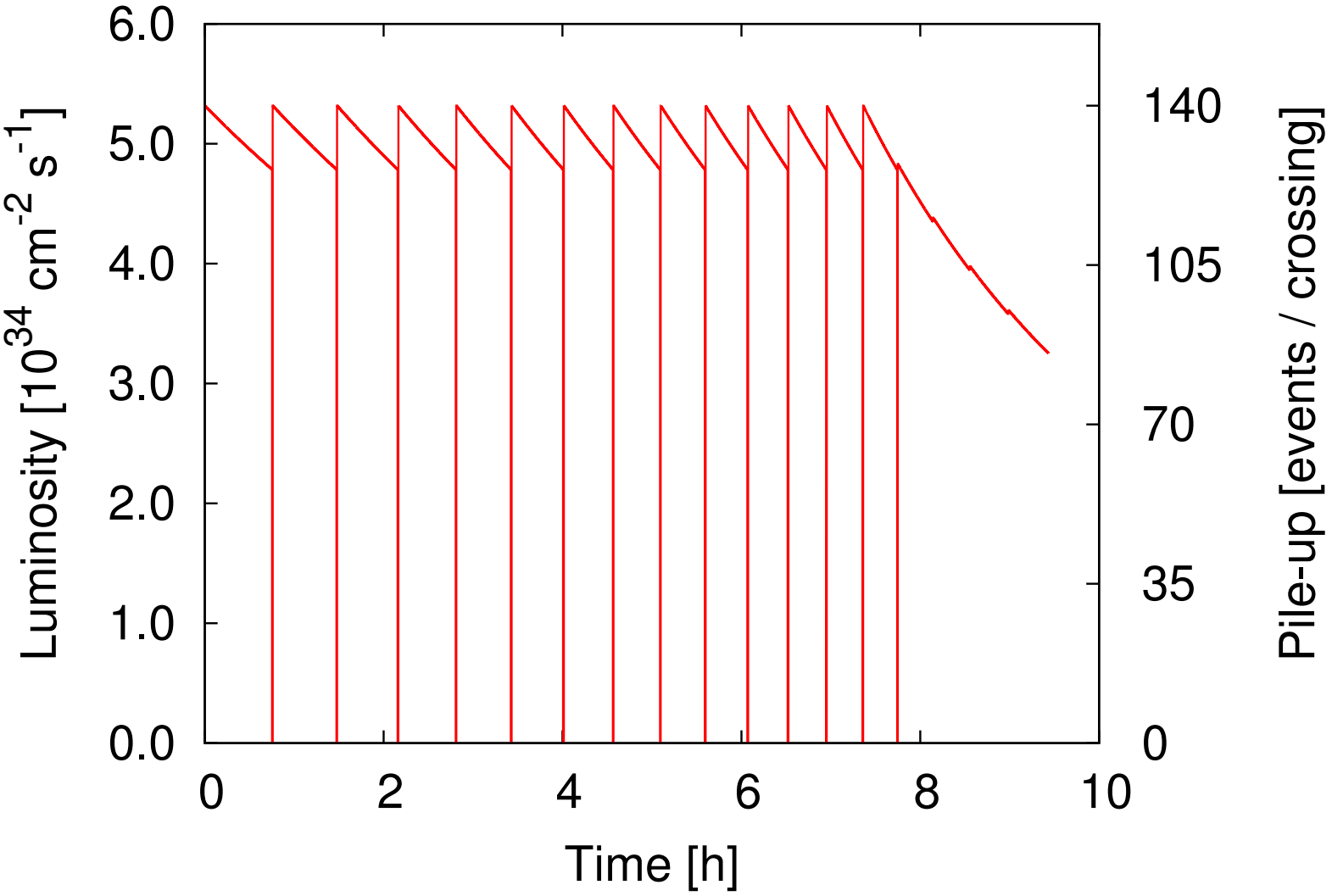
β^* leveling - How many steps? How often? price in lumi?



β^* leveling - Pessimistic penalty: 30 s/step without lumi



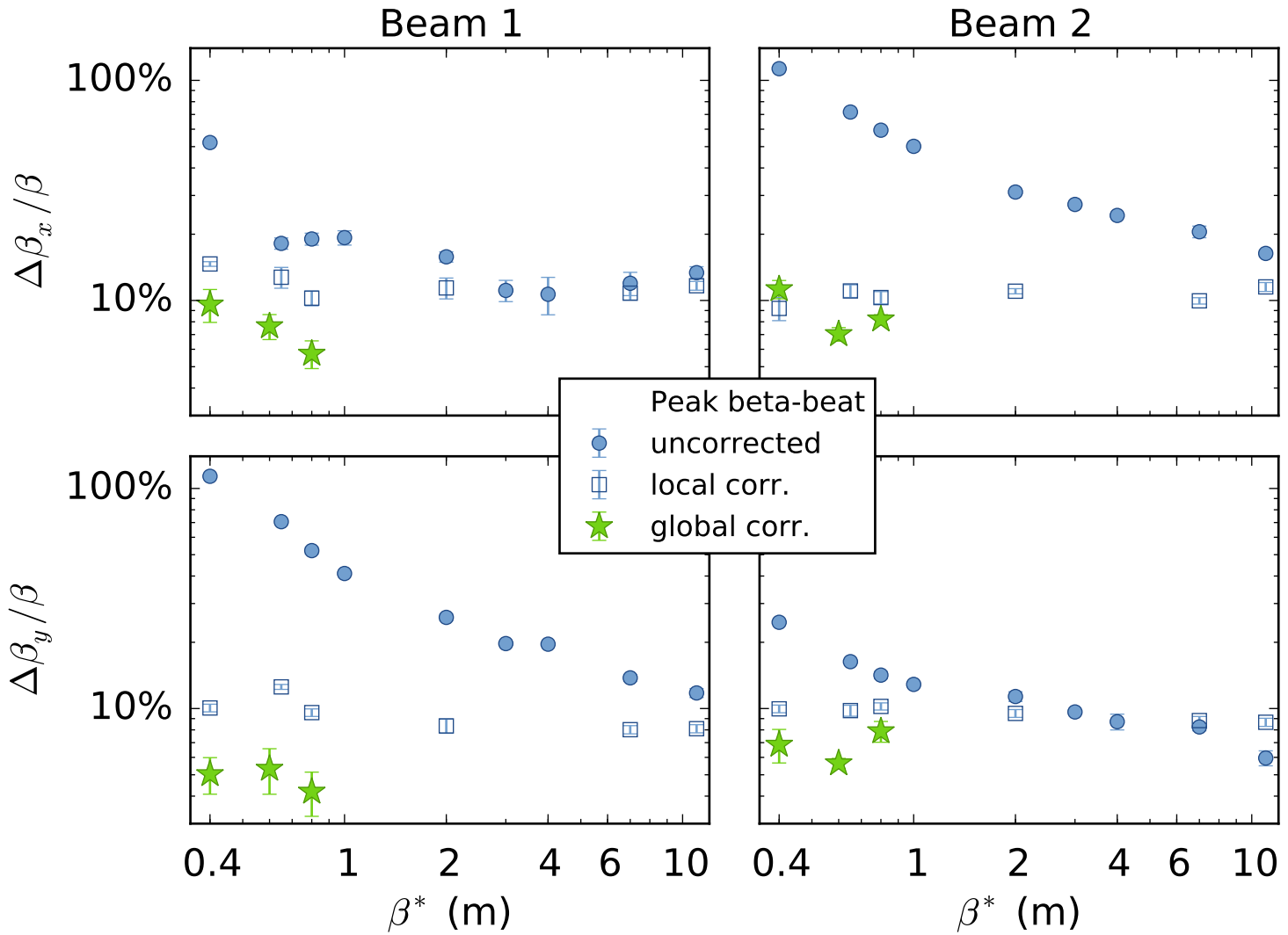
With 30s penalty and 10% luminosity step



MD tests next week

J. Wenninger estimates that the penalty can be an order of magnitude lower with DOROS BPMs

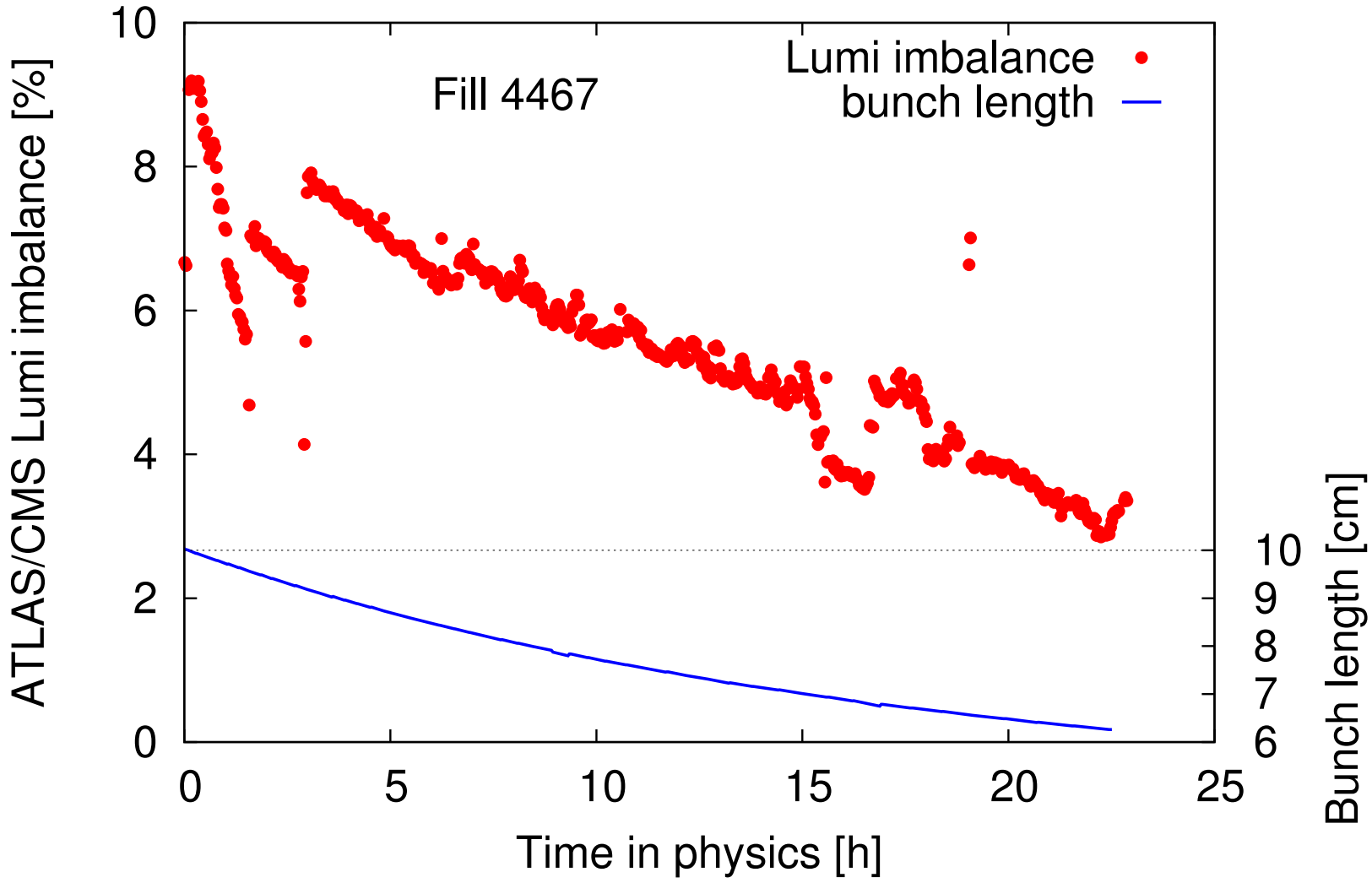
2015 Optics commissioning



Beam 2 corrections not optimal for time constraints

Green stars range took **8 shifts**. IP1/IP5 β^* imbalance was not addressed.

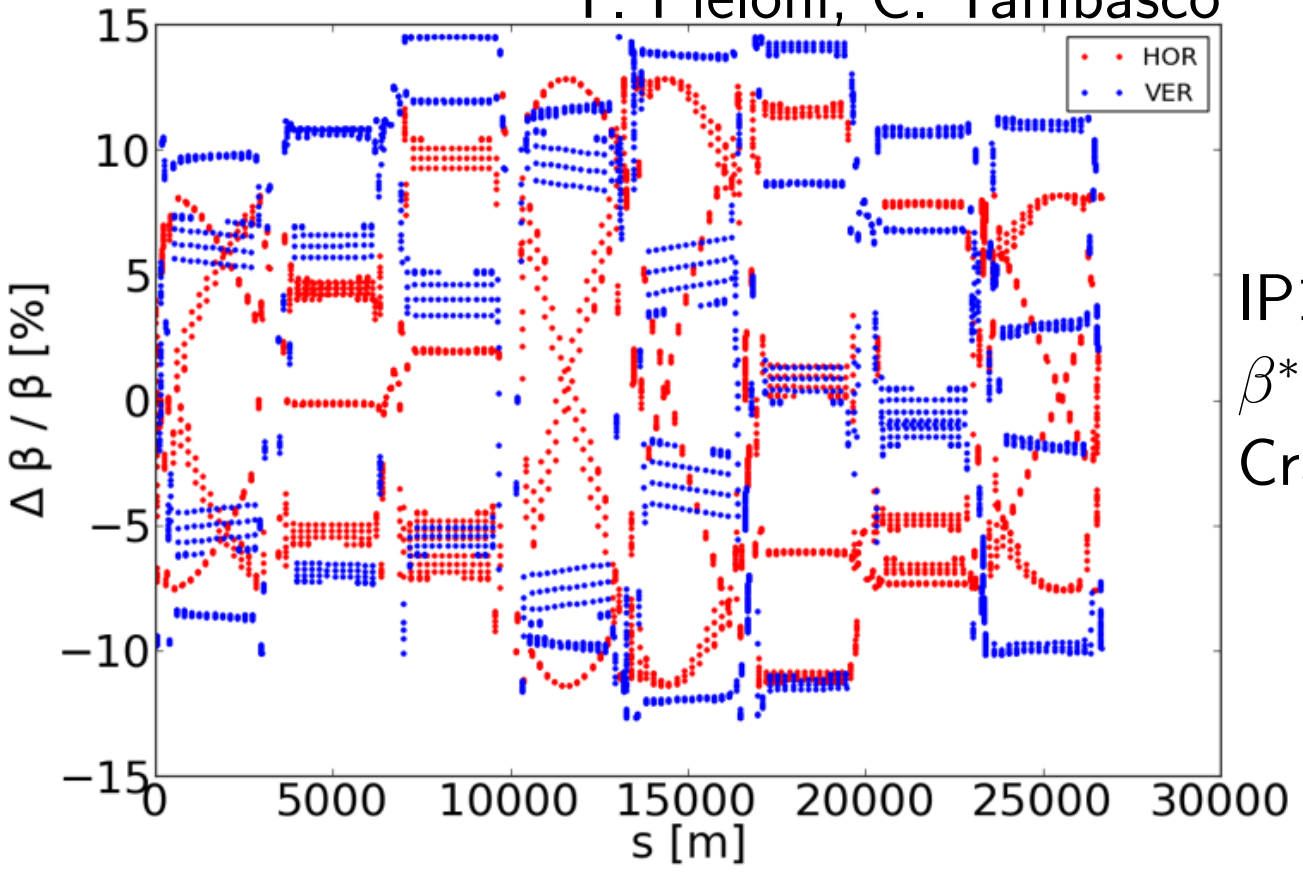
IP1/IP5 imbalance in 2015



CMS not happy. Is 10% imbalance due to different β^*s? Extra commissioning needed to guarrantee β^* balance.

β-beating from beam-beam in HL-LHC

T. Pieloni, C. Tambasco

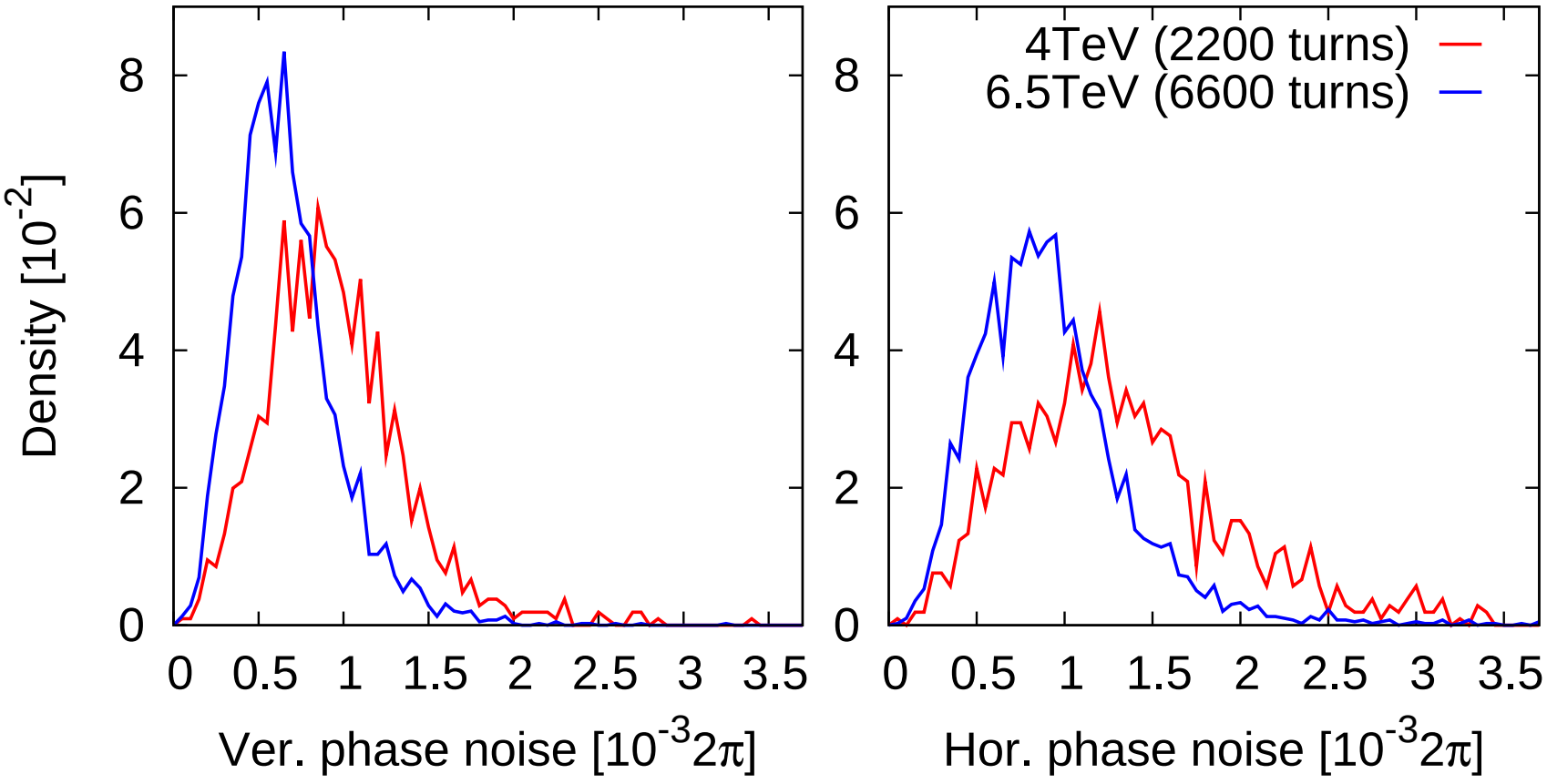


IP1&5 head-on
β^*=60cm
Crab crossing

15% β-beating from beam-beam!!!

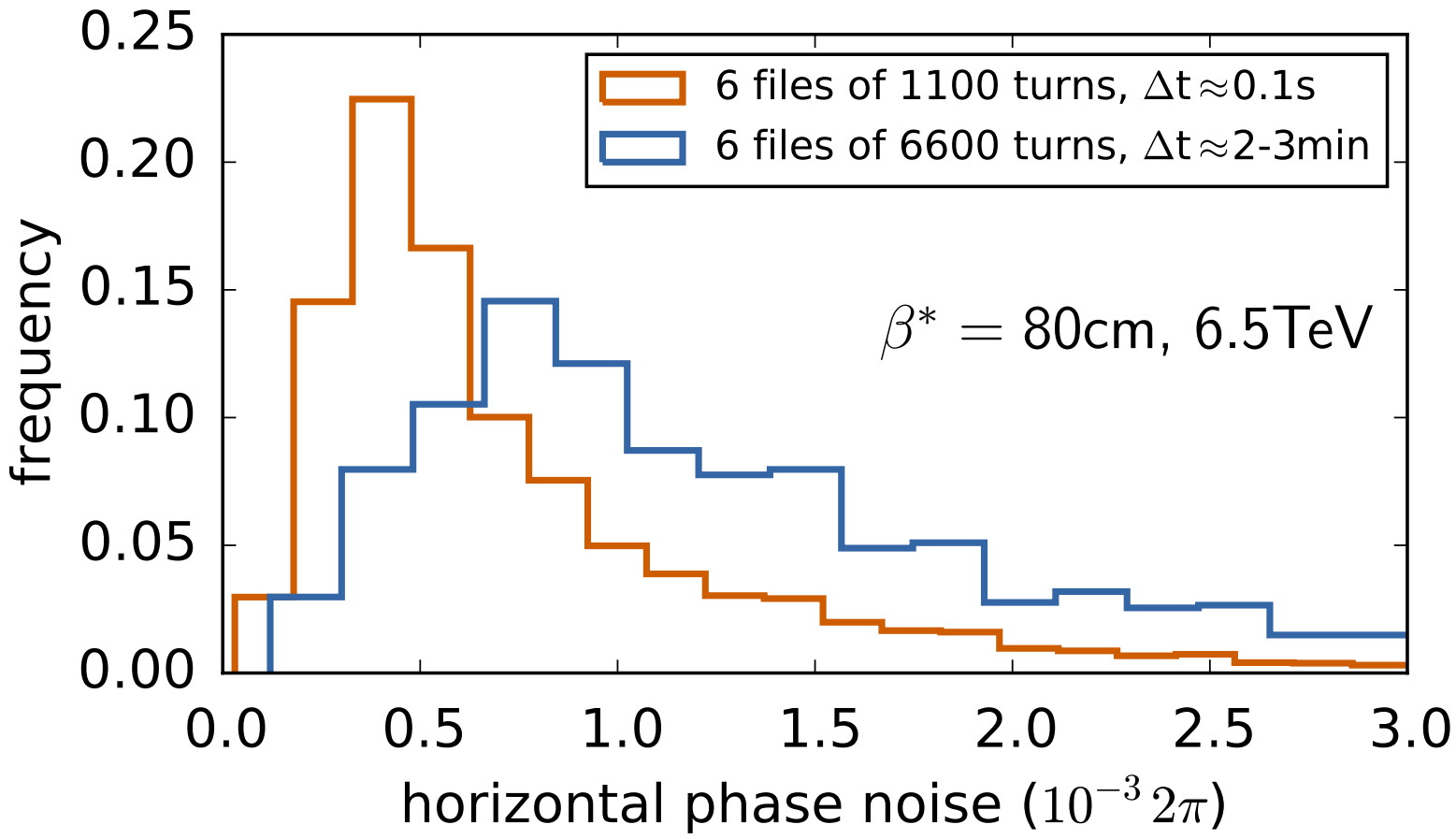
MD979: β-beating correction on colliding beams by T. Pieloni

Limitations in phase resolution



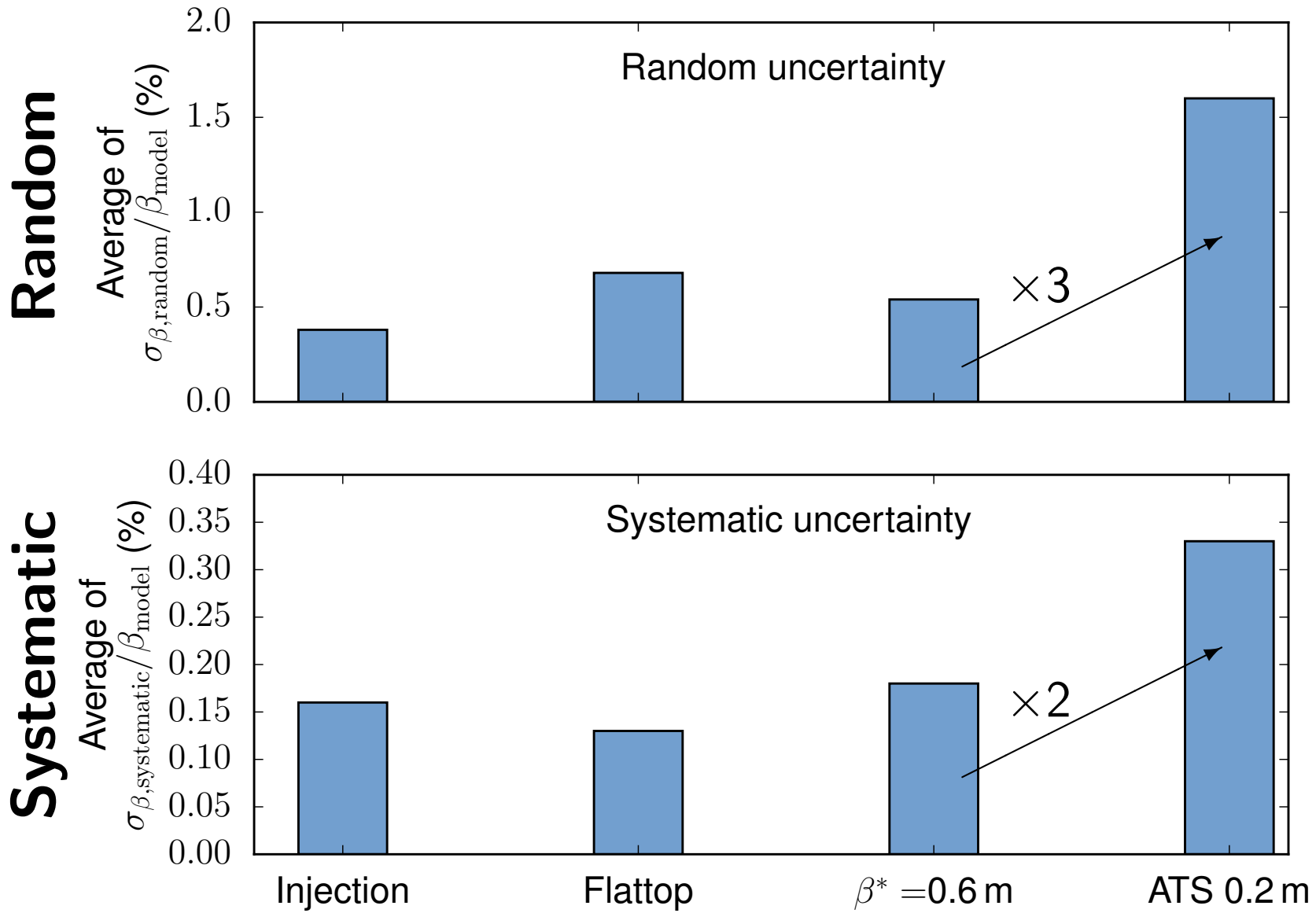
The increased number of turns improved phase resolution, but not as much as expected.

LHC changing in time scale of minutes



BPM phase advance seems to jitter in the $\approx 3 \times 10^{-4} 2\pi$ ($\Delta\beta/\beta_{jitter} \approx 0.3\%$) level in minutes $\rightarrow$ 4 times larger in HL-LHC?

Exp. ATS optics measurement resolution



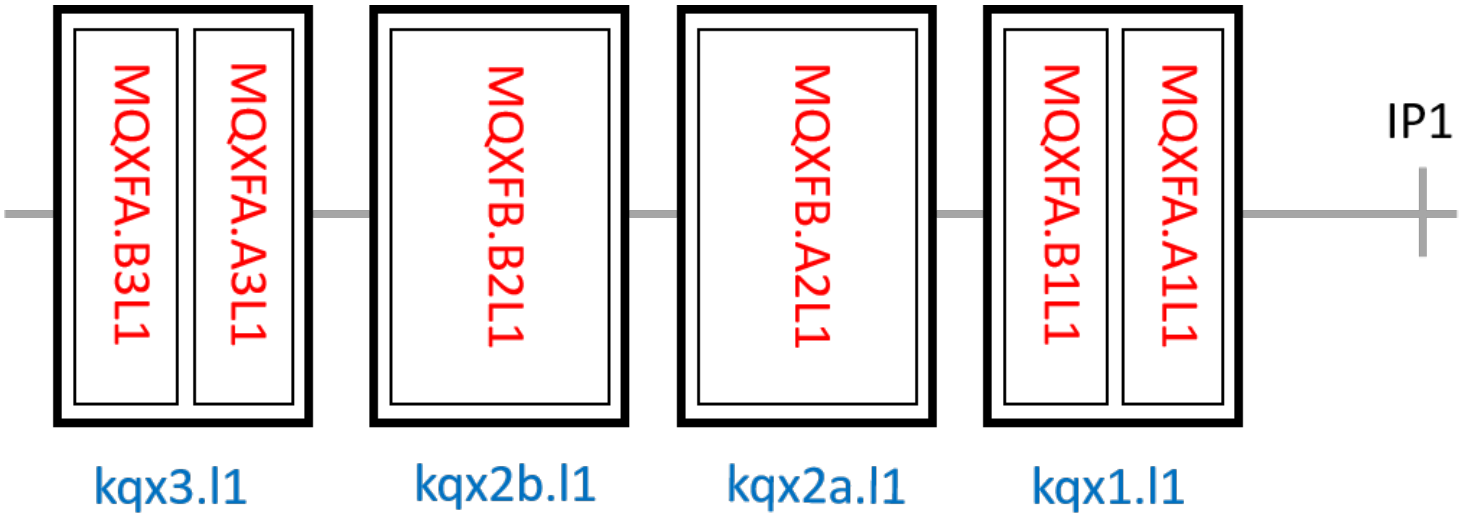
Certainly poorer optics resolution in HL-LHC

MQX and MQXF errors

- ★ LHC MQX b_2 uncertainty was rms 3-4$\times 10^{-4}$
  - From beam measurements maybe rms $b_2 \approx 10^{-3}$ (or maybe longitudinal misalignments are large)
- ★ HL-LHC MQXF b_2 error is given as rms 10^{-3}
- ★ About a factor 2 larger than for LHC
  - what will beam see?
- ★ HL-LHC β at the triplet is about a factor 4 larger than for LHC

$\rightarrow$ Factor 8 increased difficulty?

Triplet



b_2 =10 (rms) are assigned independently to every block (6) while we have only 4 variables for correction; DF=6-4=**2**

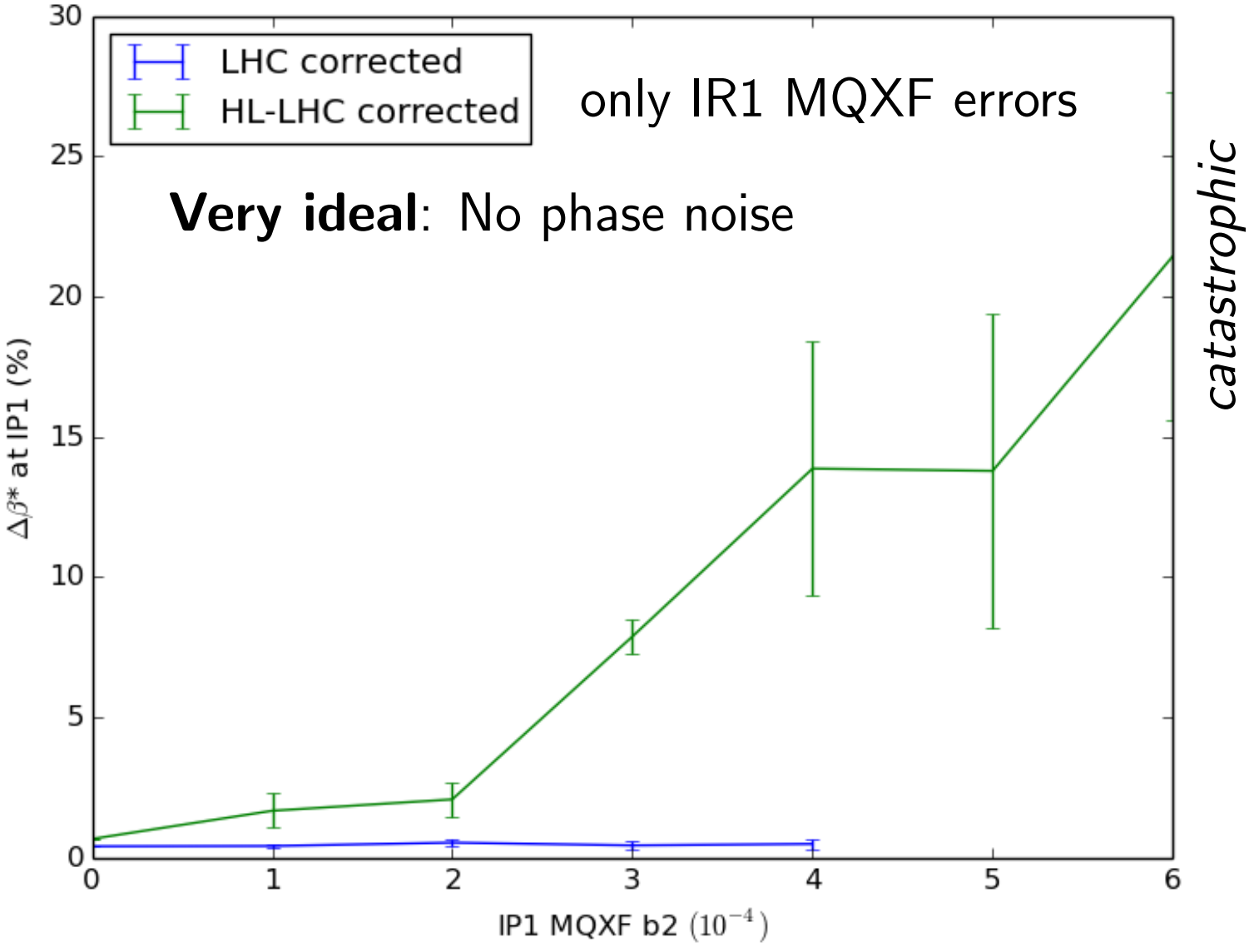
LHC recall: b_2 =4 assigned to 4 blocks; 3 variables; DF=**1**

Triplet *errors* after MADX correction

		Uncorrected $b_2[10^{-4}]$	Corrected $b_2[10^{-4}]$
kqx1	MQXFA.A1	10	6.3
	MQXFA.B1	10	7.4
kqx2a	MQXFB.A2	10	2.5
kqx2b	MQXFB.B2	10	3.0
kqx3	MQXFA.A3	10	8.9
	MQXFA.B3	10	6.3

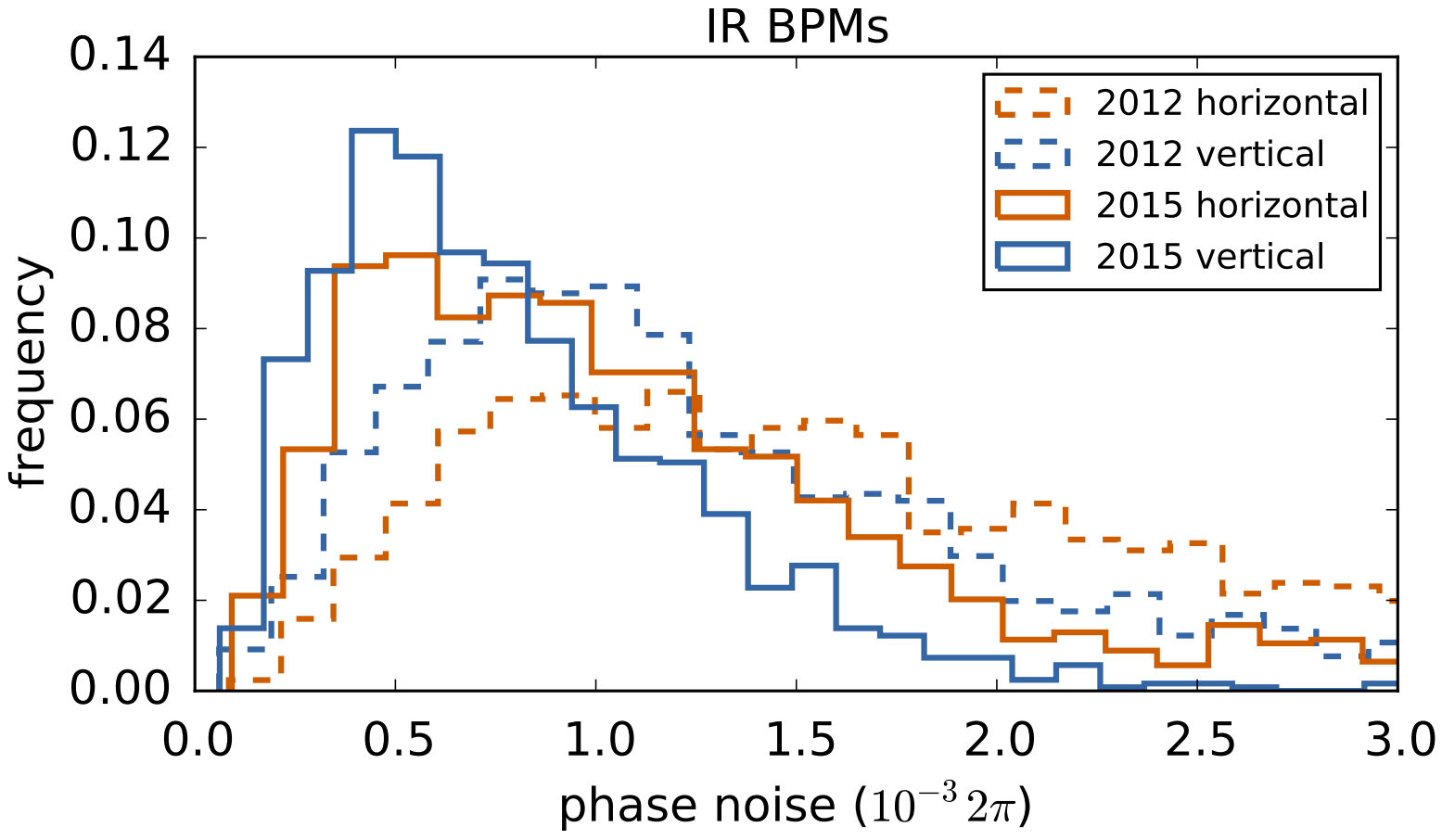
Correction exists within the triplet. Can we find it with beam measurements?

Local correction simul. at β^* =15cm



Twiss failing for b_2 >4 and $\Delta\beta^*/\beta^*$ >20% at b_2 =6.

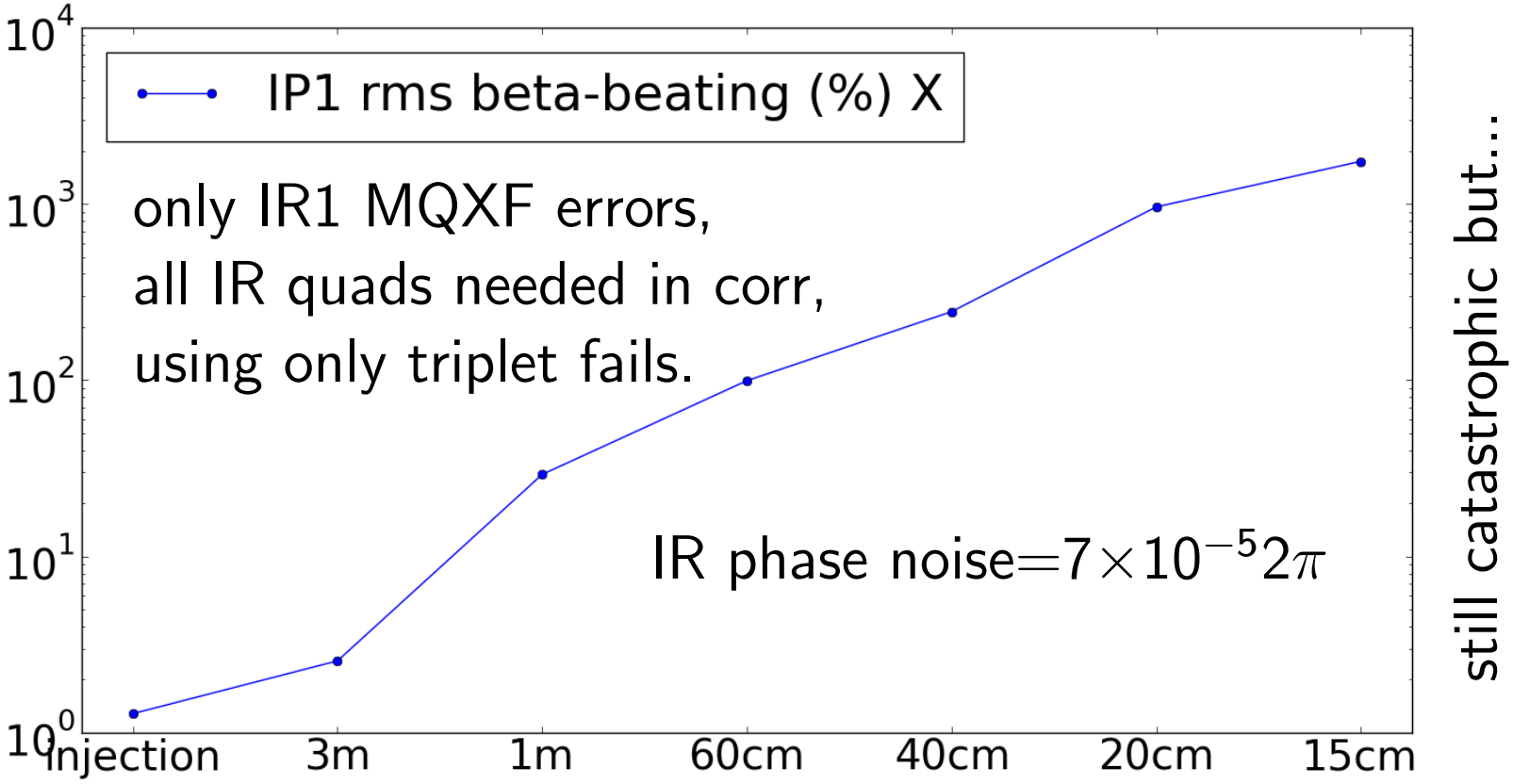
IR BPM resolution



IR BPMs feature slightly better resolution/noise than arc BPMs thanks to the larger β function.

Improved local correction simulations

Simulating corrections along the squeeze avoids Twiss failure. Let's add little phase noise



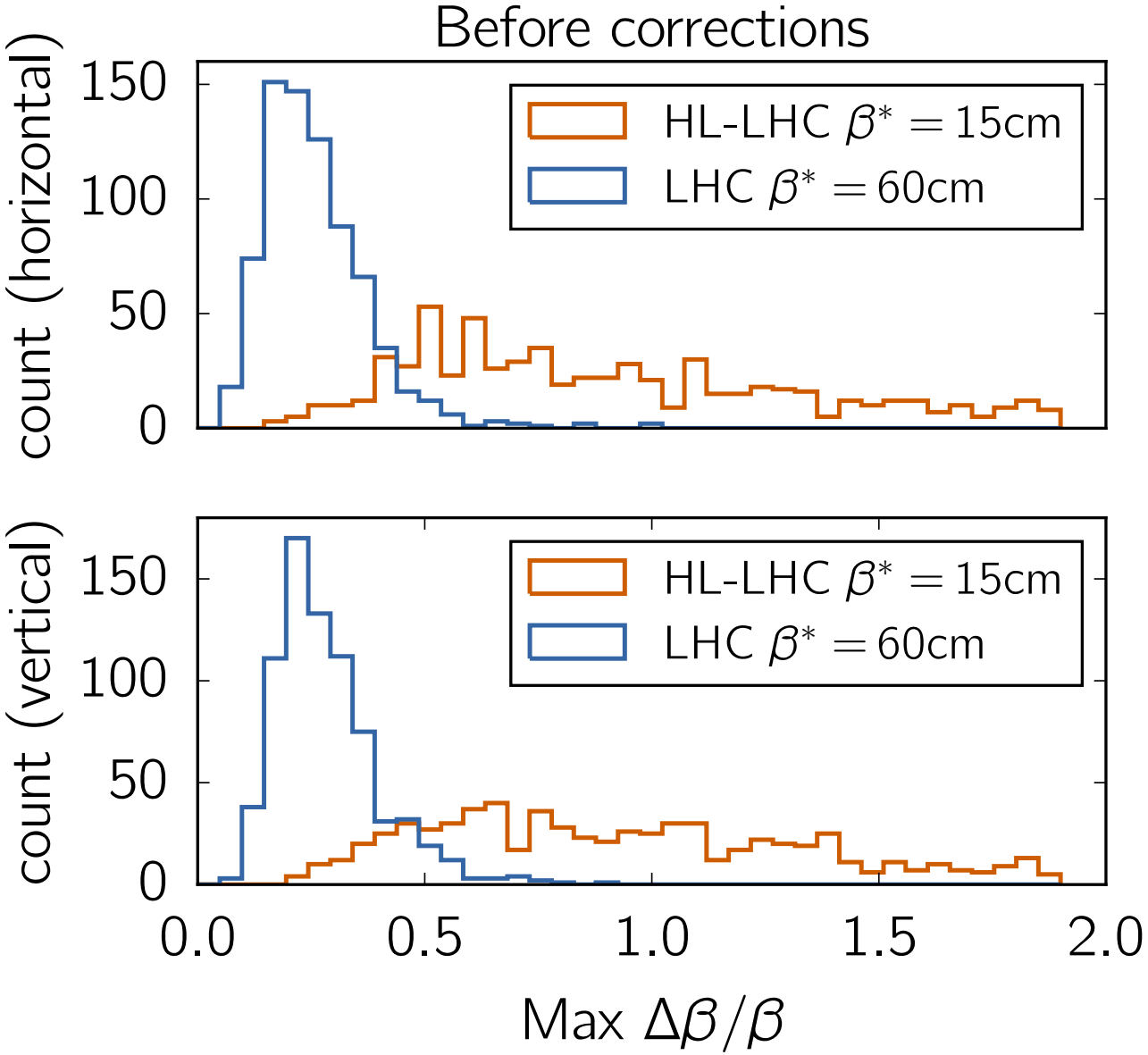
Further progress needed: Simultaneous corrections (instead of sequential), using K-modulation info, BPM amplitude info, etc.

Error table for global corrections

longitudinal quadrupole misalignment 6mm
transverse sextupole misalignment 1mm
dipole b_2 errors as tabulated

Quadrupole	**Error relative to their main field (10^{-4})**	
MQ	14	
MQM	12	
MQY	7	
MQXA/B	2	
MQW	16	
MQT	73	
MQXF	**2**	*optimistic local corr*
MQYY	10	
MQYL	7	

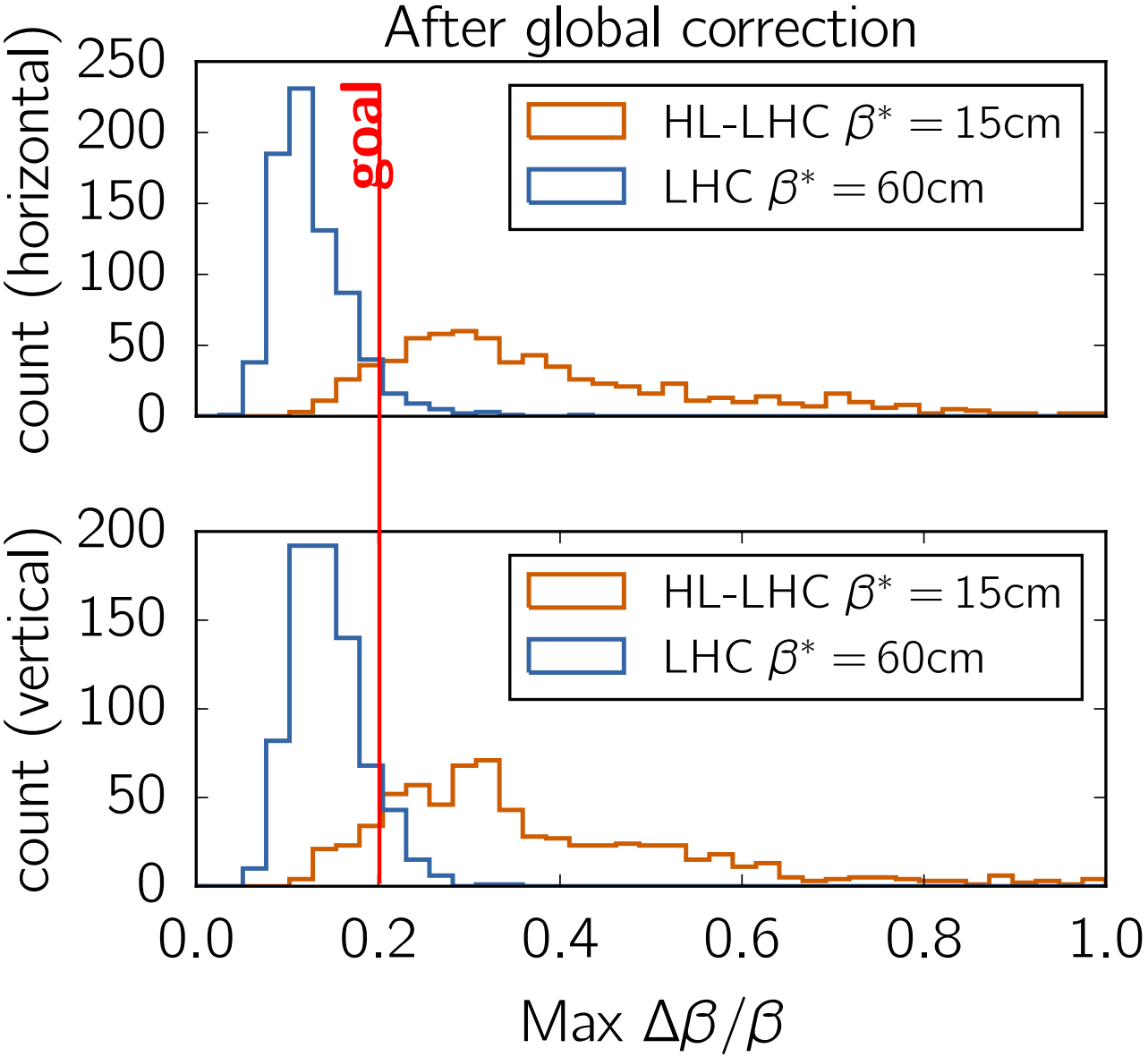
β-beating simulations before global corrs



Almost 200% β-beating...

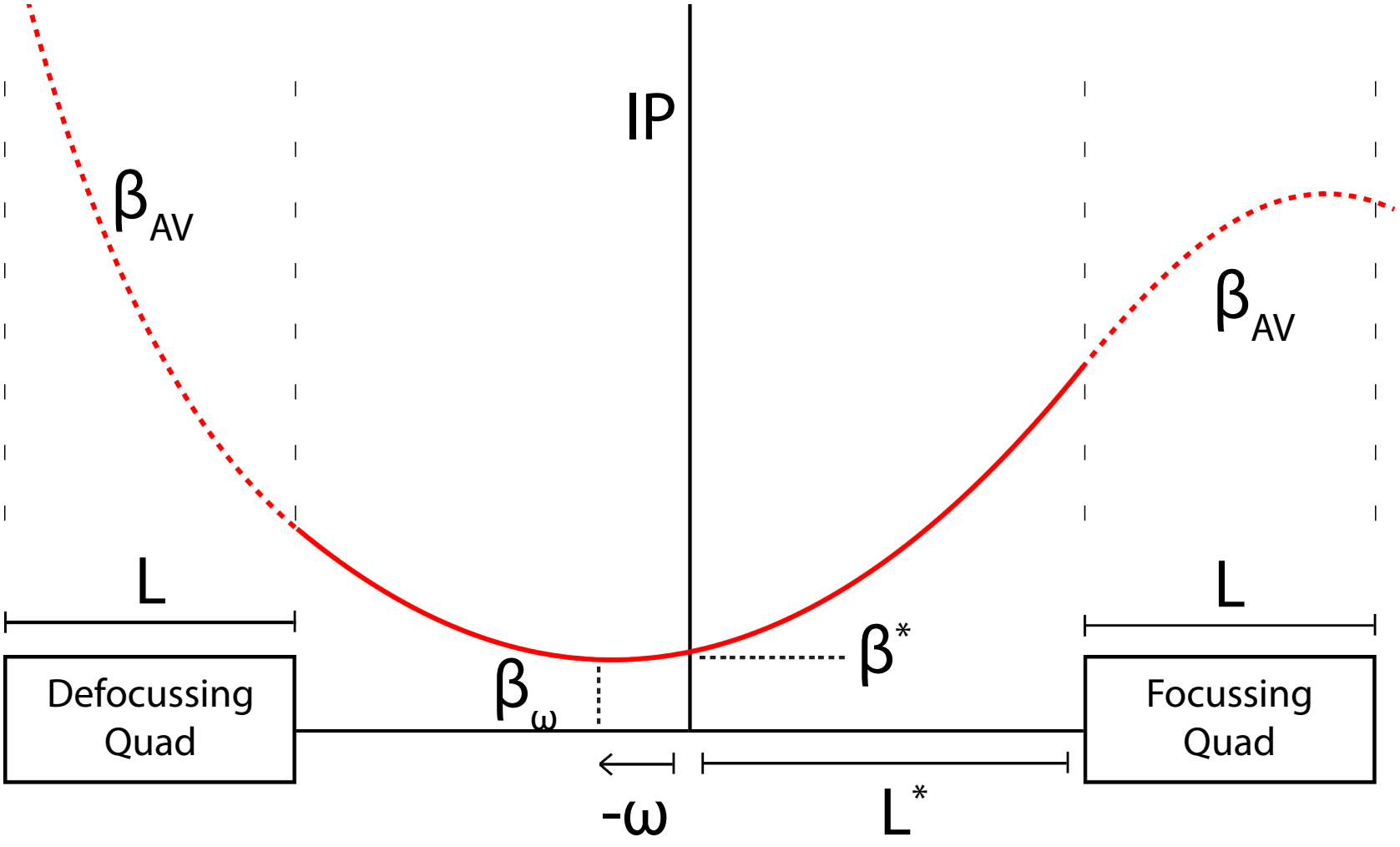
...is it possible?

Global correction simulations (1 iteration)

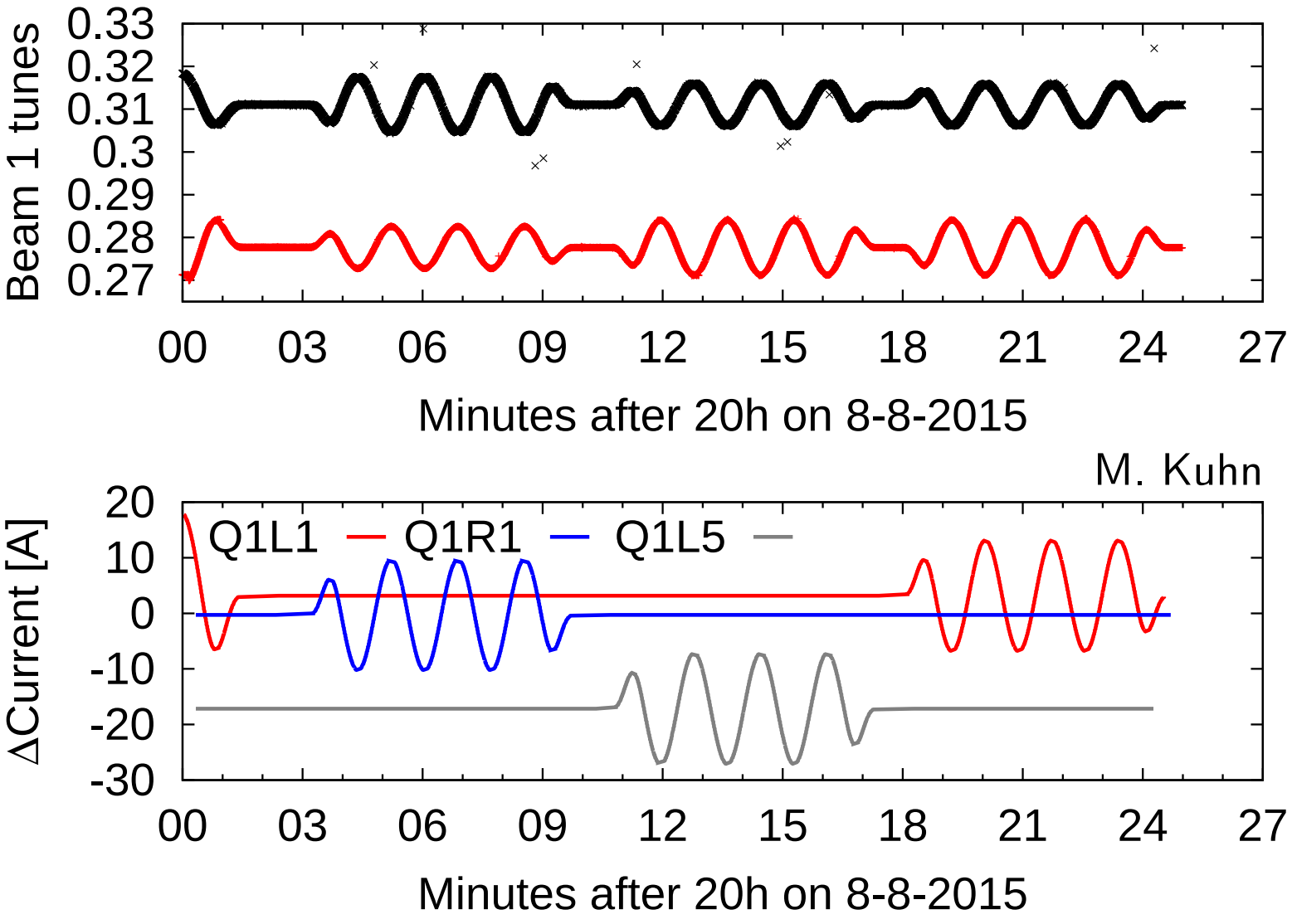


HL-LHC global corrections also harder than LHC

K-modulation



LHC K-modulation - sine example



After fitting, tune shift resolution close to 10^{-5}.

Tune jitter from triplets

M. Fitterer

(LHC baseline 0.25×10^{-4})

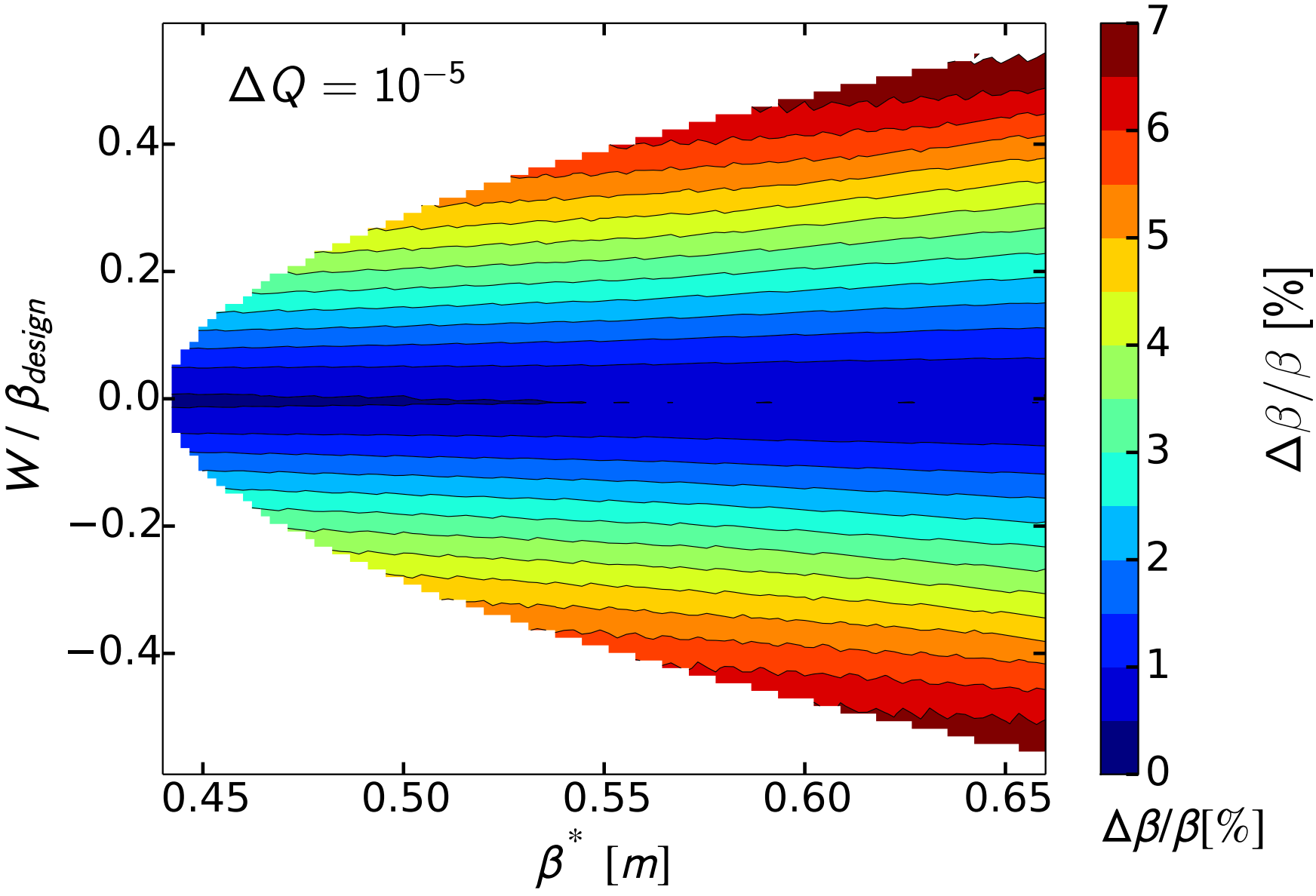
HL-LHC	rms((Q_z-Q_{z0})) [10^{-4}]			
	round	flat	sround	sflat
IT Baseline	1.37	1.98	2.05	2.97
IT Q1-Q2-Q3	0.67	0.98	1.03	1.46
IT Q1-Q2a Q2b-Q3	0.55	0.79	0.83	1.19

Lowest rms tune jitter expected for HL-LHC at β^*=15cm is 5.5×10^{-5} $\rightarrow$ Poor tune measurement!

Spectra of LHC IT quads have been requested to study possible filters.

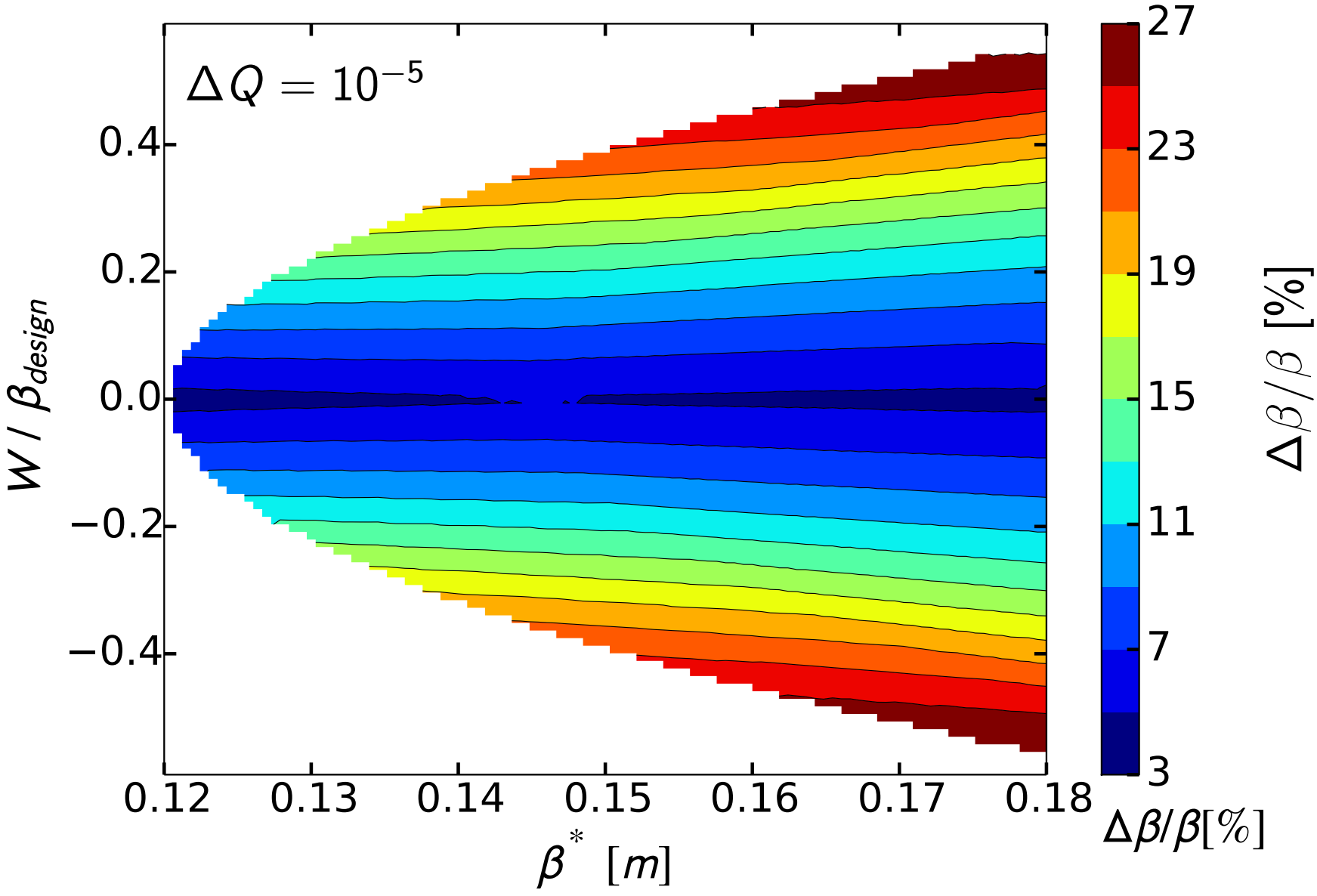
Let's assume 10^{-5} tune resolution for HL-LHC

β^* resolution - LHC simulations



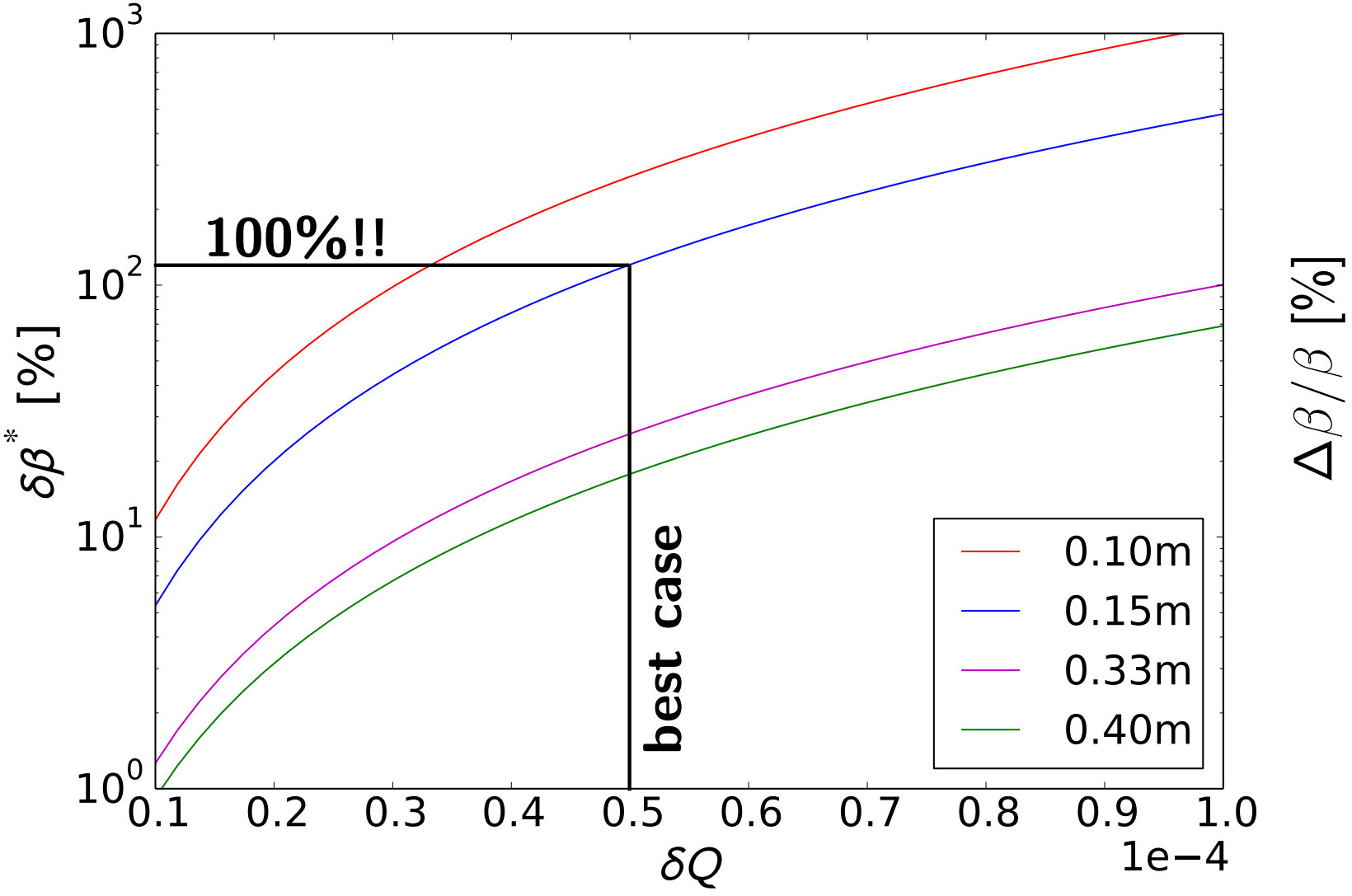
β^* resolution very sensitive to actual waist

β^* resolution - HL-LHC simulations

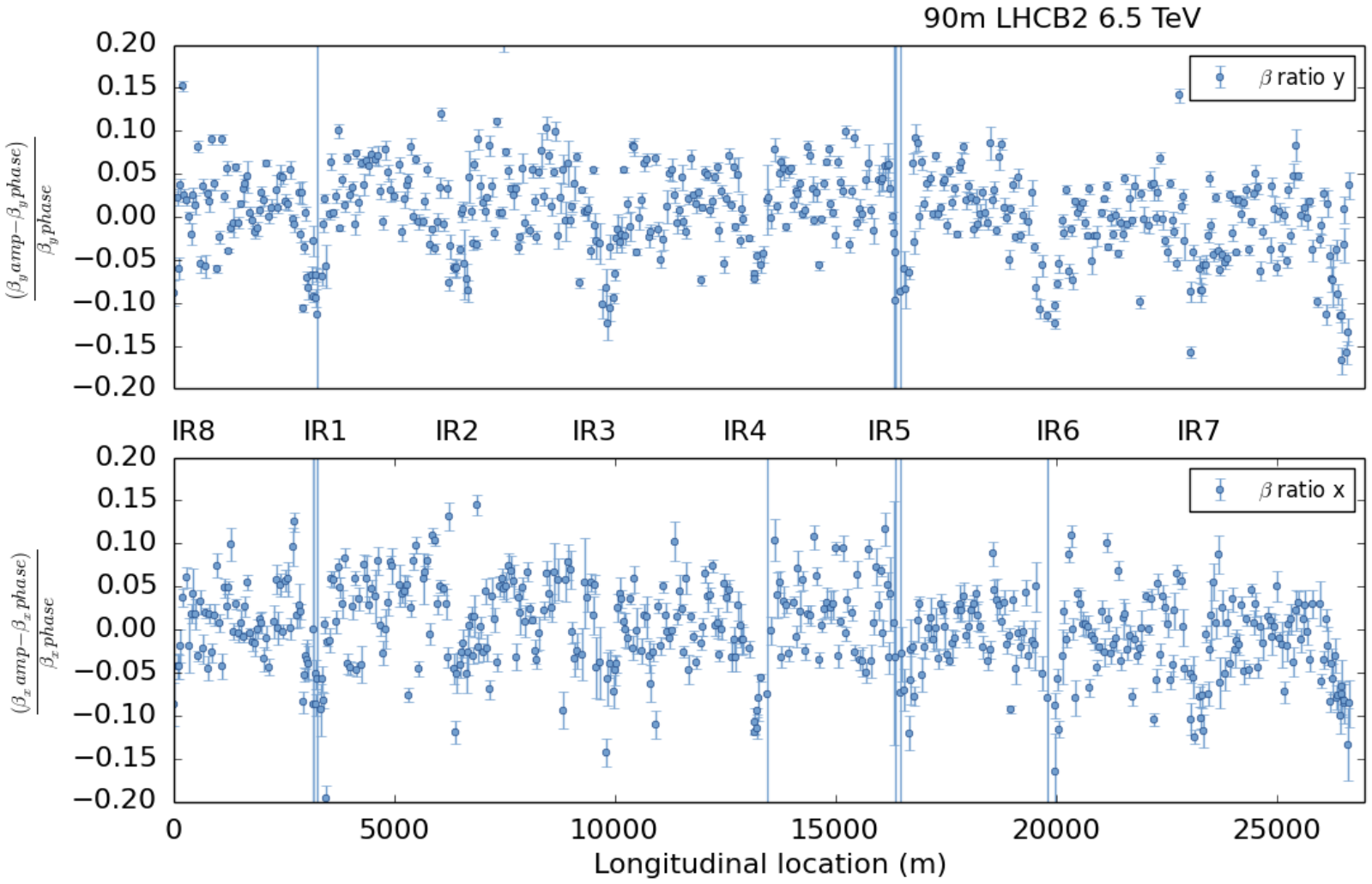


HL-LHC is harder than LHC

β^* resolution Vs tune resolution (including fringe fields)



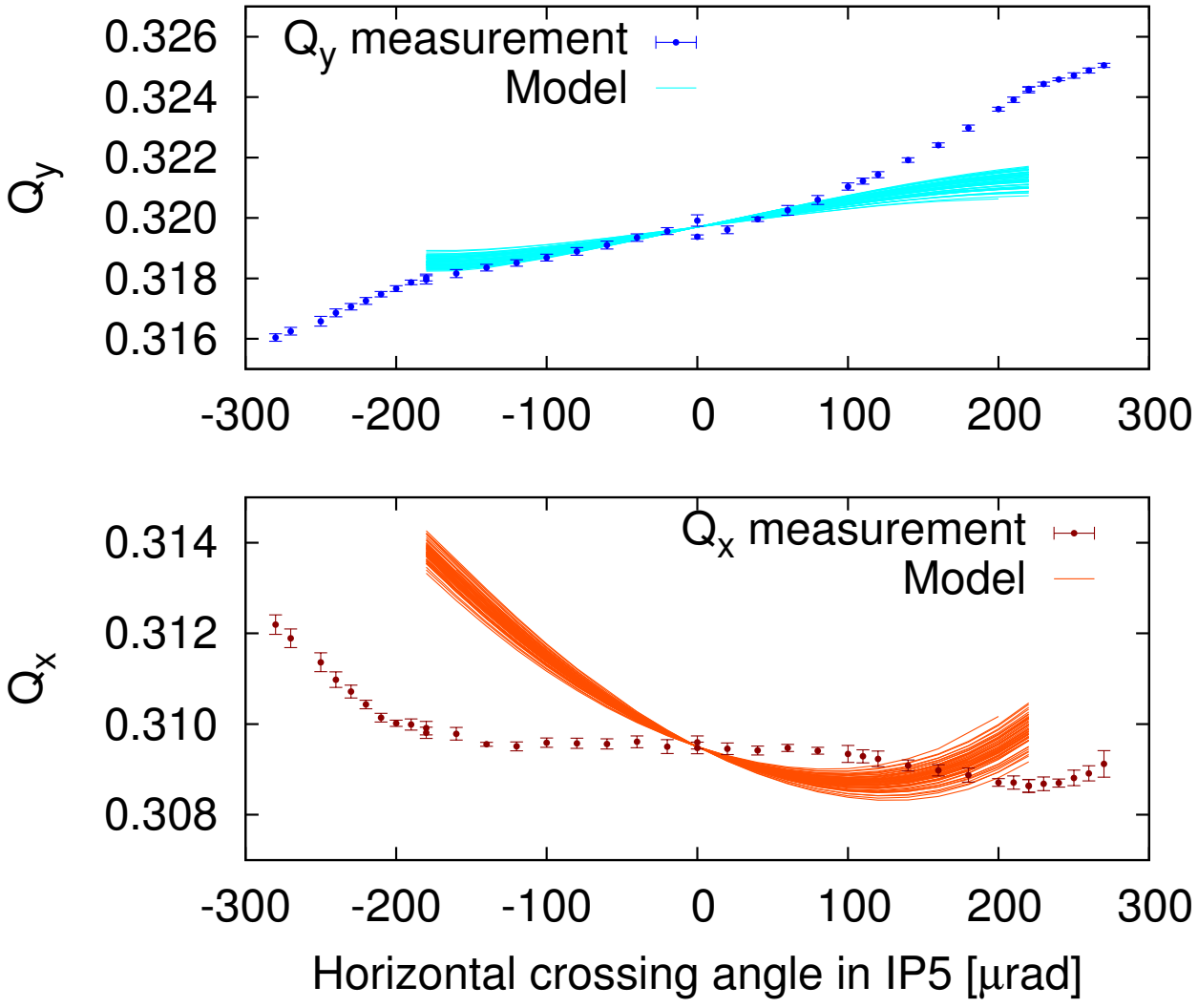
Using amplitude info from BPMs



missing key BPMs for β^* meas, etc.)

Currently up to 20% error in β from amp. Beam-based calibration might be possible but with caveats (Int., rep.,

IR non-linearities, LHC 6.5 TeV, $\beta^* = 40$ cm, IR5

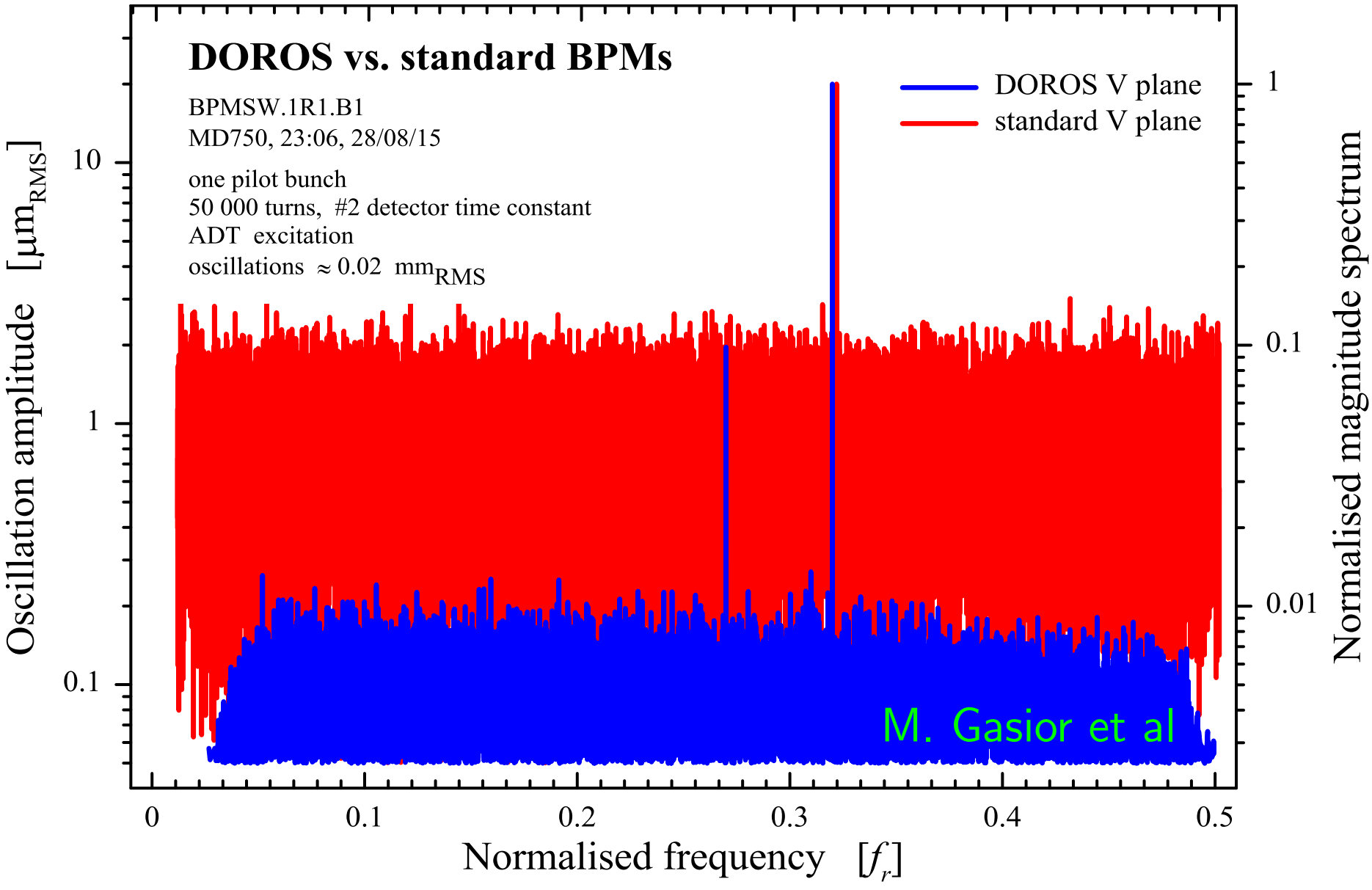


IR non-linear correction assumes knowledge of magnetic errors **but** beam measurements disagree with model predictions.

Need beam based modeling, R&D with other techniques (RDTs, amp. det. and DA measurement)

MD tests next week

DOROS - The BPMs of the future



Summary

- ★ β^* leveling:
  - A lumi reduction of at least 2%
  - A large number of high quality optics
- ★ 15% β-beating from beam-beam!!
- ★ Actual machine jitter will limit optics measurement resolution (AC dipole and K-modulation)
- ★ HL-LHC optics control is at least one order of magnitude harder than for LHC
- ★ **We need R&D to guarrantee high quality linear and non-linear optics in HL-LHC.**
- ★ Full commissioning might be spread over ≈3 years