Revisiting flux jumps impact on orbit

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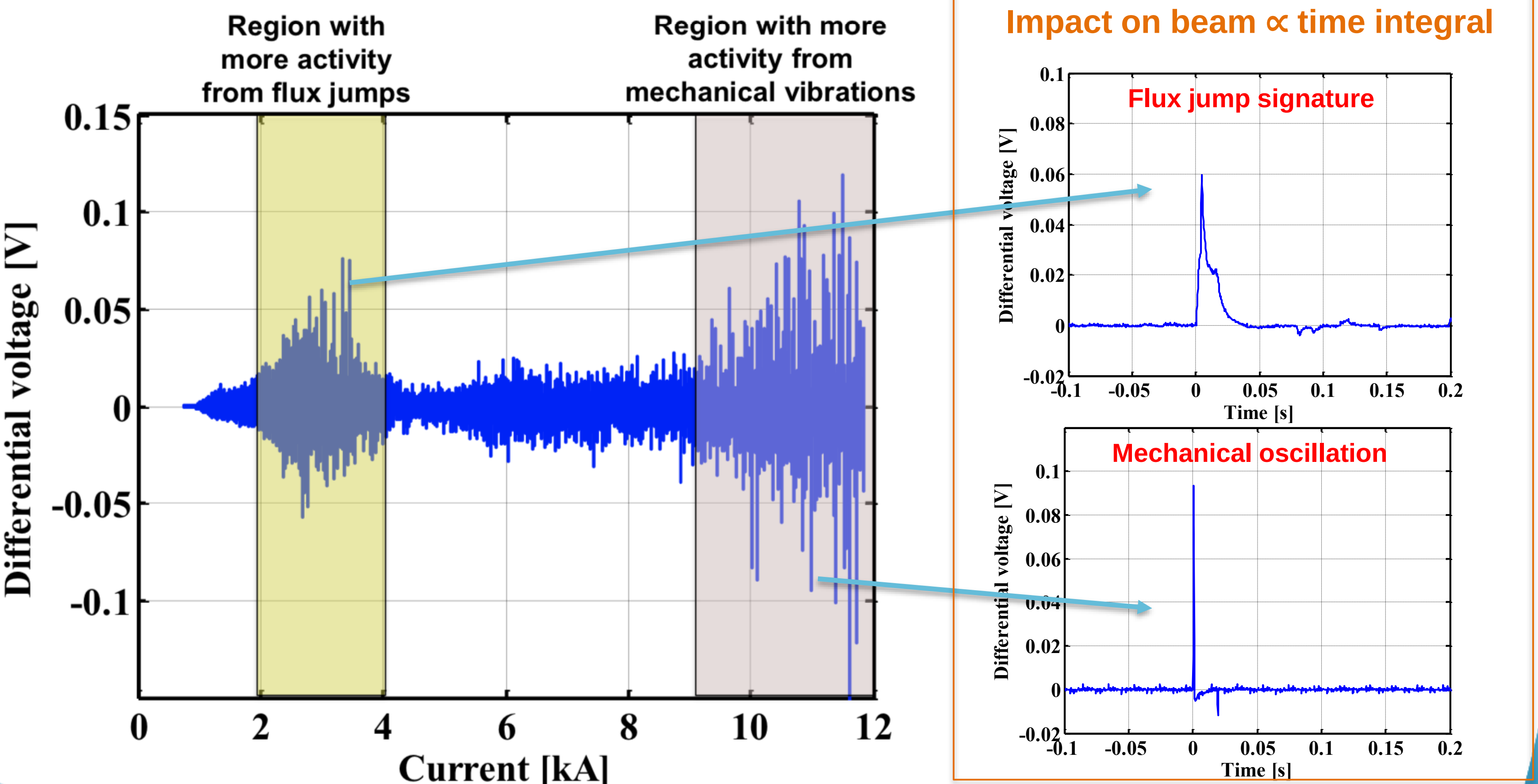
When do we expect Flux Jumps?

- Typically, most of them well **between 1-3 TeV**
  - 2 kA @10A/s are made in about **200 s**

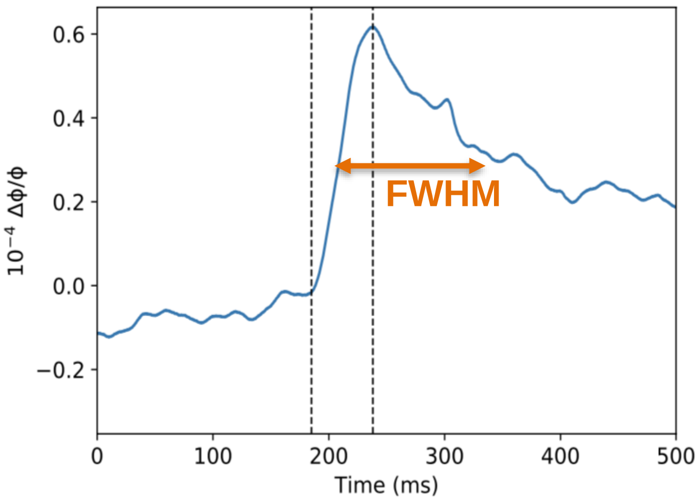
MBHSP109 - Differential voltage

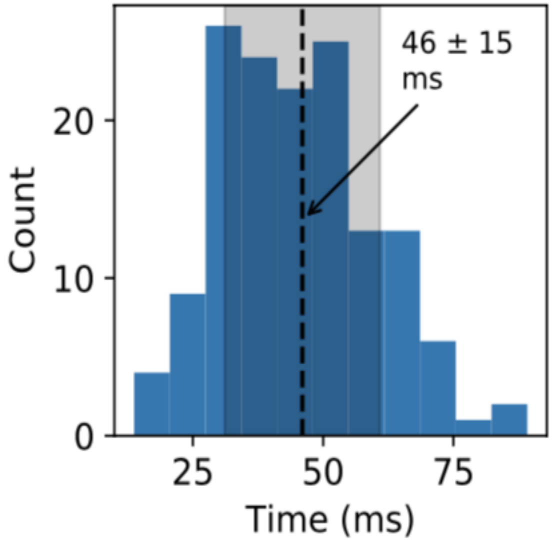


1 kA ≈ 1 T

How fast/long?

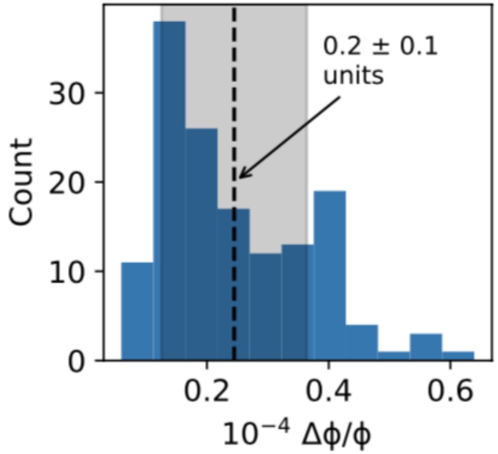
- Typically: **4.4 jumps/second**
  - **Only measured** on **11T short model.**
  - We don't know for the **quadrupoles** in the triplet
    - **Michele estimated** about **2.5 jumps/second** in this case [link]
    - **We need more measurements!!!**
- Rise time ~50 ms. Let's say **FWHM ~120 ms.**
  - 120x4.4=~500 ms: ~**half of the time a magnet is experiencing a jump**, which can be either positive or negative.





From J. Coello de Portugal **– Impact of flux jumps in future colliders (PRAB)**

How intense?



- Size of a **Flux Jump** in single magnet:
  - **0.2 units** (for the main field)
    - i.e. B0 in 11T, B1 for quadrupoles in the triplet,…
  - **WARNING1: we don't know about dipole field jump on a quadrupole**
  - **WARNING2: neglected here the 0.15 units up-down gradient measured on 11T**

- Biggest **PC-jump induced by flux jump**:
  - **0.06 units on whole RQX** circuit (at injection only)
    - It becomes **negligible at top energy** (<0.06 units)
    - **Note: PC linearity+short term stability** of the order of **0.2 units** at injection, even though those are variations at very low frequency (<1 Hz)
  - **negligible for 11T dipoles** (~0.06 units at injection only)
  - **WARNING3: PC-jumps studied only for RQX and 11T trim circuits, assuming single event in a single magnet with some *arbitrary* hypothesis on scaling laws. Dedicated studies needed!**

From *J.C. de Portugal* – **Impact of flux jumps in future colliders (PRAB)**
D. Gamba – **150th WP2 Meeting (indico)**

Impact of flux jump on orbit at TCPs

- Each value represents the orbit jump induced by the **most effective single half-magnet** affected by a **jump of 0.2 units**

Optics	Magnet	Optics sensitivity $[\sigma/10^{-4}]$	Jump-induced rms orbit $[10^{-3}\sigma]$
Injection	Q1	< 0.01	< 2
	Q2	0.01	2
	Q3	< 0.01	< 2
	Q1–Q3	0.01	2
β^*=15 cm	Q1	0.06	12
	Q2	0.28	56
	Q3	0.18	36
	Q1–Q3	0.48	96
β^*=1 m	Q1	0.02	4
	Q2	0.11	22
	Q3	0.06	12
	Q1–Q3	0.11	22

TABLE III. R.m.s. closed orbit variation at HL–LHC TCPs under the effect of the expected flux jumps for each half quadrupole composing the triplet (Q1; Q2; Q3) and for a whole triplet (Q1–Q3) computed in units of beam sigma. The optics sensitivity in units of beam sigma per unit of magnetic field change is also reported.

Optics	Optics sensitivity $[\sigma/10^{-4}]$	Jump-induced rms orbit $[10^{-3}\sigma]$
Injection	0.02	4
β^*=15 cm	0.07	14
β^*=1 m	0.07	14

TABLE V. R.m.s. closed orbit variation at HL–LHC TCPs under the effect of the expected flux jumps at the 11 T dipoles computed in units of beam sigma. The optics sensitivity in units of beam sigma per unit of magnetic field change is also reported.

Assumptions:

- **2.5 um norm. emit.**
- **7 TeV for 1m and 15 cm optics**
- **450 GeV for injection optics**

=> A jump in some key magnet could lead to ~2% beam sigma jump at TCPs

From J. Coello de Portugal **– Impact of flux jumps in future colliders (PRAB)**

Some numbers

- **Affected magnets**:
  - 2 halves x 2 sides P7 of **11 T dipoles**
    - Acting mainly on horizontal plane
  - 2 halves x 2 sides x 1 IP1/5 of **Q1 + Q2 + Q3**
    - Each IP is acting mainly on one plane due to crossing angle
- **Number of events:**
  - Over 200 s (**one ramp**, from ~1.2 to ~2.3 TeV), we expect 200x4.4 = **880 jumps** for each single magnet
  - Number of fills in **lifetime** of HL-LHC:
    - 10 years x 300 fills/year = **3000 fills**.
    - **Total number of events/magnet = 2.64x10^{6}**

Some probability of concurrent jumps

- At **a given time**, **probability** of a single magnet to be in a jump of a given sign is ¼.
- At a given time, probability that ***n* magnets** are in a jump of a given sign is therefore **$(¼)^n$**

- Additional assumptions:
  - **Assuming 1 m optics at 3 TeV** (still conservative)
    - **need to scale optics sensitivity values by** sqrt(3/7) = **0.65** as beam size is then bigger, i.e. size of jump in beam sigma is smaller.
  - **no cross-talk between magnets**
  - **all flux jump** of **0.2 units, 120 ms long, 4.4 isolated events/s**
  - **neglected** the contribution of the **power converters**
  - **Considering here only the horizontal plane**

First order estimate of cases

NumberOfEventsPerRamp	880
NumberOfRamps	3000
Numer of events	2640000

Units	0.20
Beam Energy (TeV)	3.00

		# magnet halves being affected													
Magnet	sigma@TCP/unit	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Q2B IP1 L	0.10	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Q2A IP1 L	0.10	0	1	1	1	1	1	1	1	1	1	1	1	1	1
MBH.A8L7	0.07	0	0	1	1	1	1	1	1	1	1	1	1	1	1
MBH.B8L7	0.07	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Q3B IP1 R	0.06	0	0	0	0	1	1	1	1	1	1	1	1	1	1
Q3A IP1 R	0.05	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Q2B IP1 R	0.04	0	0	0	0	0	0	1	1	1	1	1	1	1	1
Q3A IP1 L	0.03	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Q3B IP1 L	0.03	0	0	0	0	0	0	0	0	1	1	1	1	1	1
Q2A IP1 R	0.02	0	0	0	0	0	0	0	0	0	1	1	1	1	1
Q1B IP1 L	0.02	0	0	0	0	0	0	0	0	0	0	1	1	1	1
Q1B IP1 R	0.01	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Q1A IP1 L	0.01	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Q1A IP1 R	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1/probability:		1	2	8	32	128	512	2048	8192	32768	131072	524288	2097152	8388608	33554432
Cases during 1 ramp		880	440	110	28	7	2	0	0	0	0	0	0	0	0
Cases Lifetime		2640000	1320000	330000	82500	20625	5156	1289	322	81	20	5	1	0	0
Impact at TCP [% beam s.]		1.3	2.6	3.5	4.5	5.2	5.9	6.5	6.9	7.2	7.5	7.8	8.0	8.1	8.3

- At least **one event** of **~6% σ_{beam} jump/ramp** (~8% σ_{beam} during HL-LHC lifetime)

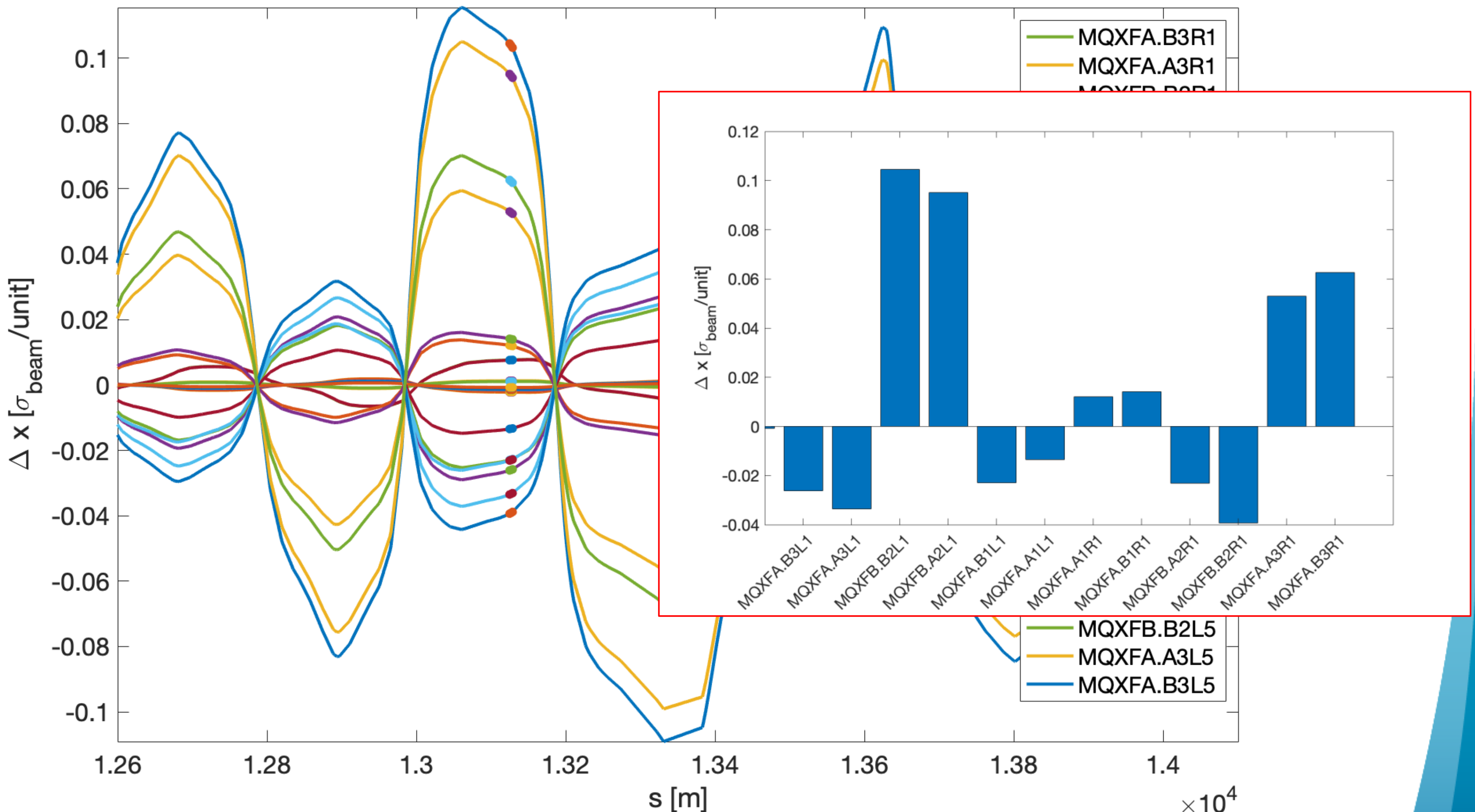
- **Similar in vertical/diagonal direction** (i.e. x3 number of “bad” events)
- **One can be more conservative** (i.e. 0.6 units jumps => up to ~20% σ_{beam} jumps)

Conclusions

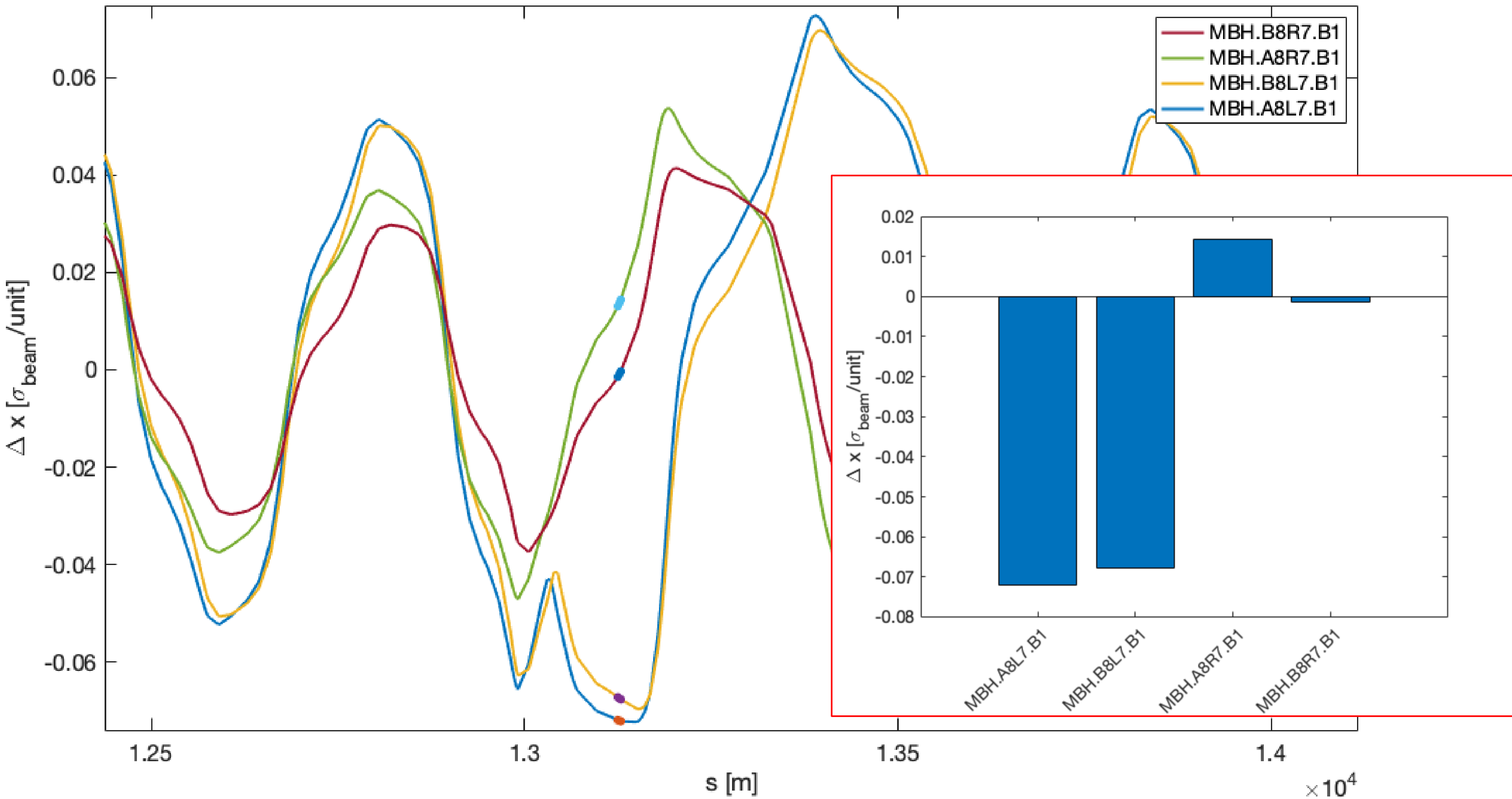
- Typically, **a few % σ_{beam} orbit jumps at TCPs**
  - For **every ramp**: >**1 case** with a jump up to ~**6% σ_{beam}**
  - During HL-LHC **lifetime**, >**1 case** with a jump up to **~8% σ_{beam}**
  - **Values can be scaled up to x3 to be very conservative**
- We have **limited knowledge** on:
  - **PC behavior** for **complex circuits** like the triplet
  - **Amplitude of B_0 jump** in a **quadrupole** magnet
- **Run3** will be **fundamental** to collect more data from 11T:
  - Firing **6k-turn-by-turn BPM data** every “second”
  - **ADT** spectra
  - **BPM** 25Hz rms data
  - *Other signals*? *BLM data*?
- **String tests** could be another place where **to learn more.**

Backup

Impact of quads @TCP @1m beta* @7TeV @295 urad crossing



Impact of 11T @TCP @1m beta* @7TeV



More complicated: diagonal kick + PC effect

NumberOfEventsPerRamp	880
NumberOfRamps	3000
Numer of events	2640000

Flux jump [units]	0.20
PC jump [units]	0.06
Beam Energy (TeV)	3.00

								# magnet halves being affected													
Magnet	H	V	IP1 L	IP1 R	IP5 L	IP5 R	sigma @TCP/unit	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RQX circuit IP1 L	1	0	1	0	0	0	0.10	1	1	2	2	2	2	2	2	2	2	3	3	4	4
RQX circuit IP1 R	1	0	0	1	0	0	0.10	0	0	0	0	0	0	1	1	2	2	2	2	2	2
RQX circuit IP5 L	0	1	0	0	1	0	0.10	0	0	0	0	0	0	0	1	1	2	2	2	2	2
RQX circuit IP5 R	0	1	0	0	0	1	0.10	0	1	1	2	2	2	2	2	2	2	2	3	3	4
Q2A IP1 L	1	0	1	0	0	0	0.10	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Q2A IP5 R	0	1	0	0	0	1	0.10	0	1	1	1	1	1	1	1	1	1	1	1	1	1
Q2B IP1 L	1	0	1	0	0	0	0.10	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Q2B IP5 R	0	1	0	0	0	1	0.10	0	0	0	1	1	1	1	1	1	1	1	1	1	1
MBH.A8L7	1	0	0	0	0	0	0.07	0	0	0	0	1	1	1	1	1	1	1	1	1	1
MBH.B8L7	1	0	0	0	0	0	0.07	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Q3A IP1 R	1	0	0	1	0	0	0.06	0	0	0	0	0	0	1	1	1	1	1	1	1	1
Q3A IP5 L	0	1	0	0	1	0	0.06	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Q3B IP1 R	1	0	0	1	0	0	0.05	0	0	0	0	0	0	0	0	1	1	1	1	1	1
Q3B IP5 L	0	1	0	0	1	0	0.05	0	0	0	0	0	0	0	0	0	1	1	1	1	1
Q1A IP1 L	1	0	1	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	1	1	1	1
Q1A IP5 R	0	1	0	0	0	1	0.04	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Q1B IP1 L	1	0	1	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Q1B IP5 R	0	1	0	0	0	1	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1/probability:								1	2	8	32	128	512	2048	8192	32768	131072	524288	2097152	8388608	########
Cases during 1 ramp								880	440	110	28	7	2	0	0	0	0	0	0	0	0
Cases Lifetime								2640000	1320000	330000	82500	20625	5156	1289	322	81	20	5	1	0	0
Impact at H TCP [% beam s.]								1.7	1.7	3.4	3.4	4.3	5.2	6.4	6.4	7.5	7.5	8.4	8.4	9.3	9.3
Impact at V TCP [% beam s.]								0.0	1.7	1.7	3.4	3.4	3.4	3.4	4.6	4.6	5.6	5.6	6.5	6.5	7.5
Impact at diag TCP [% beam s.]								1.2	2.4	3.6	4.8	5.5	6.1	6.9	7.8	8.5	9.3	9.9	10.6	11.2	11.9

- Actual result is very similar (within 10-20%) to horizontal plane computation only.
- Still missing full analysis of PC behavior