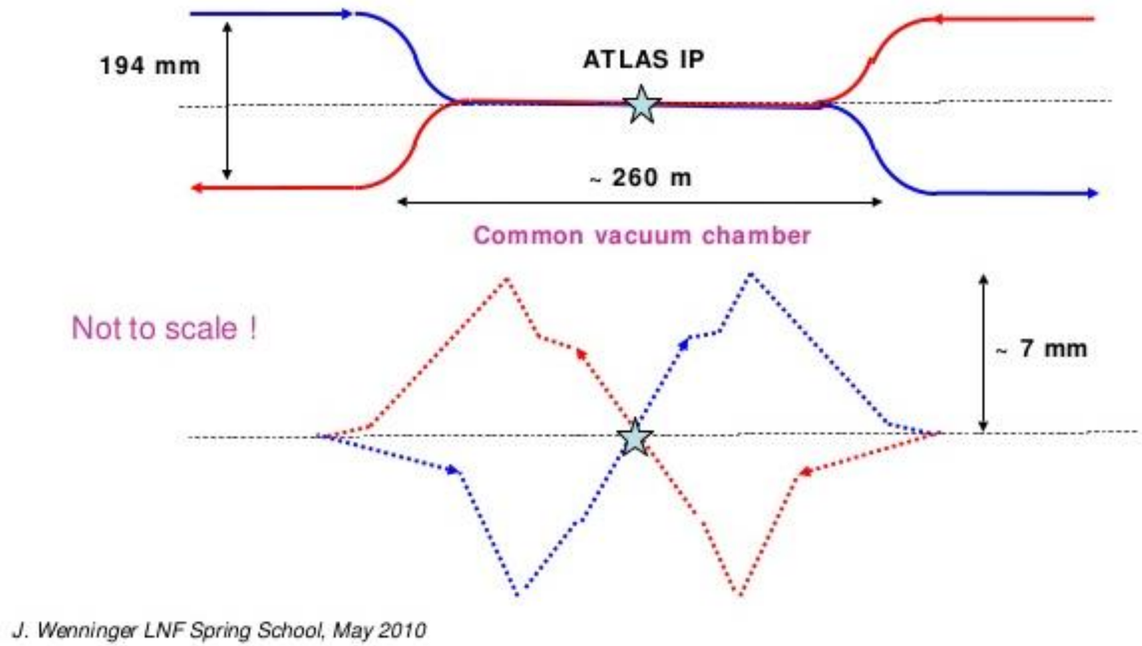
CERN

Powering perturbation to the warm D1 magnet circuits:
-> effects on orbit
-> FMCM thresholds
-> prospects for 2.5km and ATS optics

M. Valette

Introduction – D1 circuit

- The D1 magnet allows the recombination of the two beams in the // plane, upstream and downstream of the IP



// plane

Xing plane

- It is a warm magnet in IP1 & 5 because of luminosity debris. Its discharge time constant is thus shorter:

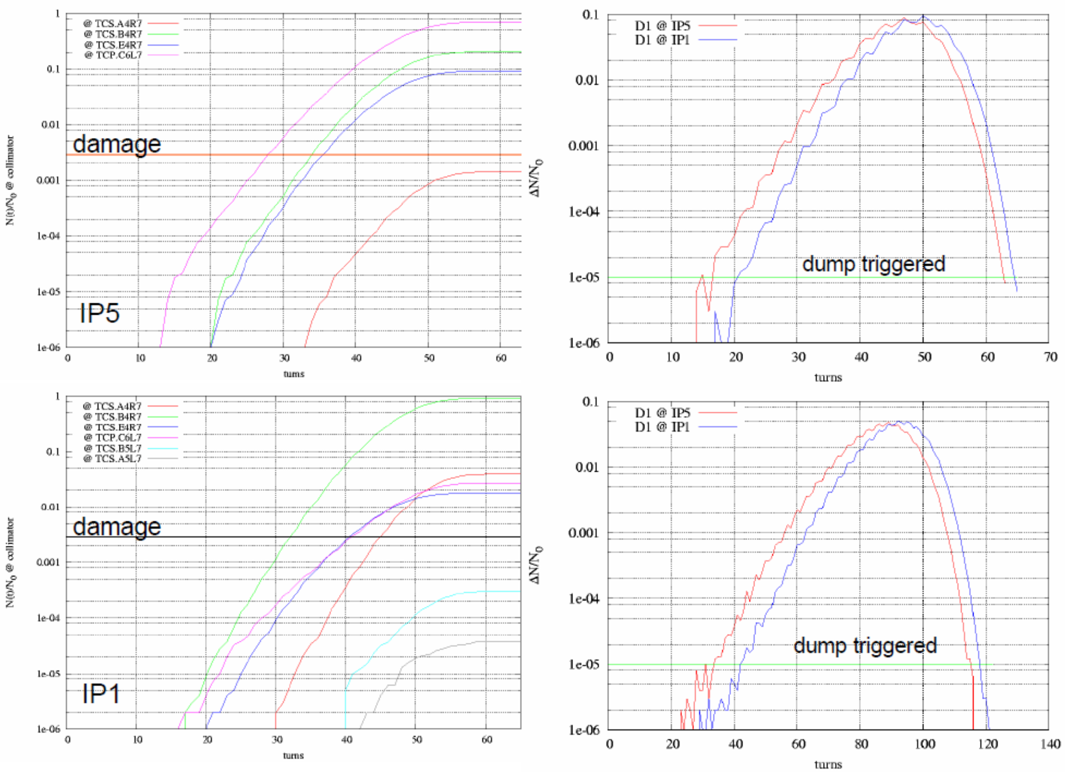
$$\tau_{LR} = 2.53\ s$$

Introduction – D1 failure

- The D1 magnets on both sides of the IP are powered by the same PC, for optics stability.

- A failure in the D1 circuit is the fastest failure mode excepting the kickers in the LHC (before the Hi-Lumi upgrade)

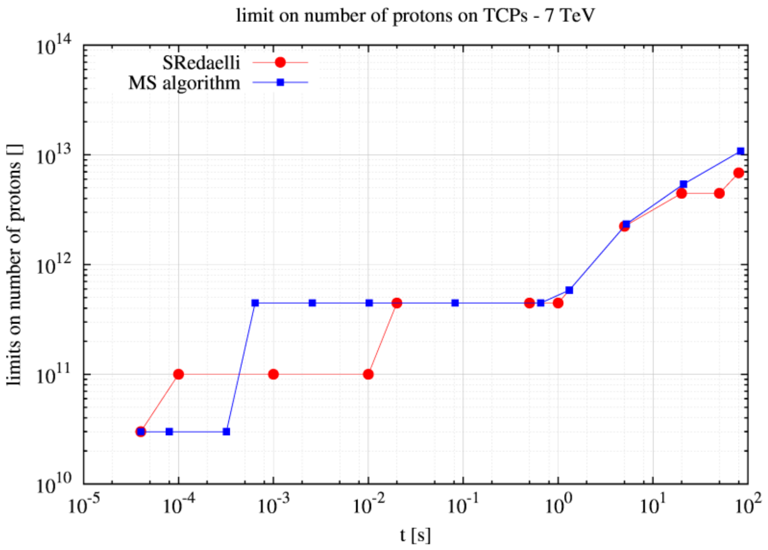
- This failure case has been revisited for current optics and in view of the ATS and 2.5km optics. Previous studies date from 2005.



Courtesy V. Kain

Introduction – Redundant protection

- The losses on the primary collimators in case of a D1 powering failure are going from a detectable to a damage level in only a few turns.
- The shortest running sums of the BLMs at the TCP position have low threshold to have a second layer of protection against such failures.



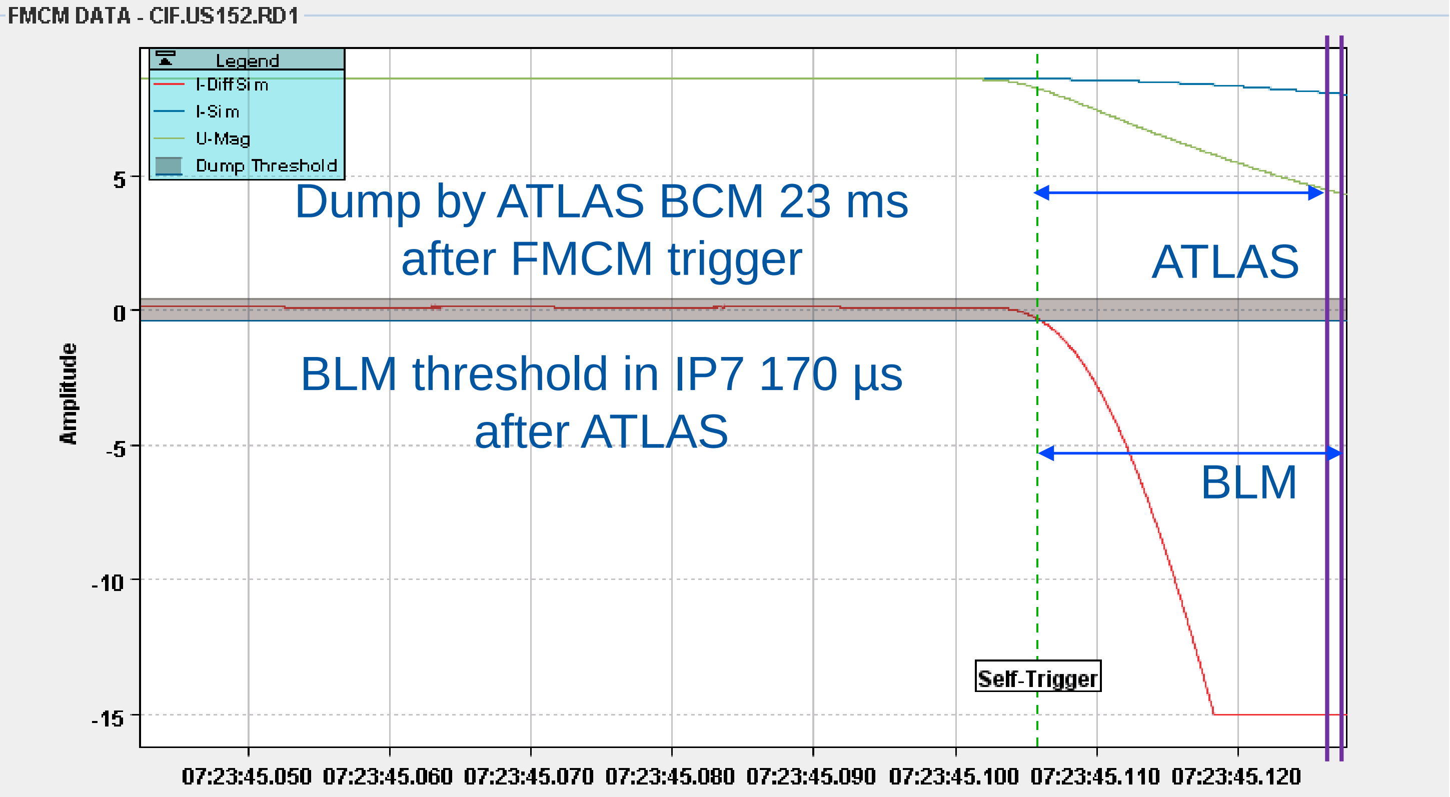
Courtesy A. Mereghetti

Introduction – FMCM

- The Fast Magnet Current change Monitor (FMCM) is designed to protect against such failures by detecting small changes in the magnet current.
- The current in the magnet is derived from the voltage on the magnet.
- Detection level of 5E-4 from nominal current in less than 100 µs.
- There are currently 12 LHC and 16 SPS-LHC TL magnets protected by FMCMs:
  - **RD1@IP1 & 5 (2)**
  - **RD34 L/R 3/7 (2)**
  - RMSD L/R 6 (2)
  - RBXWTV L/R 2 (2)
  - RQ4 L/R 3/7 (2)
  - RQ5 L/R 3/7 (2)

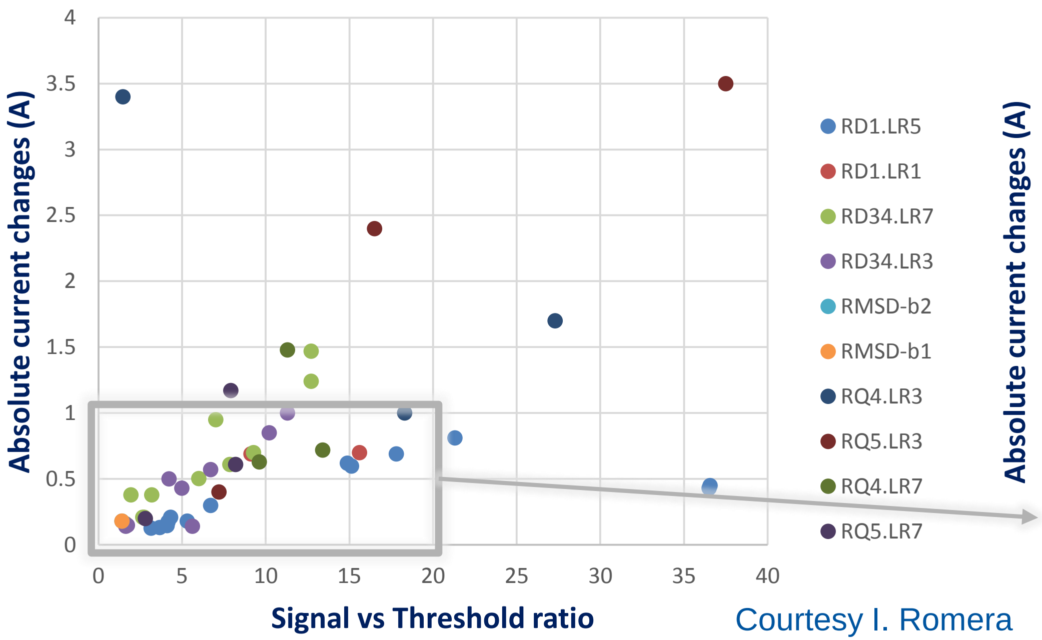
Introduction – Machine Protection test

- The FMCM allows dumping tens of milliseconds before the failure is visible in the experiment's BCMs and the BLMs
- Data from April the 14th D1 powering failure test with masked FMCM:

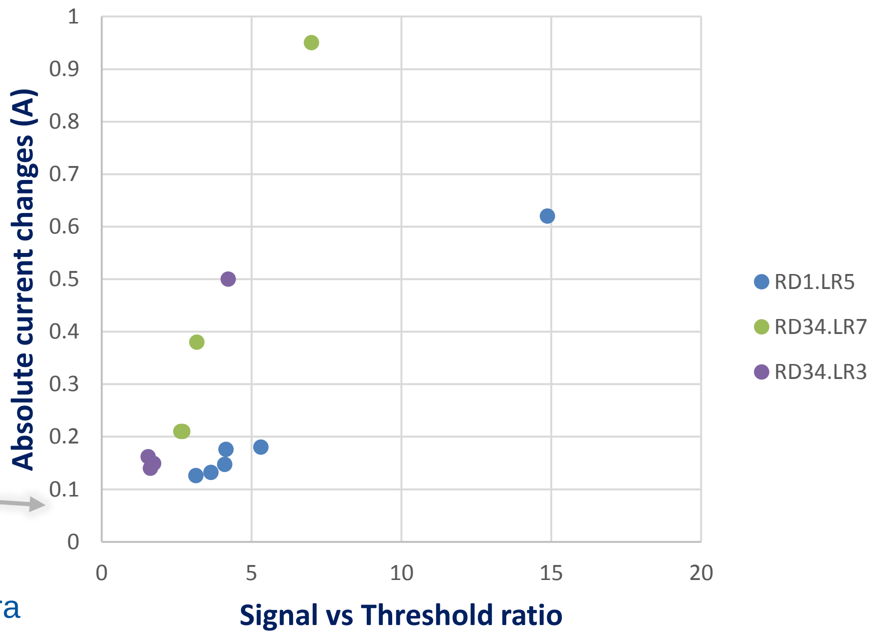


FMCM dumps

- The FMCM is the most sensitive element in case of a network perturbation.
- Due to minor electrical perturbations causing dumps, the thresholds for the Alice magnets were relaxed by a factor 3 and the ones for the RD34 by a factor 1.5 in 2012.
- In 2016: a total of 29 dumps involved the FMCM
- In 17 events only the FMCM triggered and in 5 only the D1 FMCM tripped.
- No spurious triggering happened.
- Most perturbations involving only the FMCM caused a small current change in the magnet:



Courtesy I. Romera

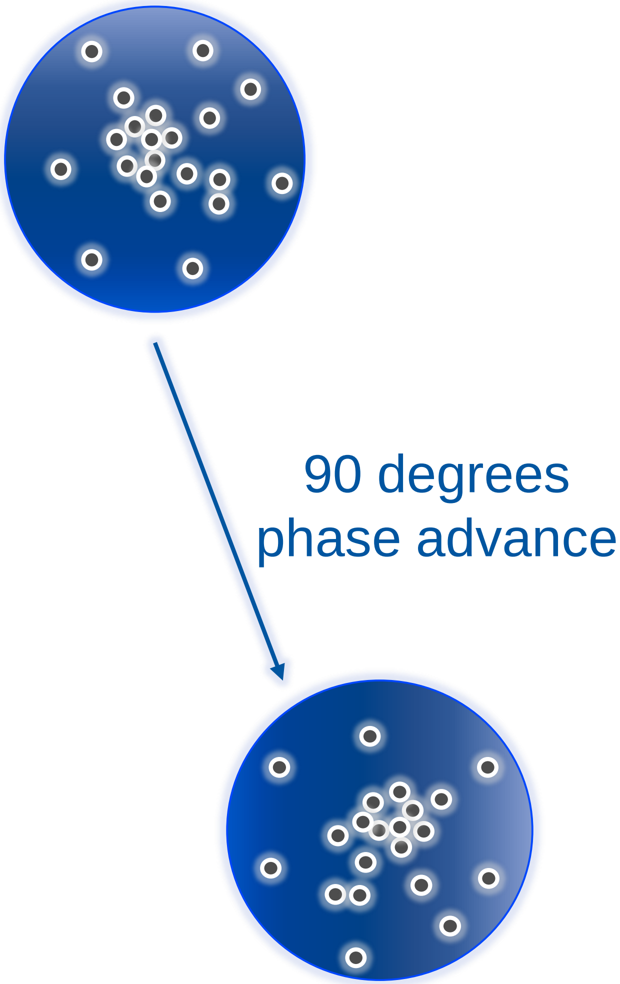


Optics Model – Motivations

- The simulations run for the LMC talk were closed orbit MADX simulations.
  - Valid because the change in current is "slow", the beam is assumed to be at equilibrium.
  - Allows knowing the maximum orbit excursion at the top of the perturbation.
  - Doesn't take into account the transient and how fast the losses would occur.
- A special orbit model was developed to study this aspect of the D1 powering perturbations and failures.

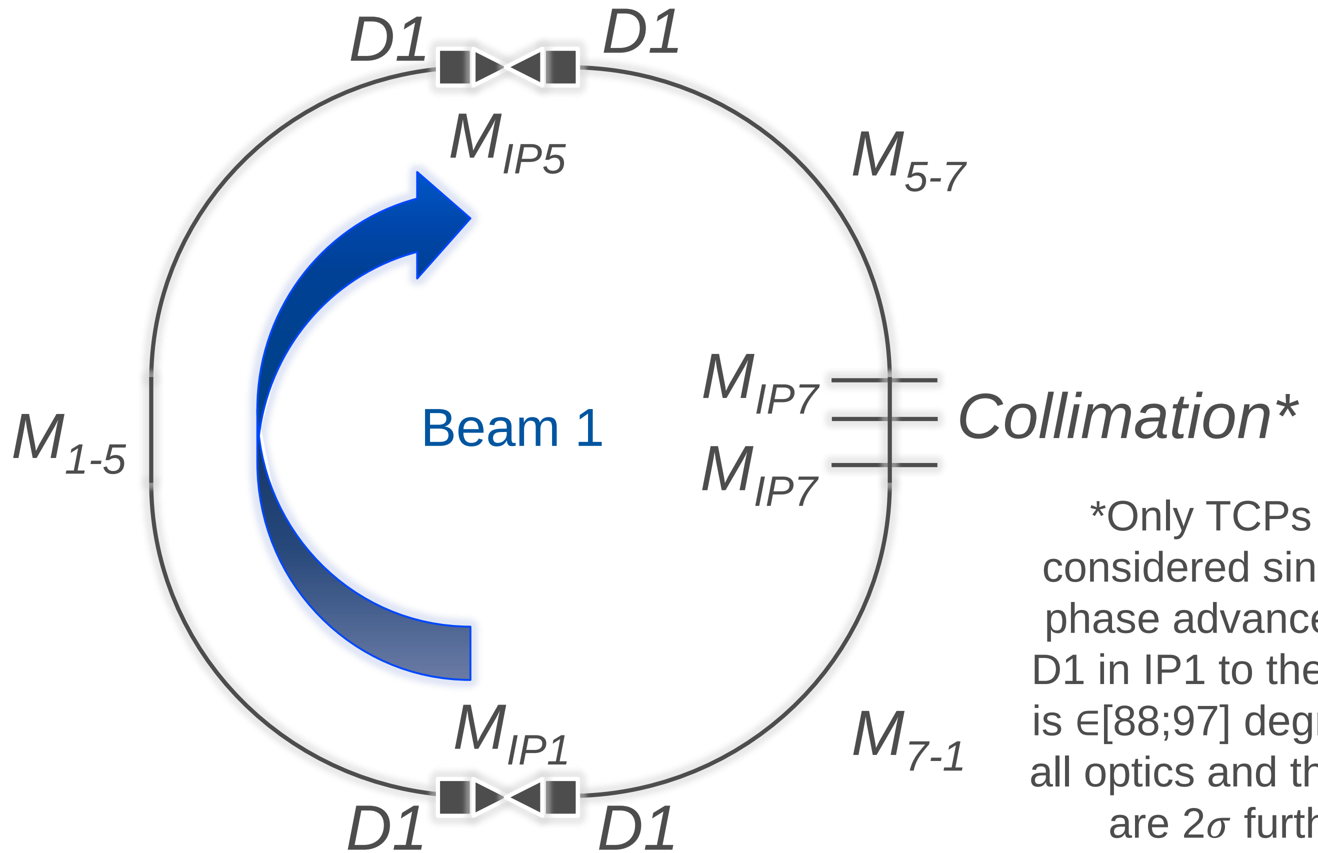
Optics Model – Linear Optics

- We are interested in:
  - Effects affecting the closed orbit
  - ~~tune, chromaticity, coupling or emittance growth~~
  - Losses with levels on orders of magnitude in the Halo of the beam
- We need:
  - a lot of particles
  - few hundreds of turns
  - second order effects can be neglected
- Linear optics were assumed: The beam is considered in normalised phase space and just rotates with the phase advance.
  - Allows for fast calculations with a large number of particles.



Optics Model – LHC Ring

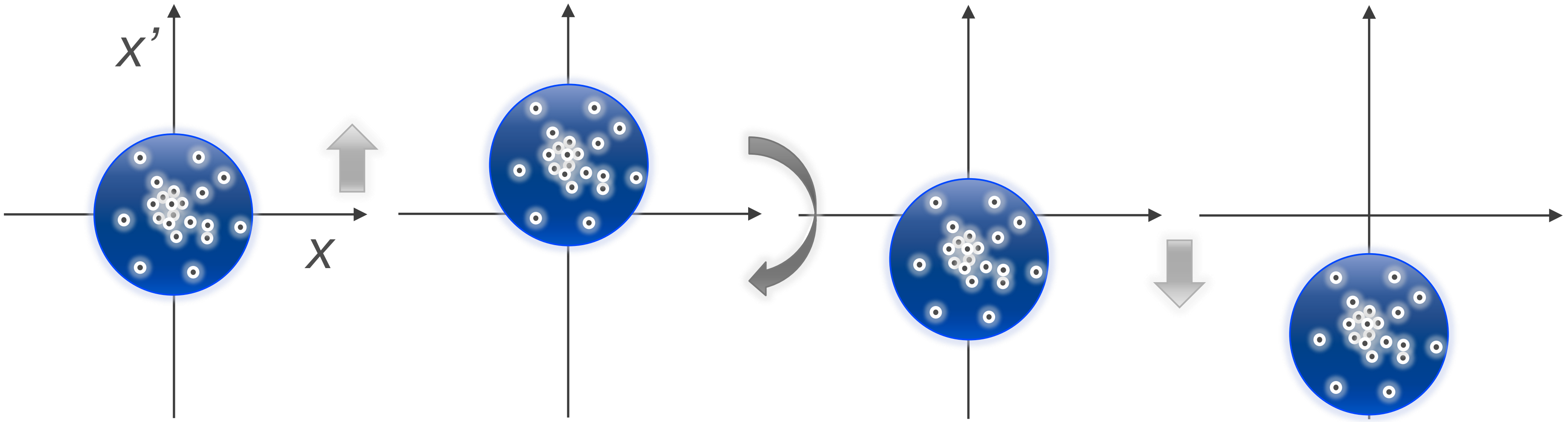
- The LHC ring is thus modelled with a few transfer matrices and a collimation section.



*Only TCPs are considered since the phase advance from D1 in IP1 to the TCPs is ∈[88;97] degrees in all optics and the TCS are 2σ further

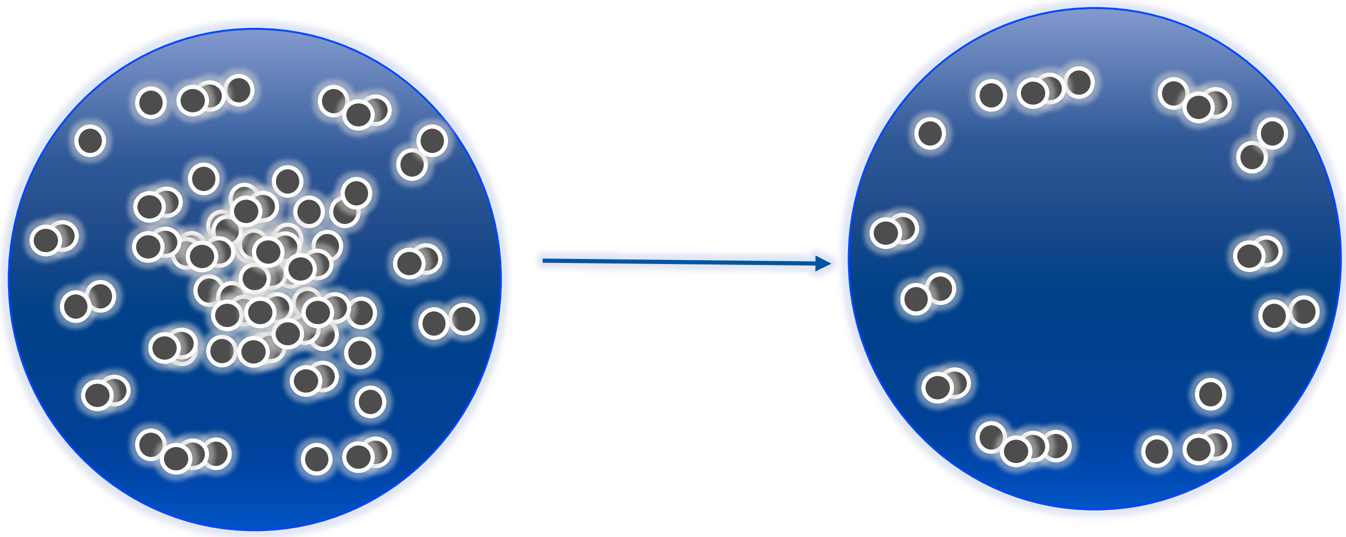
Optics Model – LHC Ring

- The upstream D1 gives a kick to the beam which has a 180 degrees phase advance in the IP and the downstream D1 gives a kick in the other direction.



Optics Model – Hollow distribution

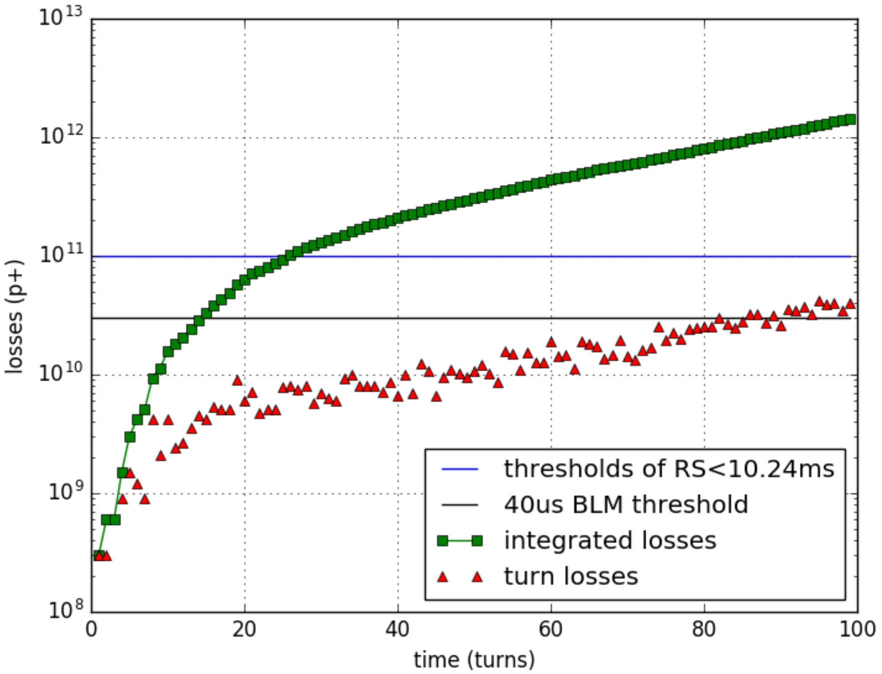
- In such a model, the action (area of the ellipse each particle is moving on) of every particle is constant. The particles in the core will never move out of it.
- To speed up the calculus they were removed: with a 5.5 sigma wide beam, considering only the particles ∈[3.5σ;5.5σ], allows only transporting 0.4% of the total particles in the distribution.



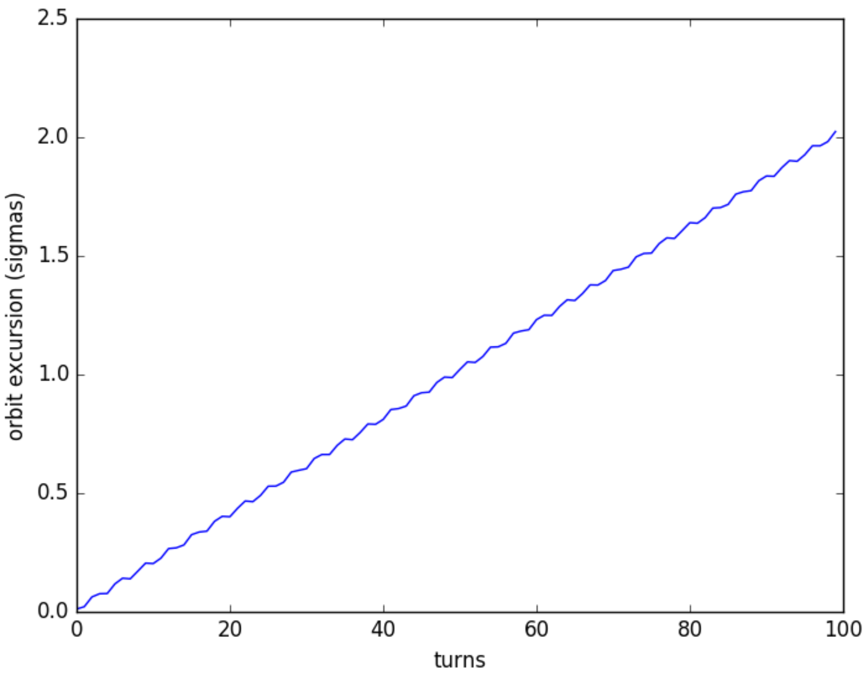
Optics Model – Results

- For the first 100 turns for a D1 powering failure (exponential decay of the current).
- In order to ensure redundant protection, the BLM threshold for the shortest running sum is lowered.

Losses



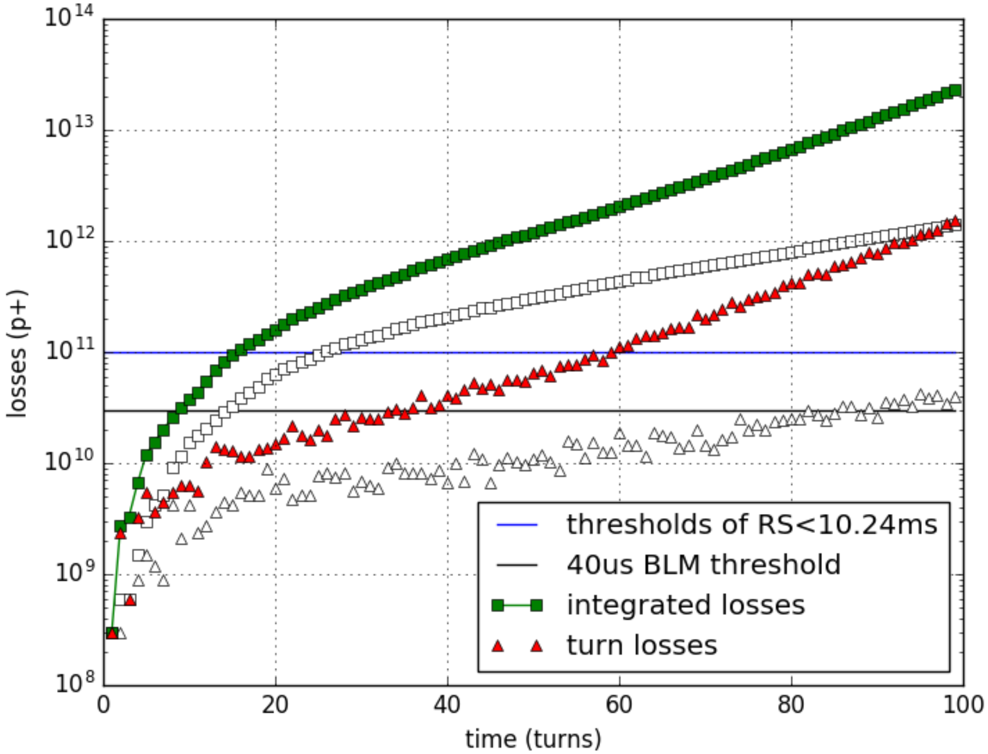
Orbit shift



Combined D1 failure

- In case of a combined failure of D1 power converters in both IP 1 and 5 the losses would rise significantly faster.

Losses



Difference in optics:

Opt_400_10000_400_3000_totem5.madx
Opt_25000000_10000_25000000_10000_totem5.madx
/sfar/public/newATS/opticsfile.19

- ## Upstream D1 MBXW.C4L1

Optics	Beta function (m)	Beam size (µm)	Gamma function	Beam divergence (µrad)
40 cm	2583	1142	0.0035	1.335
2.5 km	1402	841	0.063	5.67
ATS 40 cm	2417	1105	0.011	2.43

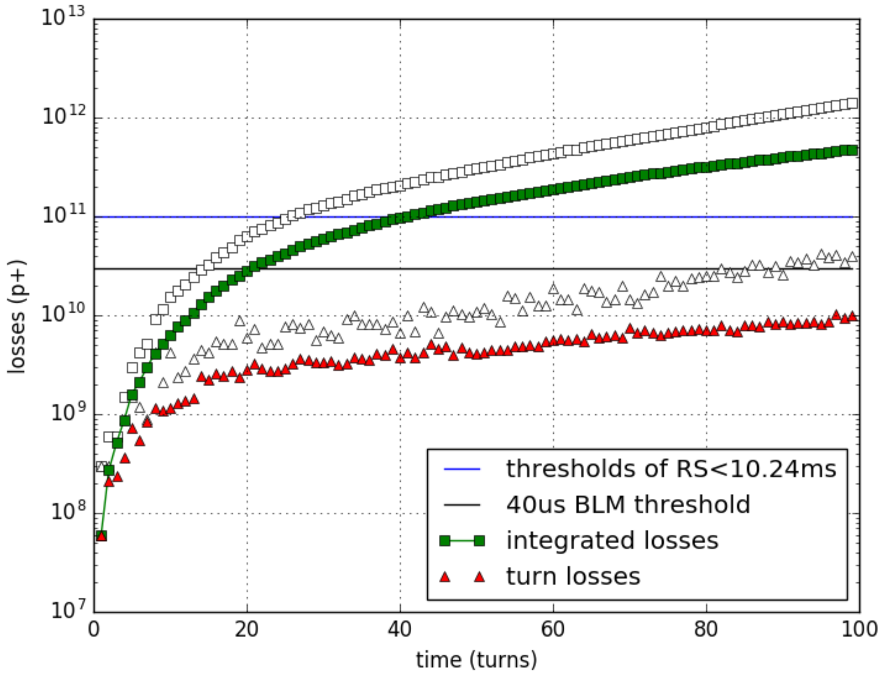
- ## Downstream D1 MBXW.C4R1

Optics	Beta function (m)	Beam size (µm)	Gamma function	Beam divergence (µrad)
40 cm	4181	1453	0.22	10.64
2.5 km	850	655	0.29	12.11
ATS 40 cm	4435	1497	0.21	10.39

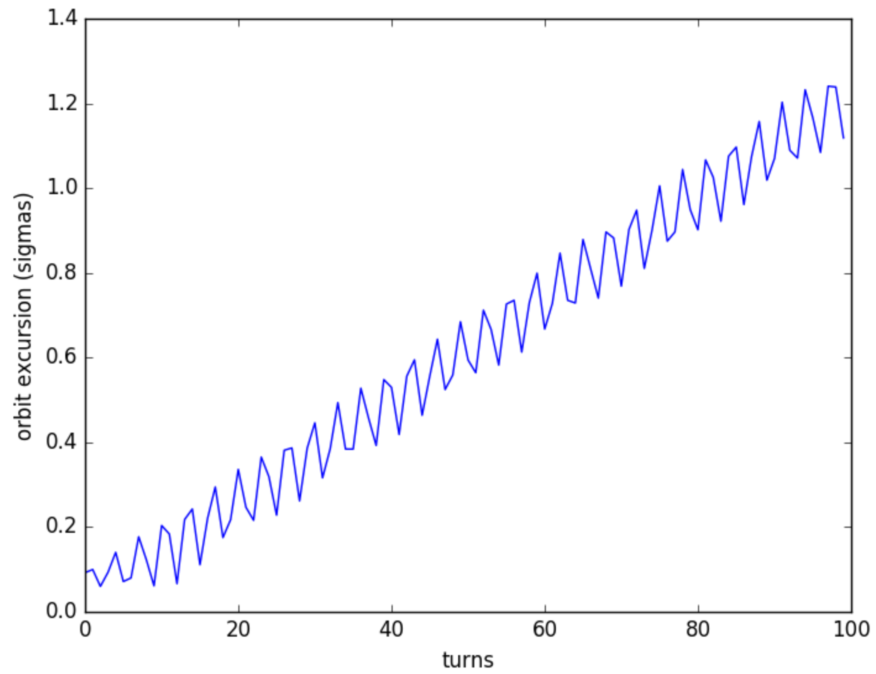
Outlook – ATS optics

- With the new ATS optics, the beta function is slightly smaller in the upstream D1, hence a larger divergence and a smaller normalized kick, thus slightly slower losses.

Losses



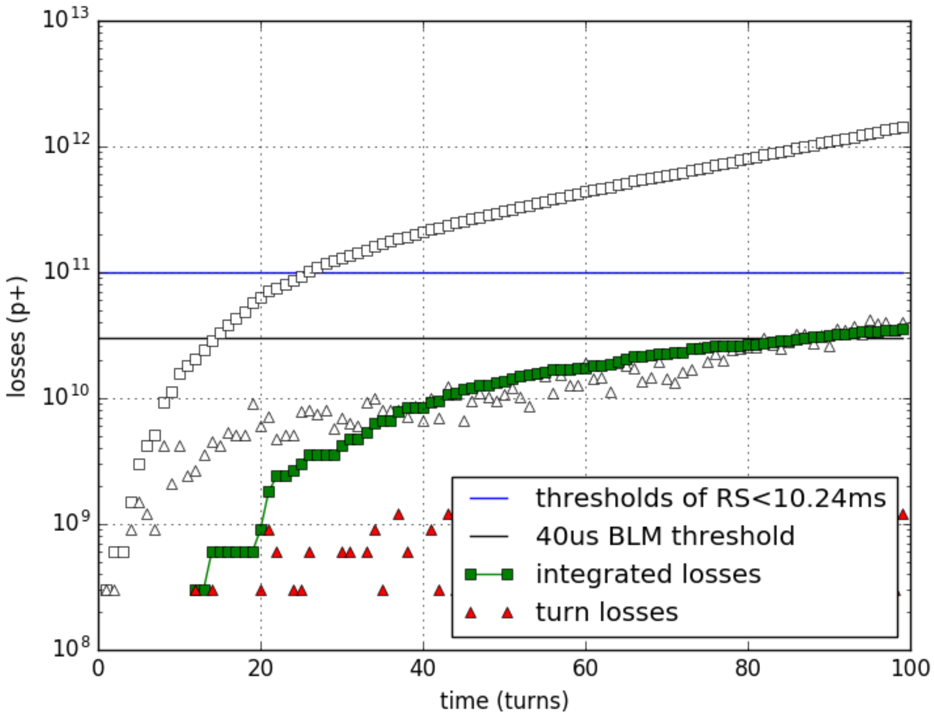
Orbit shift



Outlook – 2.5km optics

- With the high beta optics, the beta function is much smaller in the D1, hence a smaller kick and slower losses.

Losses



Outlook – BLM threshold for TCPs

- In such failure cases the lower threshold for the shortest running sum of the BLMs at the position of the TCPs is not giving additional protection any more.

- These cases will be reviewed with the Collimation Working Group and the BLM Threshold Working Groups in the coming weeks.

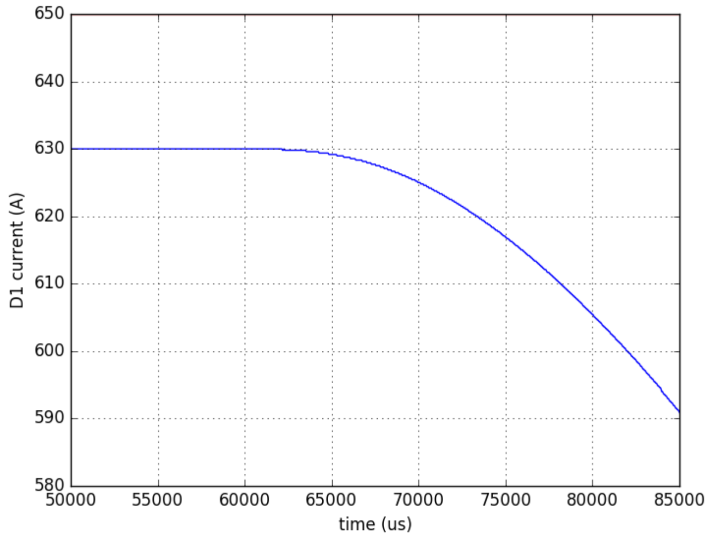
Relaxing the FMCM Thresholds ?

- During a powering failure the current change in the D1 circuit is three orders of magnitude above the FMCM threshold.
- During a network perturbation the losses go to a maximum in a few milliseconds then stop.
- One could relax the FMCM threshold to tolerate such perturbations and dump on the BLMs in case of a large one and still sufficiently protect against a powering failure.

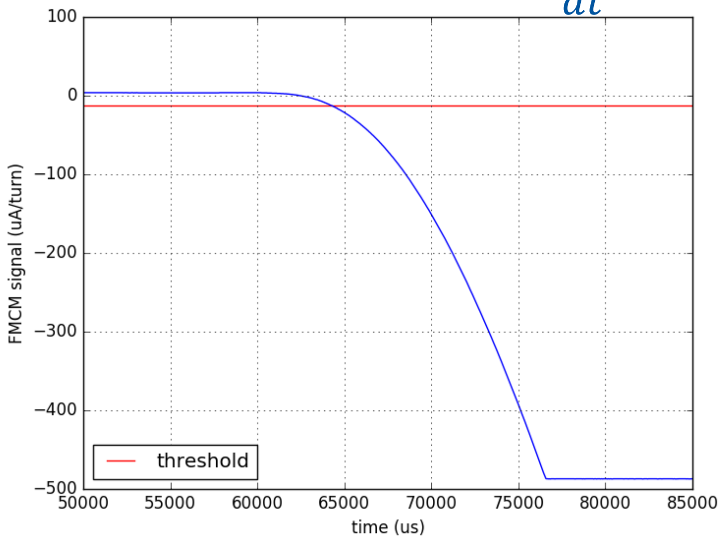
$\frac{dI}{dt}$ in the beginning of a failure

- In an actual D1 powering failure, the current change is slower in the beginning of the failure than in a pure LR discharge:

D1 current

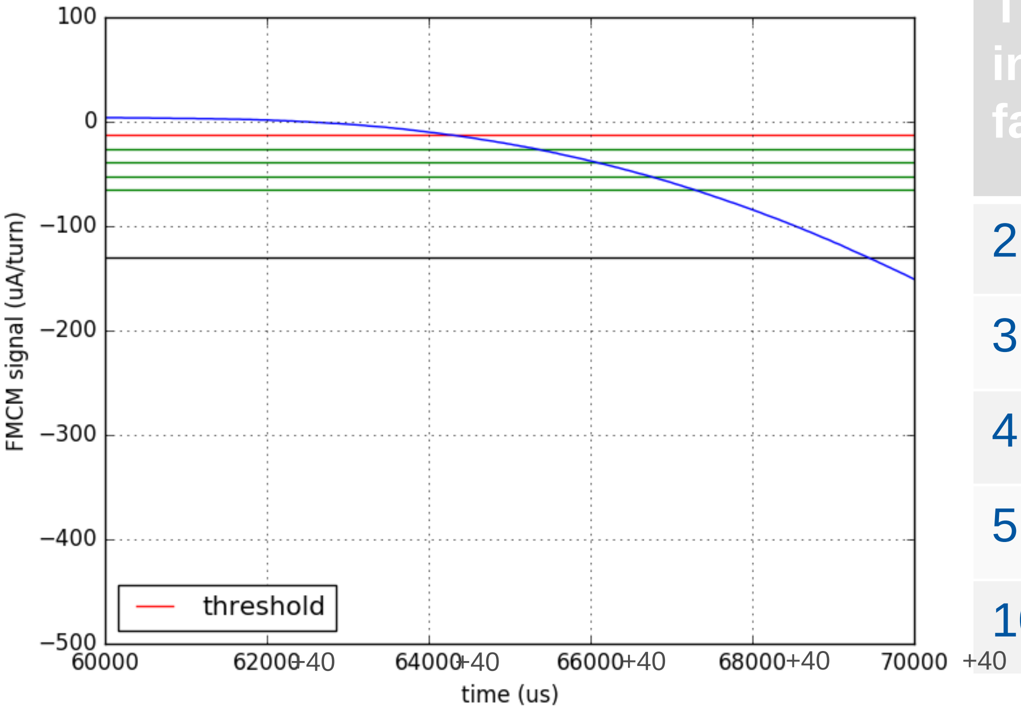


FMCM signal ($\frac{dI}{dt}$)



FMCM Thresholds

- Increasing the FMCM threshold by a certain factor would mean dumping a few turns later.

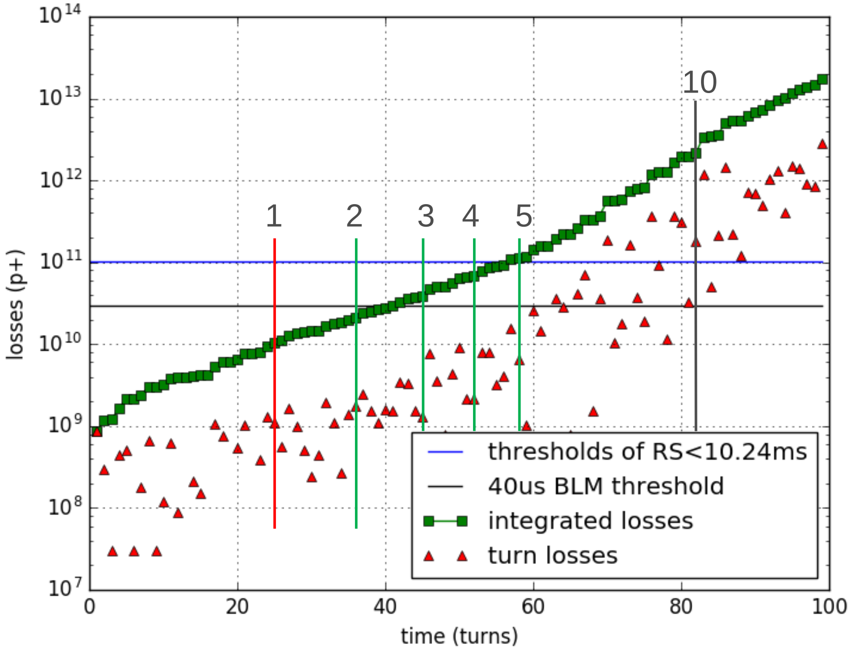


Threshold increase factor	Delay on dump (turns)	Delay on dump (µs)
2	11	1016
3	20	1775
4	27	2419
5	33	2982
10	57	5118

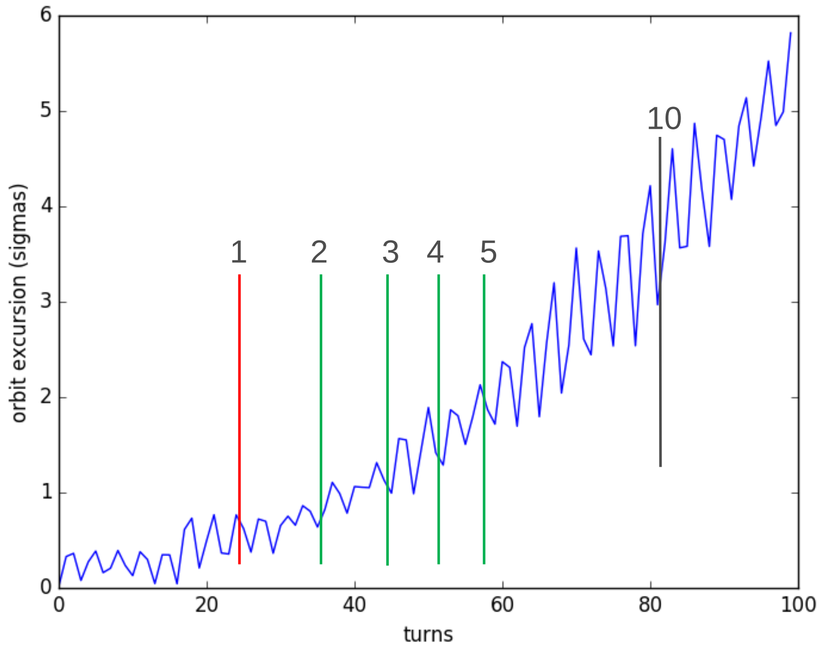
FMCM Thresholds

- Increasing the FMCM threshold by a certain factor would mean dumping a few turns later.

Losses

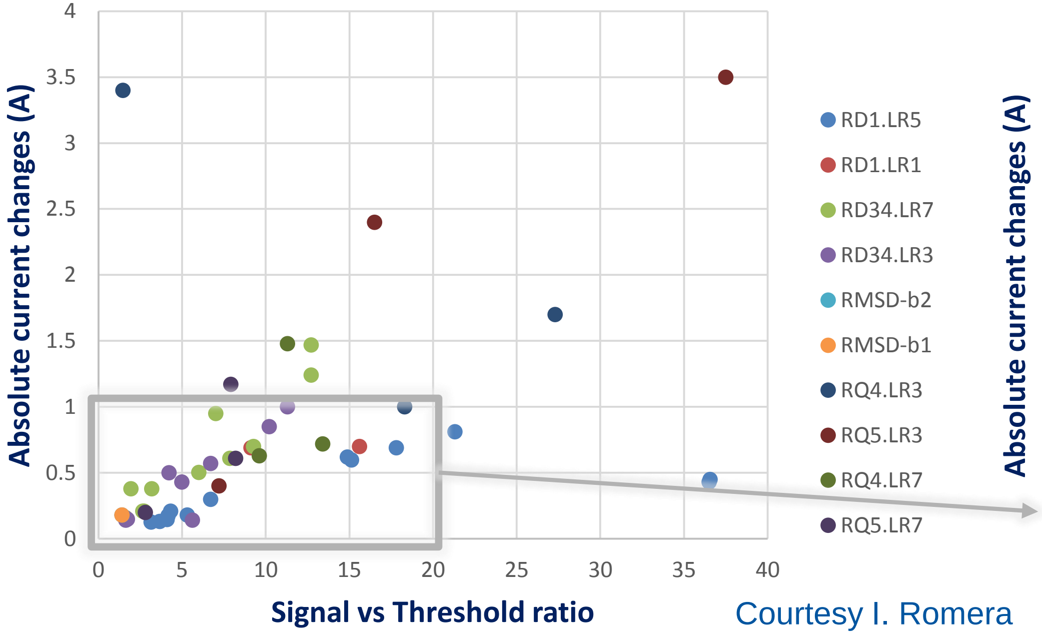


Orbit shift

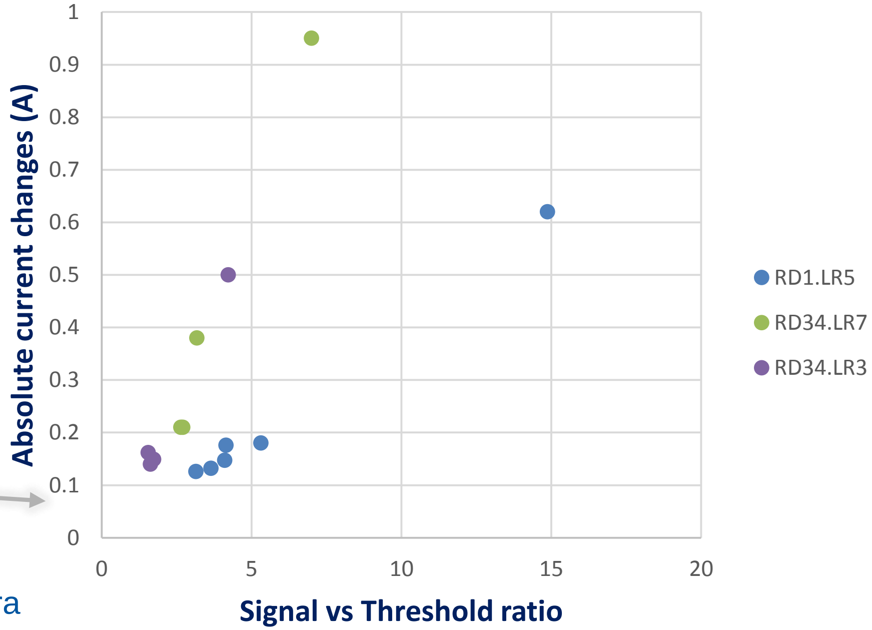


FMCM Thresholds - Conclusions

- Including a 3 turn margin to dump, in this approach it would be conceivable to increase the threshold by a factor 4 and still trigger a few turns before the BLMs.
- One would see a significant orbit shift before the dump.
- The sensitivity to most network perturbation would be lost.



Courtesy I. Romera



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