



Update on impact of flux jumps in 11T dipoles in Run3

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Assumptions [4]

- Looking **only at 11 T dipoles** assuming they may show a measurable effect in **Run 3**
 - Little information about RQX behavior to be able to be fully predictive for HL-LHC

Description	Measured or Estimated	Value	Ref.
Flux jump B1 amplitude (all in the same “direction”)	Measured	mean 0.2 units peak 0.6 units	[1,3]
Flux jump B2-like amplitude	Measured (neglected here)	mean 0.15 units at 17 mm	[1,3]
Trim power converter reaction	Estimated	6 ppm σ (of 600 A)	[2,3]
Main dipole power converter reaction	Estimated (neglected here)	8e-3 ppm σ (of 13 kA)	[2]
Single flux jump duration	Measured → Estimated →	50 ms mean rise time 120 ms FWHM	[1,3]
Beam energy when <i>most</i> flux jumps occur	Measured	≈1.2 – ≈2.4 TeV → <3 TeV (2 – 4 kA current)	[1,3]
Frequency of the flux jumps	Measured	4.4 jumps/s	[1,3]
Number of flux jumps per fill	Computed	880 jumps	[4]
Probability of a unit to be in a jump at a given time	Computed	1/2	[4]

[1] L. Fiscarelli – Measurements and analysis of flux jumps ([indico](#))

[2] M. Martino – Impact of Flux Jumps on PC Performance ([indico](#))

[3] J. Coello de Portugal – Impact of flux jumps in future colliders ([PRAB](#))

[4] D. Gamba – Revisiting flux jumps impact on orbit ([indico](#))

Putting numbers together

- We expect to have **4 11T units** installed in **LHC** after LS2
- A **flux jump** in each unit **will cause** a small **orbit jump at the TCPs**
 - **Several units could jump at the same time**, so their effect would add up (with sign!)
 - One can make **some simple probability estimate**:

Events per second [#s]	4.4			Flux jump [units]	0.20
Affected ramp time [s]	200			11T Trim jump [ppm]	6.00
Number of events per ramp [#]	880			11T Trim I_rat/I_nom	0.05
Number of ramps lifetime [#]	3000			11T Trim jump [units]	0.01
Numer of events lifetime [#]	2640000			Beam Energy (TeV)	3.00
		# magnet halves being affected			
Magnet	sigma@TCP/unit	1	2	3	4
MBH Trilm L7	0.14	1	2	2	2
MBH Trilm R7	-0.02	0	0	1	2
MBH.A8L7	0.07	1	1	1	1
MBH.B8L7	0.07	0	1	1	1
MBH.A8R7	-0.02	0	0	1	1
MBH.B8R7	0.00	0	0	0	1
1/probability:		1	2	4	8
Cases during 1 ramp		880	440	220	110
Cases Lifetime		2640000	1320000	660000	330000
Impact at TCP [% beam s.]		1.0	2.0	1.8	1.8

Impact on beam losses

- Double Gaussian beam distribution measured in LHC and typically used for HEL simulations [5]

$$f(x) = \frac{I_1}{\sqrt{2\pi}\sigma_1} e^{-\frac{x^2}{2\sigma_1^2}} + \frac{I_2}{\sqrt{2\pi}\sigma_2} e^{-\frac{x^2}{2\sigma_2^2}}$$

where: $I_1/I_2 = 65/35$

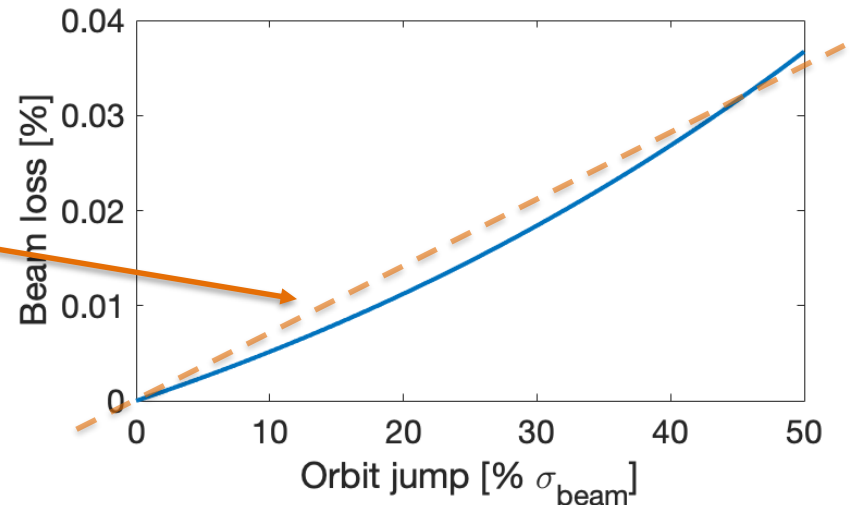
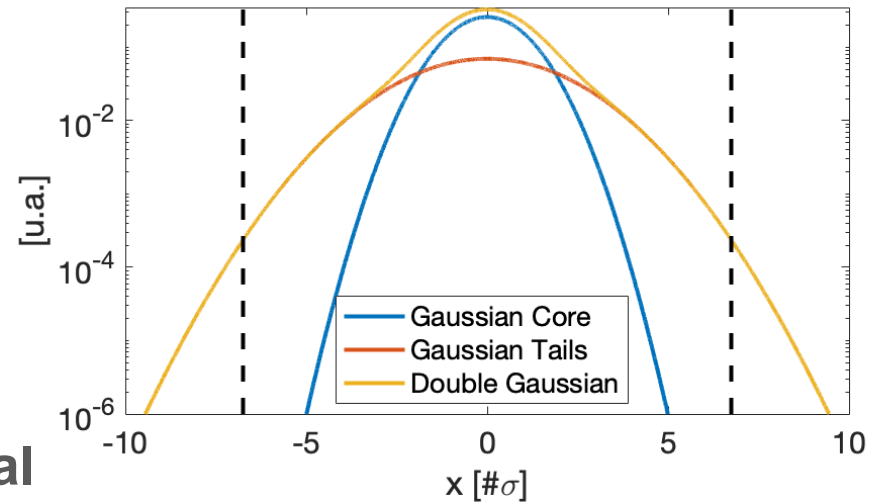
$$\sigma_2 = 2\sigma_1$$

- Losses assuming TCP opening equal to 6.7σ ($2.5 \mu\text{m } \epsilon_N$)

- (equivalent to 5.7σ ($3.5 \mu\text{m } \epsilon_N$))

- 1% σ_{beam} orbit jump induces $\approx 7e-6$ relative beam losses.

- 2.5 kJ (w.r.t. 360 MJ @7TeV)
- 2.3e9 protons (w.r.t. 3.22e14 full beam)



[5] P. Racano - Review of halo measurements at Large Hadron Collider with collimator scans. University of Rome La Sapienza - 2019.

BLM Thresholds and Dump

- BLM thresholds in IR7 are based on a semi-analytical model from [2009](#);
 - Values at FT are updated every year during commissioning, based on qualification loss maps;
 - Values during the ramp have never been verified/benchmarked!**
- BLM thresholds during the ramp have been set **assuming**:
 - Linear interpolation** of design figures for collimation protection at **450 GeV** and **7 TeV**
 - It should be hyperbolic, though...
 - A **constant BLM conversion factor: 1 pGy/proton**;
 - No change with beam energy, jaw material, collimator skew angle, ...
 - Recent FLUKA simulations estimate the conversion factor for TCPs at 4-5 pGy/proton @7 TeV;
 - Recent FLUKA simulations show that the conversion factor decreases by a factor 10 when going from 450 GeV and 7 TeV;

BLM Thresholds @ Hor TCP @ 2.95 TeV

	[s]	[Gy/s]	[p] or [p/s]	[kJ] or [kW]
RS01	4.0E-05	9.27	3.71E+08	0.17
RS02	8.0E-05	9.27	7.41E+08	0.35
RS03	3.2E-04	9.27	2.97E+09	1.40
RS04	6.4E-04	9.27	5.93E+09	2.80
RS05	2.6E-03	9.27	2.37E+10	11.20
RS06	0.010	9.27	9.49E+10	44.79
RS07	0.082	9.27	7.59E+11	358.32
RS08	0.655	2.18	1.43E+12	675.00
RS09	1.311	2.18	2.18E+12	1029.90
RS10	5.243	2.18	2.18E+12	1029.90
RS11	20.97	2.18	2.18E+12	1029.90
RS12	83.89	0.87	8.73E+11	412.01

- Values should not be wrong by more than a factor of a few;
 - e.g. BLMs at other collimators may dump earlier!

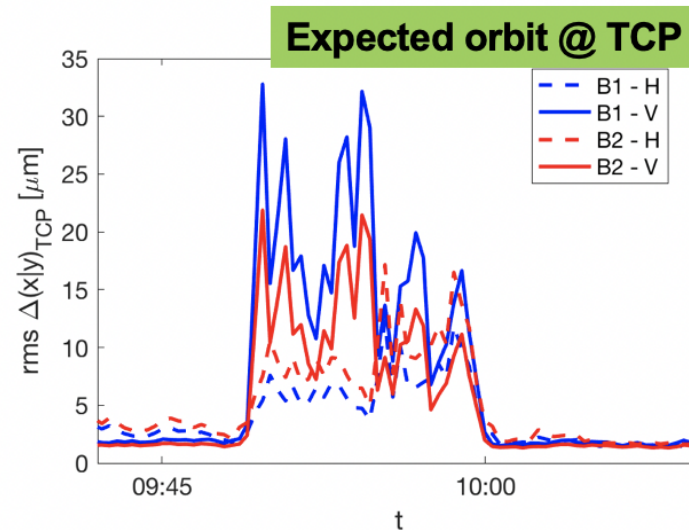
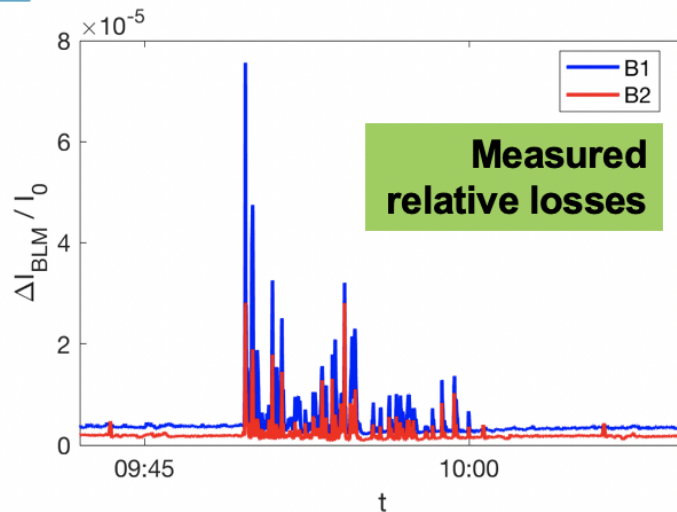
- Take home message:
 - We may see at most warnings in IR7 BLMs;
 - Thresholds could be tuned/adjusted based on operational experience;



Comparison to ground motion

- During **2018** run we could see beam losses with **ground motion-induced orbit jumps** of the order of **10% σ_{beam}** [6] – **similar to strong flux jumps**.

Fill 6757 impact on beam losses @TCP



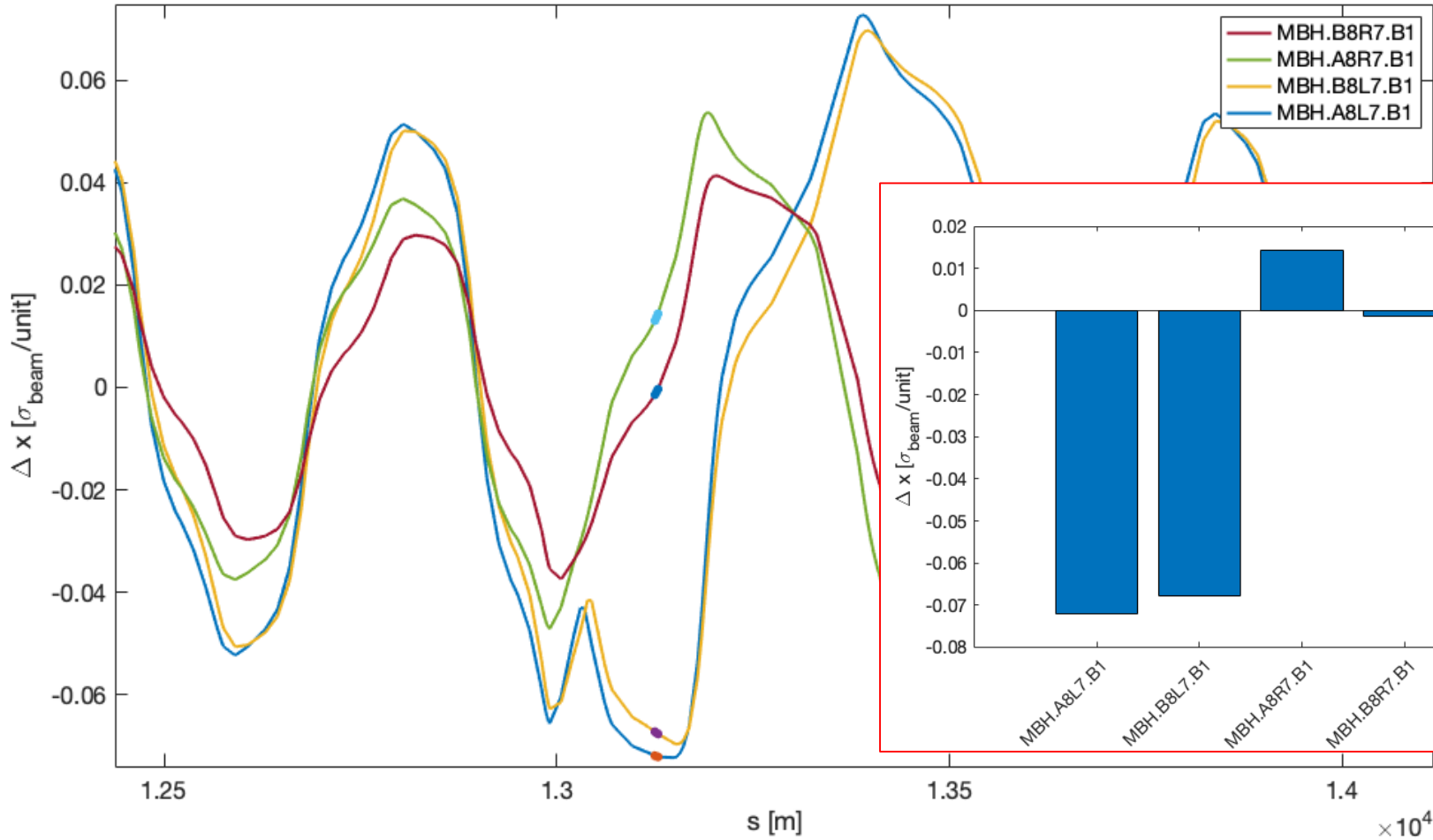
- Losses of the order of a few 10^{-5} wrt beam intensity.
 - Difficult to translate losses into orbit variation at collimators
 - From ground motion, we would expect 20-30 μm orbit jitter wrt total aperture of TCP (2.7 mm H; 2 mm V)
 - If correct, losses compatible with over-population of tails wrt simple Gaussian

Conclusions

- In Run 3 we expect several **orbit jumps** at the **TCPs** of the order of 2% and up to **6% (worst case)** of σ_{beam} at 3 TeV
- Those would induce of the order of **4e-5 beam losses in the worst case.**
 - **<15 kJ** energy lost on collimators in about 50 ms
 - **≈1 order of magnitude below dump thresholds**
- *In comparison:*
 - **ground motion** observed in 2018 (<10% of σ_{beam} at 6.5 TeV) was not an issue for operation.
 - But of course much more rare event!
 - Also: **~3 % σ_{beam} collimator jaw steps during ramp: no critical BLM spikes ever observed.**

Backup

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



Beam loss as a function of orbit jump

- Starting from 6.7σ aperture of TCPs ($2.5 \mu\text{m } \epsilon_N$)
 - Equivalent to 5.7σ at $3.5 \mu\text{m } \epsilon_N$

