Effects of flux jumps on emittance blow-up

Jaime Maria Coello de Portugal - Martinez Vazquez

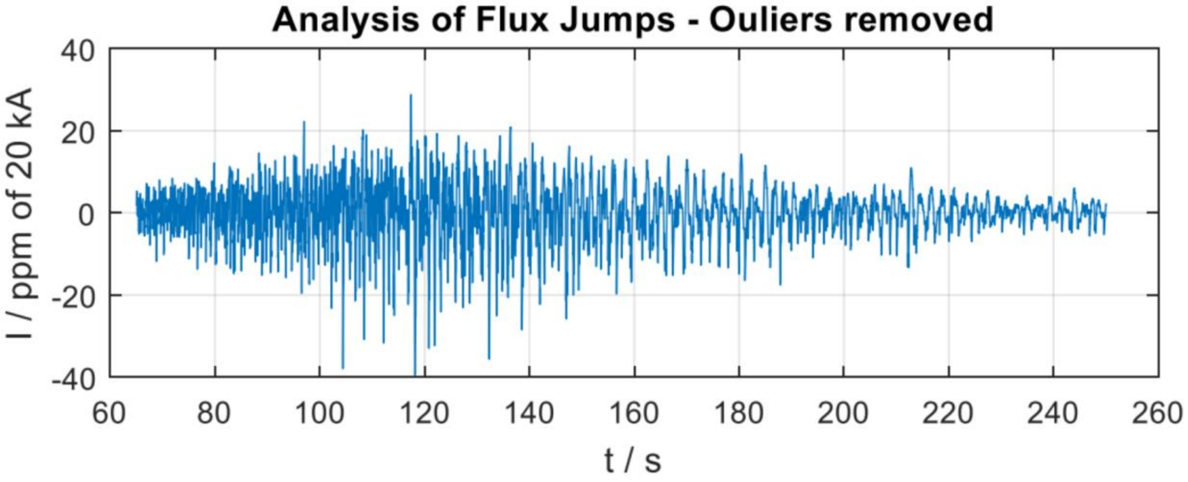
Flux jumps simulations

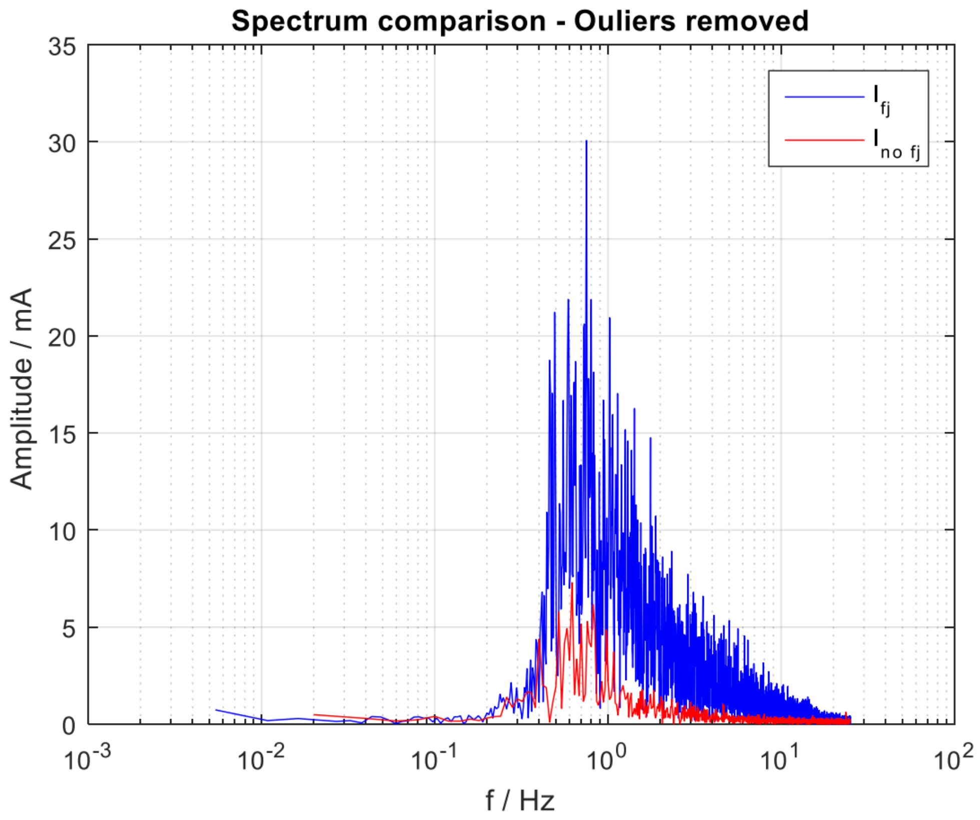
Unstable behaviour shown by all type II superconductors when subjected to a magnetic field.

We have only **very preliminary measurements*** that show:

- Flux jumps happen only during the early ramp (up to around 50% energy).
  - Simulate injection and middle of the ramp (3725 GeV with 1m optics).

- Measurements show about 30ppm of rated intensity.
  - This 30 ppm intensity will be assumed in this study.



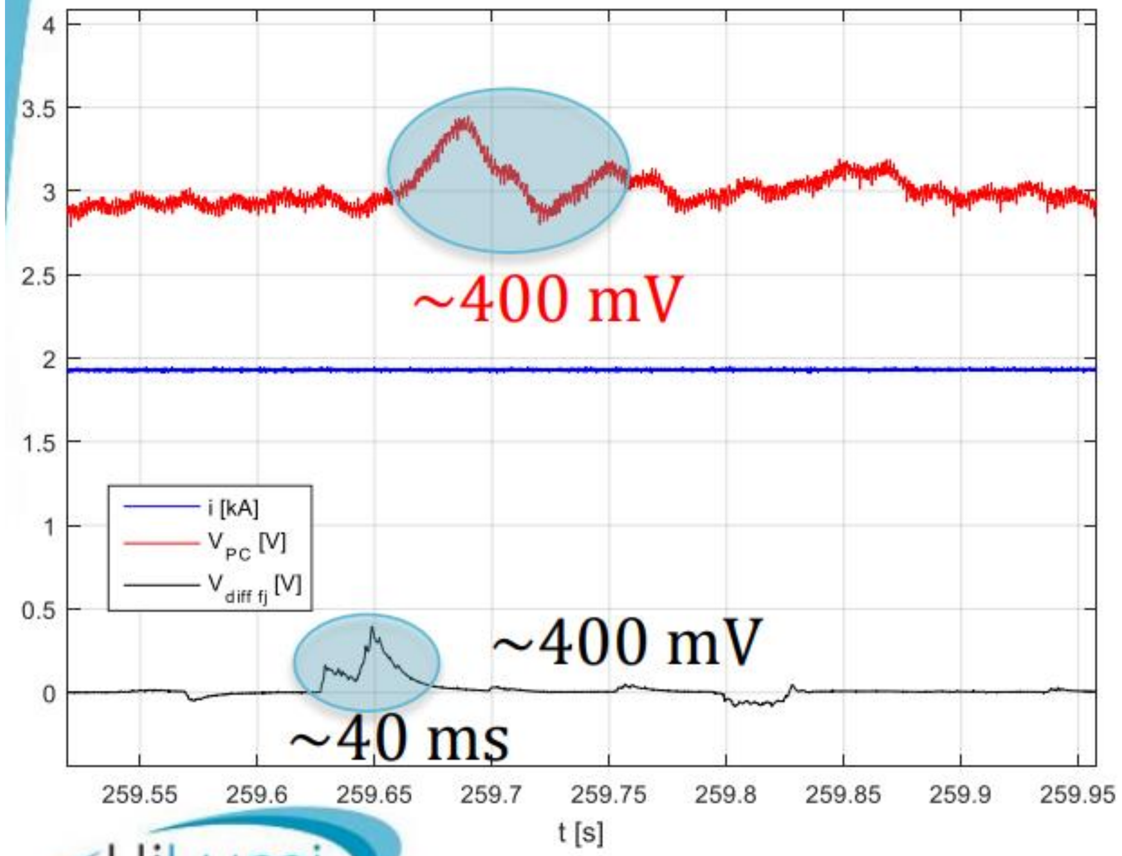


Very preliminary measurements and plots by Michele Martino

The **very preliminary measurements*** also show:

- Time scale of a flux jump seems to be “few tens of ms”.
    - Between 10 and 60ms will be taken in to account.

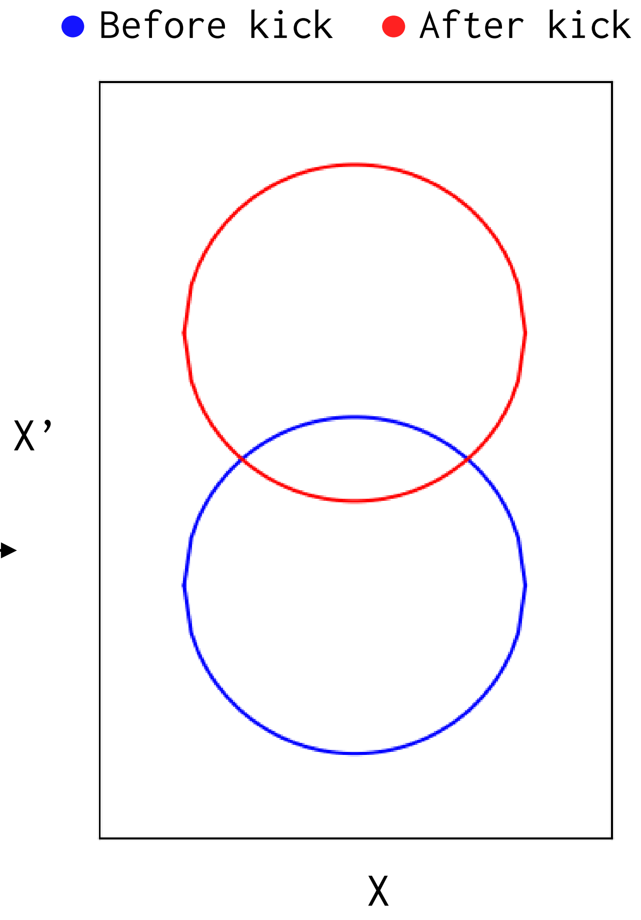
- It is unclear if the effect will show up at circuit or magnet level.
    - Simulate both cases: jumps in the circuit and jumps in individual magnets.



Flux jumps kick: Effect of dipolar component

- The flux jump will appear like a fast error in the triplet field.
- Dipolar kicks will be applied to the beam via feeddown due to the crossing angles.
- The effect of the kick on the emittance if $\epsilon_f = \epsilon_0 + \Delta\epsilon$:

$$\epsilon_f = \epsilon_0 + \beta_Q(\Delta kl \cdot x_{co})^2$$



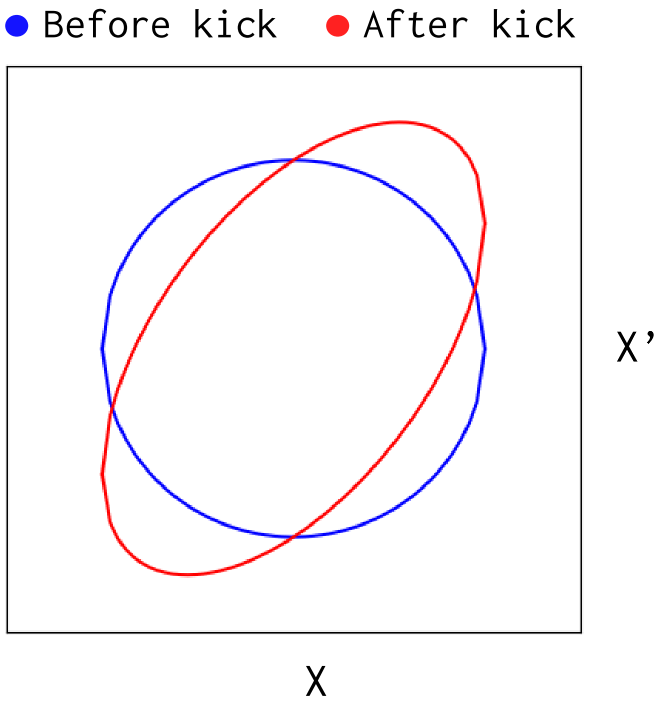
- This is the effect taken into account in the study.

Flux jumps kick: Effect of quadrupolar component

- The flux jump will appear like a fast error in the triplet field.
- The quadrupolar kick will also disturb the shape of the beam phase space.
- The effect on the emittance is:

$$\epsilon_f \approx \epsilon_0 + \underbrace{\boxed{\frac{3\epsilon_o\left(\beta_Q \Delta k l\right)^2}{4}}}_{\Delta\epsilon} + O(\Delta k^4)$$

Small compared with dipolar kick -> **ignored in this study.**



Flux jumps simulations

- Assumed a jump of $30 \cdot 10^{-6}$ in the field of the IR magnets relative to nominal.
- Used MAD-X to compute a Twiss of the IR with the flux jumps applied computed emittance as:

$$\gamma(s)y^2 + 2\alpha yy' + \beta(s)y'^2 = \epsilon$$

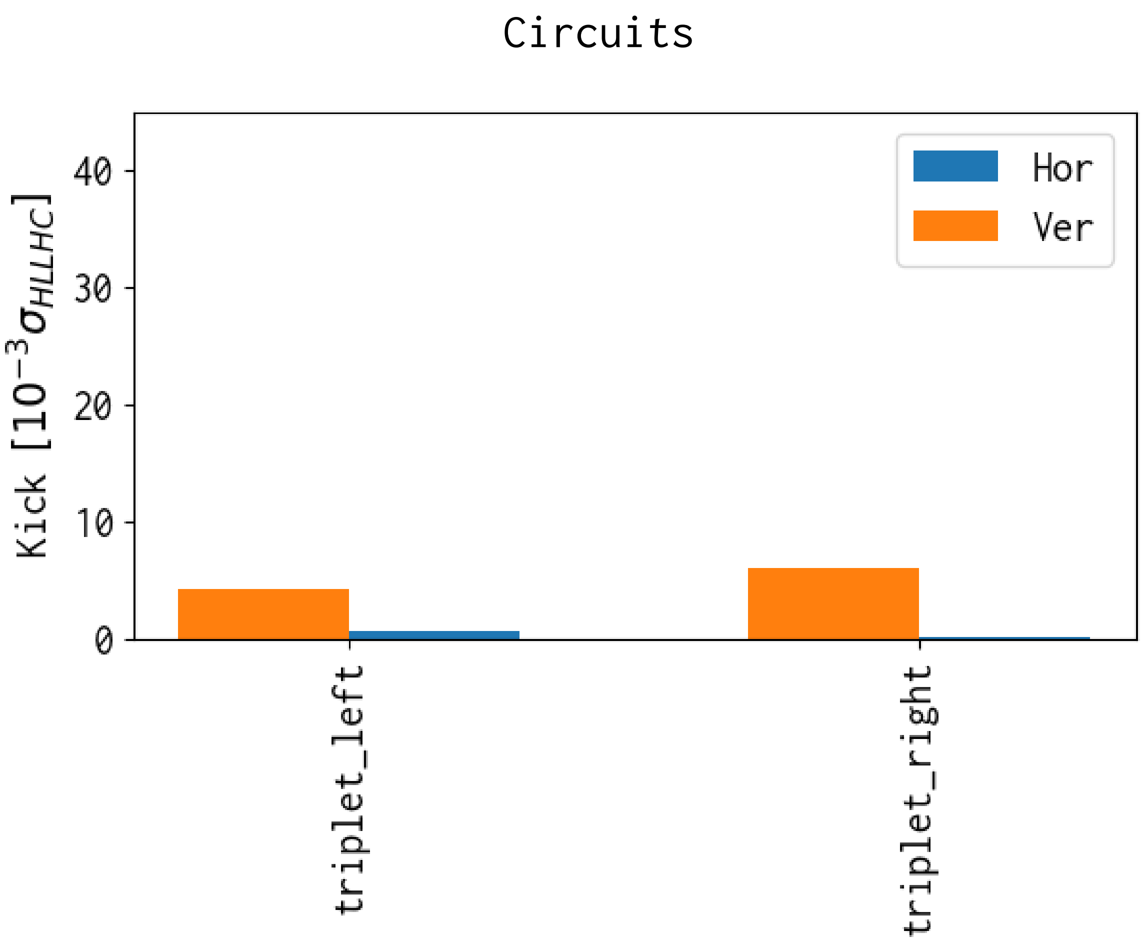
$$\epsilon_N = \epsilon\gamma_{rel}$$

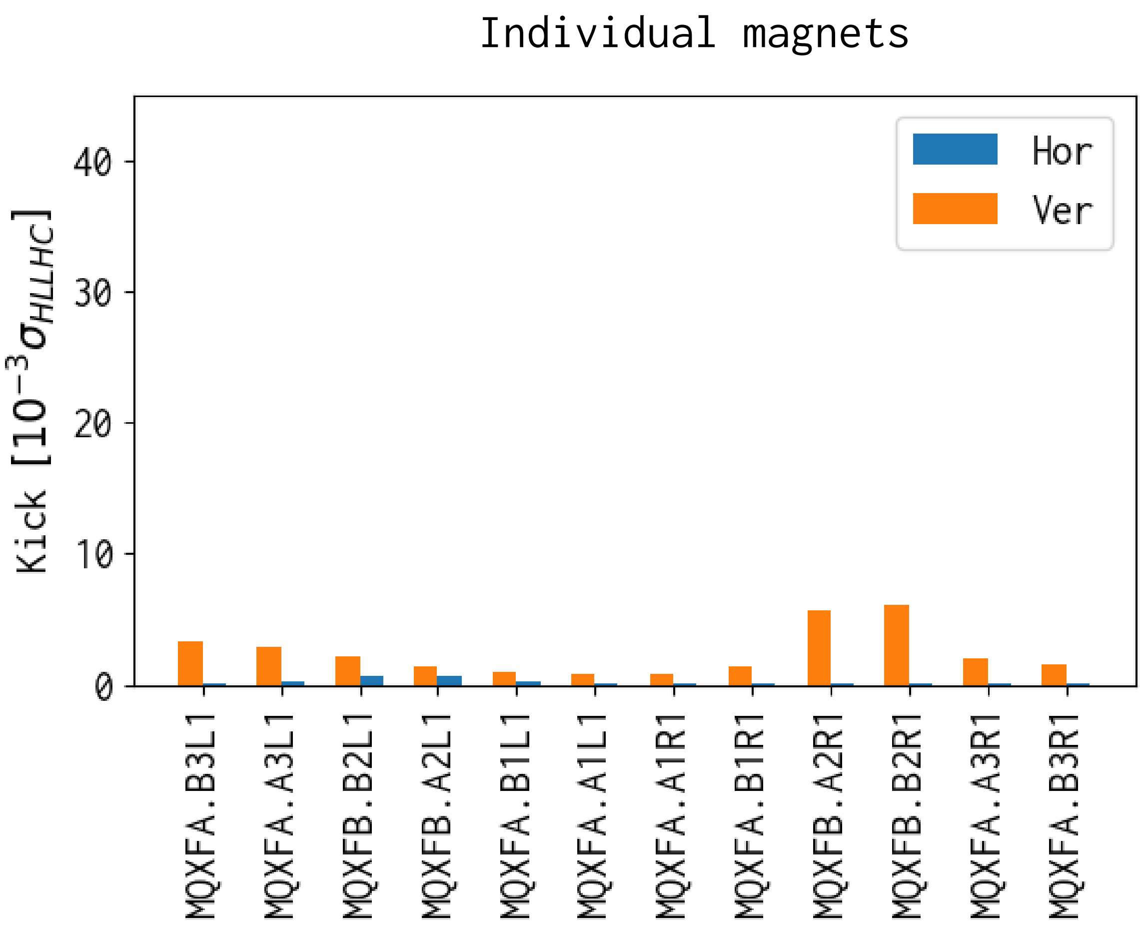
- Then used the nominal emittance of HL-LHC at injection $\epsilon_{HLLHC} = 1.7\mu m$ to compute the kick in σ:

$$k_\sigma = \sqrt{\frac{\Delta\epsilon_N}{\epsilon_{HLLHC}}}$$

- Simulations made magnet-by-magnet and circuit-by-circuit.
- Studied only IP1 (identical to IP5 with horizontal crossing)

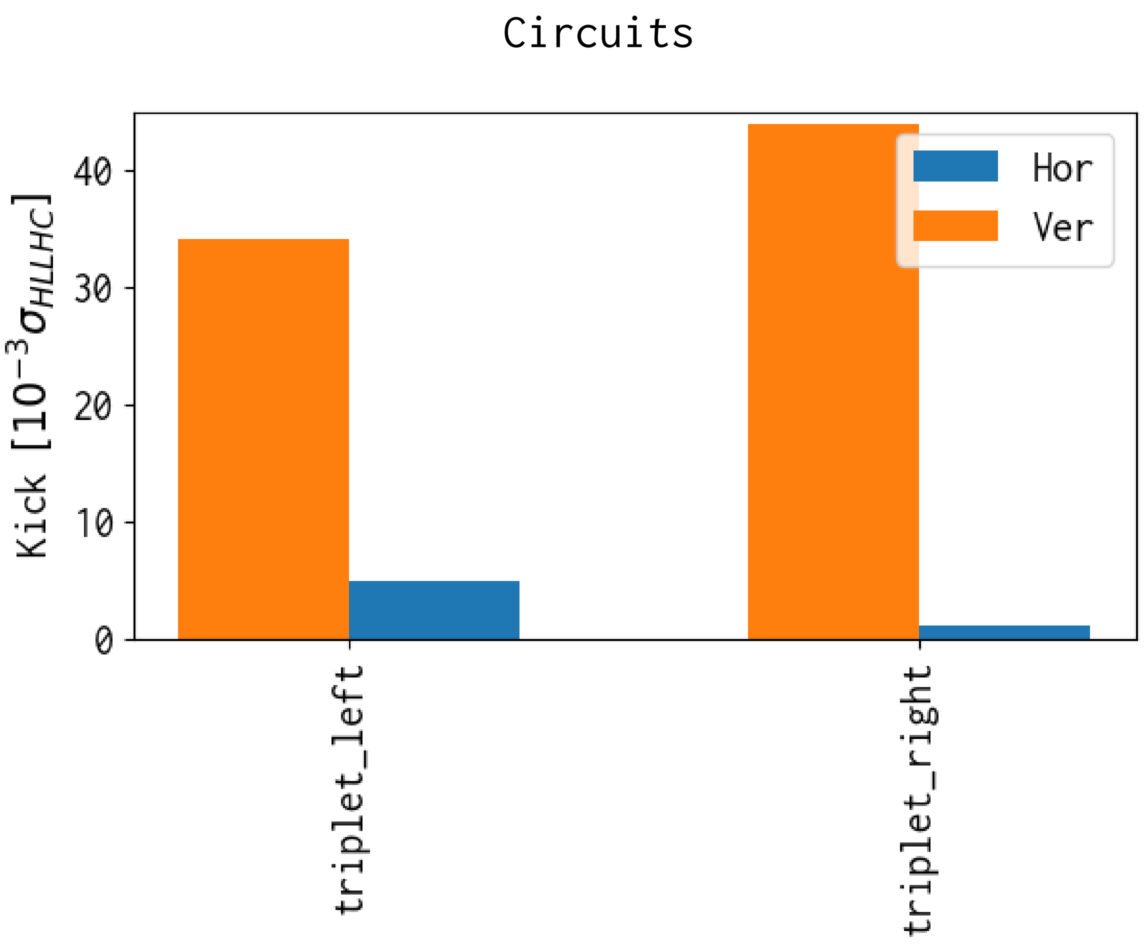
Flux jumps kick at 450GeV and injection optics

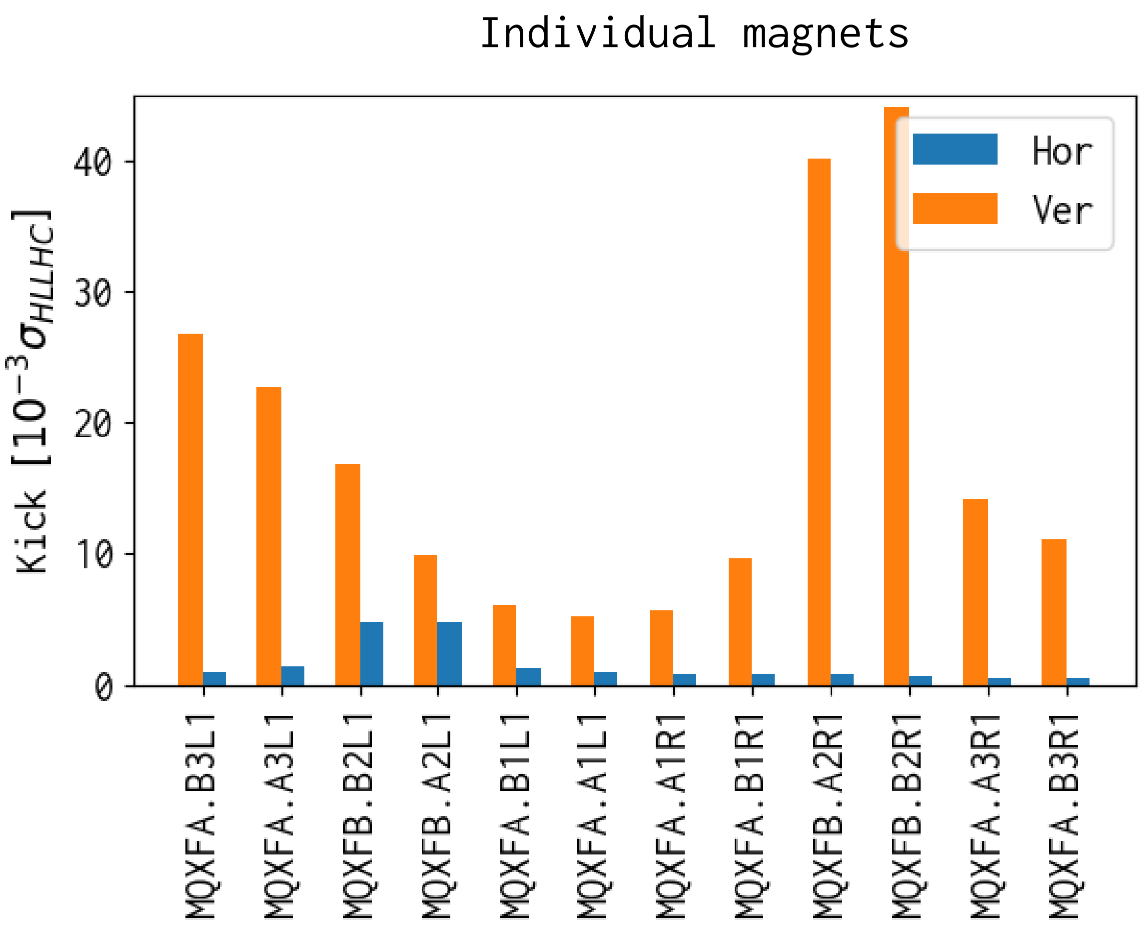




- For 0.45TeV and injection optics.
- 30 ppm intensity.

Flux jumps kick at 3.2TeV and 1m optics

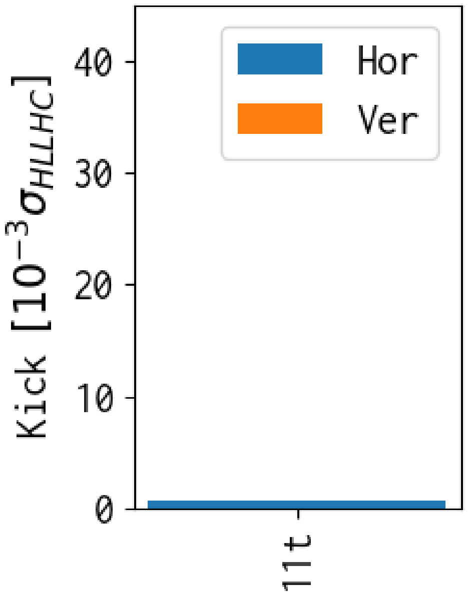


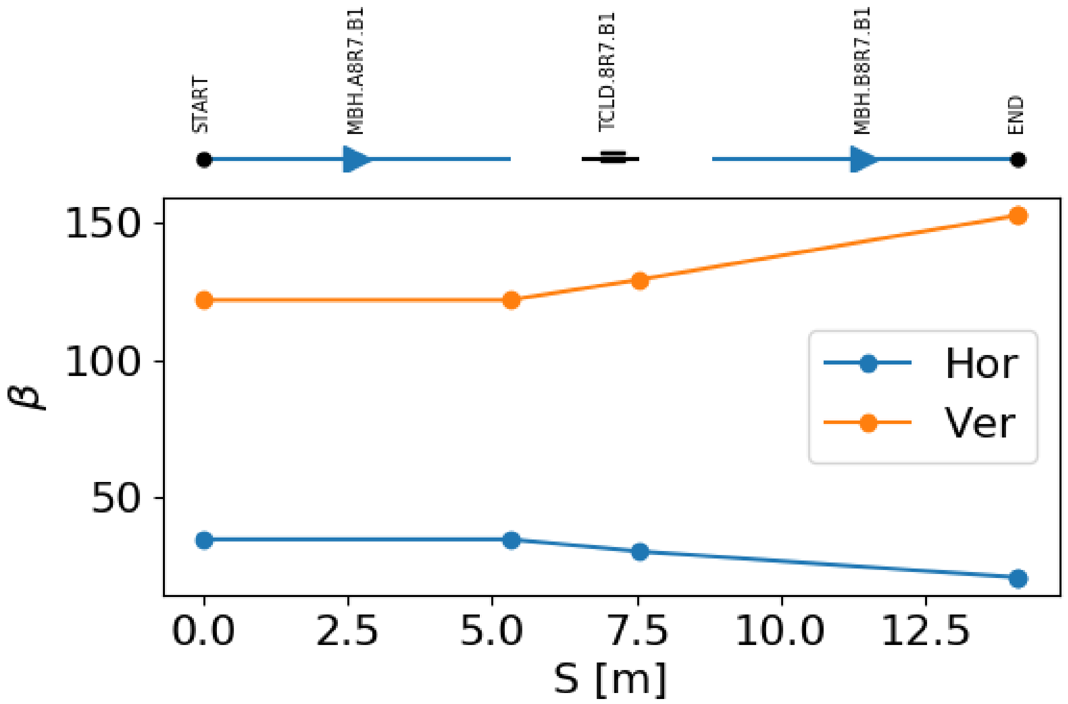


- For 3.2TeV and 1m optics.
- 30 ppm intensity.

Flux jumps kick in the 11 tesla dipoles

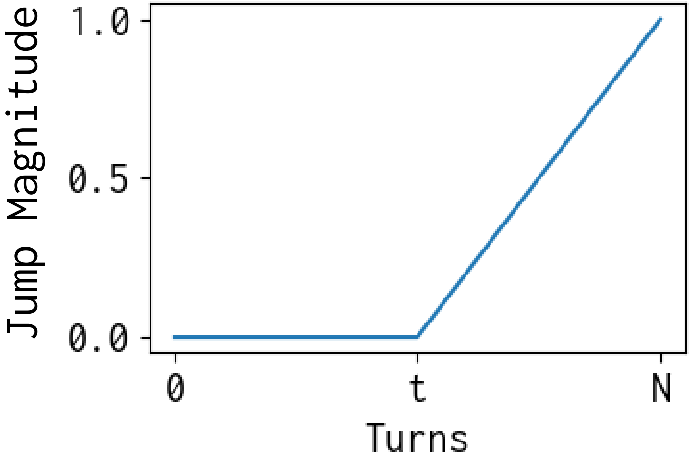
- 4 additional (2 per beam) dipoles with Nb_3Sn technology
- The highest horizontal β-function in their region is small (about 30m)
- The 1-turn kick of these dipoles is $0.7 \cdot 10^{-3}\sigma$ -> Negligible compared with the triplet quadrupoles



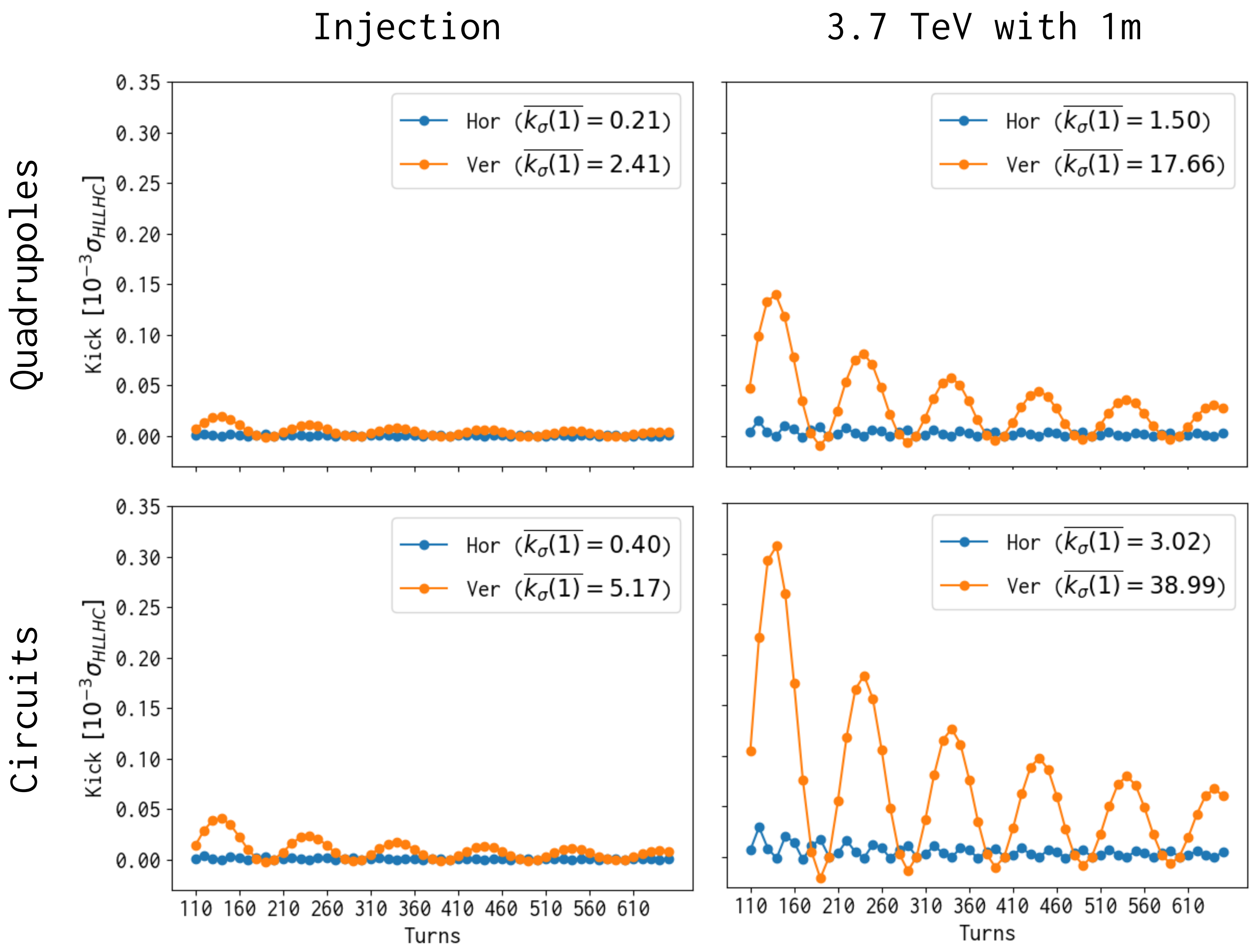


Flux jumps simulations

- Assuming all quadrupoles are equally likely to have a flux jump.
- If the $30 \cdot 10^{-6}$ kick develops over N turns assuming a linear increase starting at t:



- Plotting only 1 every 10 turns.
- The kick develops during “few tens of ms”, here from 10 to 60:



Flux jumps simulations

- Assuming all 12 quadrupoles are equally likely to have a flux jump.
- The total number of individual (with duration in the worst case of the 10 to 60ms range) $30 \cdot 10^{-6}$ kicks per individual quadrupole to get an 1% emittance growth would be:

	Number of jumps per magnet
Magnets Inj.	439
Circuits Inj.	205
Magnets 3.7 TeV	60
Circuits 3.7 TeV	28

- This number of kicks in all IP1 and IP5 triplet quads would therefore cause an 1% luminosity loss

Flux jumps simulations -> UPDATED FLUX JUMP STRENGTH TO 100 PPM

- Assuming all 12 quadrupoles are equally likely to have a flux jump.
- More recent measurements show a stronger flux jump of about $100 \cdot 10^{-6}$ ppm.
- The total number of individual (with duration in the worst case of the 10 to 60ms range) $\mathbf{100 \cdot 10^{-6}}$ kicks per individual quadrupole to get an 1% emittance growth would be:

	Number of jumps per magnet
Magnets Inj.	131
Circuits Inj.	61
Magnets 3.7 TeV	18
Circuits 3.7 TeV	8
11T dipole 3.7TeV	337

- This number of kicks in all IP1 and IP5 triplet quads would therefore cause an 1% luminosity loss

Flux jumps simulations

- This presentation is based on **very preliminary measurement.**
- Assuming jumps of **100 ppm** that affect the whole triplet in the middle of the ramp of around ~110 turns length (10ms) -> 8 individual flux jumps per quadrupole will cause a 1% luminosity loss.
- At injection flux jumps cause smaller emittance growth.
- The kick from the 11 tesla dipoles in IR7 is negligible.

- In quadrupoles the flux jump will appear as a fast change in the strength of the quadrupole Δkl.

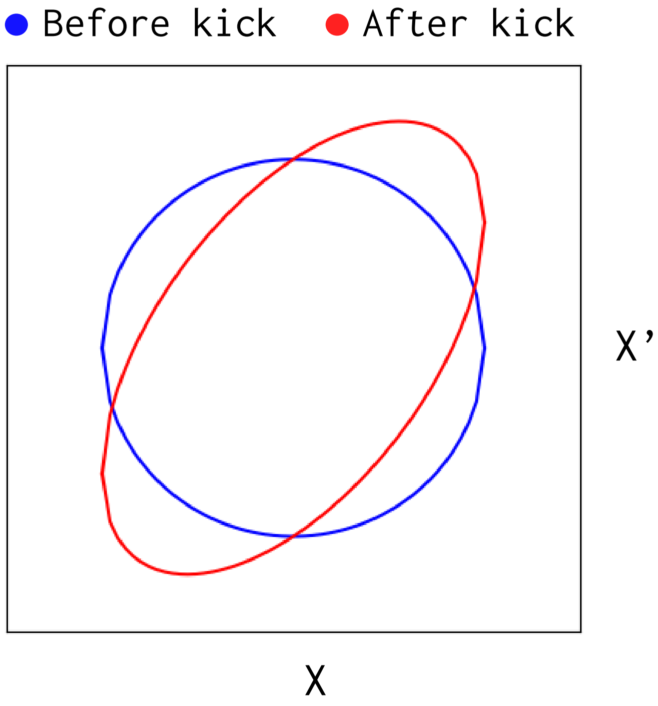
If ϵ_0 is the initial emittance and we start with a distribution $\Psi_0(J)$:

$$\Psi_0(J) = \frac{1}{2\pi\epsilon_0}\exp\left(-\frac{J}{\epsilon_0}\right)$$

Transforming J for a quadrupolar kicks: $J \rightarrow \frac{1}{2\beta}\left[x^2 + \left(p + \beta_Q \Delta klx\right)^2\right] \approx J[1 - \beta_Q \Delta klsin(2\phi)]$

The distribution after the kick:

$$\Psi_1(J,\phi) = \frac{1}{2\pi\epsilon_0}\exp\left(-\frac{J[1 - \beta_Q \Delta klsin(2\phi)]}{\epsilon_0}\right)$$



Averaging the action:

$$< J > = \int_0^\infty \int_0^{2\pi} J\,\Psi_1(J,\phi)\,dJ\,d\phi = \frac{\epsilon_0}{\left(1 - \left(\beta_Q \Delta kl\right)^2\right)^{\frac{3}{2}}} \approx \epsilon_0 + \underbrace{\boxed{\frac{3\epsilon_o\left(\beta_Q \Delta kl\right)^2}{4}}}_{\Delta\epsilon} + O(\Delta k^4)$$

Looks small compared with dipolar kick -> **ignored in this study.**