Impedance and instabilities

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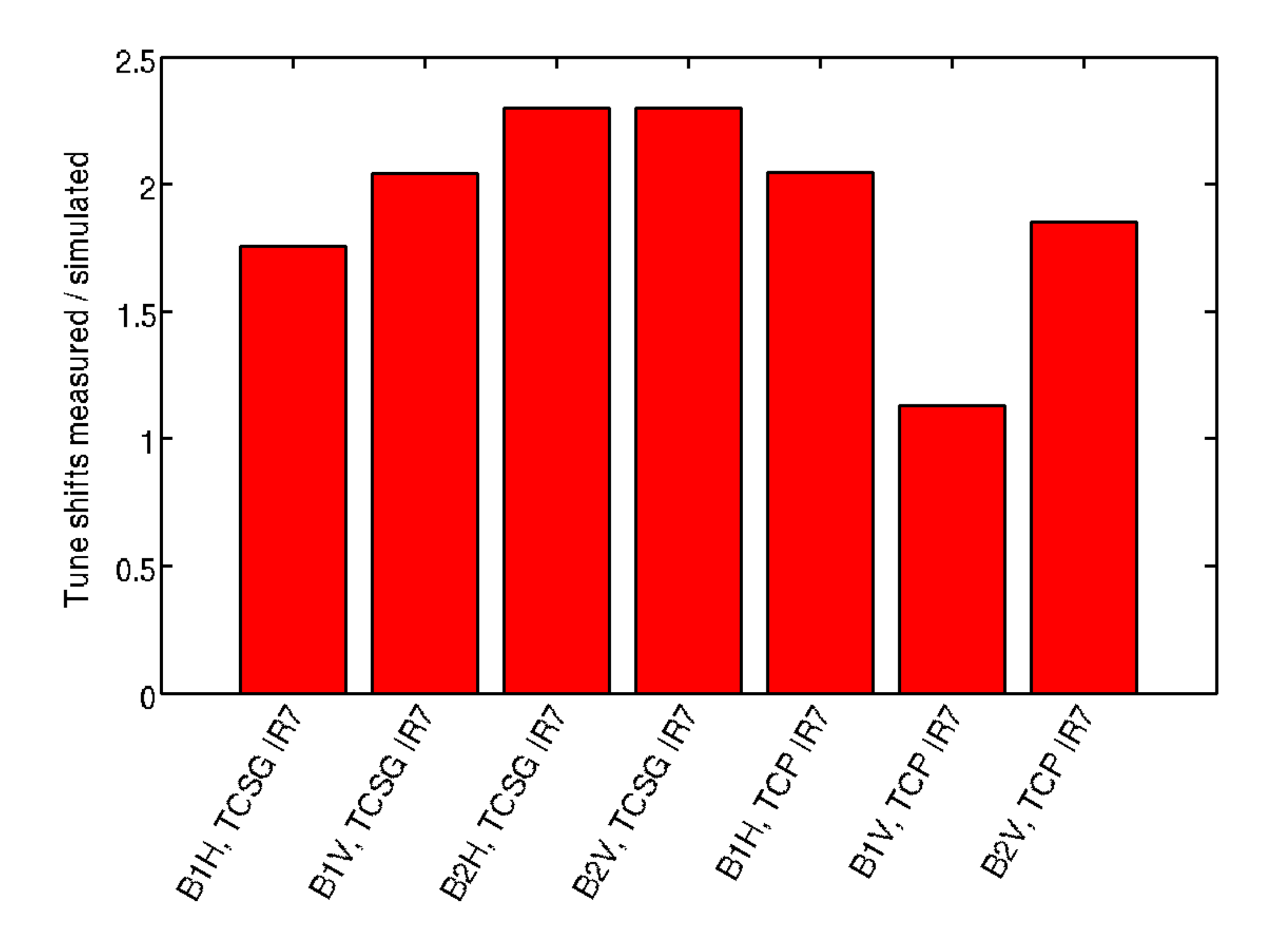
Acknowledgements: G. Arduini, D. Astapovych, H. Bartosik, J. Esteban-Müller, O. Frasciello, M. Giovannozzi, W. Höfle, G. Kotzian, K. Li, A. Mostacci, S. Redaelli, G. Rumolo, B. Salvachua, R. Tomàs, S. Tomassini, G. Valentino, D. Valuch, R. Wanzenberg, S. White, O. Zagorodnova, C. Zannini, M. Zobov.

Impedance and instabilities

- Summary of observations and updated comparisons with LHC impedance model.
- Effect of optics change in IR4 & IR8.
- Impact of bunch length.
- Stability limits for several collimator scenarios.
- Can we do better ?
- Conclusions.

Collimator impedance: old model (RW only)

- Collimator tune shift measurements (compared with resistive-wall impedance model + HEADTAIL)



Discrepancy factor with model is ~2 for the tune shifts at low chromaticity.

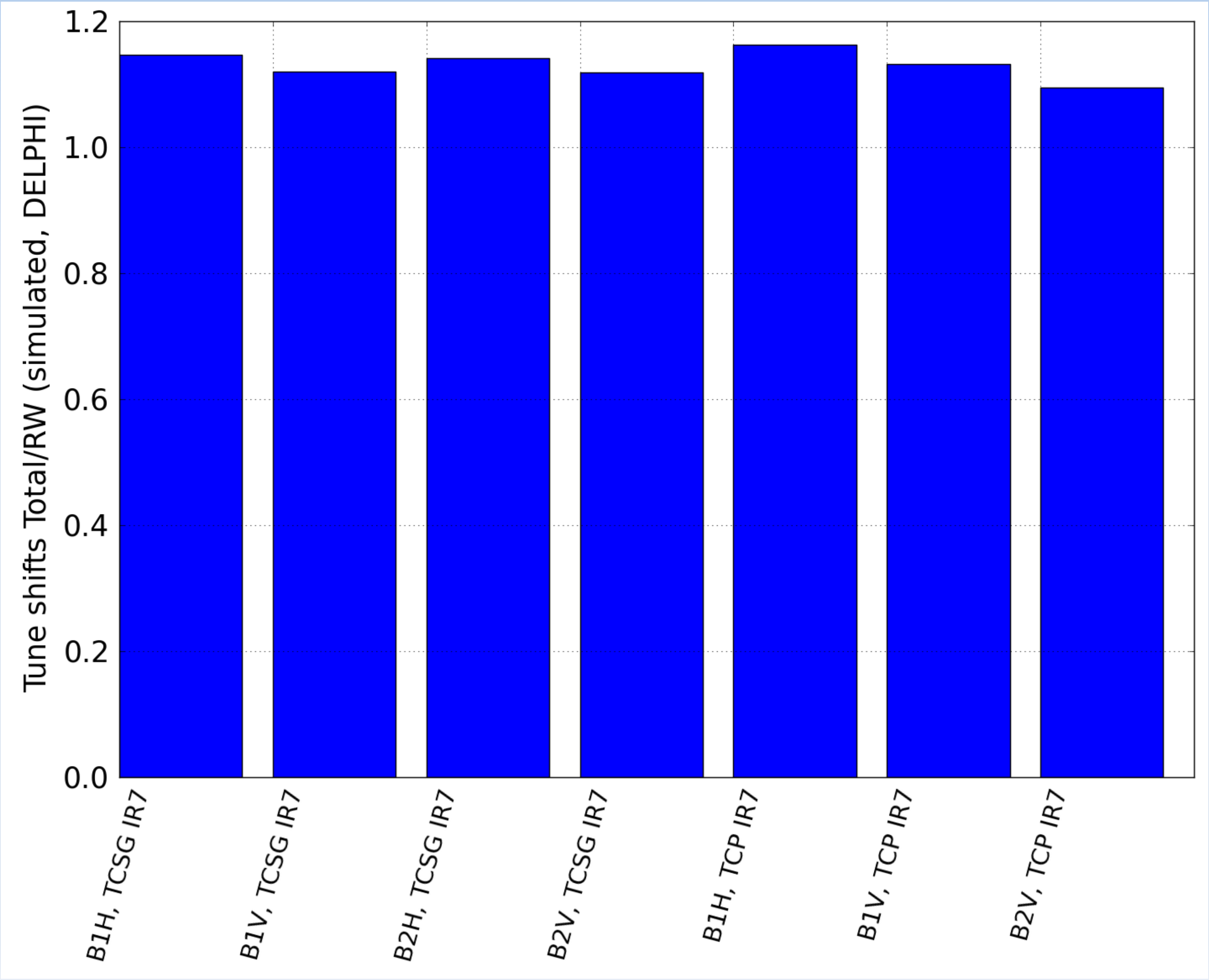
IPAC'13, TUPWA047

Refining the LHC impedance model

- Updates / additions to the LHC model:
  - geometric impedance of collimators re-evaluated from Stupakov formula (pessimistic, maybe by factor 2), geometric wake function directly from GdFidl computations (M. Zobov & O. Frasciello - INFN),
  - refine resistive-wall impedance of beam screens and warm vacuum pipe, including NEG for the latter, effect of weld for the former (C. Zannini),
  - pumping holes impedance re-evaluated thanks to S. Kurennoy formula & A. Mostacci,
  - details of the triplet region (tapers – Yokoya formula, BPMs from B. Salvant),
  - Broad-band and high order modes of RF cavities (E. Haebel et al, CERN sl-98-008), CMS (R. Wanzenberg, LHC Project Note 418), ALICE and LHCb experimental chambers (B. Salvant).
  - Cutoff frequency of all broad-band resonators ”artificially” put to a very high value (50 Ghz), to avoid ”dip” in the wake at ~5cm.

Impact of collimators geometric impedance

- Tune shifts increase due to the geometric impedance:



From Stupakov formula (thanks to *M. Zobov & O. Frasciello*) for geometric impedance.

Tune shifts from DELPHI Vlasov solver.

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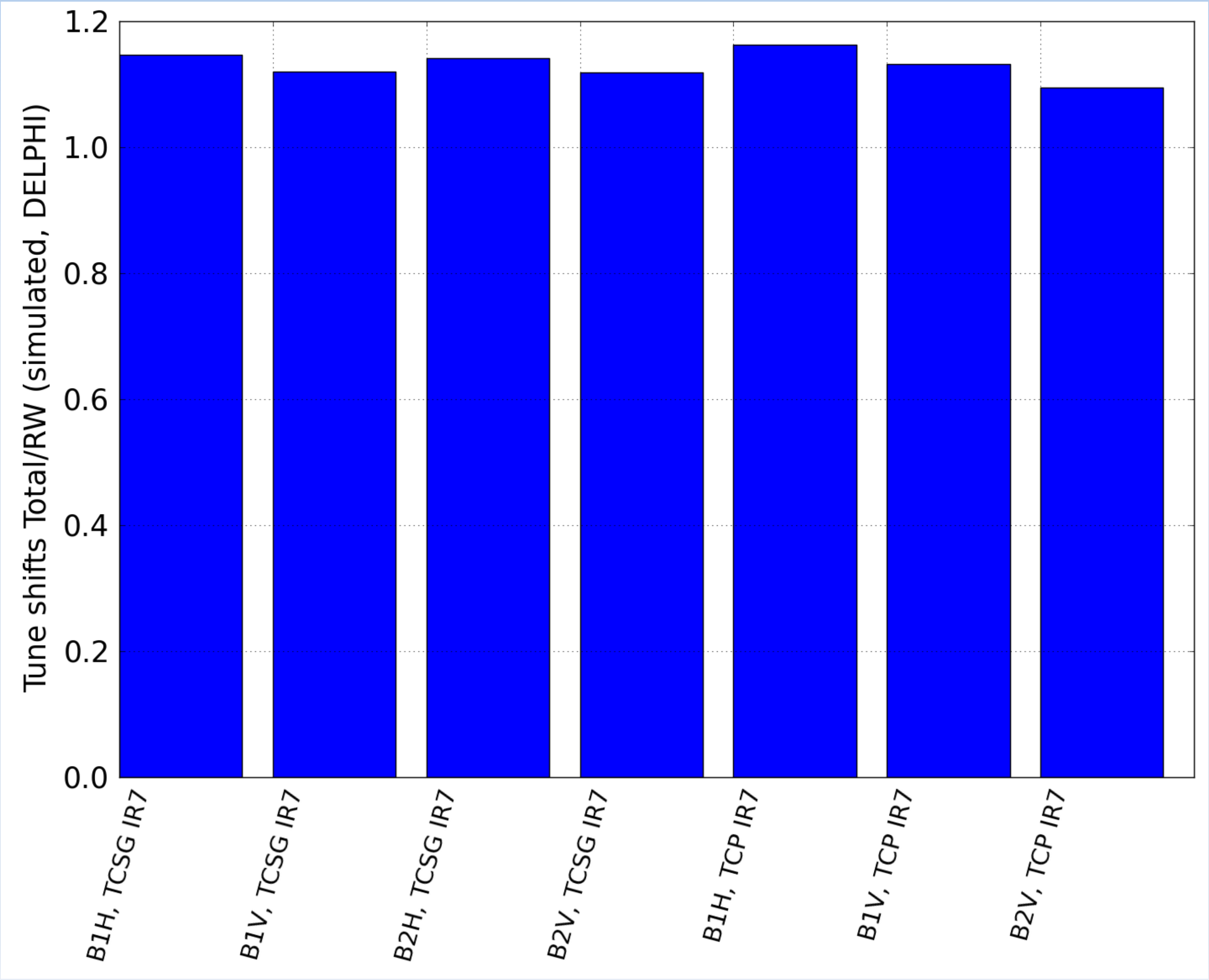


From Stupakov formula (thanks to *M. Zobov & O. Frasciello*) for geometric impedance.

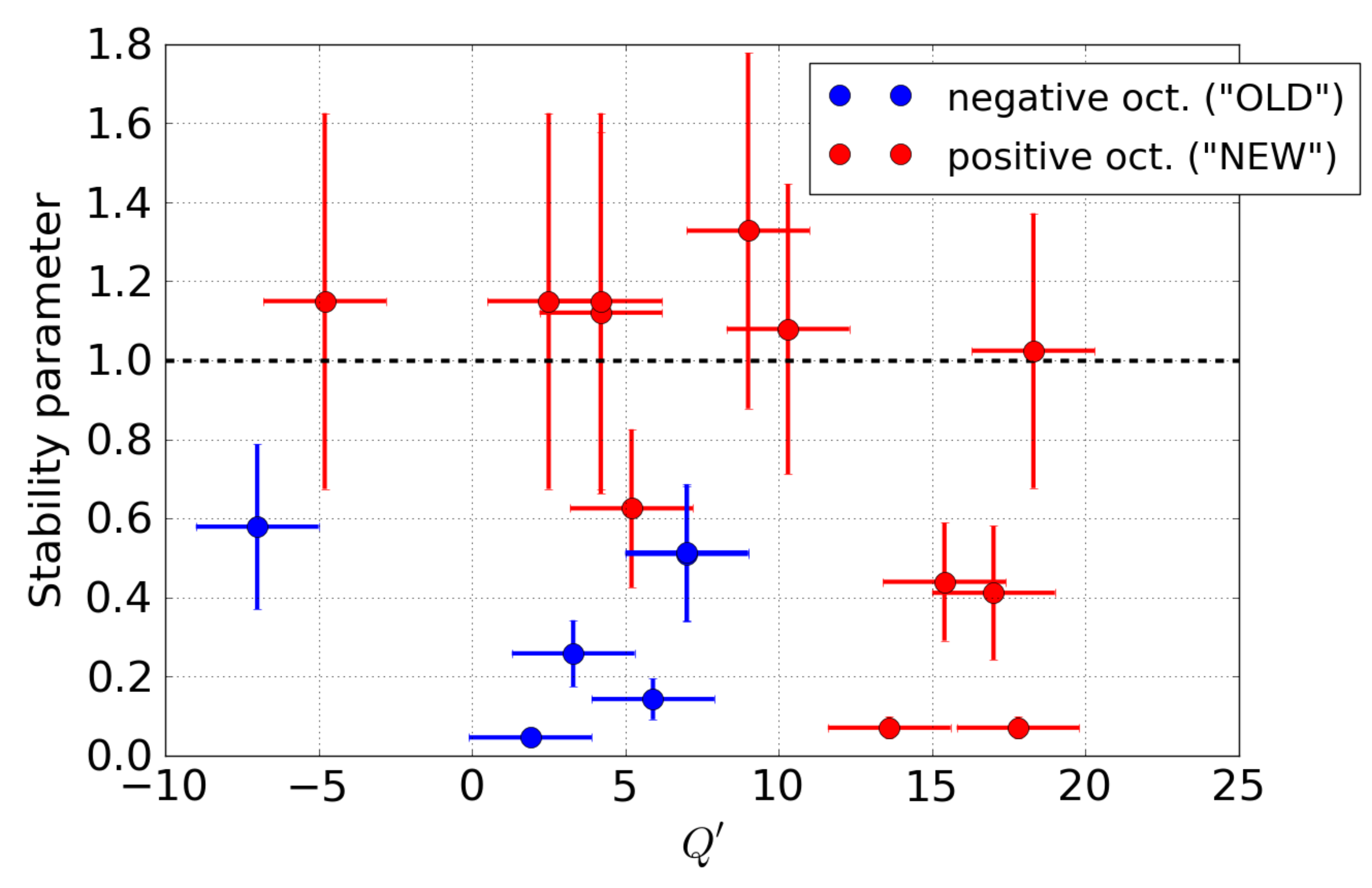
Tune shifts from DELPHI Vlasov solver.

→ effect of geometric impedance: at most 15-20%.
→ potential reduction of discrepancy w.r.t. measurements.

But pb: some systematic difference between Vlasov solver and HEADTAIL observed → ongoing convergence study by D. Astapovytch.

Single (and separated) beam stability in 2012: summary

- ”Stability parameter” µ Oct * emittance / intensity, vs Q' (higher means worse for stability):



Note: damper gain variation neglected & assume no blow-up after ramp.

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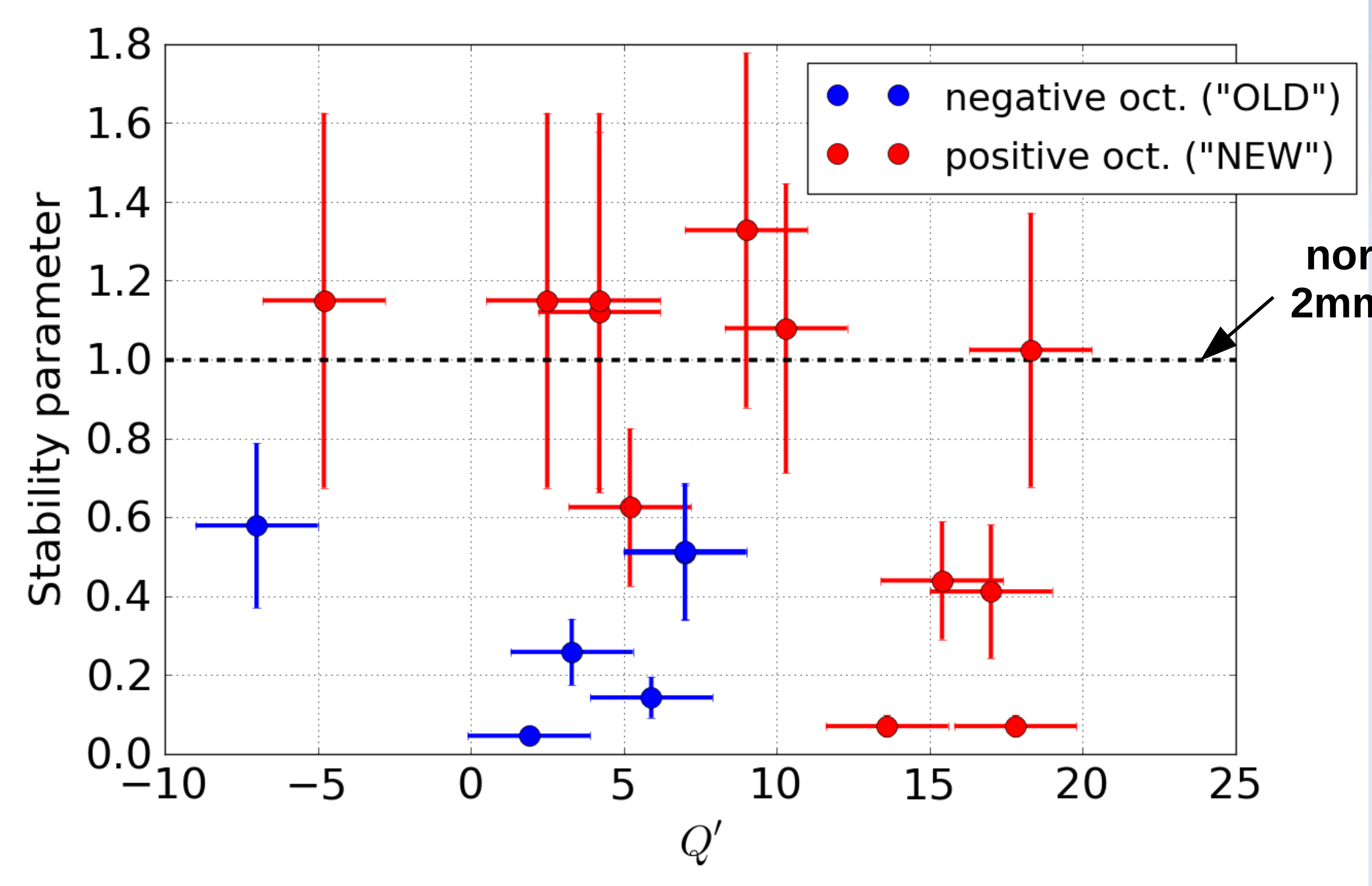

normalized to 1 for 500 A, 2mm.mrad and 1.5e11 p+/b.

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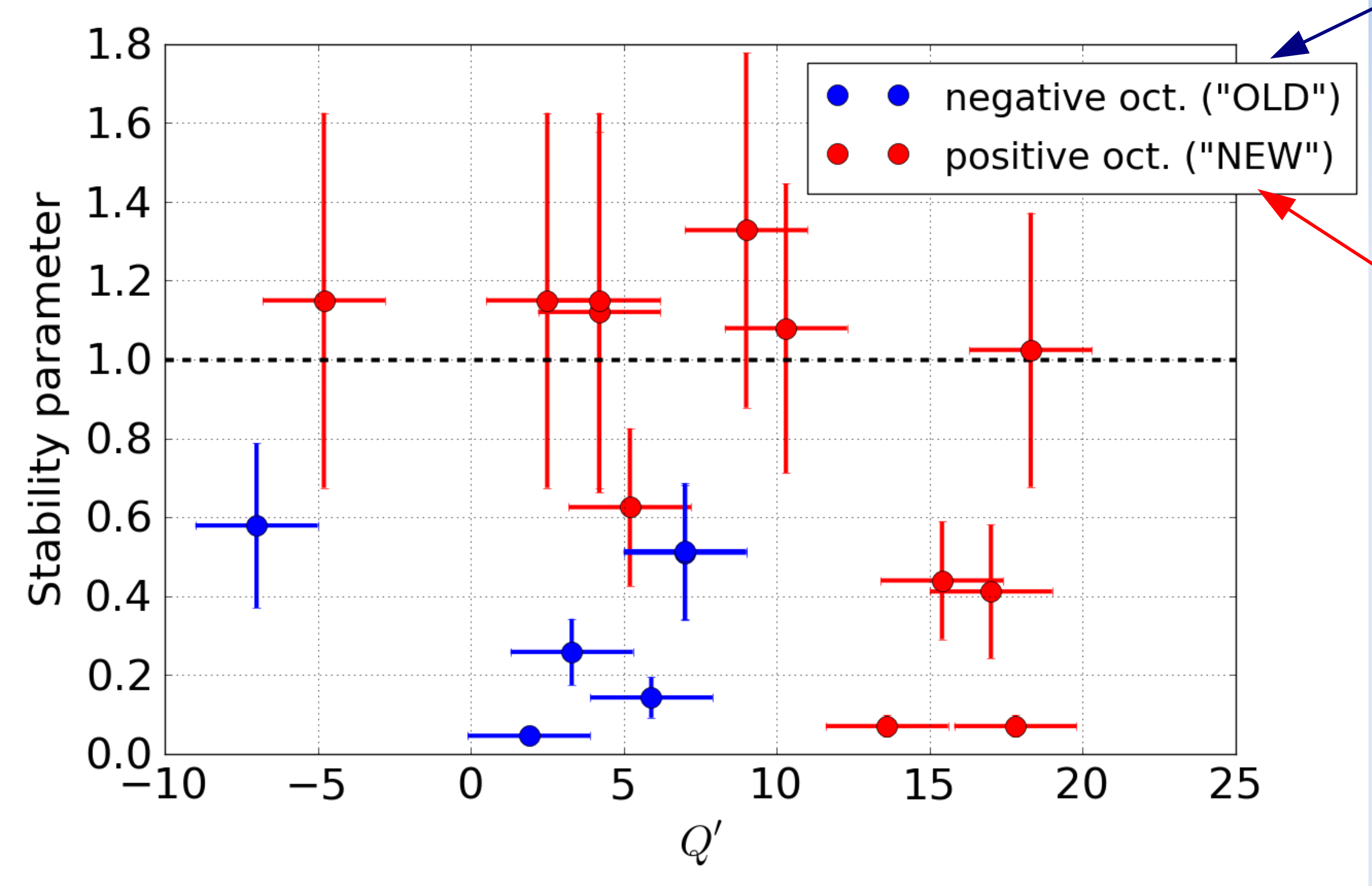

Octupole polarity used until Aug. 2012 (defocusing tunespread)

Octupole polarity used after Aug. 2012 (focusing tunespread)

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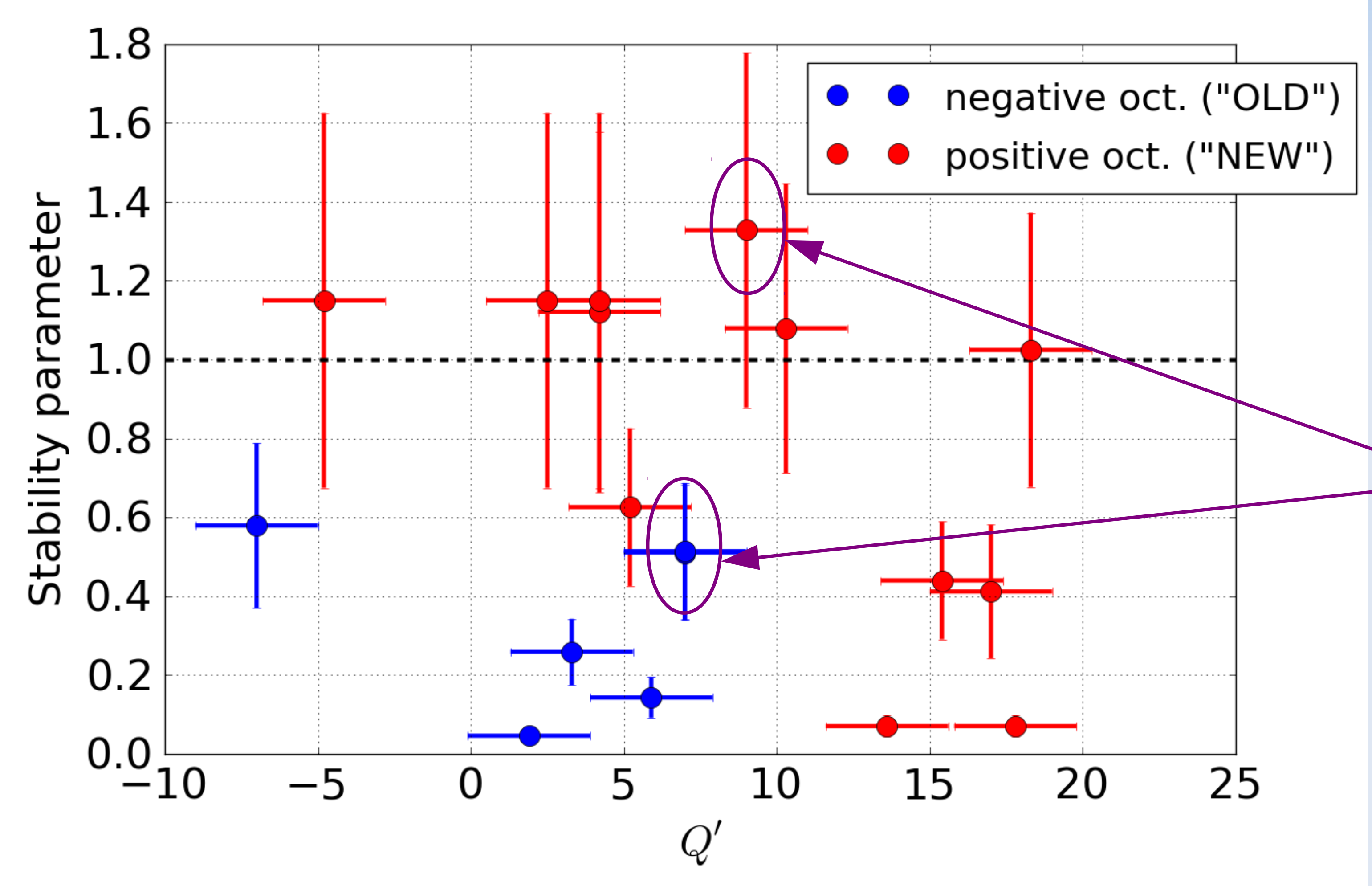

Observed at flat top during operation (G. Arduini, LMC 15/08/2012)

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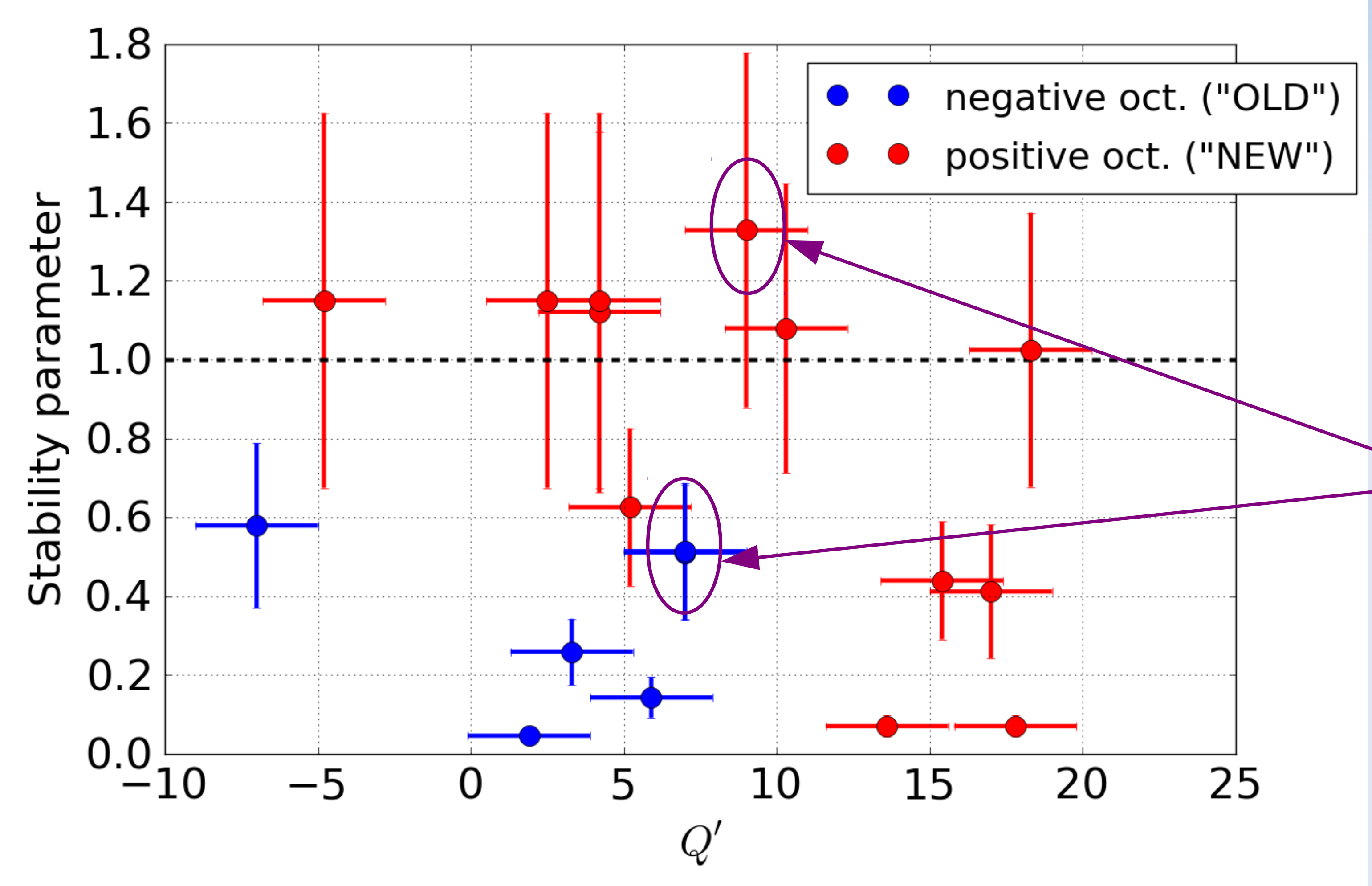

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→ large difference between negative and positive octupole polarity

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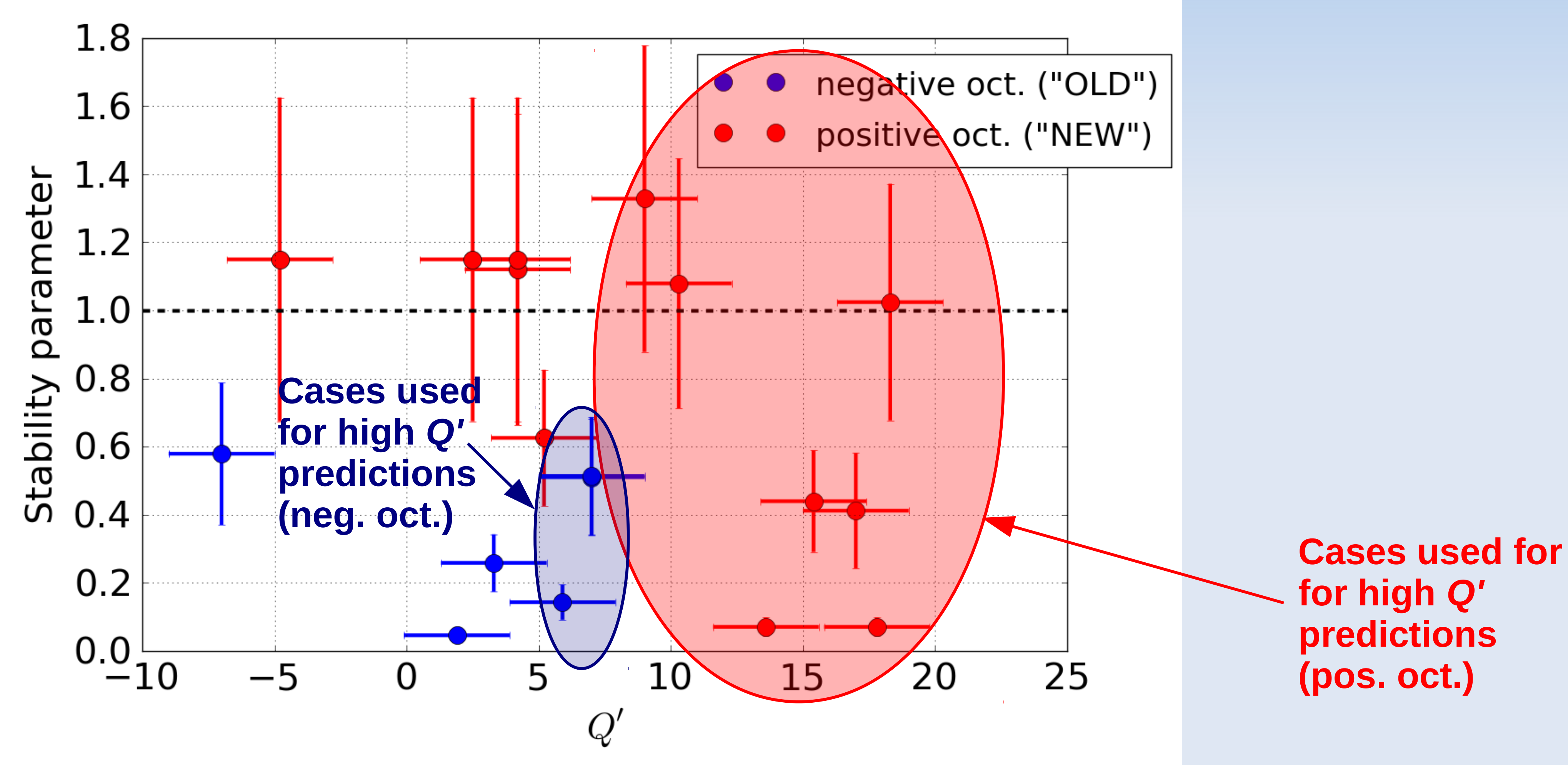
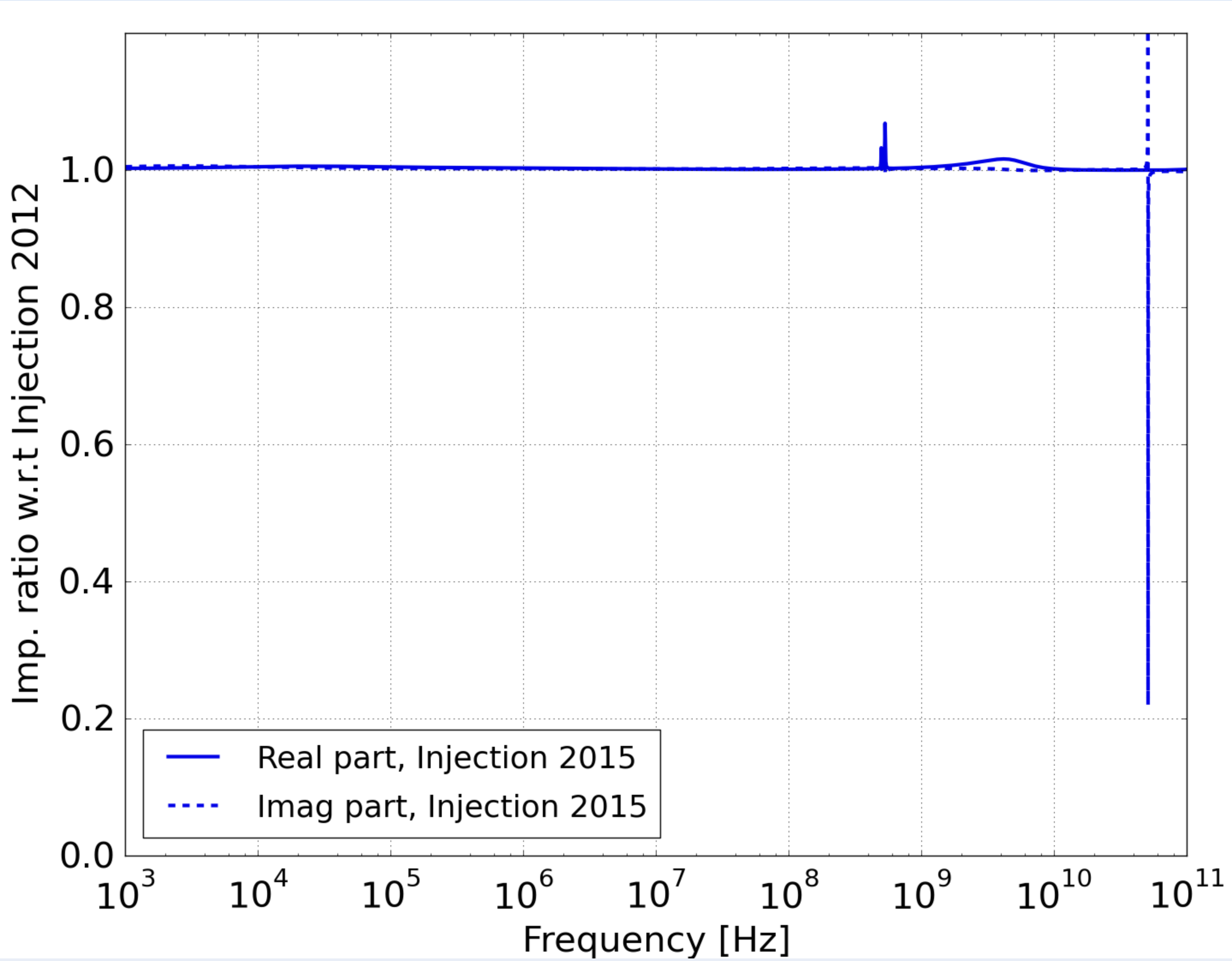


→ large difference between negative and positive octupole polarity

Effect of optics change in IR4 & IR8

- At injection, ratio of 2012 vs. 2015 vertical dipolar impedances (only difference is from beta functions change in IR4 & IR8):

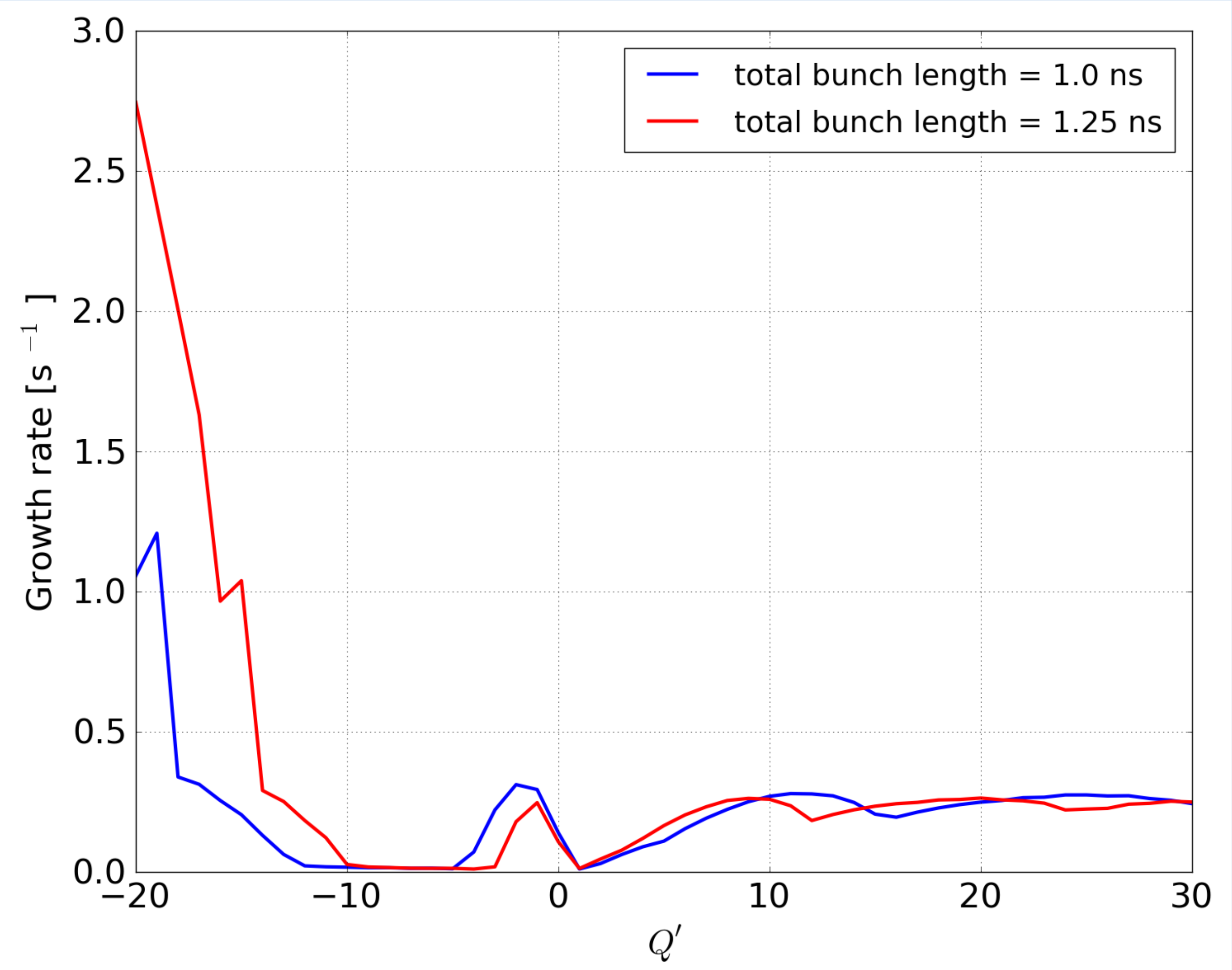


→ negligible effect of the optics change (as expected),

→ it is similar in horizontal.

Impact of bunch length

- At 6.5TeV, horizontal growth rates vs. chromaticity for different bunch lengths, for Q_s=1.83 10^{-3} (25ns, 1.3 10^{11} p+/b, damper 50 turns):



Obtained from the DELPHI Vlasov solver

→ small impact of bunch length for *Q'>0*.

It is similar in vertical.

Estimate of single-beam stability limits in 2015

- Strategy is based on 2012 observations but is slightly different from the one adopted until recently (which was considering only most pessimistic cases):
  - for each case considered in slide 6 (inside ellipses), beam assumed to be at the threshold of instability at 4TeV (with beam parameters measured at time of instability). Compute then "stability parameter" *F*

$$F = \frac{I_{oct} \cdot \varepsilon_{norm}}{E^2 \cdot \Im(\Delta Q_{coh})}$$

with $\Im(\Delta Q_{coh})$ imaginary tune shift of most critical mode, from DELPHI Vlasov solver

  - Compute the average value and standard deviation of all such *F* for the cases circled in slide 6, and assume that in 2015:

I_{oct} = +/- 570 A in the octupoles, *Q'=15 +/- 1,*

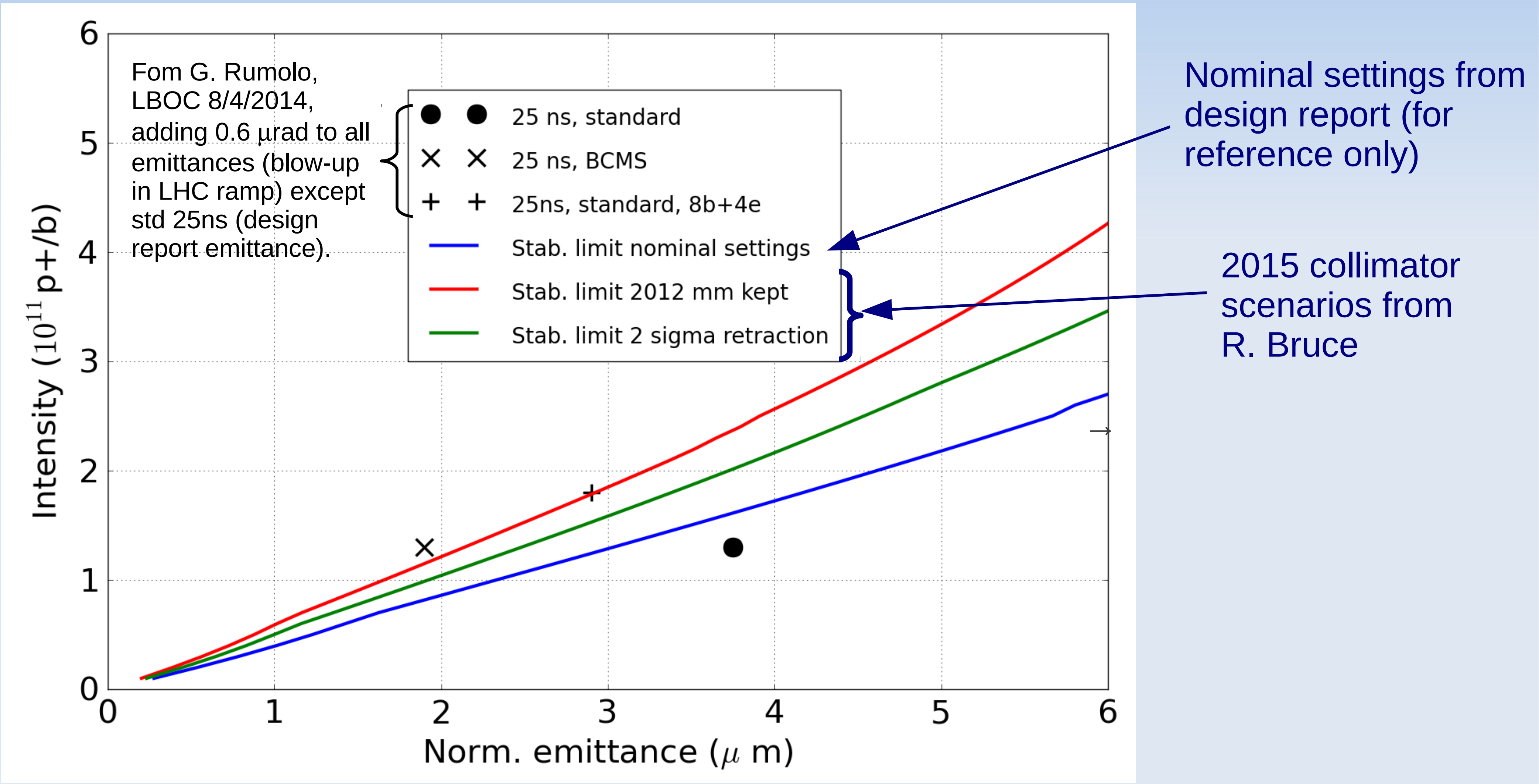
and at the threshold of stability we have the same "stability parameter" *F* as in 2012

→ this gives the imag. tune shift $\Im(\Delta Q_{coh})$ vs. norm. emittance ε_{norm} at the threshold, which is translated into N_b vs ε_{norm} through DELPHI computations.

  - **This procedure is very approximate and reflects our lack of reliable and reproducible measurements. Error bars are therefore very large.**

Estimate of single-beam stability limits for post LS1 LHC: octupole polarity>0 ("new")

- Intensity limit vs emittance for 25ns, with positive oct. polarity (6.5 TeV, 570A in octupoles, 50 turns damper, Q'~15, 1ns total bunch length): average values only



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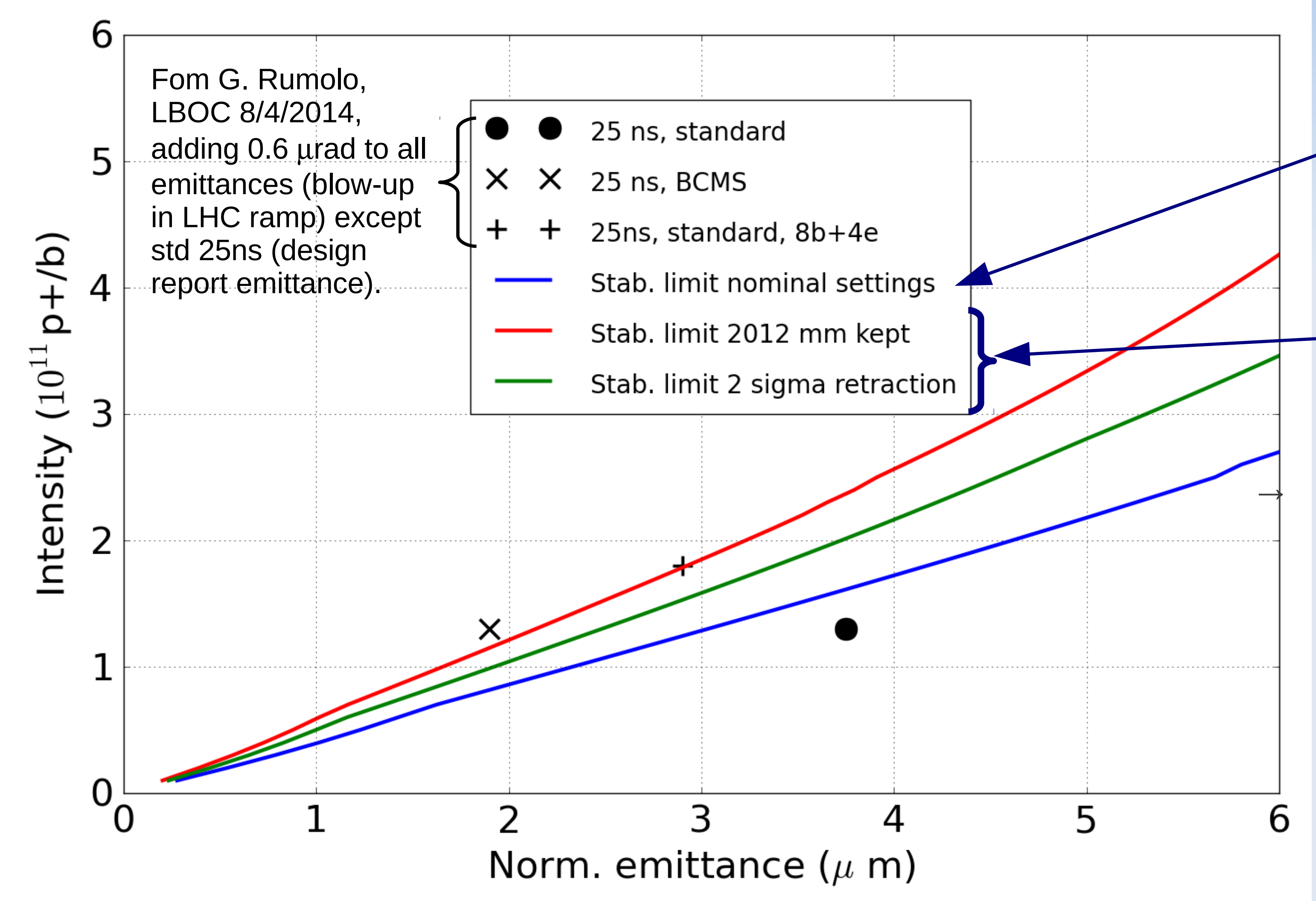


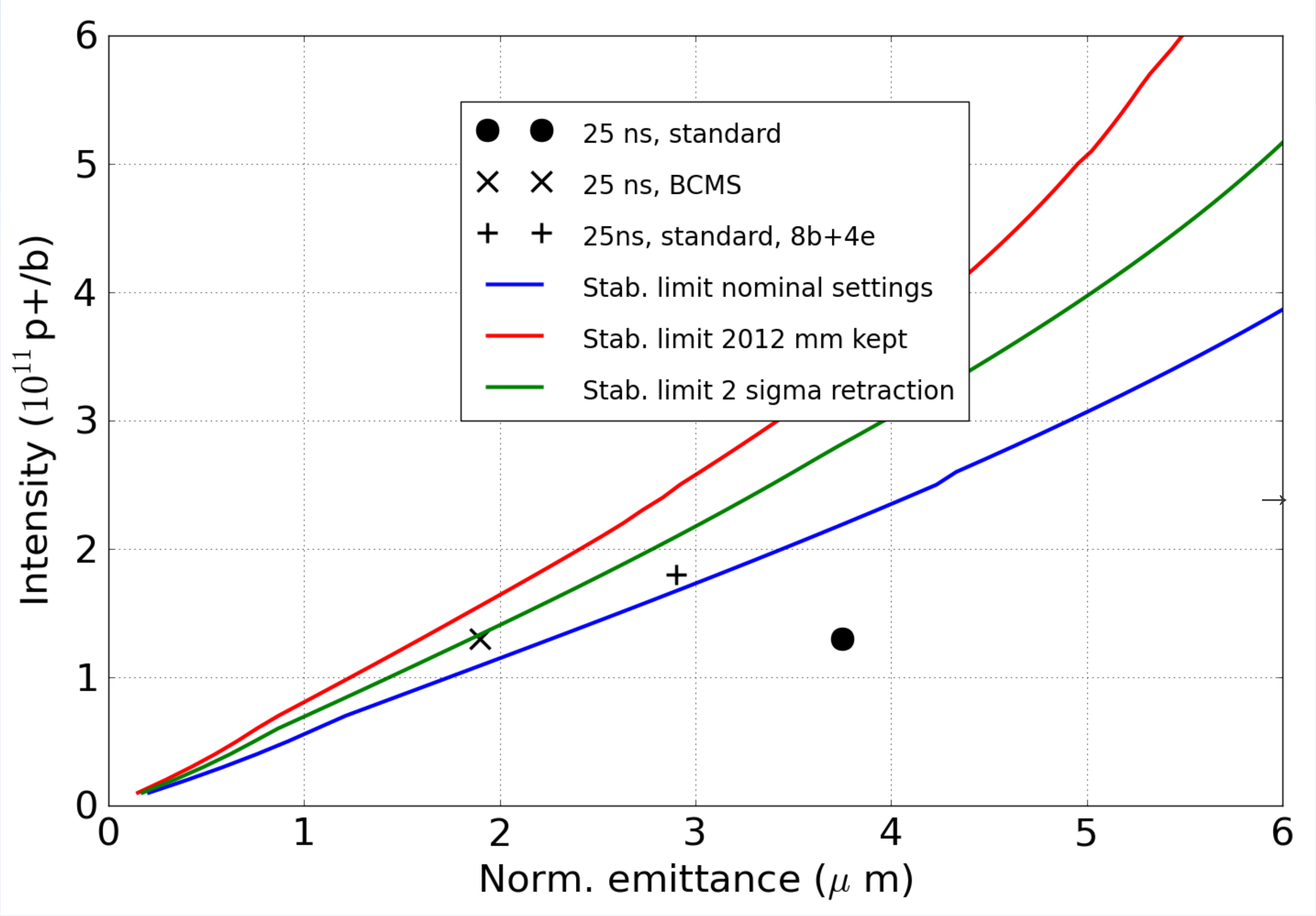
Nominal settings from design report (for reference only)

2015 collimator scenarios from R. Bruce

→ only standard 25ns beam should be stable with positive polarity.

Estimate of single-beam stability limits for post LS1 LHC: octupole polarity<0 (”old”)

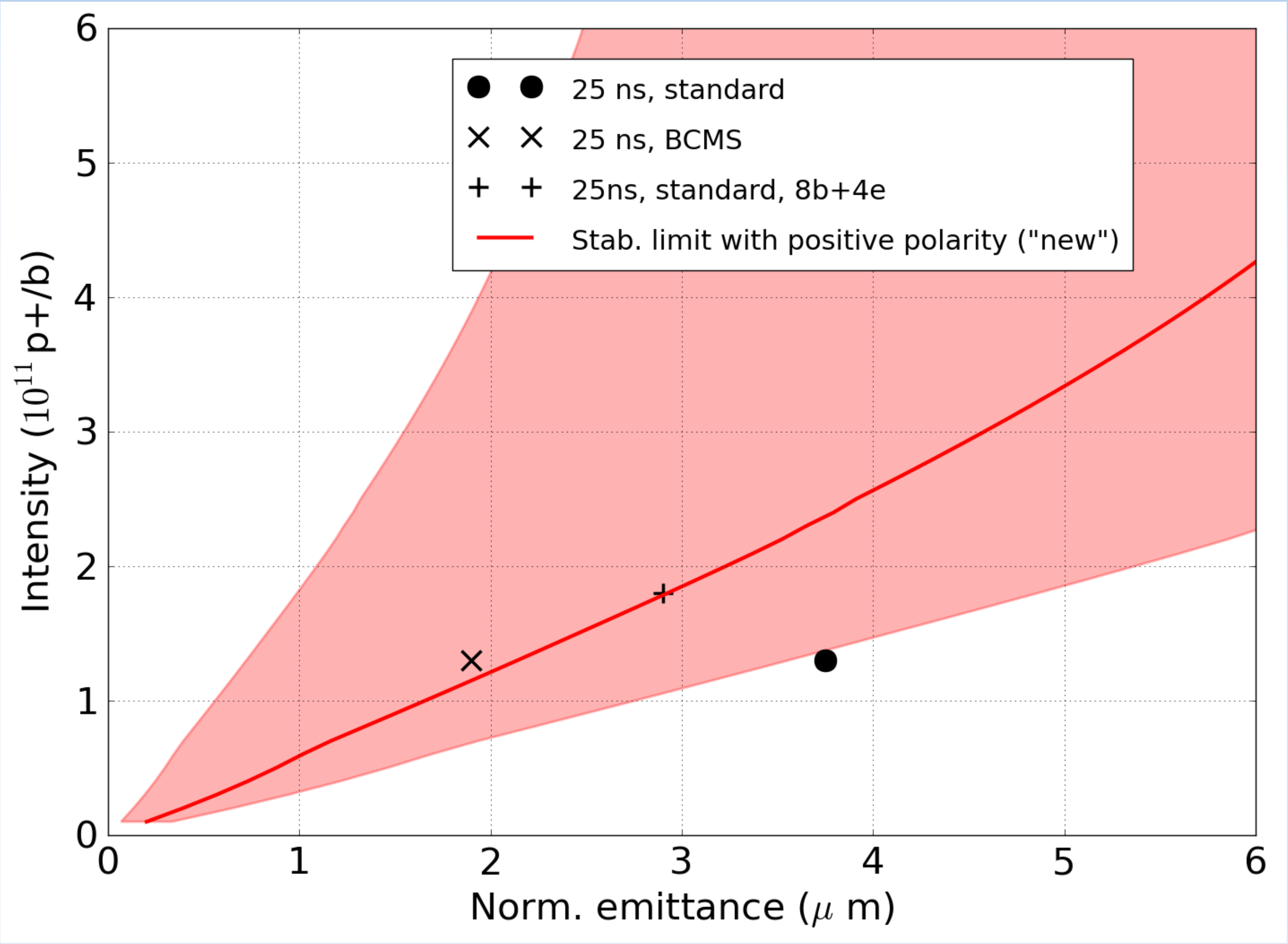
- Intensity limit vs emittance for 25ns, with negative oct. polarity (6.5 TeV, 570A in octupoles, 50 turns damper, Q'~15, 1ns total bunch length): average values only



→ all 25ns beams should be stable with negative polarity, in the 2 foreseen scenarios (but 25ns BCMS marginally stable in ”pushed” scenario).

Estimate of single-beam stability limits for post LS1 LHC with error bars

- Intensity limit vs emittance for 25ns (6.5 TeV, 570A in octupoles, 50 turns damper, Q'~15, 1ns total bunch length), for "2012 mm kept" collimator settings:



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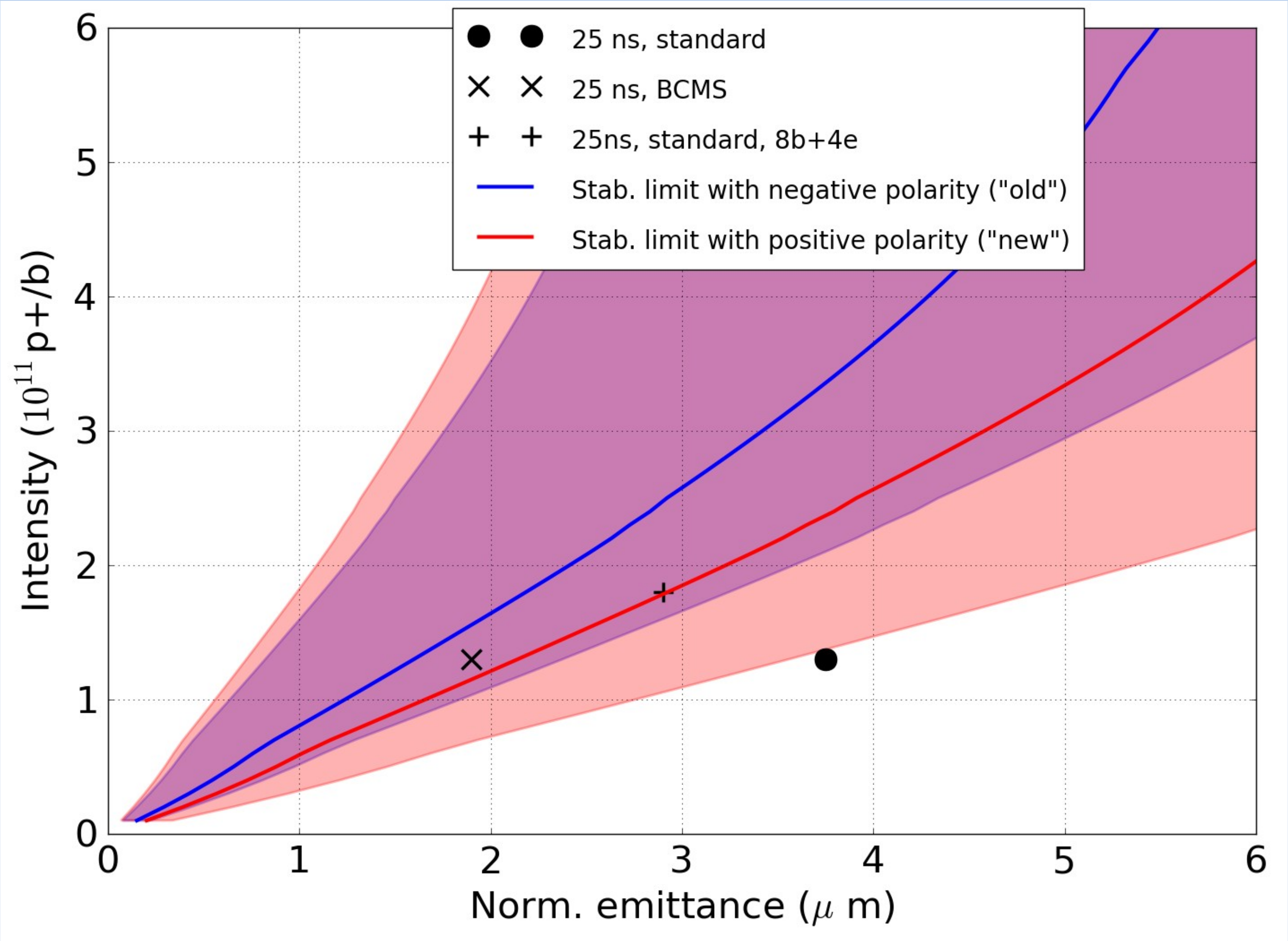

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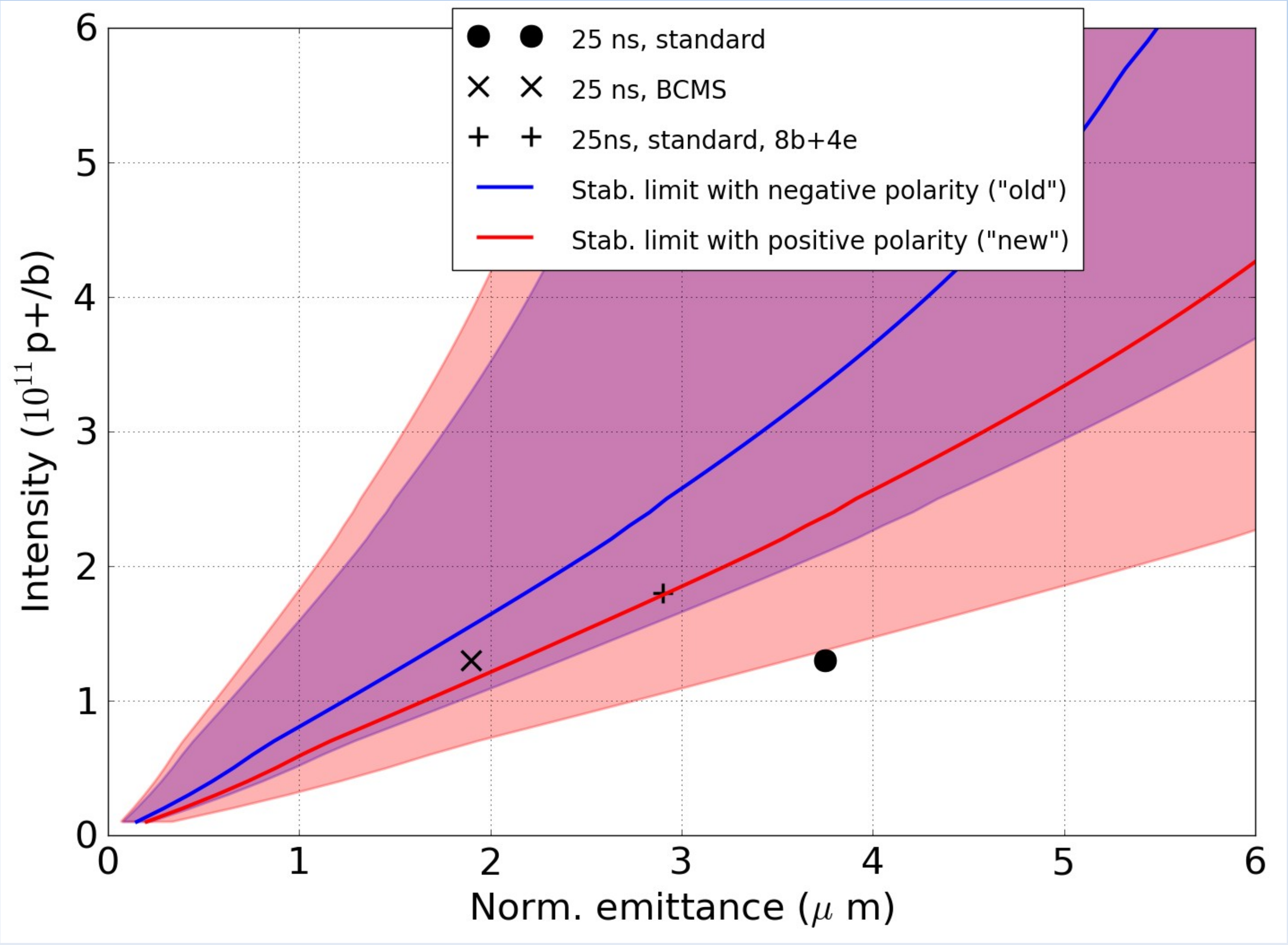
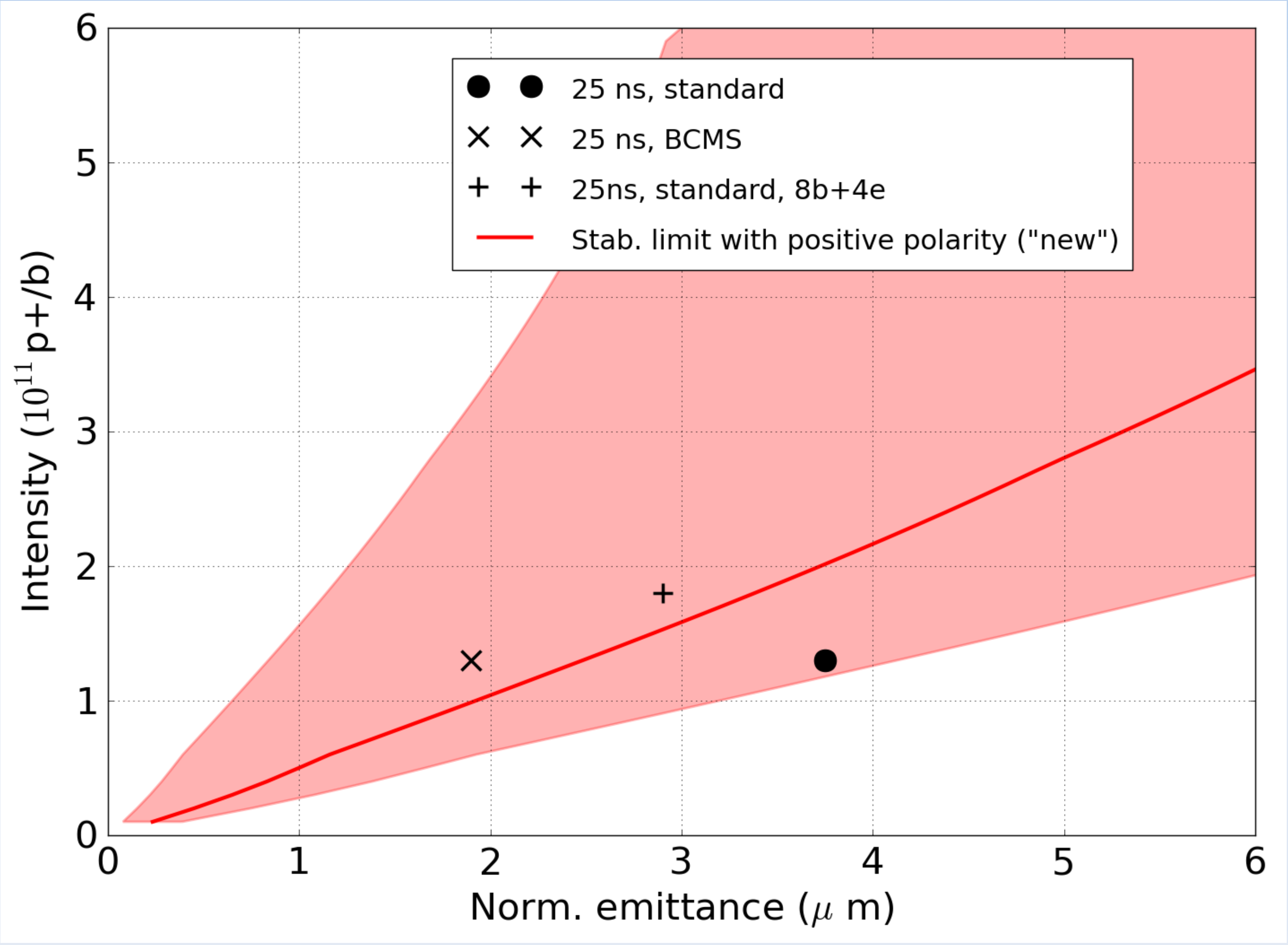


→ there could be some cases where std 25ns unstable with pos. polarity, or BCMS & 8b+4e unstable with neg. polarity.

Estimate of single-beam stability limits for post-LS1 LHC with error bars

- Intensity limit vs emittance for 25ns (6.5 TeV, 570A in octupoles, 50 turns damper, Q'~15, 1ns total bunch length), for "2 sigma retraction" collimator settings:



Estimate of single-beam stability limits for post-LS1 LHC with error bars

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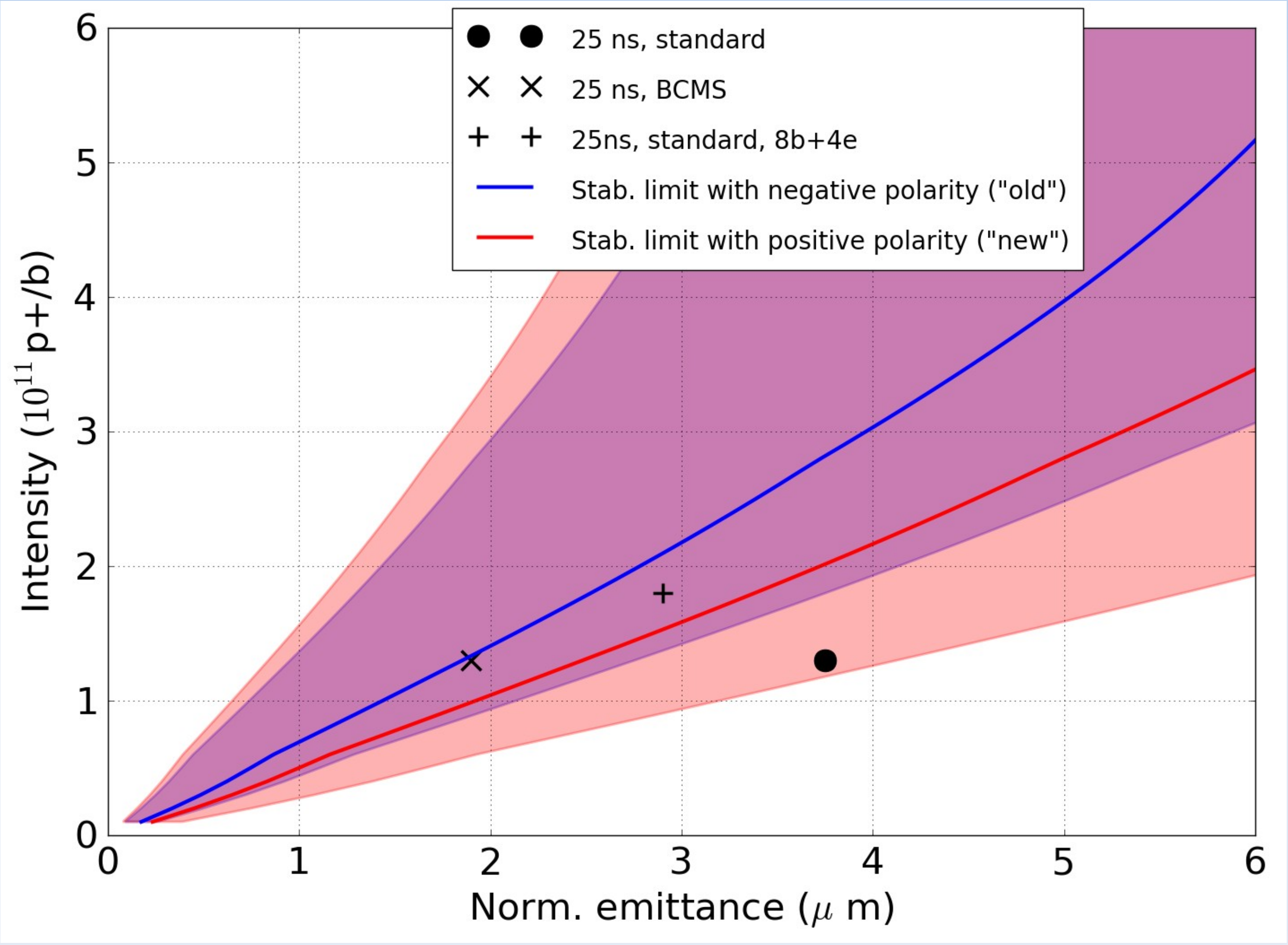

Estimate of single-beam stability limits for post-LS1 LHC **with error bars**

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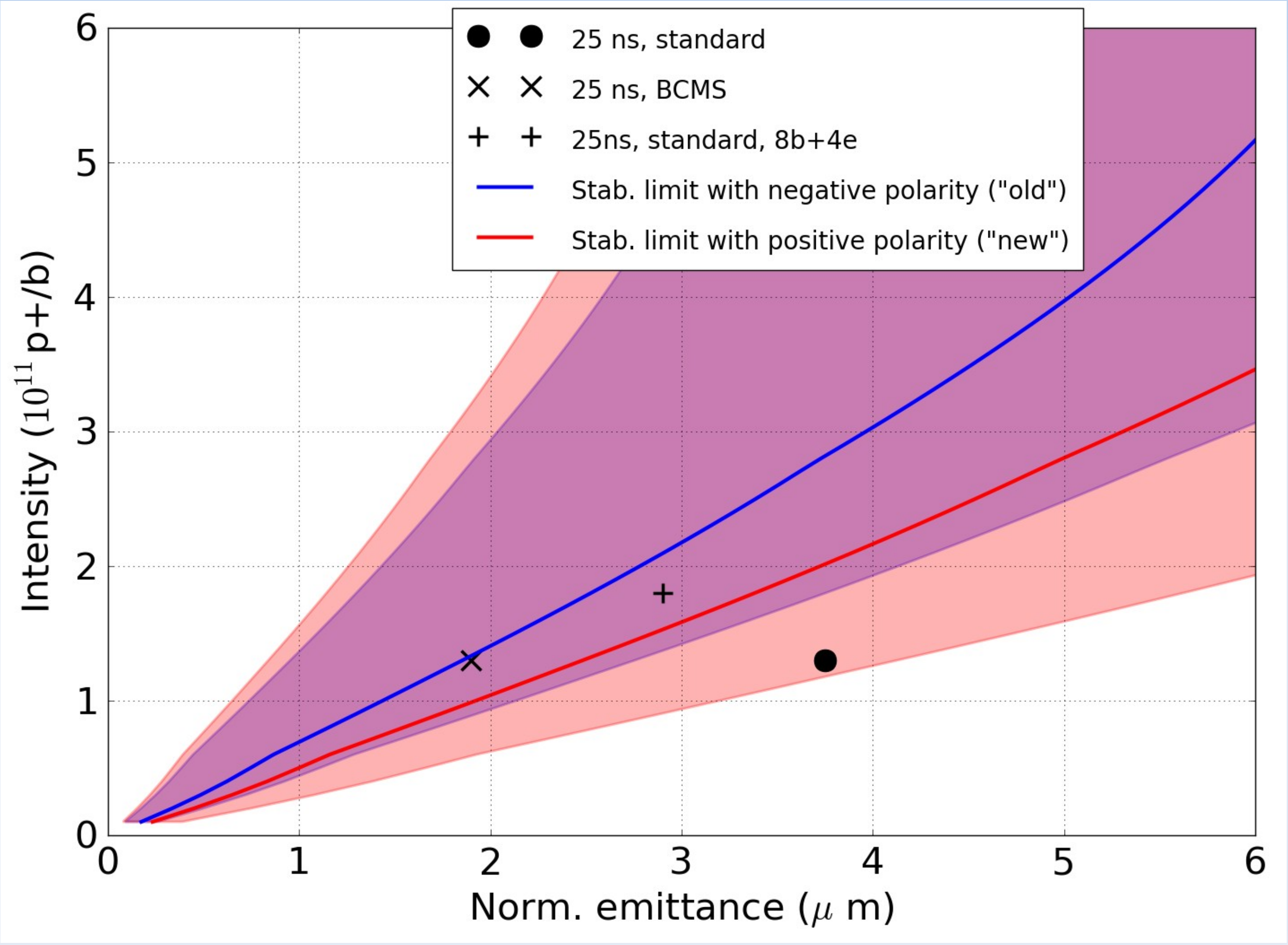
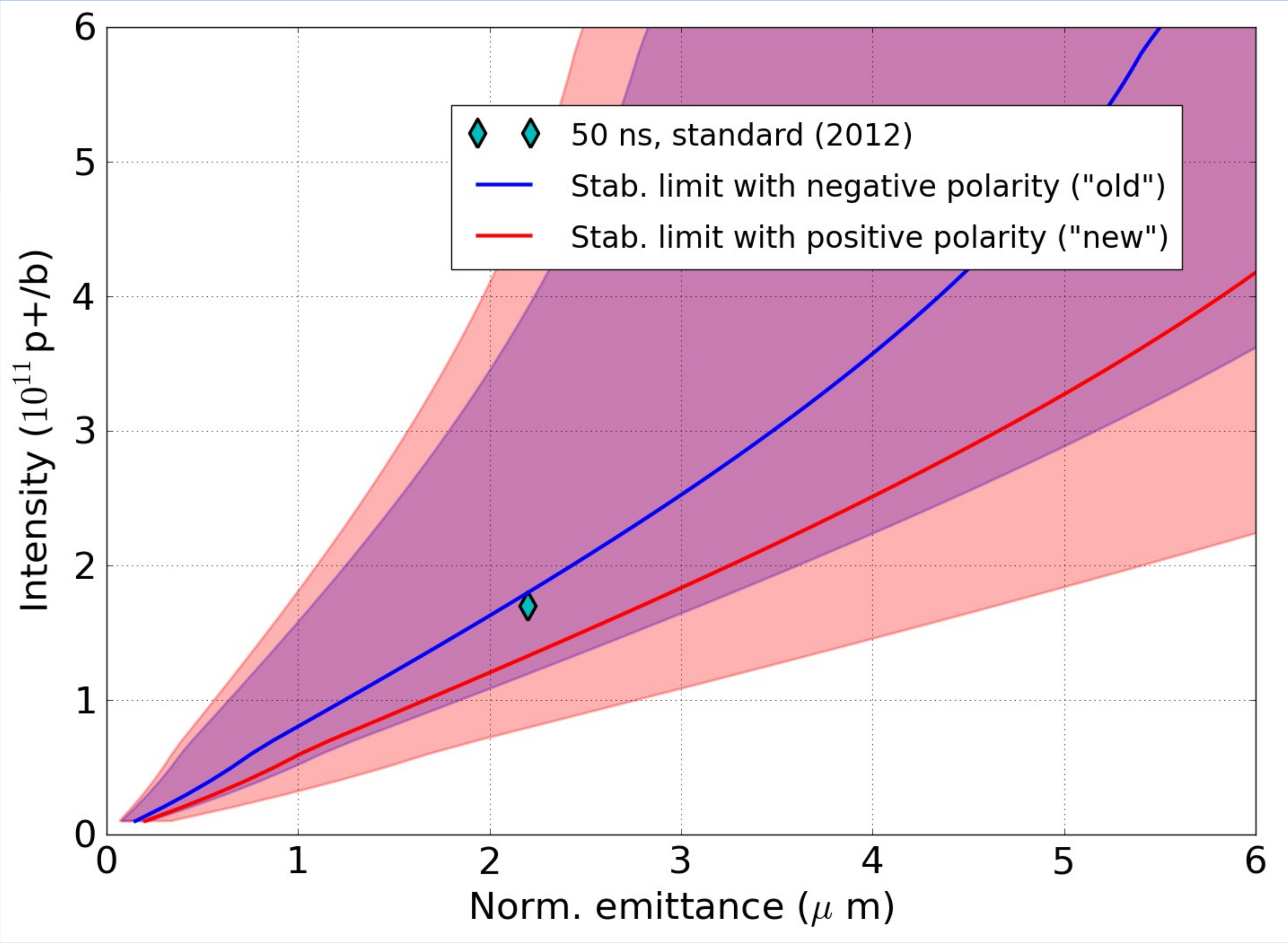


→ with even more probability, we could have std 25ns unstable with pos. polarity, or BCMS & 8b+4e unstable with neg. polarity.

One word about the 50ns beam

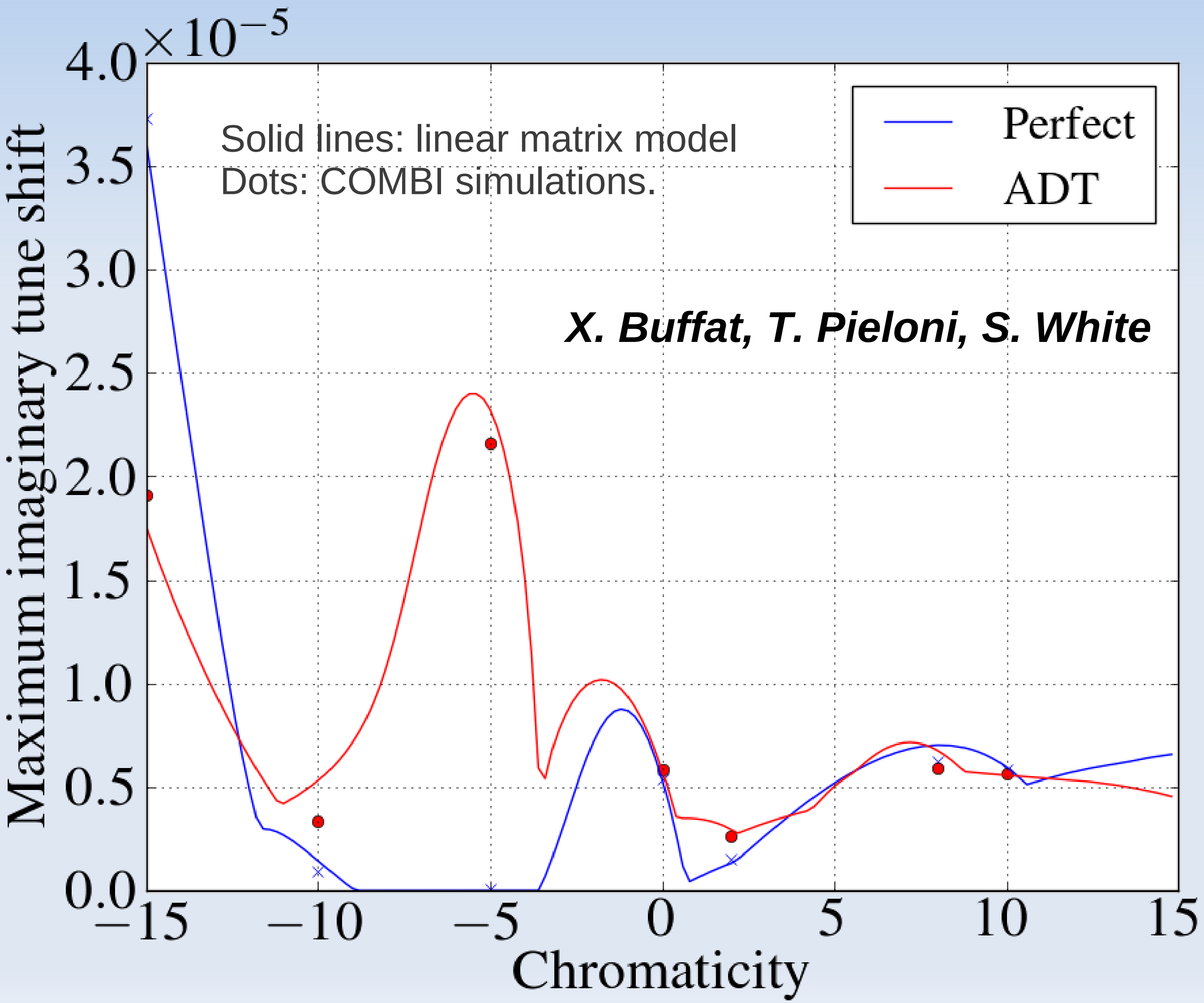
- With typical 2012 beam (not BCMS), at 6.5 TeV with ”2012 mm kept” collimator settings:



→ should be stable only with negative polarity.

Can we do better ?

- Single-bunch imag. tune shift (=growth rate/ω_0) vs. Q' with typical 2012 4TeV beam (50 turns damper, 1.5e11 p+/bunch), for a perfect or more realistic (”ADT”) damper model:



Note: this is done with the old LHC impedance model (not updated)

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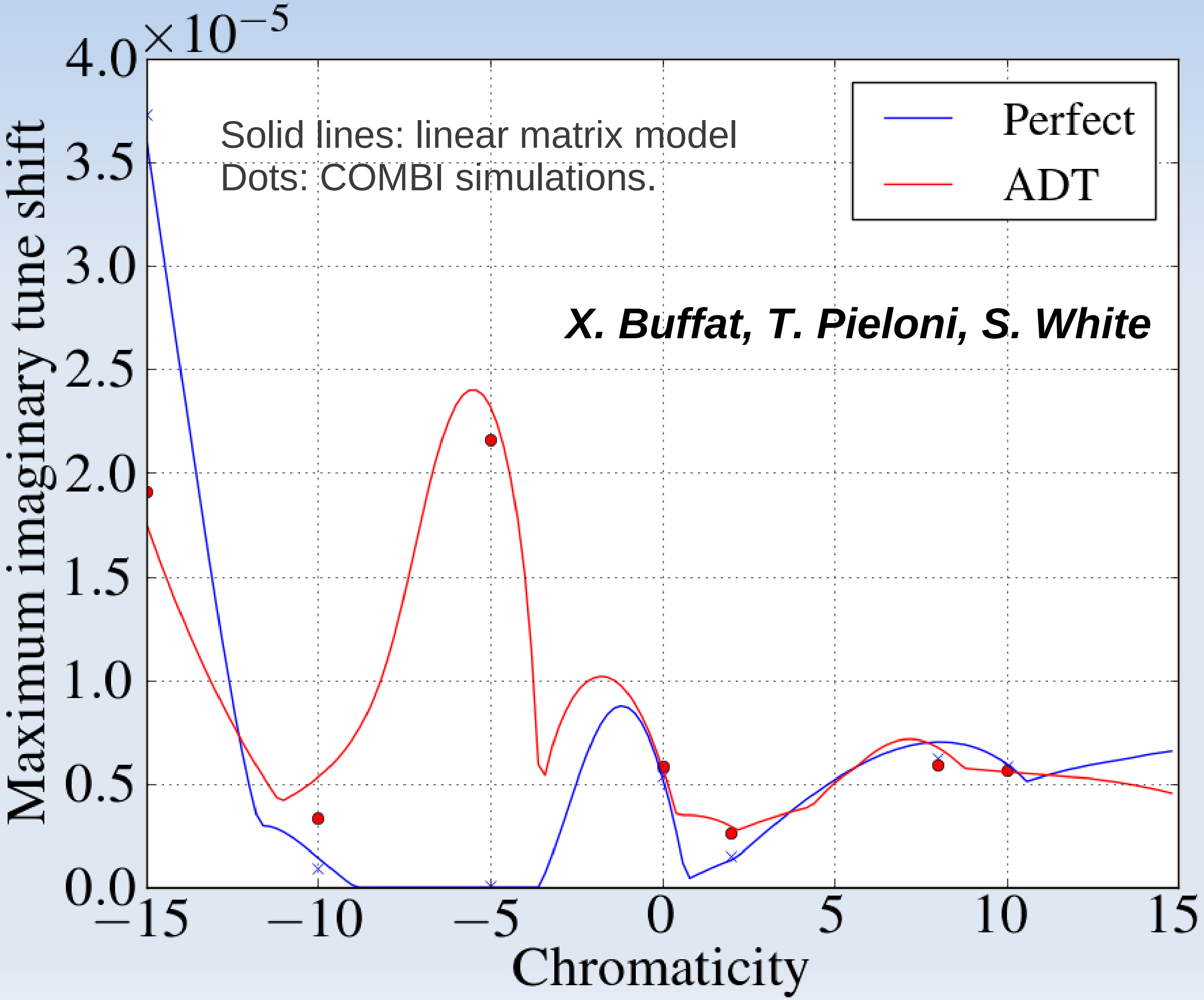


Note: this is done with the old LHC impedance model (not updated)

→ some optimization of chromaticity might be possible,
→ damper model is crucial (ongoing work of beam-beam & ADT teams),
→ we need the same curve from measurements !

Conclusions

- For single-beam stability, up to the long-range regime (”separated beams”), negative octupole polarity is significantly better.

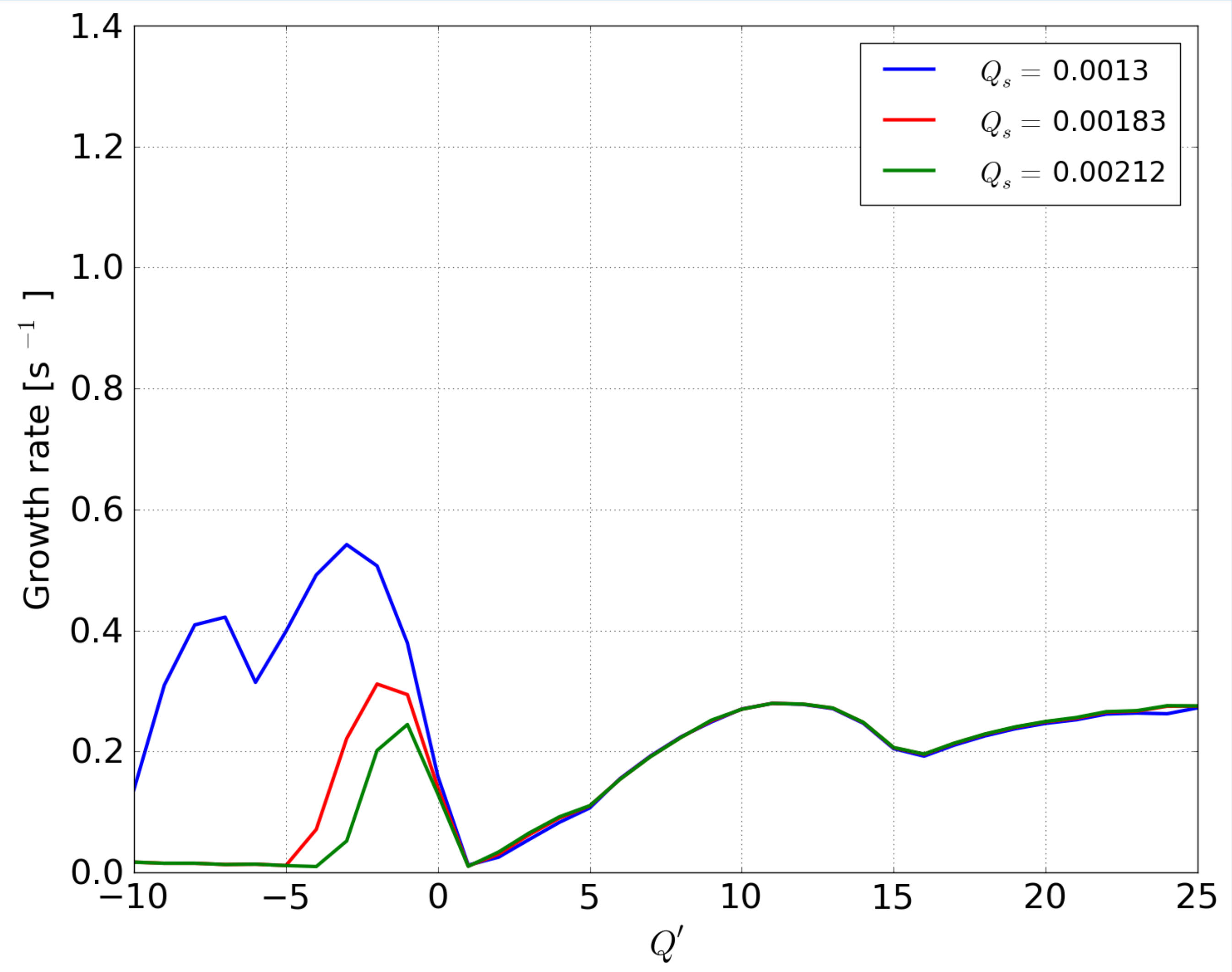
- Only approximate instability thresholds can be predicted for post-LS1 operation, from the current knowledge of the LHC machine. Several scenarios foreseen are close or beyond such limits.

- It is crucial to get a better knowledge of the machine, from dedicated measurements of beam instability growth rates vs. chromaticity and damper gain, in a systematic and progressive manner (i.e. first with single bunch).

Appendix

Impact of synchrotron tune

- At 6.5TeV, horizontal growth rates vs. chromaticity for different Q_s, for 1ns total bunch length (25ns, 1.3 10^{11} p+/b, damper 50 turns):



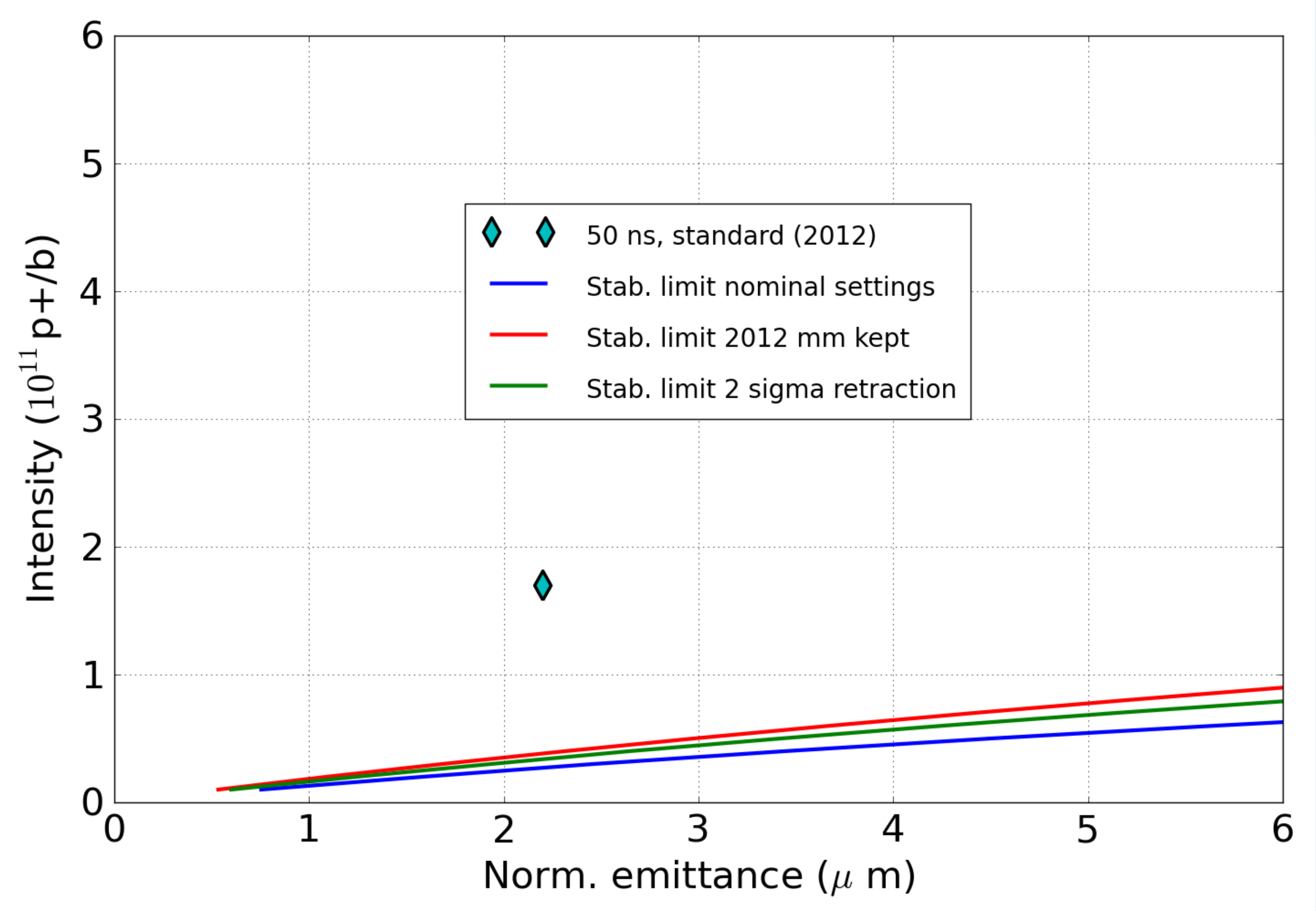
Obtained from the DELPHI Vlasov solver

→ no impact for *Q'>0* but strong impact for negative *Q'* (not clear why),

It is similar in vertical.

Estimate of single-beam stability limits for post-LS1 LHC: 50ns, no damper, neg. oct.

- Intensity limit vs emittance, 50ns, for negative oct. Polarity (6.5 TeV, 570A in octupoles, no damper, Q'~15, 1ns total bunch length): average values only



→ all scenarios unstable if 2012 instabilities were mainly coupled-bunch,
→ all other cases without damper (25ns or positive oct.) are even worse.

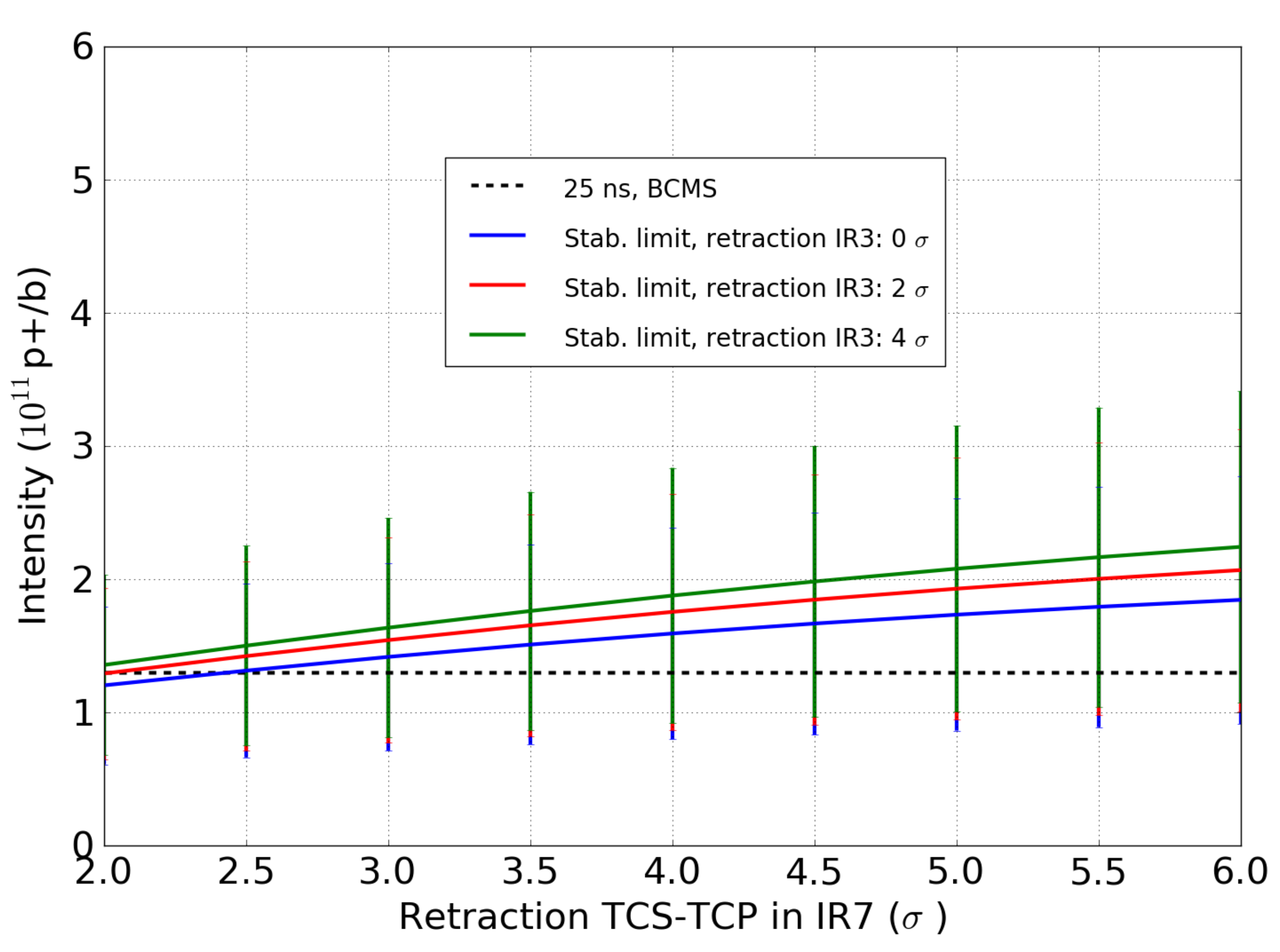
Details on collimator settings: half-gaps in σ

- Initial collimator settings used, in number of σ (with ε=3.5 mm.mrad and E=6.5 TeV) (R. Bruce):

Collimator family	2012 mm kept (# σ)	2 sigma retraction (# σ)	Nominal (# σ)
TCP IR3	15	12	12
TCS IR3	18	15.6	15.6
TCLA IR3	20	17.6	17.6
TCP IR7	5.5	5.5	6
TCS IR7	8	7.5	7
TCLA IR7	10.6	9.5	10
TCL IR 1 & 5 (except TCL6)	12	10	10
TCL6 IR 1 & 5	retracted	retracted	10
TCT IR 1 & 5	11.6	10.3	8.3
TCT IR 2 & 8	15	15	15
TCDQ IR6	9.6	8.8	8
TCS IR6	9.1	8.3	7.5
TDI & TCLI	retracted	retracted	retracted

Estimate of single-beam stability limits for post-LS1 LHC: scan of collimator half-gaps

- Intensity limit vs #σ retraction between TCS and TCP in IR7, for BCMS 25ns, negative oct. polarity (6.5 TeV, 570A in octupoles, 50 turns damper, Q'~15, 1ns total bunch length), for different retractions of all collimators in IR3 (w.r.t nominal settings), keeping constant retraction between TCLA in IR7 / IR6 collimators w.r.t to TCS in IR7:



Baseline used: 2012 mm kept scenario (except for IR3 - nominal)

TCT IR1 & 5: 11.1σ

TCT IR2 & 8: 15σ

TCLs: 10σ

Other ongoing efforts

- Analysis & systematic comparison with HEADTAIL of single-bunch instabilities observed (2011-2012), by D. Astapovych.

- Attempt to reduce, if possible, collimator impedance, thanks to:
  - Retraction of well chosen collimators (with R. Bruce & collimation team).
  - Further optimization of IR7 beta functions (with optics team).