Impact of flux jumps on orbit stability

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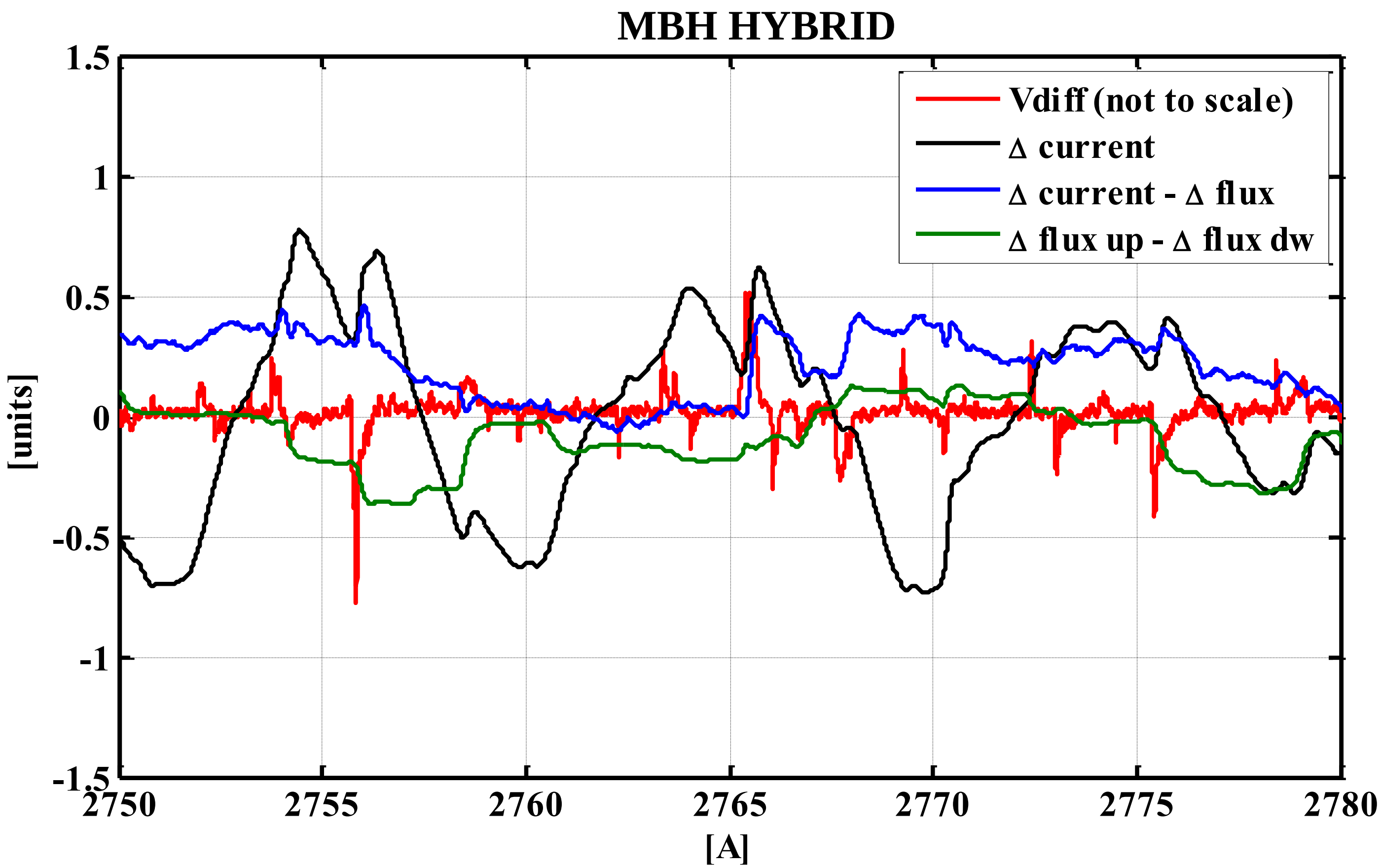
MBH HYBRID - Residuals and differential voltage



- **Current shows peaks related to voltage spikes σ = 0.3 units.**
- **The difference of current minus flux shows changes σ = 0.2 units.**
- **Gradient (up/dw) shows changes σ = 0.14 units.**

Flux jumps seems to be concentrated at “low energy”

σ is computed in the interval [2kA, 4kA]

From L. Fiscarelli– **144th WP2 Meeting (indico)**

Lucio's conclusions

- We have tested many short models and we have data for the first full-size aperture (MBH HYBRID)

From circuit point of view, we consider "linearity" and "Short term stability – 20 min" as boundary of "tracking" performance

- A[…]ux jumps and during ramps at nominal ramp-rate (10 A/s) we see:
  - fluctu[…]

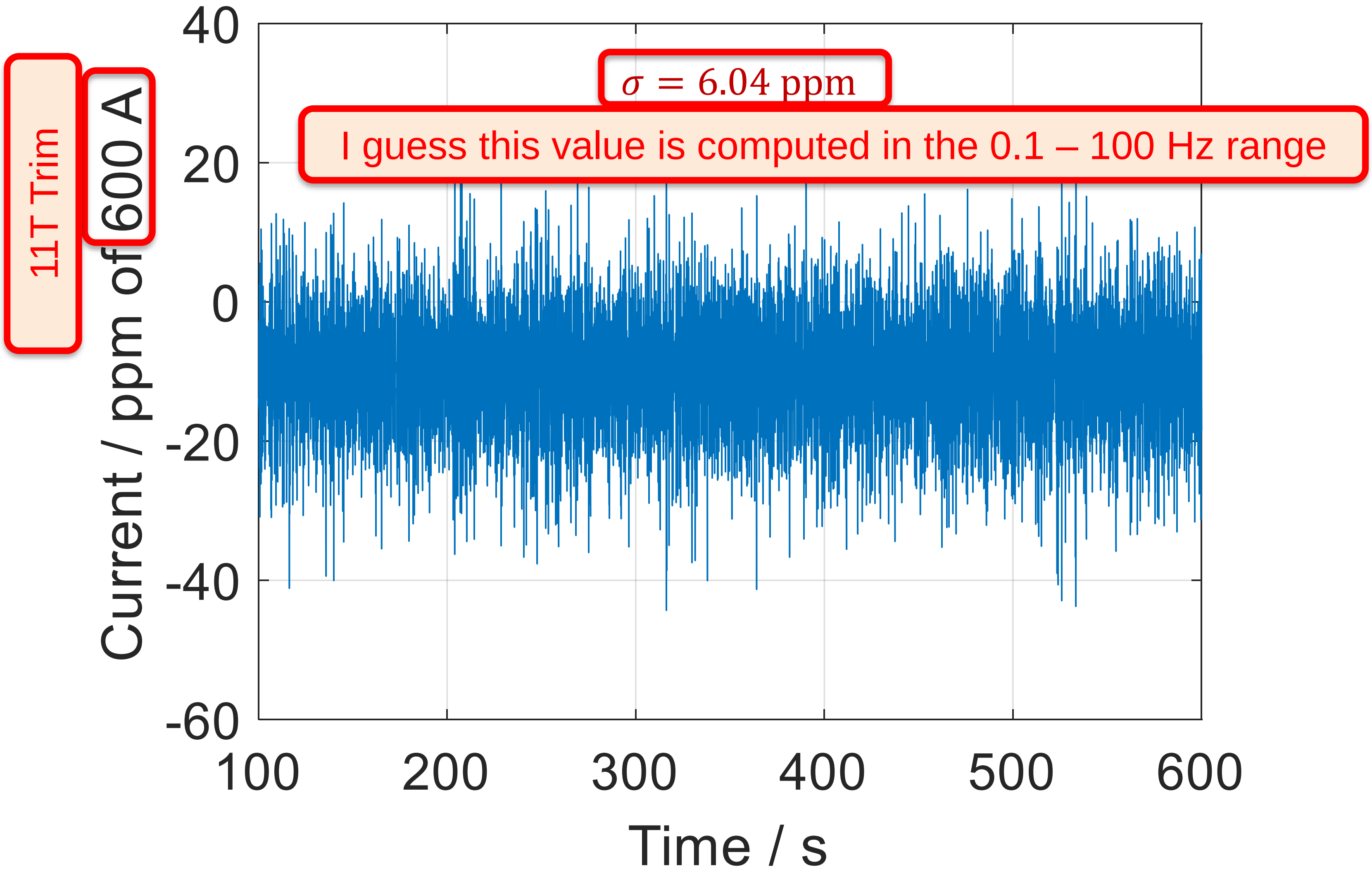
This is the contribute of flux jumps according to Lucio

  - changes on the main field not related to the current (σ = 0.2 units)
  - changes of the up-down gradient (σ = 0.15 units)

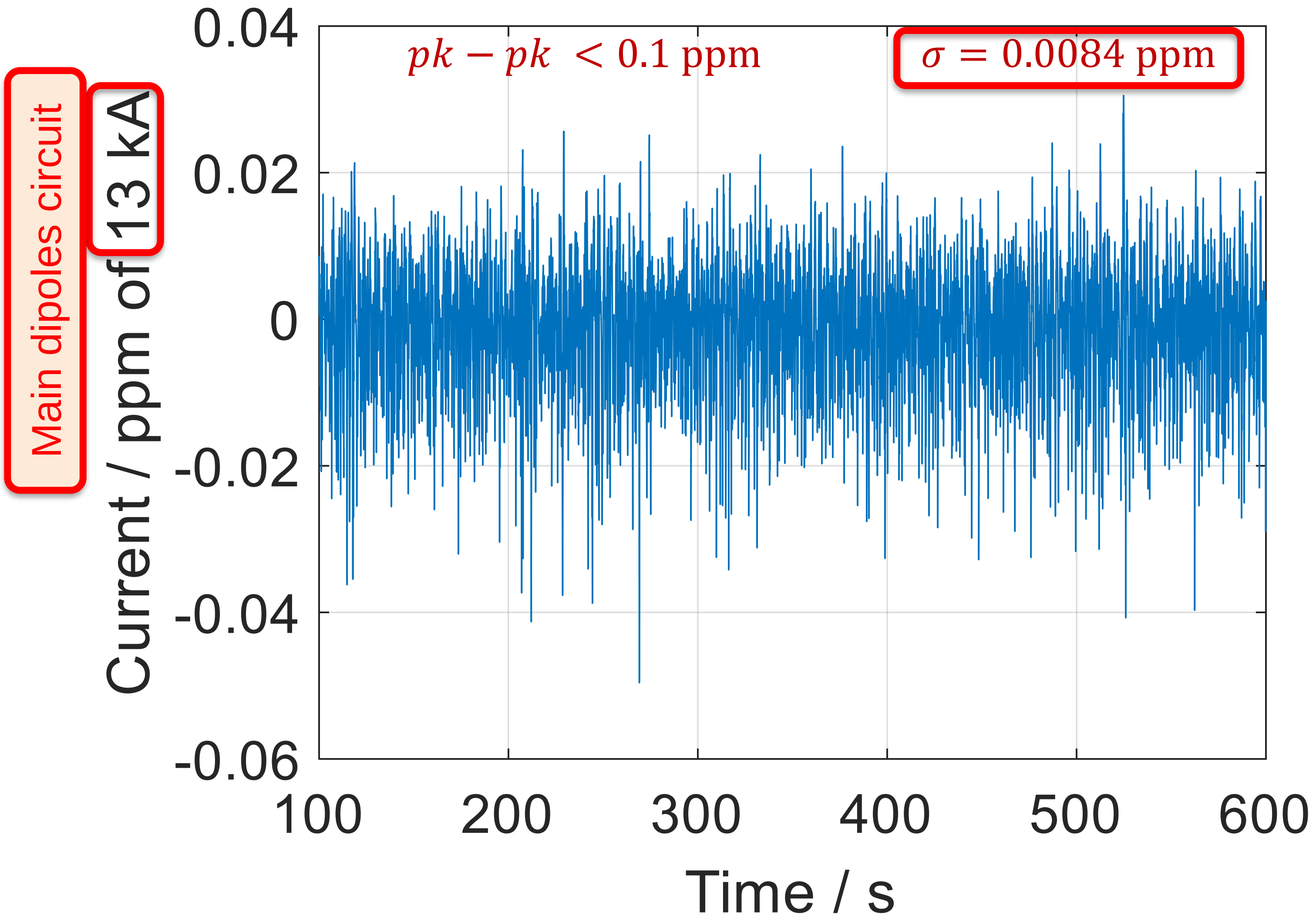
- The spectral density of the flux jumps is mainly concentrated in the interval 0.1-10 Hz

In this range PC don't have a detailed specification!
-> still under discussion how to use "Noise"

Inductance Jump Model – O/C Voltage Loop



Inductance Jump Model – O/C Voltage Loop



Putting numbers together (11T)

- **flux jumps** given in **unit** – **worst case** (in equivalent ppm) at **top energy**
- **PC specs** given in **ppm** of I_{rated} – **worst case at injection**
- **Impact of PCs in units** computed as [ppm] * 10^{-2} * $I_{PC\ rated}/I_{dipoles(inj./nom.)}$

	11T Magnet/Trim	Main Dipoles
PC class	3	1
I_{rated} [A]	600	13000
$I_{injection}$ [A]	(0)	**728**
$I_{nominal}$ [A]	(250)	**11850**
Short term stability [r.m.s. ppm]	**1**	**0.2**
Linearity [r.m.s. ppm]	**4.6**	**1.2**
Flux jump -> PC -> circuit [rms ppm]	**6.04**	**0.01**
Flux jump [rms units of 1e-4]	**0.2**	-
Tot. PC [rms units] inj. / nom.	**0.063 / 0.004**	0.217 / 0.013

Concerns here: flux jump on itself has an about 50 times bigger effect than PC stability at top energy

Comparable values!

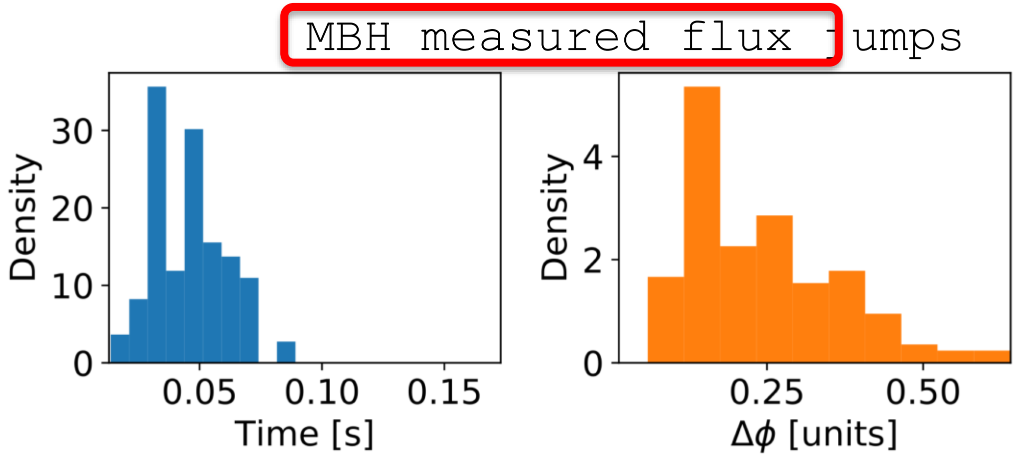
performance dominated by short term stability and linearity

Comparison: flux jumps statistics for RQX

From a manual selection. Very probably biased towards larger strengths (easier to spot…).

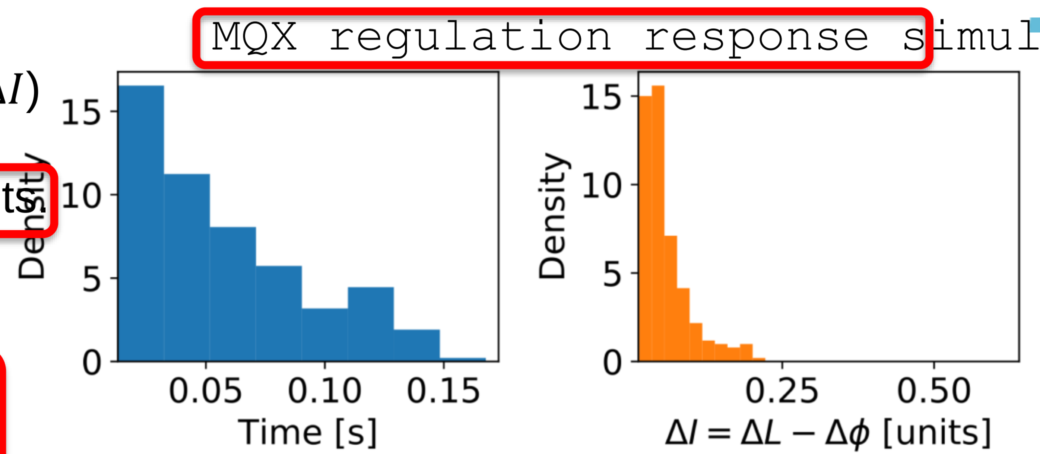
145 jumps measured in the error of the magnetic flux ($\Delta\phi$).

- Average $\pm$ Std strength: **0.2$\pm$0.1** units.
- Average $\pm$ Std length: 40$\pm$10 ms.



244 jumps seen in the current deviation (ΔI) of the regulation circuit.

- Average $\pm$ Std strength: **0.06$\pm$0.03** units
- Average $\pm$ Std length: 60$\pm$40 ms.



Comparable effect as 11T trim (due to comparable inductances?)

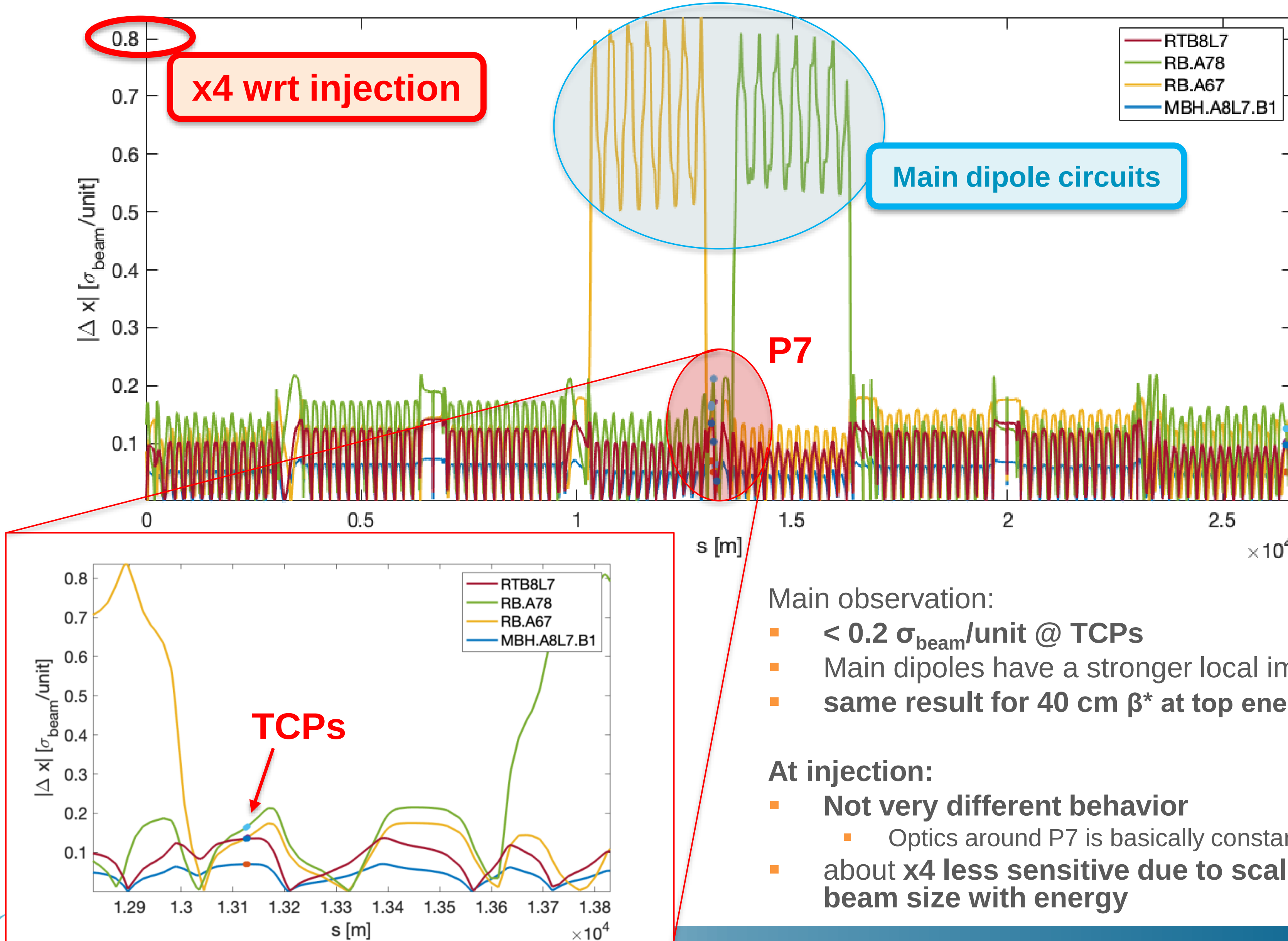
Putting numbers together (Triplet)

- **Impact of PCs in units** computed as [ppm] * 10^{-2} * $I_{PC\ rated}/I_{RQX(inj./nom.)}$

	RQX	RTQX1/3	RTQXA1
PC class	0	2	4
I_{rated} [A]	18000	**2000**	**60**
$I_{injection}$ [A]	**1059**	(0)	(0)
$I_{nominal}$ [A]	**16470**	(1647)	(35)
Short term stability [r.m.s. ppm]	0.2	0.6	2.5
Linearity [r.m.s. ppm]	1.2	2.9	5.2
PC Short + Lin. [rms units] inj. / nom.	0.207/0.013	0.056/0.004	0.003/ <0.001
Flux jump -> PC -> circuit [rms units]	0.06/ <0.06?	???	???
Tot. PC [rms units] inj. / nom.	0.22/ <0.06?	???	???

- **Circuit performance still dominated by PC stability** (at least for RQX)
- Values **to be compared with 0.2 units flux jump** expected **in each single magnet,** independently
  - **Comparable at injection for RQX circuit**

11T: impact on B1 orbit at 15 cm β*, 7 TeV



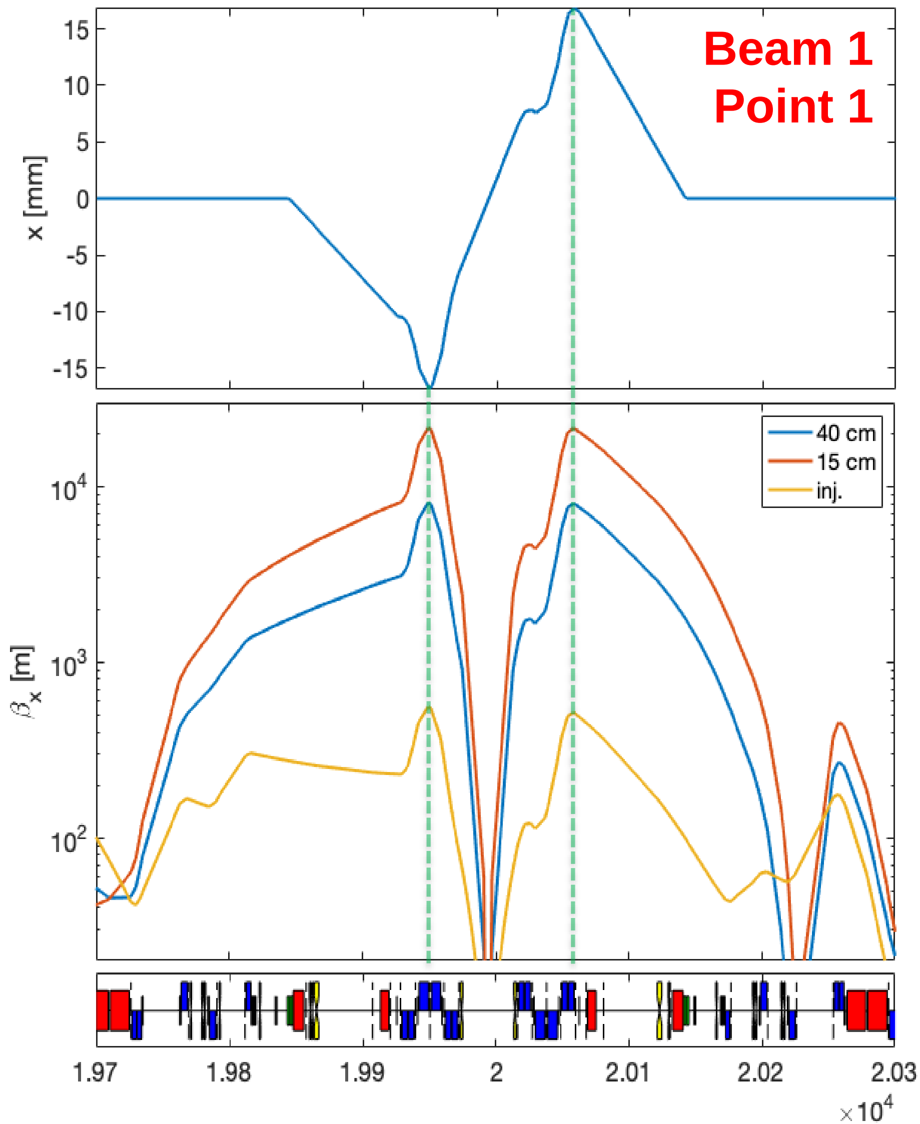
Main observation:

- **< 0.2 σ_{beam}/unit @ TCPs**
- Main dipoles have a stronger local impact
- **same result for 40 cm β* at top energy**

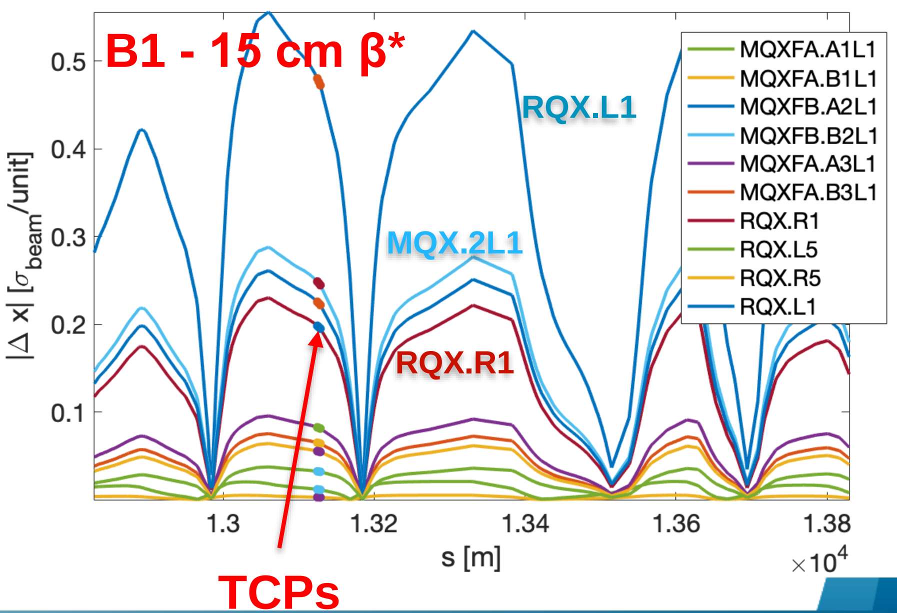
At injection:

- **Not very different behavior**
  - Optics around P7 is basically constant
- about **x4 less sensitive due to scaling of beam size with energy**

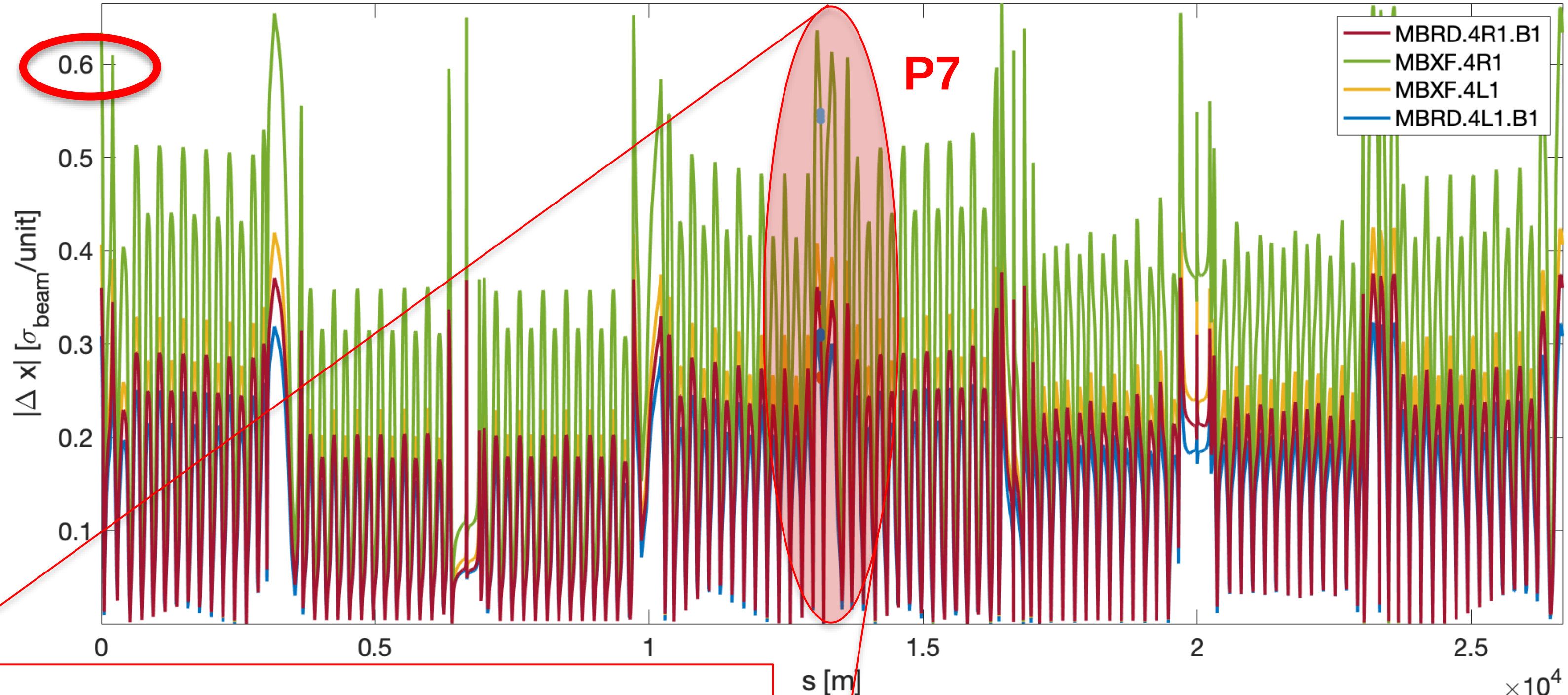
Feed-down from IR1/5 triplet: impact on orbit

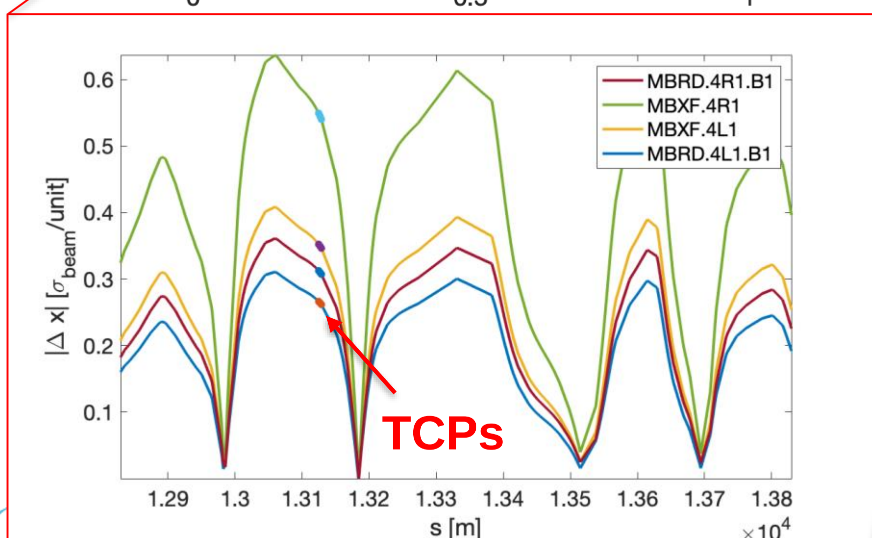


- Assuming pessimistic case of **295 urad half-crossing** for all optics
  - Kick **linear with crossing** angle
- The lower the β* the most sensitive to "jumps"
  - Kick goes like **sqrt(β)** in the quadrupole
  - **40 cm β* is x1.6 less sensitive than 15 cm β***
- **Dominated by Q2.L1** (for B1)
  - **~0.25 σ_{beam}/unit @ TCPs**
    - **per Q2L magnet!**
  - **(~0.15 σ_{beam}/unit @ TCPs per Q3R magnet)**



D1/D2: impact on B1 orbit at 15 cm β*, 7 TeV





- D1/D2 other main players for orbit stability
- Based on Ni-Ti technology
  - **No flux jumps expected**
- **Class 0 PC; 13 kA I_{rated}**
  - Basically, **same performance as RQX**

Conclusion: impact on orbit at TCP @ inj / 15 cm β*

	TCP orbit var. from optics [σ_{beam}/unit]	Expected jitter [rms units]	Expected TCP orbit var. [rms e-3 σ_{beam}]
11T magnet (flux jump)	0.02 / 0.07	0.2	**4 / 14**
11T trim circuit	0.04 / **0.14**	0.063/0.004	**<1 / <1**
RB.A78 circuit	0.06 / **0.21**	**0.217**/0.013	**13 / 3**
Q1 single magnet	<0.01 / 0.06	**0.2**	**<2 / 12**
Q2 single magnet	0.01 / **0.28**	**0.2**	**2 / 56**
Q3 single magnet	<0.01 / **0.18**	**0.2**	**<2 / 36**
RQX main circuit	0.01 / **0.48**	**0.22** / <0.06**?**	**2 / 29***
Q1 trim circuit	<0.01 / **0.10**	~0.056**?** / ~0.004**?**	**< 1? / < 1?**
Q3 trim circuit	0.01 / **0.33**	~0.056**?** / ~0.004**?**	**< 1? / 1?**
D1/D2 circuit	0.02 / **0.63**	0.205 / 0.013	**4 / 8**

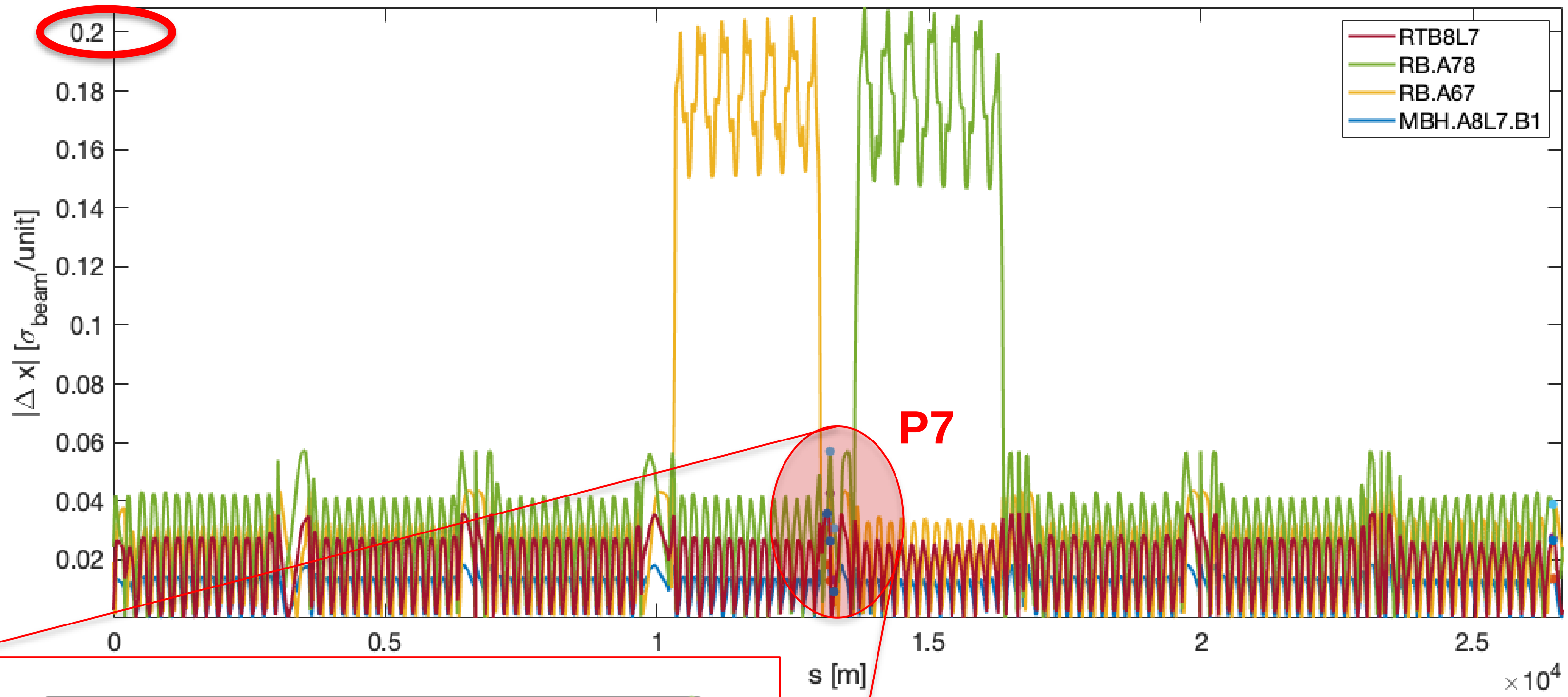
- The impact of **flux jump** at **top energy** for a **15 cm β*** with **295 urad half crossing can reach up to 5.6% σ_{beam} (MQX2) or 1.4% σ_{beam} (MBH)**
- At **injection** energy dominated by **main dipole PC (1.3% σ_{beam})**
  - in this case it should be a **slow variation (<< 1 Hz)**, which can be **corrected by orbit feedback**, while a **flux jump is a sudden variation (a few Hz)!**

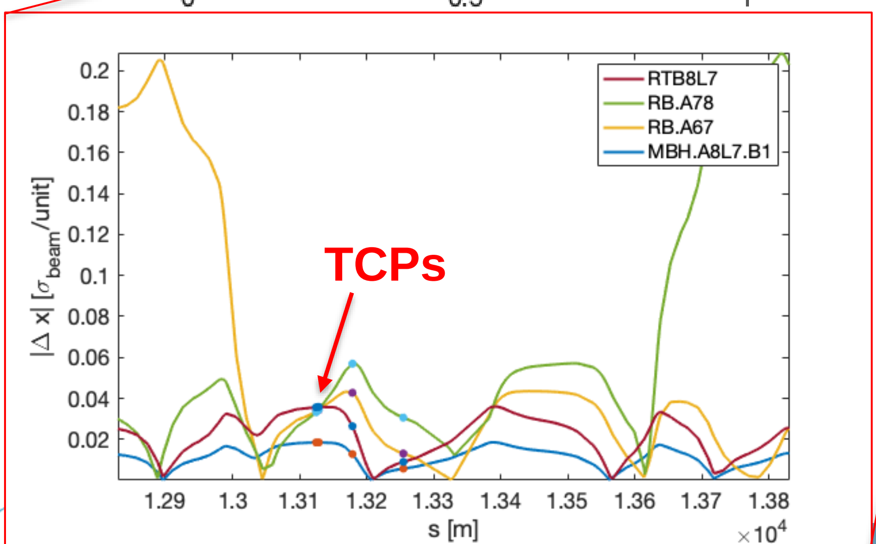
*** Note:** during stable beam, PC "linearity" should not play a role, i.e. about x6 better stability.

Thanks for your questions and comments!

Appendix

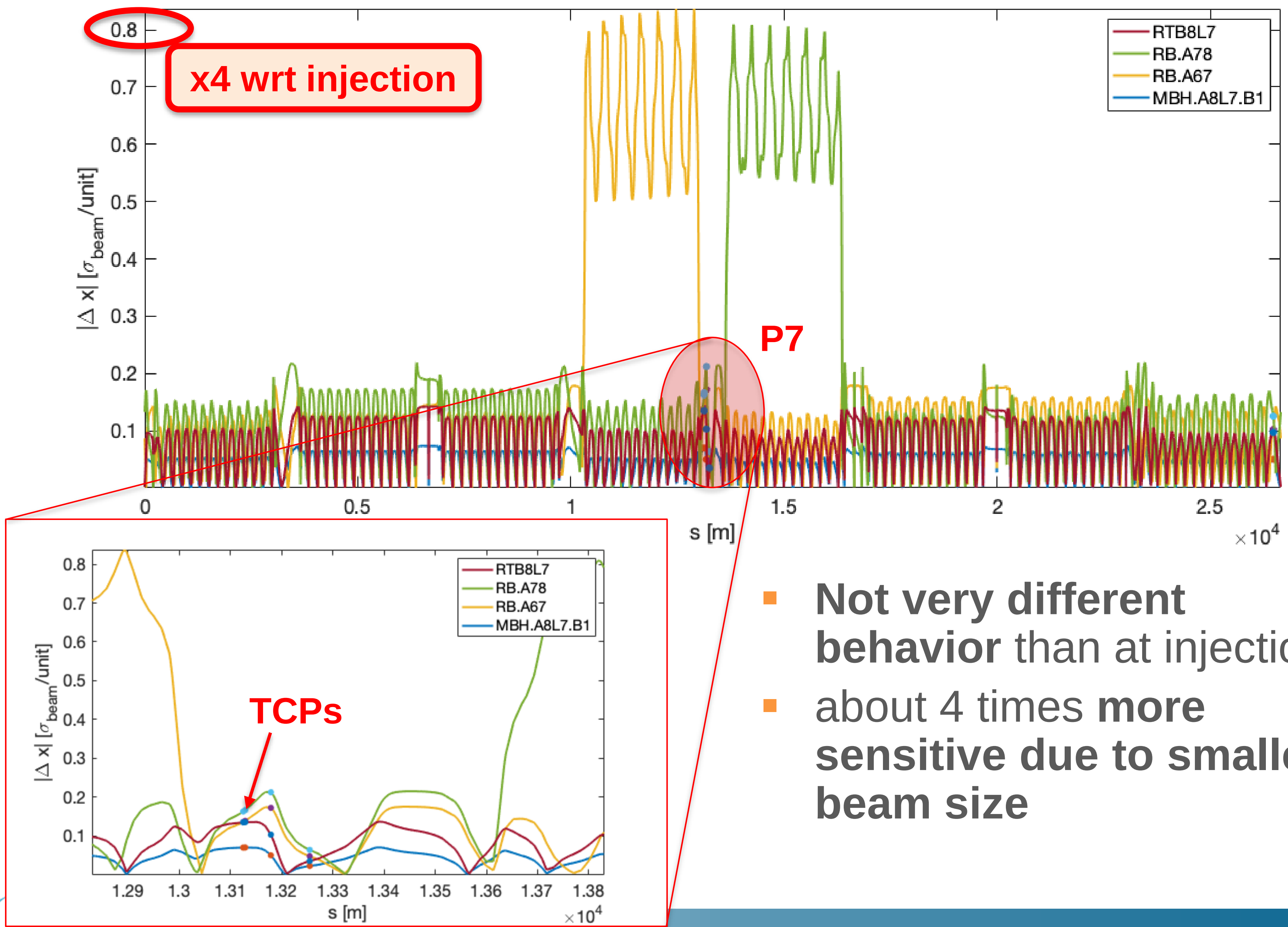
11T: impact on B1 orbit at injection





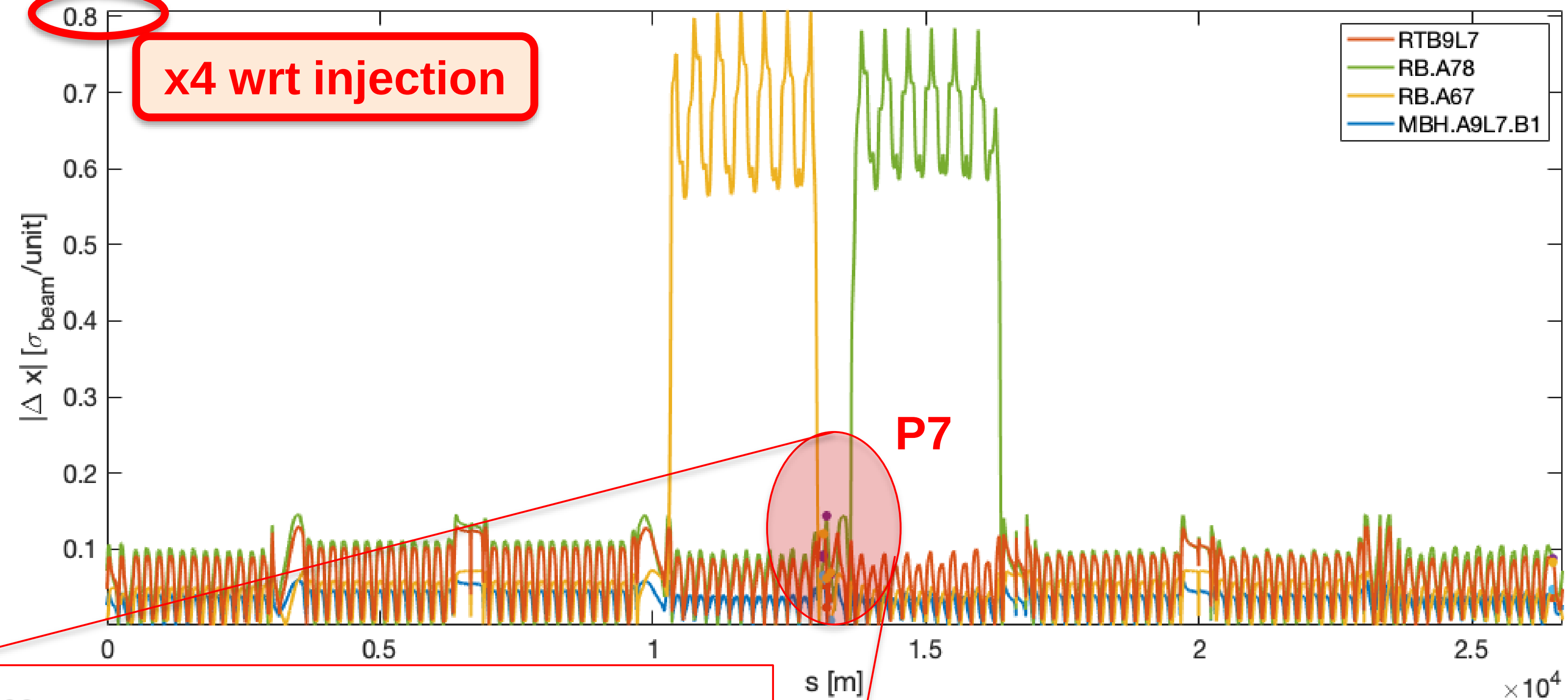
- Assuming 1 unit variation on RTB8L7 circuit (2x11T magnets), RB.A78 and RB.A67 circuits, single MBH.A8L7 magnet
- **Impact on orbit at TCPs within factor 2 to 4 for a given amplitude.**

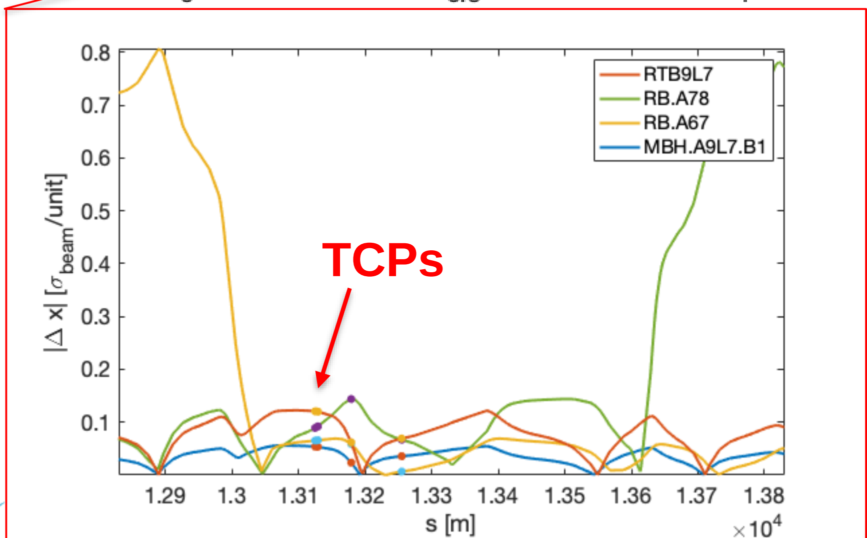
11T: impact on B1 orbit at 15 cm β*, 7 TeV



- **Not very different behavior** than at injection
- about 4 times **more sensitive due to smaller beam size**

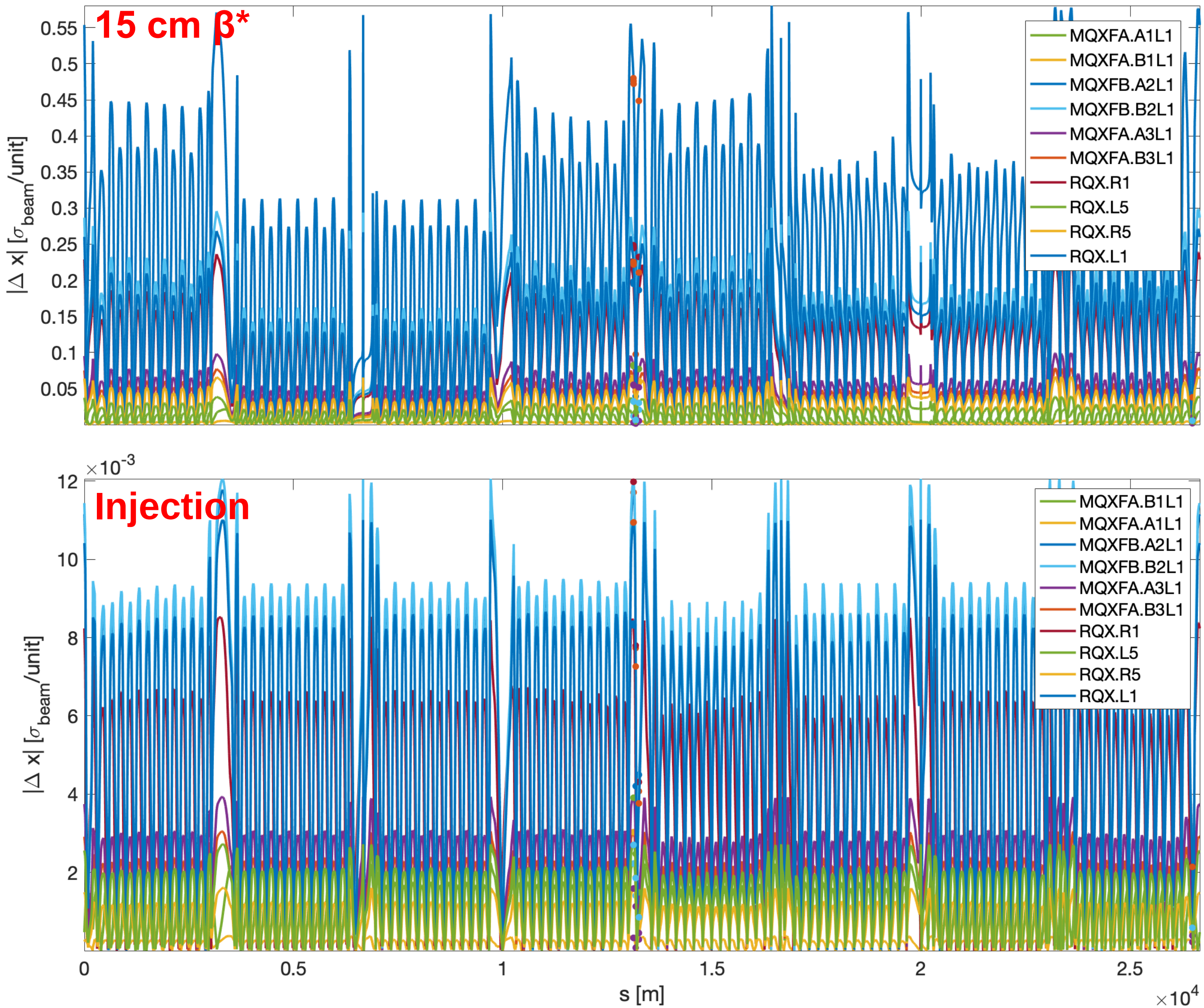
11T: impact on B1 orbit at 40 cm β*, 7.5 TeV



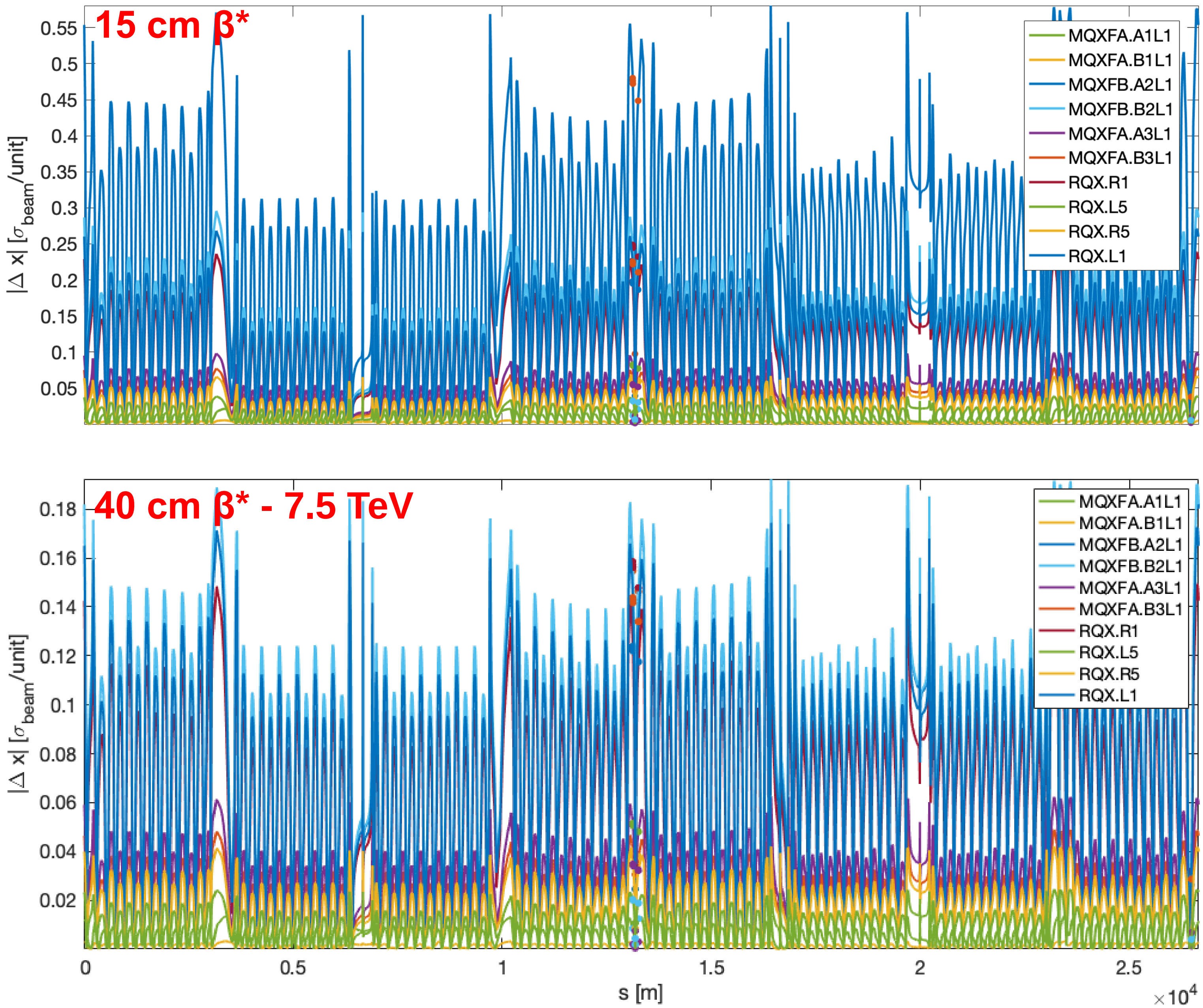


- Computed on more recent optics with **11T in cell 9 instead of cell 8**
- **No major differences wrt 15 cm β***
- **(In all cases, optics is the same around P7)**

Feed-down from IR1/5 triplet (295 urad xing)



Feed-down from IR1/5 triplet (295 urad xing)



Impact of D1/D2 elements