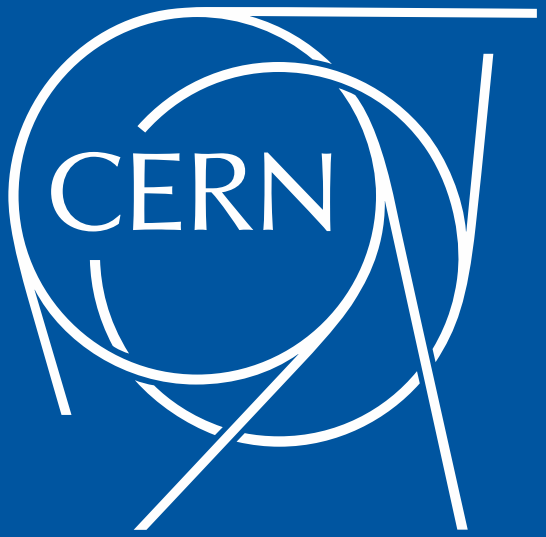
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Simulation results of D1 / D34 powering failures for ATS optics and possible consequences on FMCM thresholds

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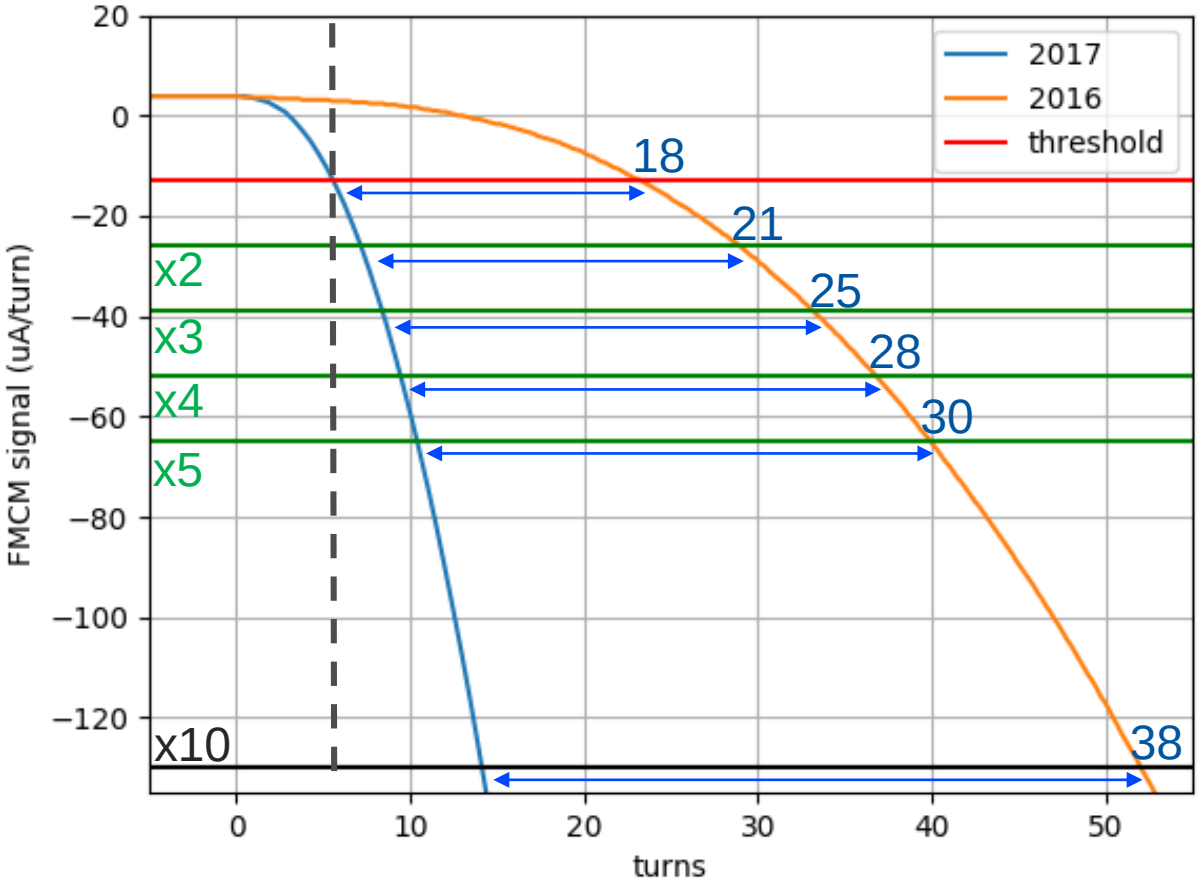
Scope

- A failure in the **warm D1 in IP1&5** is the **fastest and most critical failure** with circulating beam in the **pre-HiLumi LHC**.
- The critical magnets are equipped with **FMCMs** (Fast Magnet Current Change Monitors) in order to detect and dump at the onset of a powering failure.
- During EYETS 2016/17, the RD1 and RD34 power converters were replaced by the **new SATURN converters** in order to be less sensitive to electrical glitches.
- In 2017 and onwards, ATS optics with smaller β* and larger β functions at the D1 will be used. It is important to review the severity of D1 failures.

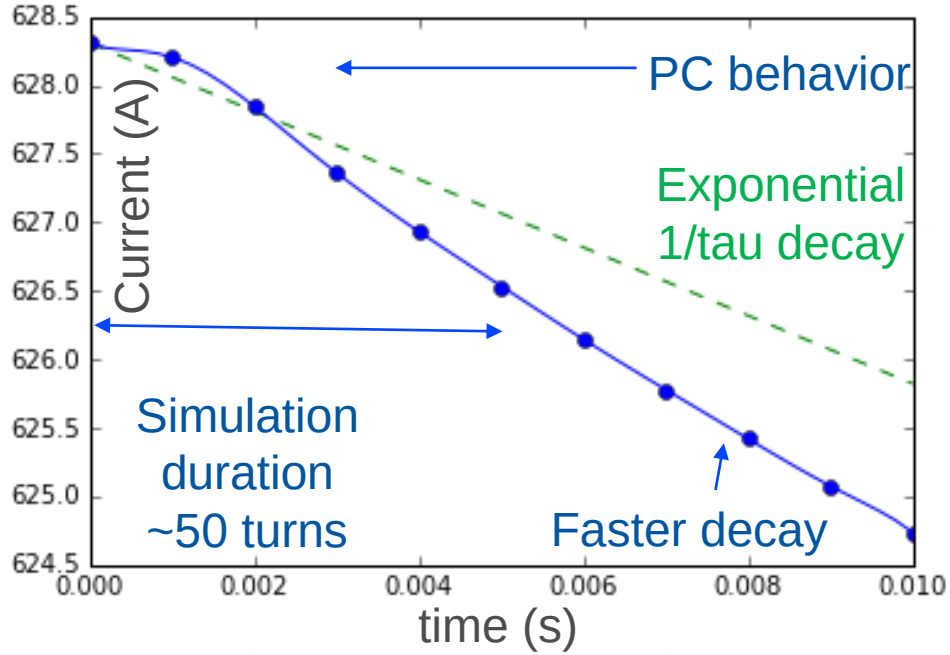
Faster triggering in 2017

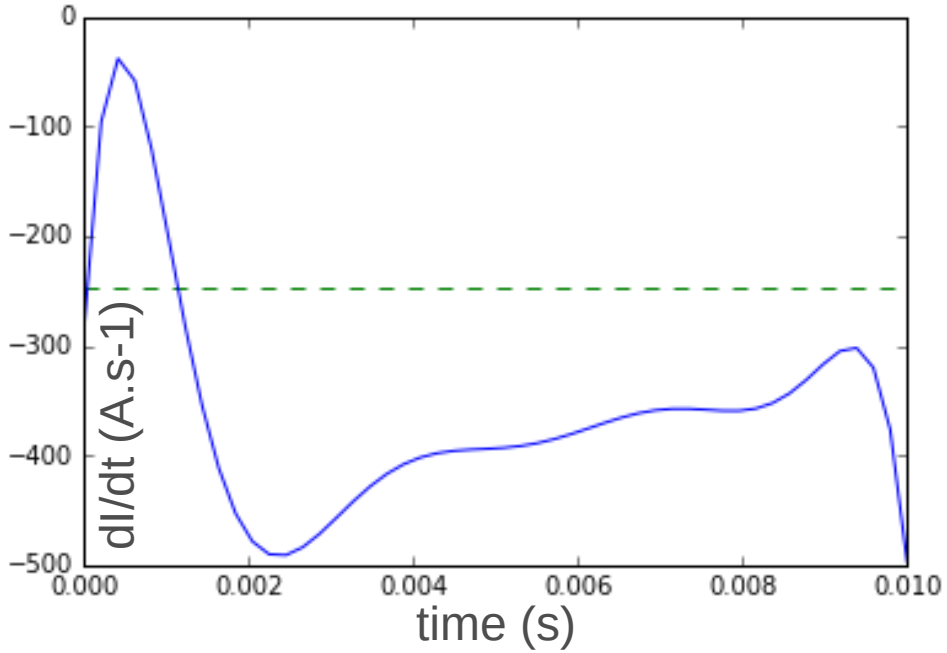


The dI/dt signal ramps faster in 2017 than 2016 due to the new power converters.

This causes faster triggering.

Current decays in 2017



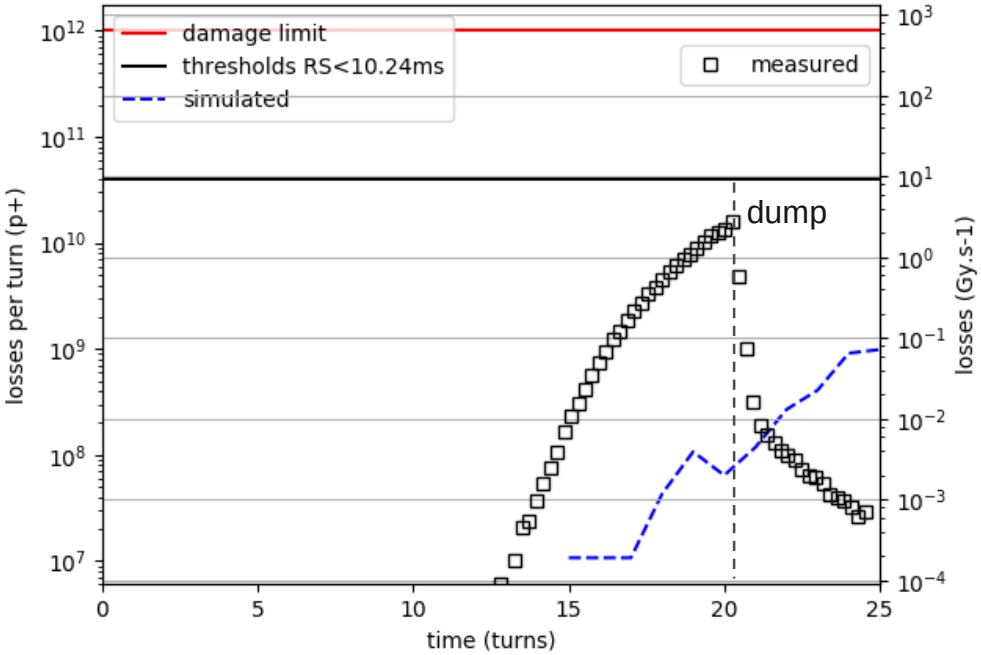


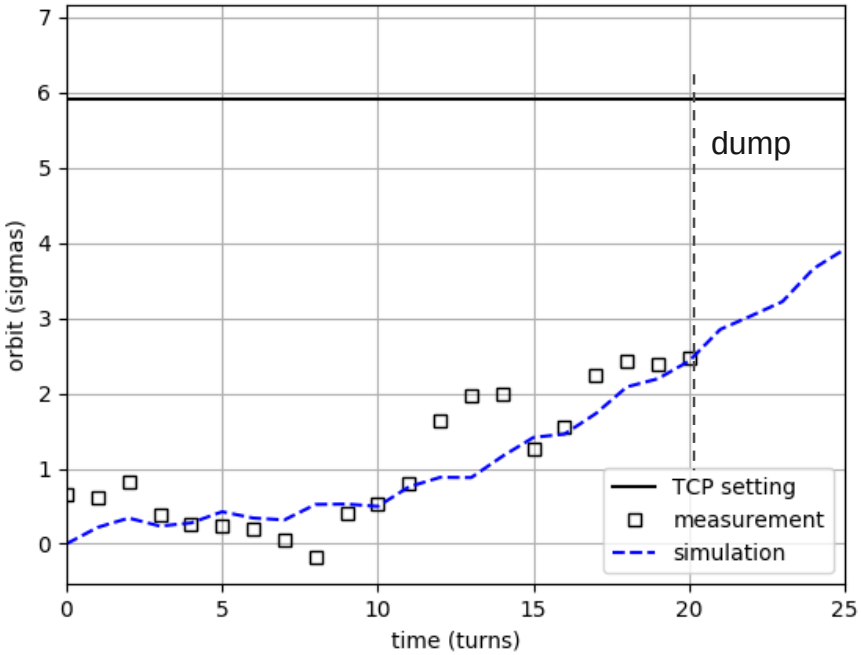
- In order to benchmark the simulation to the measurements done during beam commissioning the FGC data, with 1 ms resolution, was interpolated with a polynomial.
- The FMCM has 43 µs resolution data which cannot be directly used for the simulations, as the FMCMs are standardized for different circuits with different inductances.
- An exponential decay was also used as a possible failure scenario. The FMCM would then trigger immediately.

Simulation parameters

- Only the linear part on the optics are taken into account (transfer matrices).
- Transverse distribution is a double Gaussian with 5% of particles in a second Gaussian, which is 1.8 times wider than the main Gaussian (derived from VdM scans).
- The beam emittance is assumed to be 2.5 µm (2016).
- The primary collimators are set at 5 $\sigma_{3.5\mu m}$ which is equivalent to 5.9 σ_{beam}.
- 10 million particules are tracked (i.e. at least 1.000 outside 4 σ).

Benchmark vs measurements





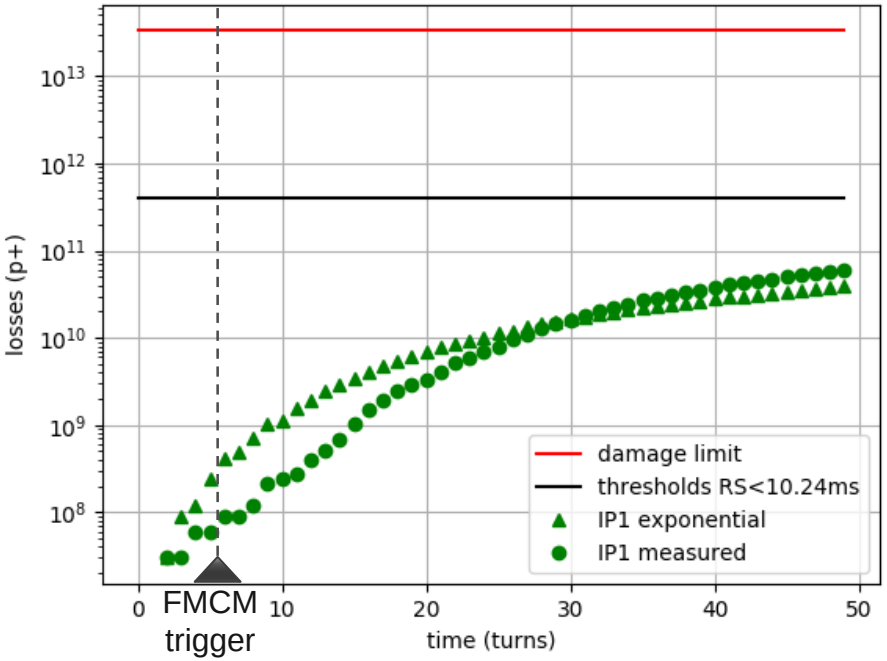
- Test done on May 16th by switching off RD1.LR1 was reproduced in simulations.
- There is a good match with the orbit data, the BLM response shows significant uncertainties (with matching slopes though).

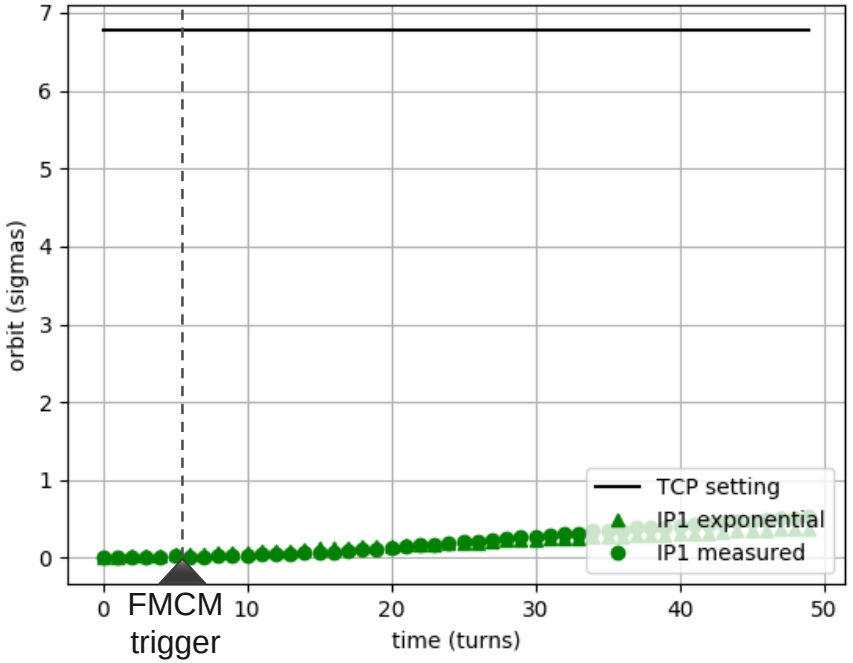
Injection

Exponential decay

Measured decay

$\beta_{D1} = 158\ \mathrm{m}$





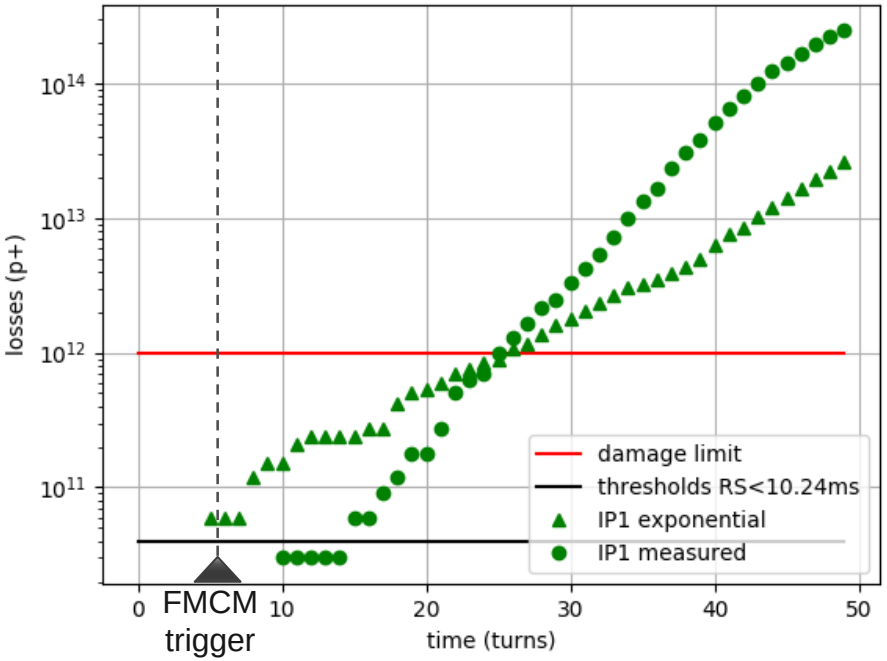
- The small β function at the D1 leads to a slow failure.

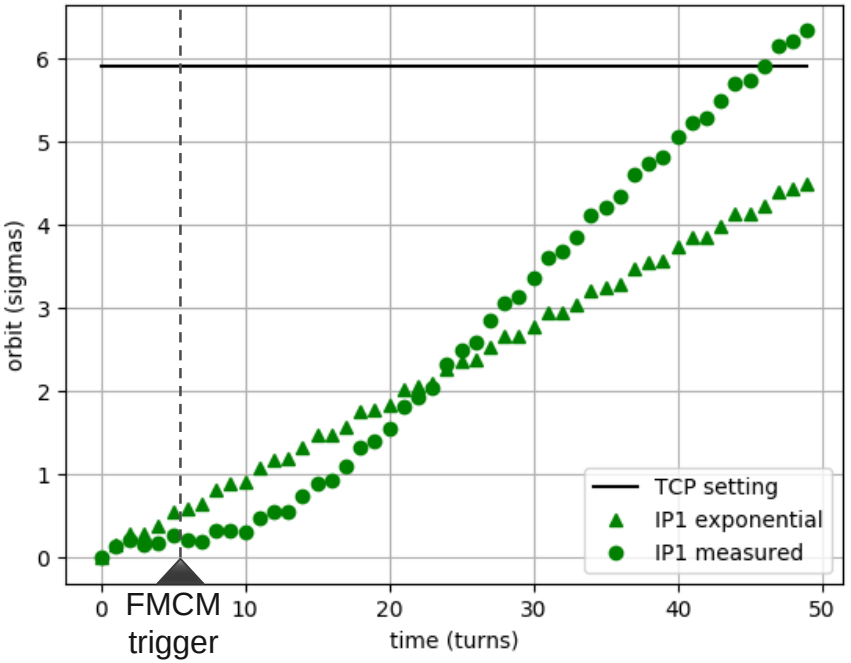
End of ramp

Exponential decay

Measured decay

$\beta_{D1} = 1673$ m

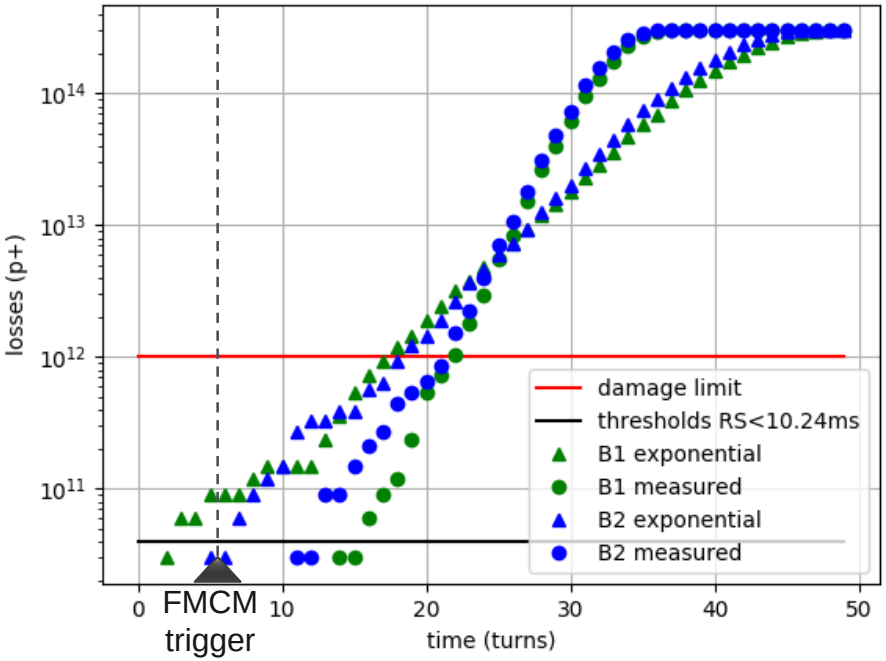


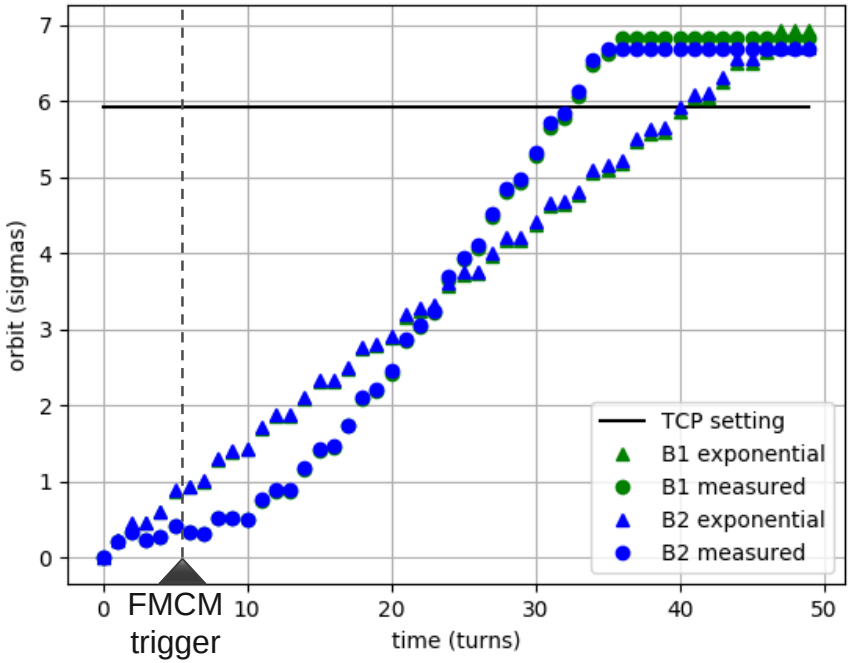


- At the end of the ramp & squeeze the β function is still relatively small (1/3rd of the collisions value).
- Damage level losses are occurring 20 turns after the FMCM trigger.

ATS 40 cm - difference between beams

$\beta_{D1} = 4253$ m

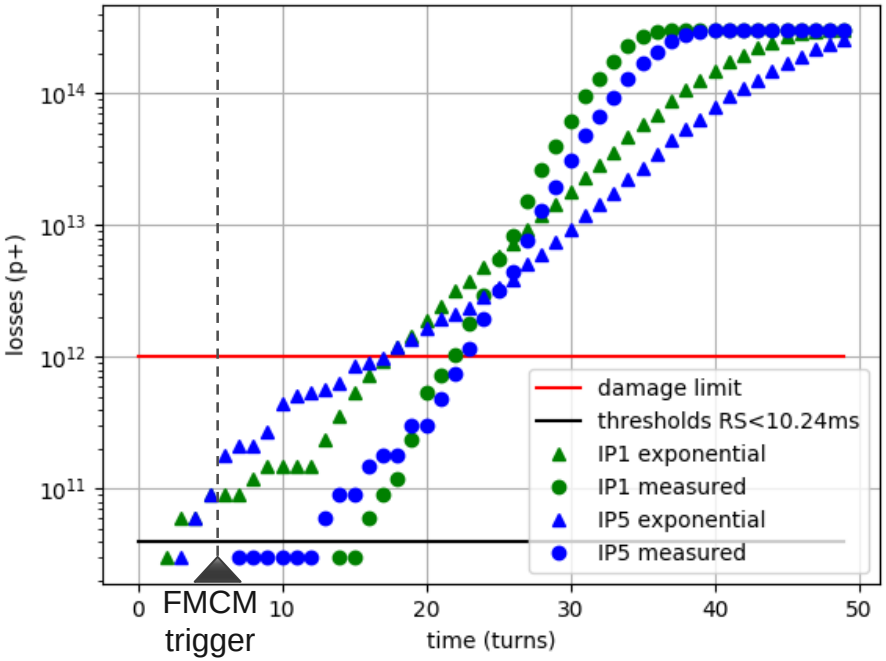


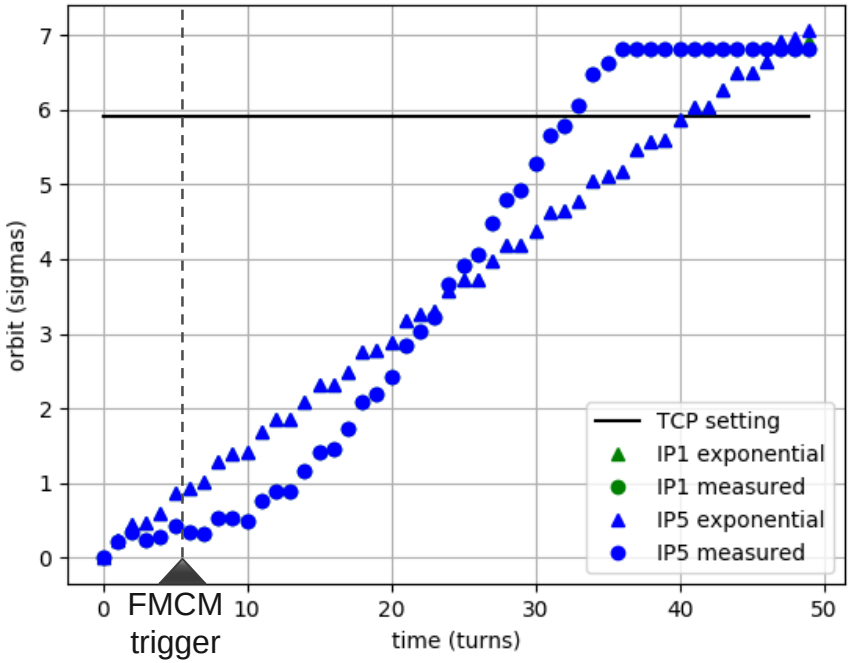


- The failure is symmetric in B1 and B2, for all optics.
- The small difference in losses comes from a few degrees of phase advance from the D1 to the IP7 TCPs.

ATS 40 cm – IP1 vs IP5

$\beta_{D1} = 4253$ m



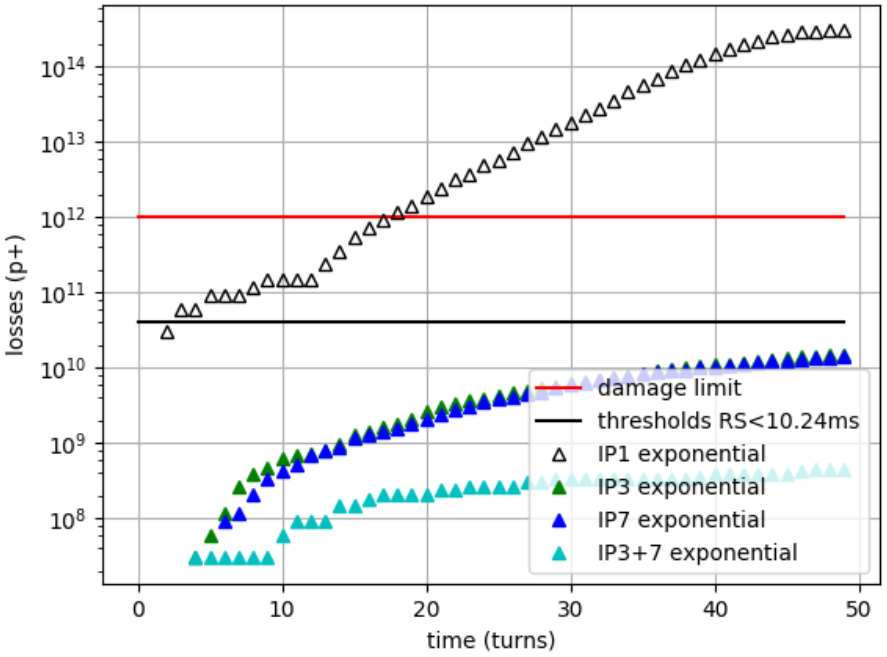


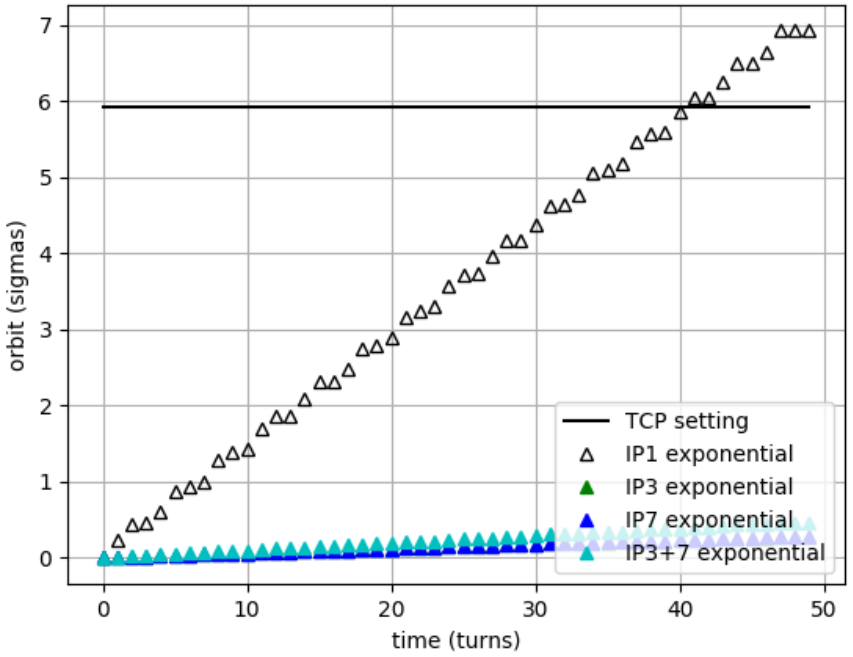
- The failure is symmetric between IP1 & 5, for all optics.
- The small difference in losses comes from a few degrees of phase advance from the D1 to the IP7 TCPs.

ATS 40 cm – IP3 & 7

△ Reference case
IP1 D1 with 40 cm optics
○ recalled in white

$\beta_{D3/D4} = 236/83$ m

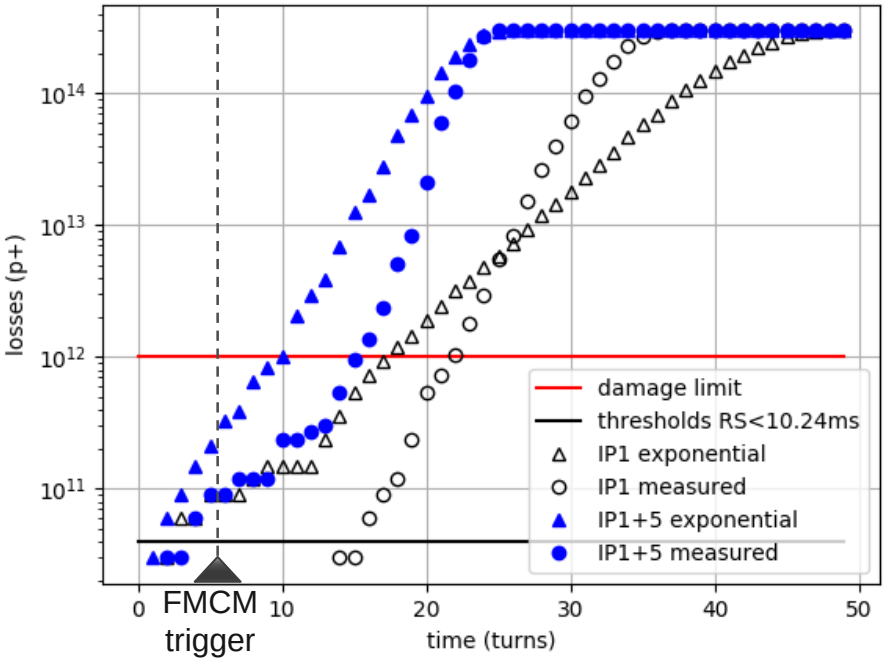


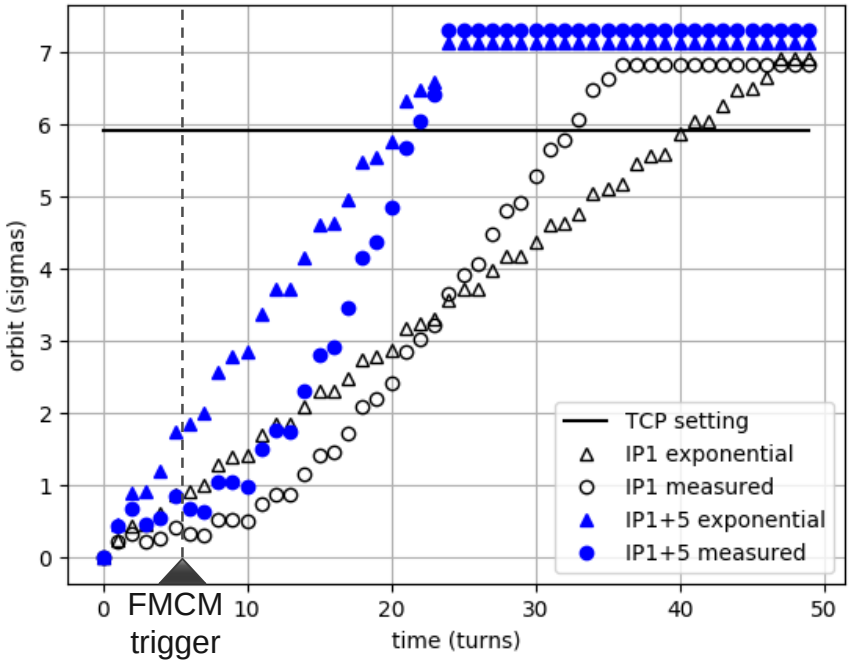


- The β functions in IR3 & 7 are small, leading to slow failures for all optics.
- Due to the phase advance from IP3 to 7 these failures partly compensate

ATS 40 cm – combined failures

$\beta_{D1} = 4253$ m

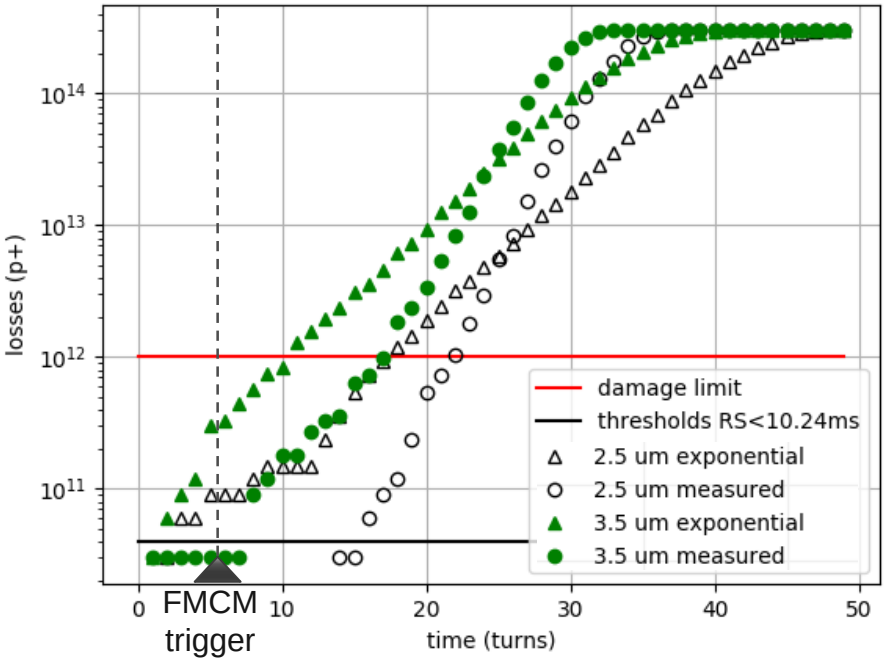


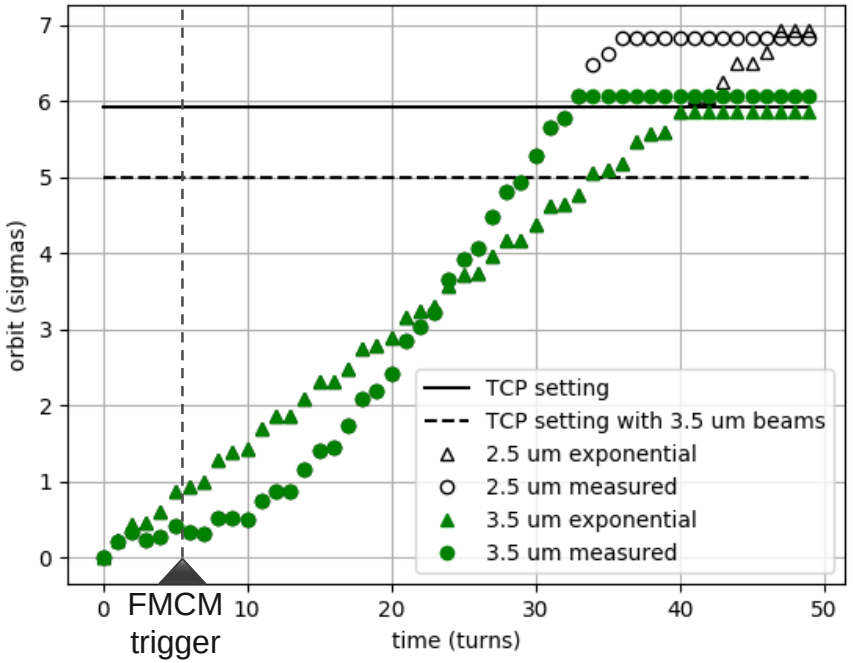


- In case of a combined failure in IP1 & 5 the BLM would trigger a dump before the FMCM.
- In case of an exponential decay the damage limit is reached in 10 turns.
- The probability of a combined failure in both IP1 & 5 has to be discussed. They would need to occur with a delay <1 ms for a build up to occur before the dump.

ATS 40 cm – larger emittances

$\beta_{D1} = 4253$ m

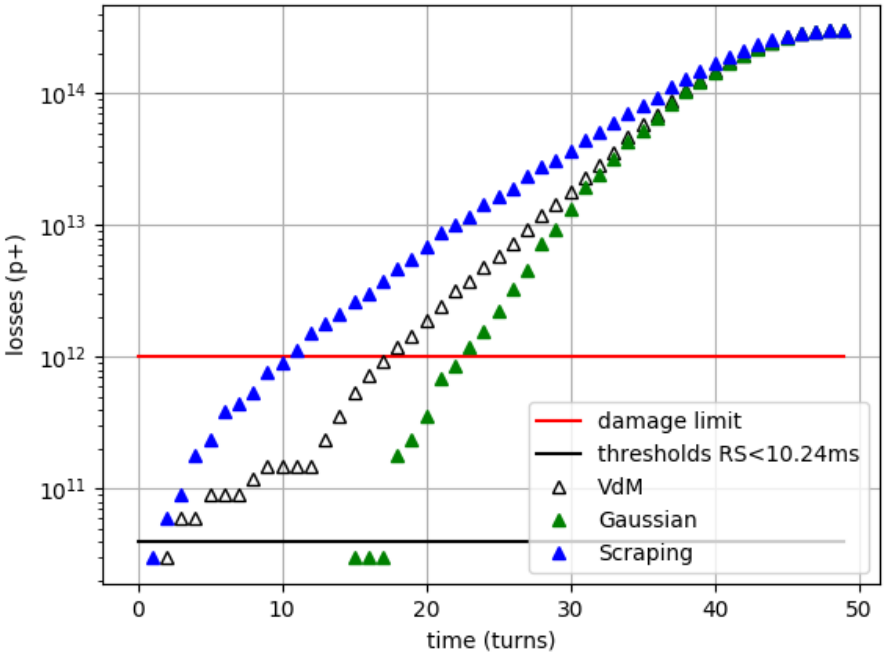


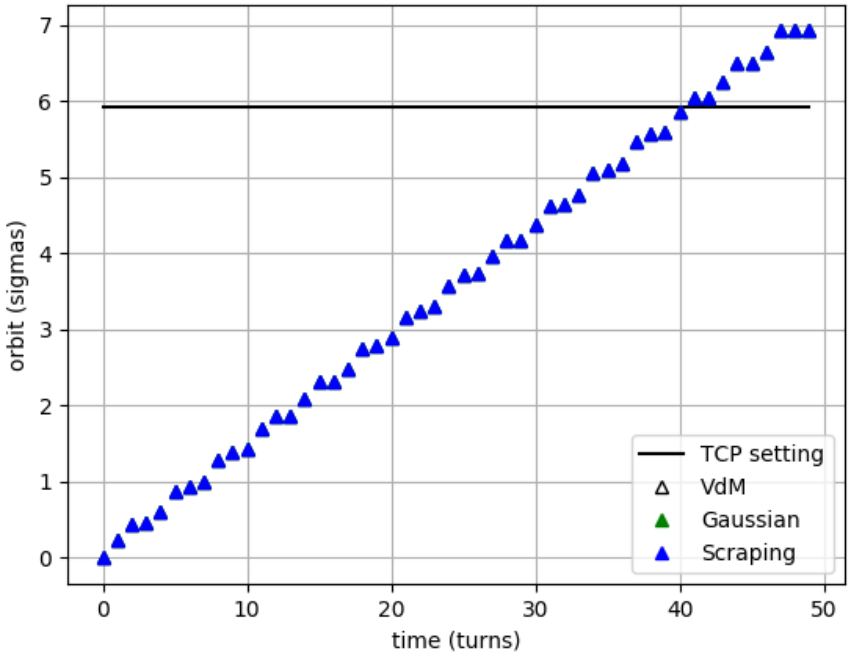


- If beams with larger emittances or blown up beams are circulating in the LHC, losses would rise faster, reducing the margin before damage by 5 turns.

ATS 40 cm – halo distribution

$\beta_{D1} = 4253$ m

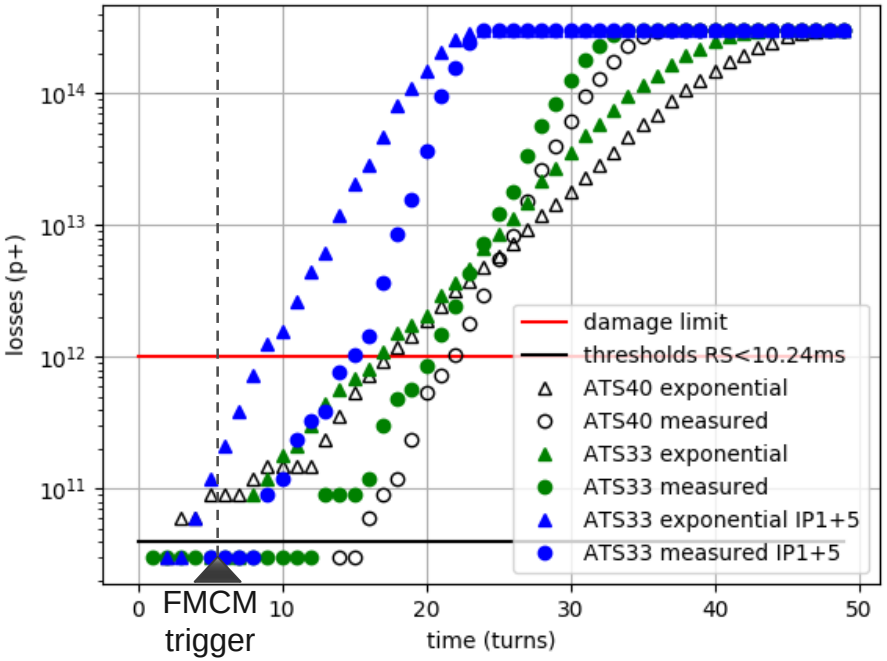


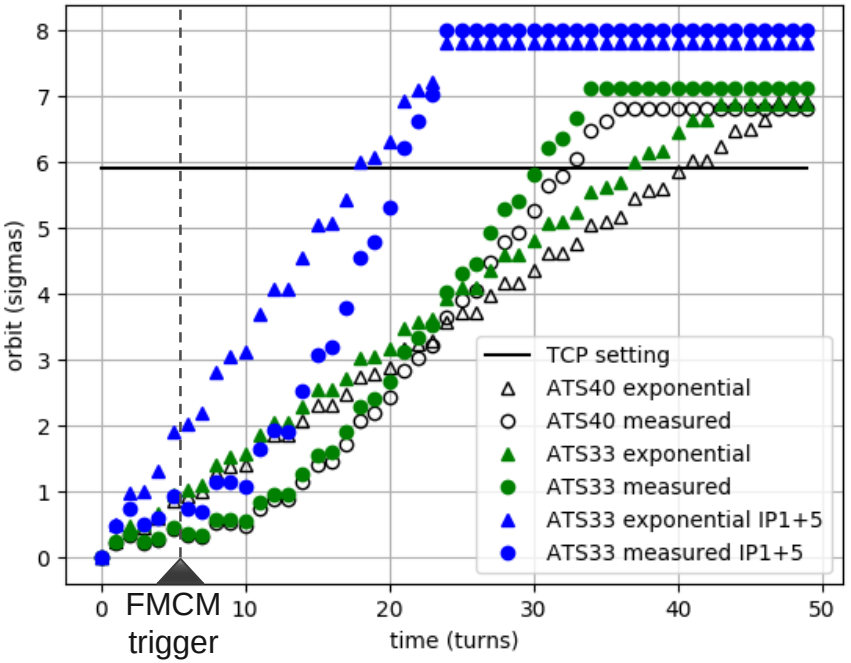


- A single Gaussian distribution and exponential decays were assumed in Verena's studies.
- Higher population in the distribution tails also leads to lower margins.

ATS 33 cm – outlook

$\beta_{D1} = 5155$ m





- Larger β functions at the D1 with 33 cm optics lead to more critical failures. The margin between FMCM trigger and damaging losses is two turns shorter for single failures.
- In case of combined failures, damage levels are reached 10 turns after the FMCM trigger and 9 turns after the beginning of the failure with an exponential decay.
- With these optics the FMCM triggers before the BLMs for a combined failure, due to changes in phase advance to the TCPs.

Conclusion on thresholds

- Revisiting of the D1 and D3/4 powering failures for current and future ATS optics (β*=40 cm, β*=33 cm) showed that the current FMCM thresholds are sufficient.

- In case of combined D1 IP1&5 failures (with alignment<1 ms) the current thresholds will not allow triggering the beam dump before the BLMs.

- For β* smaller than 33 cm the margin between detection and reaching of damage limits shrinks below 10 turns => careful analysis is required before further lowering β*.

- Powering failures of D3/4 in IR3/7 have very low impact on the beam and the current FMCM thresholds are by far sufficient.

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