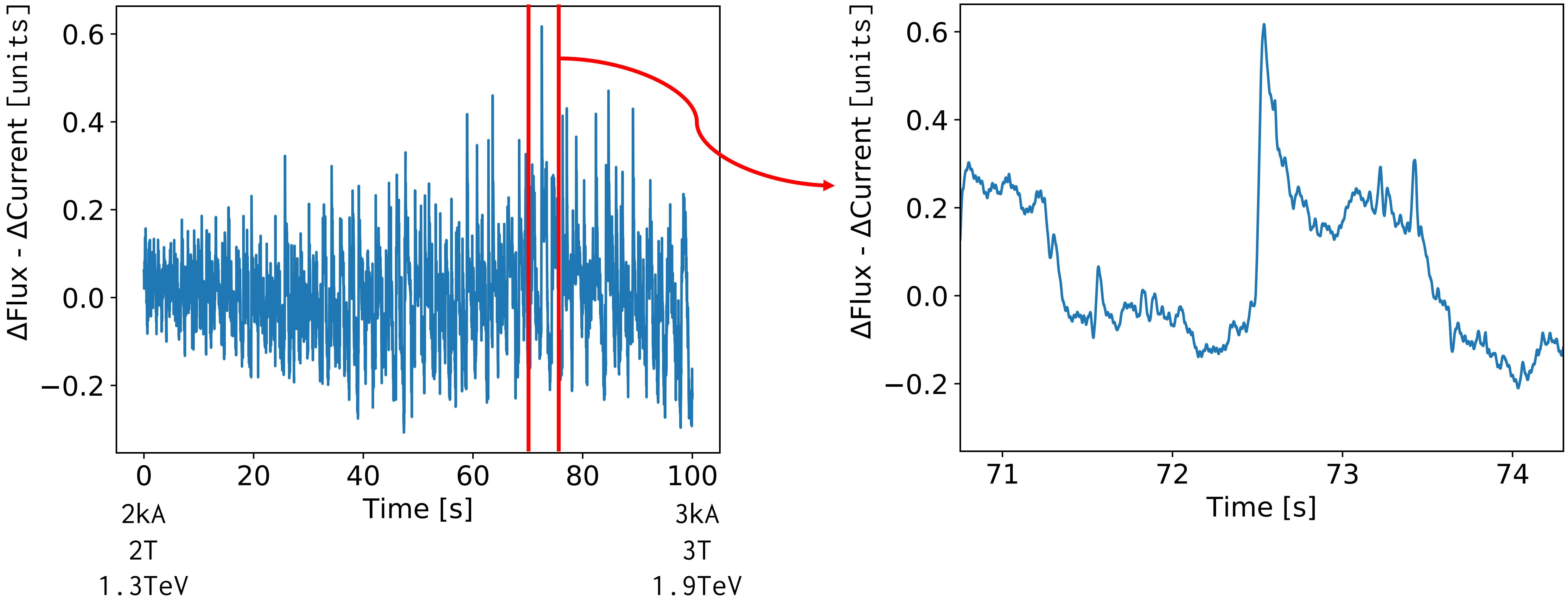
Flux jumps effect on emittance

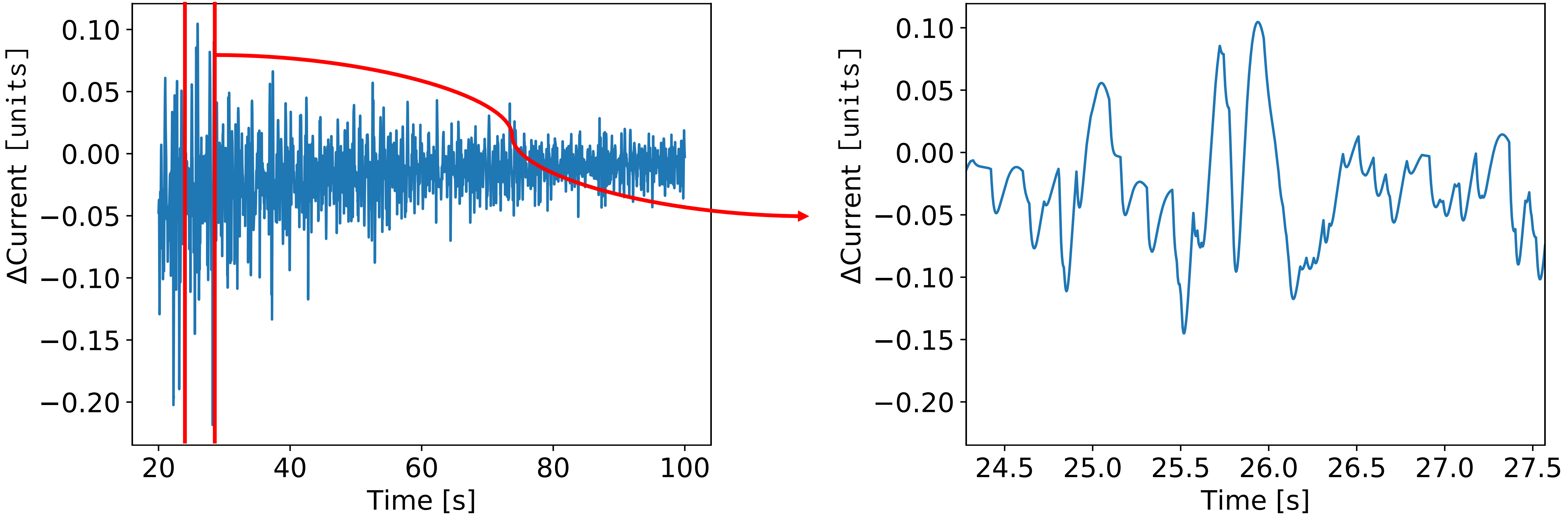
Jaime Coello de Portugal, Rogelio Tomas Garcia, Lucio Fiscarelli and Michele Martino

- Measurement of the magnetic flux provided by Lucio Fiscarelly.
- Performed on the 11T dipole model and cut to the 2-3 kA range (where most of the jump activity happens)



Measurements and simulations of the regulation circuit response

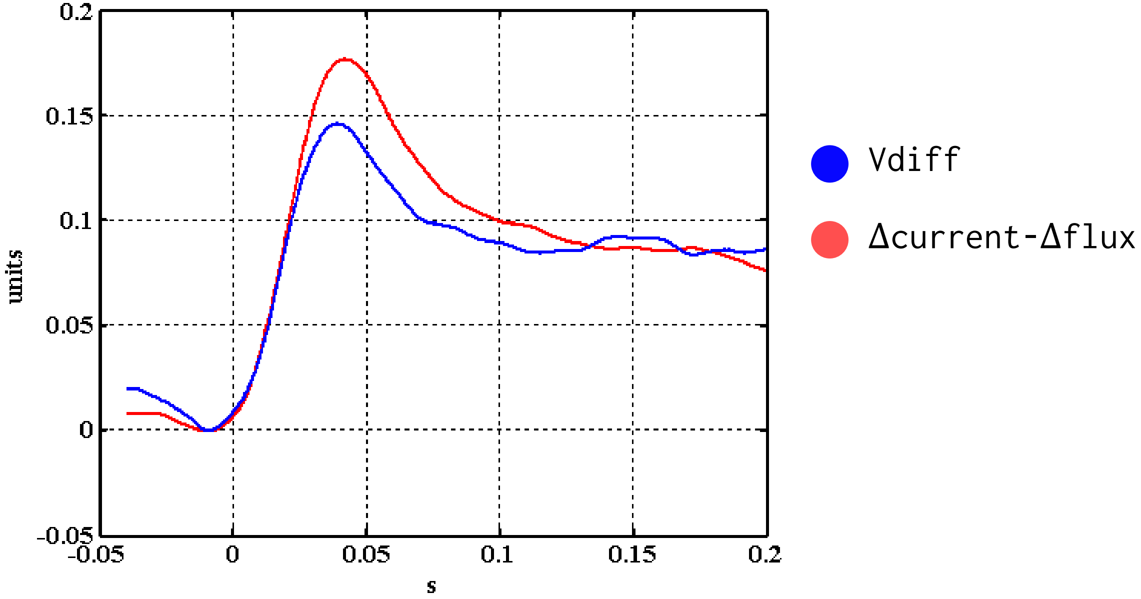
- Measurements provided by Michele Martino.
- Measured voltage on the MQXFS4b (short model) and used a model of the regulation circuit to estimate the effect on the current: ΔCurrent = ΔInductance - ΔMagnetic flux
- These measurements were done at a ramp rate of 51 A/s (pessimistic as nominal is 14.6 A/s) and estimated for the nominal ramp.

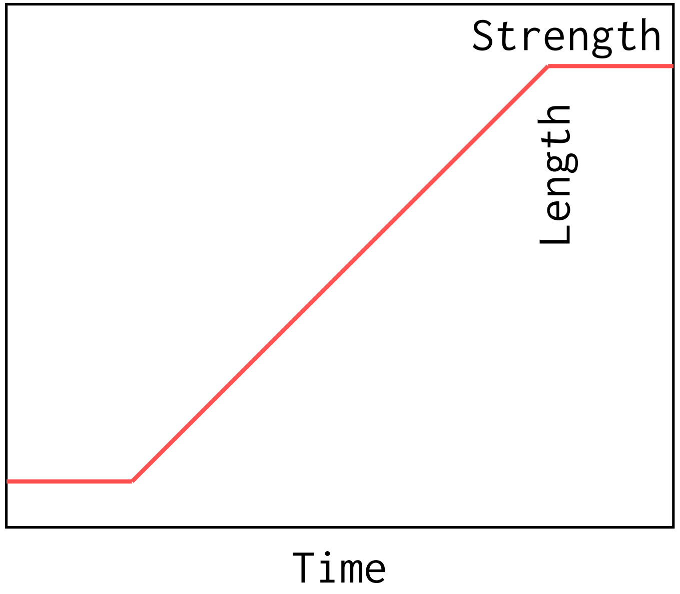


Flux jumps shape

- The general shape of the flux jumps is a fast raise of flux or differential voltage and a slower recovery.
- It is simplified here as a linear ramp on the error of magnetic field of the magnets.

“Mean” of ~80 jumps in flux*





*By Lucio Fiscarelli

Flux jumps statistics

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

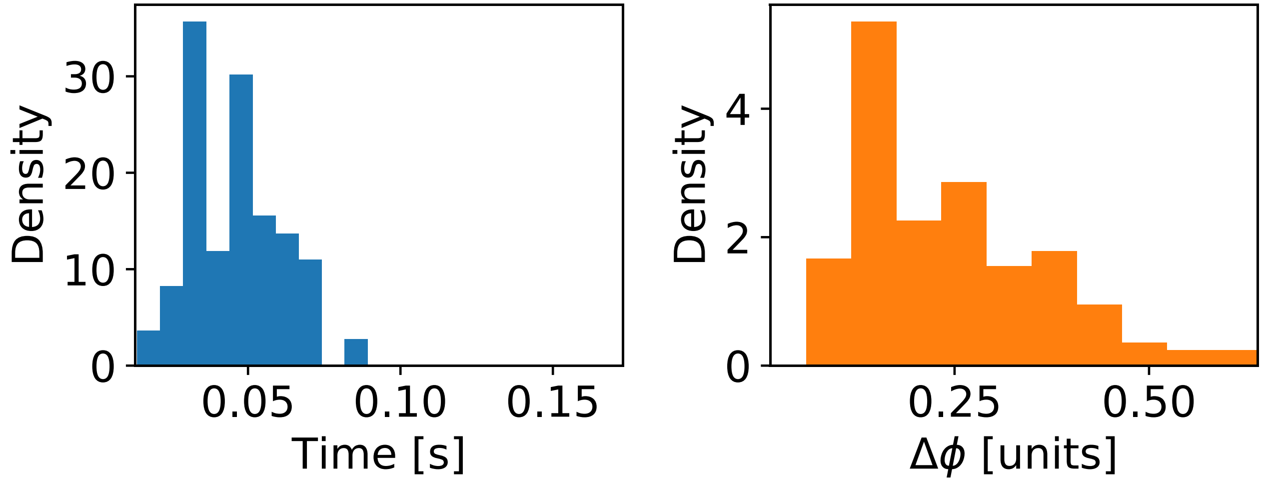
145 jumps measured in the error of the magnetic flux ($\Delta\phi$).

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

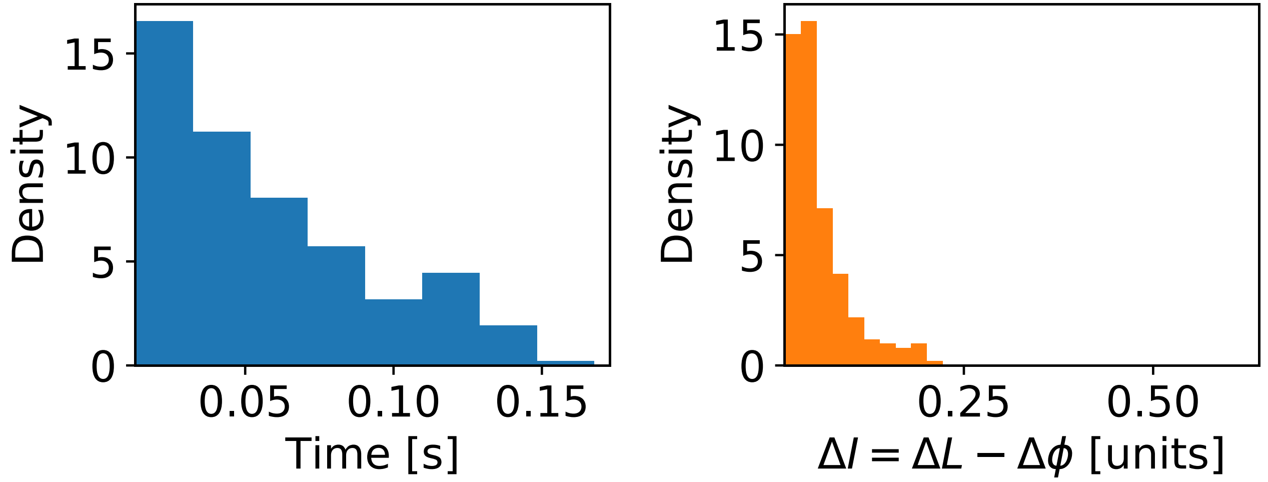
244 jumps seen in the current deviation (ΔI) of the regulation circuit.

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

MBH measured flux jumps



MQX regulation response simulation



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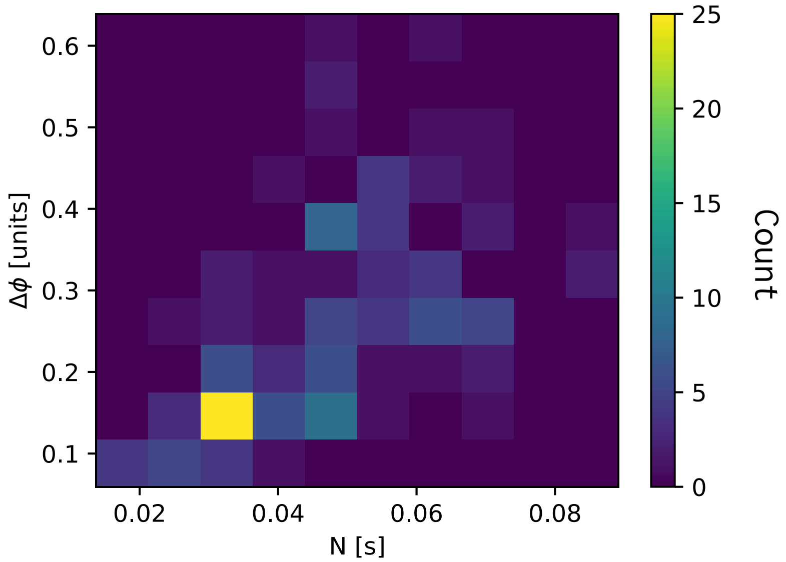

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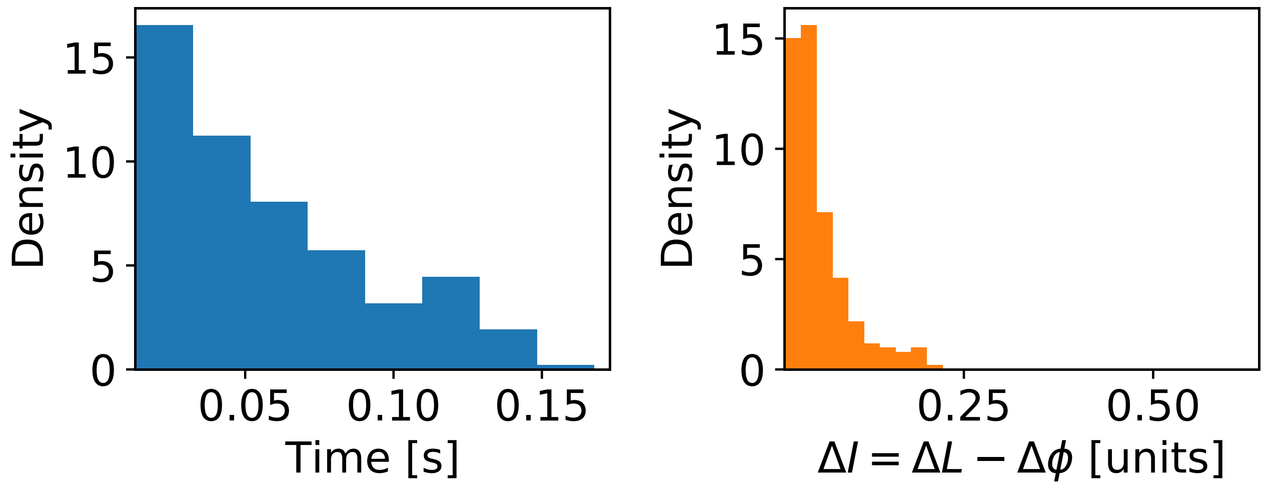
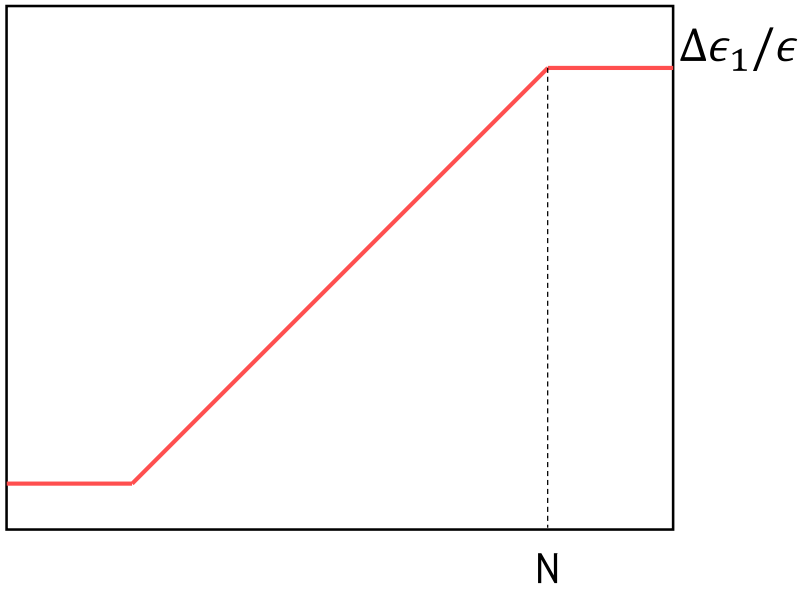


Setup for the simulations

- The flux jump will appear like a fast error in the triplet field.
- Dipolar kicks will be applied to the beam via feed-down due to the crossing angles.
- A single turn Δemittance ($\Delta\epsilon_1$) is computed applying the magnetic errors to a MAD-X model of IR1 (IR5 is the same with crossing angles in the opposite plane).
- The single turn $\Delta\epsilon_1$ is reduced by the length of the jump following the pessimistic formula:

$$\Delta\epsilon(N)/\epsilon \approx \frac{\Delta\epsilon_1/\epsilon}{4N^2\sin(\pi Q)^4} \quad \text{with}$$

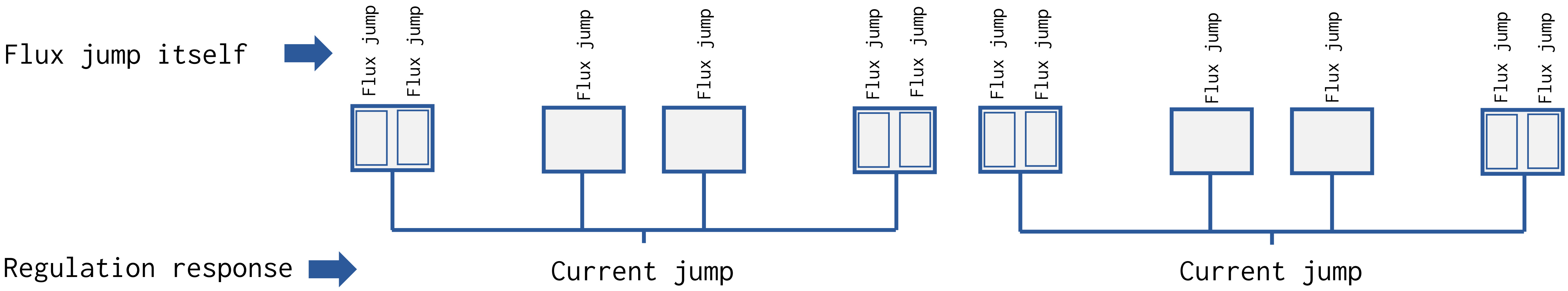


- These results ignore the effect of the transverse damper.

Setup for the simulations

A optimistic and a pessimistic case of both the effect will be computed (flux jump itself and regulation response):

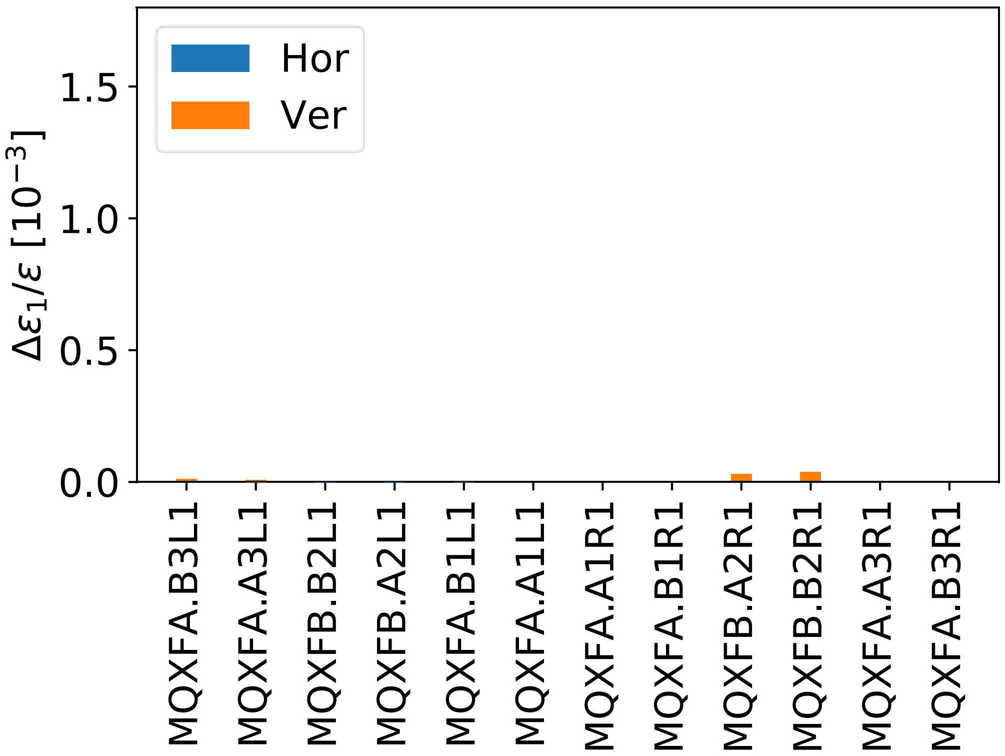
Optimistic (realistic?) case	Pessimistic case
HL-LHC injection optics	HL-LHC β^*=1 m optics
0.45 TeV	3.2 TeV



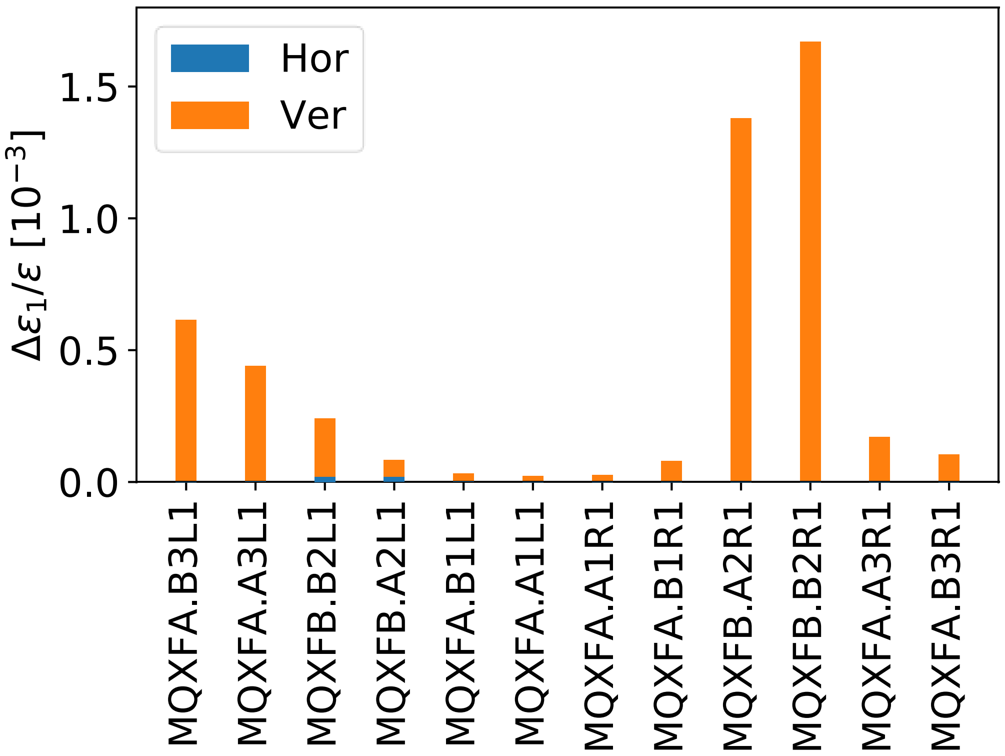
Single turn effect of the measured flux error

Single turn kick emittance growth using the pessimistic side of the error bar: **0.3 units strength**

Injection energy and optics



3.2TeV energy and 1m optics



Emittance growth produced by the measured flux error

Number of flux jumps and time needed to obtain a 1% emittance growth using the pessimistic side of the error bar, **30 ms or 330 turns**:

	Number of jumps per magnet	Time [minutes] at 4.4 events/s
Inj.	$19 \cdot 10^6$	$7 \cdot 10^4$
3.2 TeV	$4 \cdot 10^5$	$1.6 \cdot 10^3$

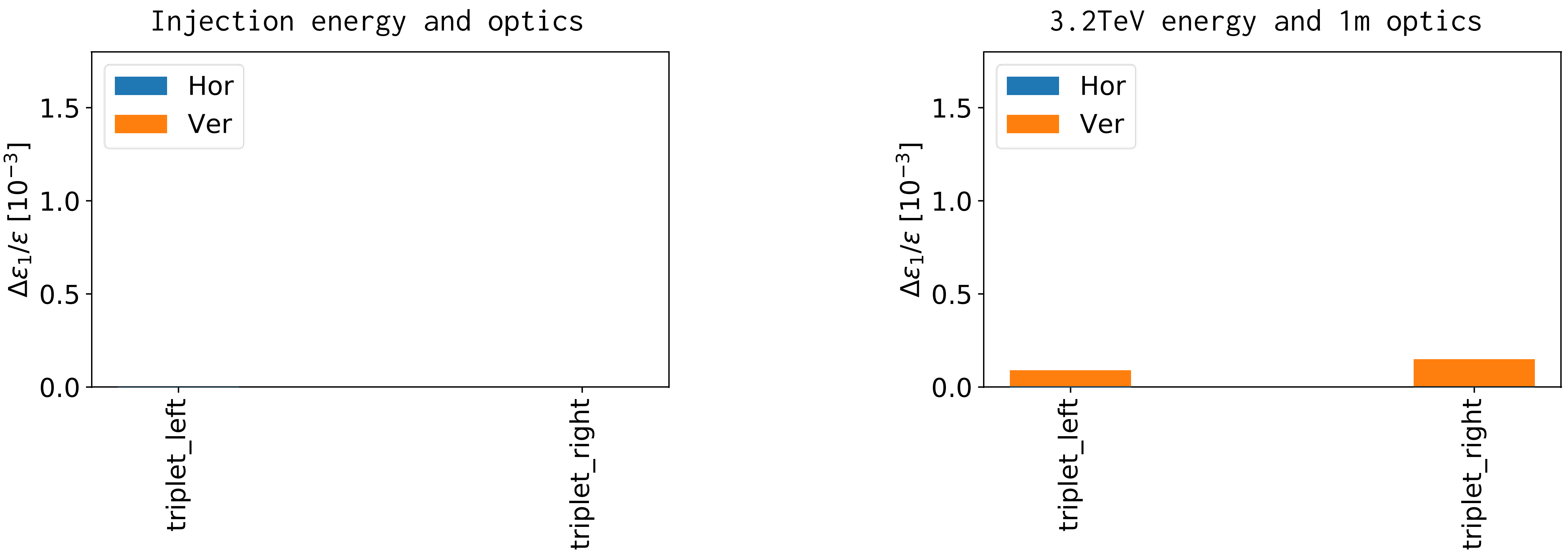
At 4.4 flux jumps per second

Assuming the effect is the same in IR1 and IR5.

With this strength the flux jumps must have a length of ~3.4 ms (37 turns) to produce a 1% blow-up in 20 minutes, assuming β^*=1 m optics.

Single turn effect of the current error of the regulation response

Single turn kick emittance growth using the pessimistic side of the error bar: **0.09 units strength**



Emittance growth produced by the current error of the regulation response

Number of flux jumps and time needed to obtain a 1% emittance growth using the pessimistic side of the error bar, **20 ms or 220 turns**:

	Number of jumps per magnet	Time [minutes] at 4.4 events/s
Inj.	$3 \cdot 10^7$	$1.1 \cdot 10^5$
3.2 TeV	$6 \cdot 10^5$	$2 \cdot 10^3$

At 4.4 flux jumps per second

Assuming the effect is the same in IR1 and IR5.

Conclusions and outlook

- Based on the latest measurements and simulations provided by Lucio Fiscarelli and Michele Martino.

- The flux jumps are too slow to provide a dangerous effect on the emittance.

- In the worst case, for β^*=1 m optics and 3.2 TeV energy with 4.4 jumps per second, it would take about 1 day to produce a 1% emittance blow-up.

- The average tune change per jump per quadrupole is: ~$3 \cdot 10^{-5}$ for β^*=1 m optics and ~$5 \cdot 10^{-6}$ for injection optics.

- Are the flux jumps going to affect the K-modulation measurements? See slides in: https://indico.cern.ch/event/818488/contributions/3418244/attachments/1840501/3017337/FluxJumpsKmod.pdf