ADT AC-Dipole mode: results of parameter validation measurements

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Acknowledgements: D. Wollmann, D.Valuch, P. Belanger, M. Valette,

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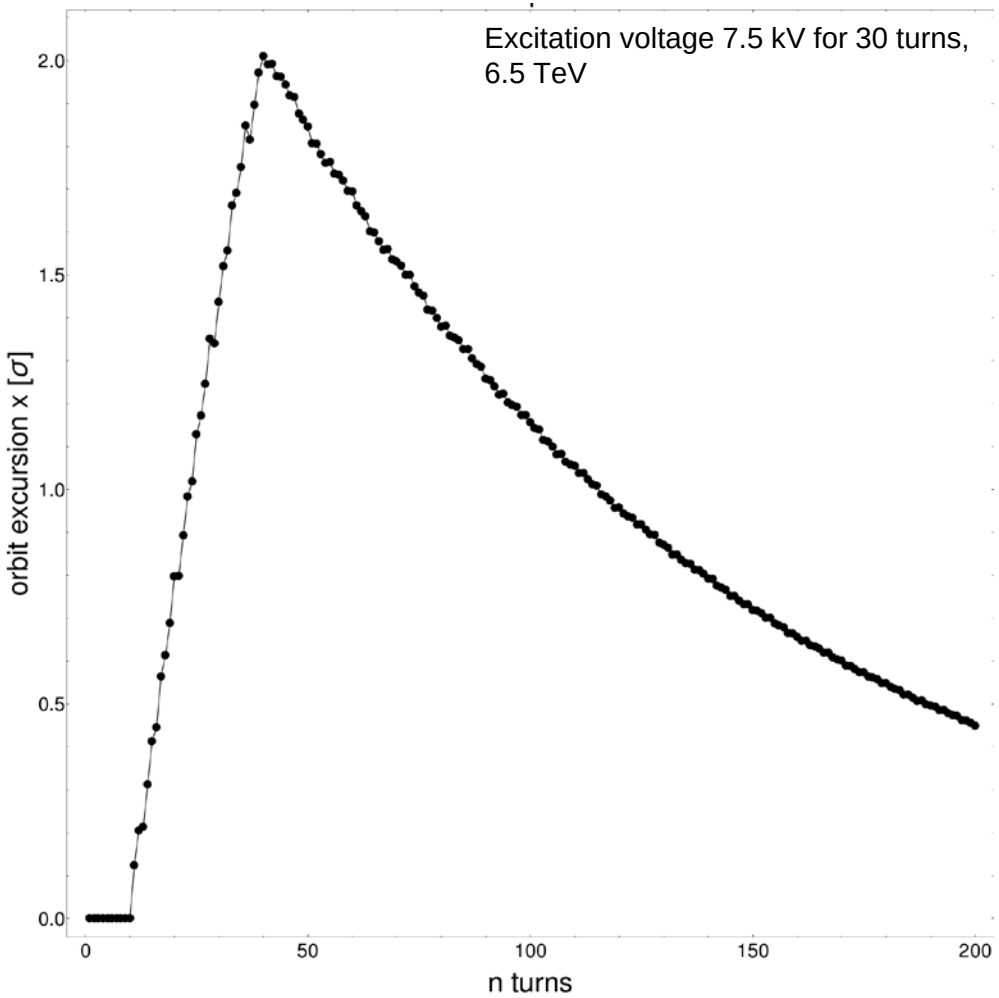
Motivation

- ADTs are strong transversally acting electric kickers
  - Damp injection oscillations
  - Stabilize beam

- ADTs have a few special modes; AC-Dipole mode allows resonant excitation of the beam
  - Requested to be used for tune measurements and x-y coupling measurements during standard operations, with full beam in



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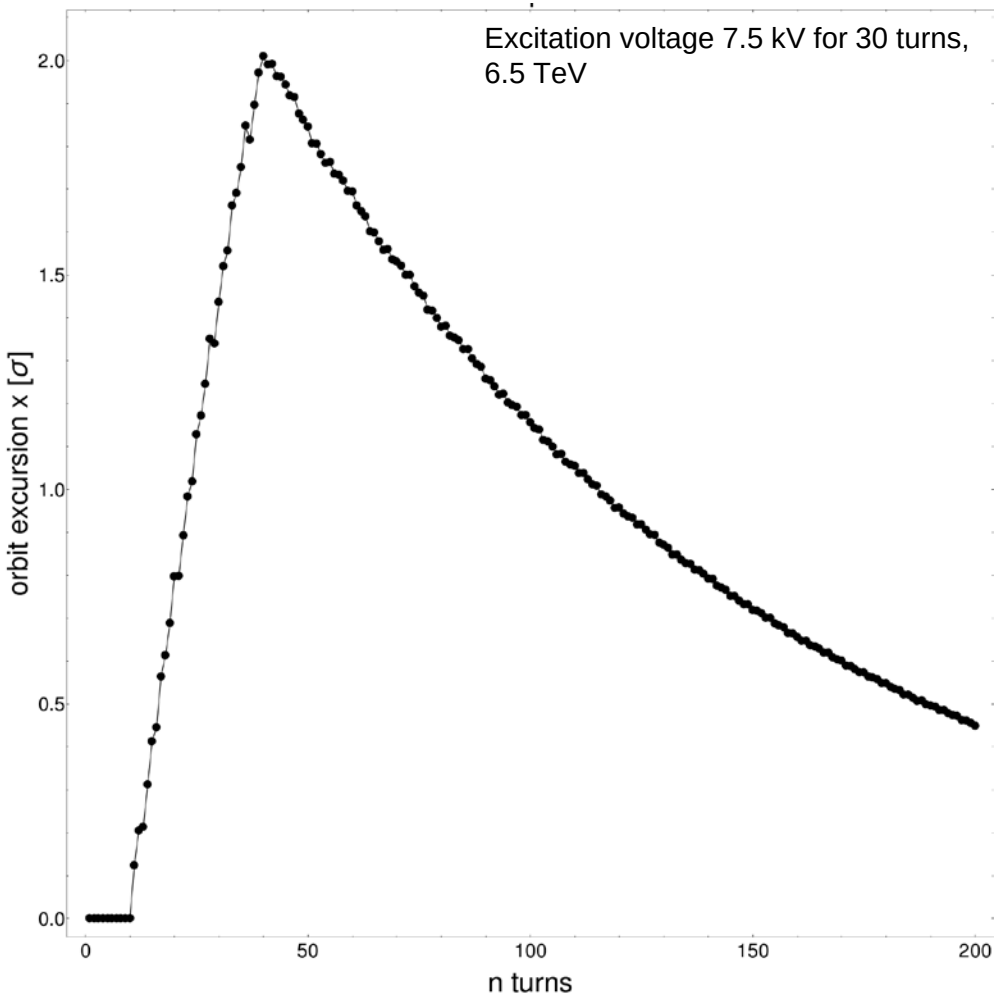


Collimator damage limit ~8 nominal bunches @ 6.5 TeV

=> 0.3 % of full LHC beam – reached at orbit excursion of 2 σ (collimator gap at 5.7 σ)

Goals of Experiment

- **Goals:**
  - Validation of the limits to put in place for the AC-Dipole mode
  - Verify the equilibrium between excitation of beam and damping of beam
    - Damping is always active in the machine
  - Benchmarking of the simulation models against measurements

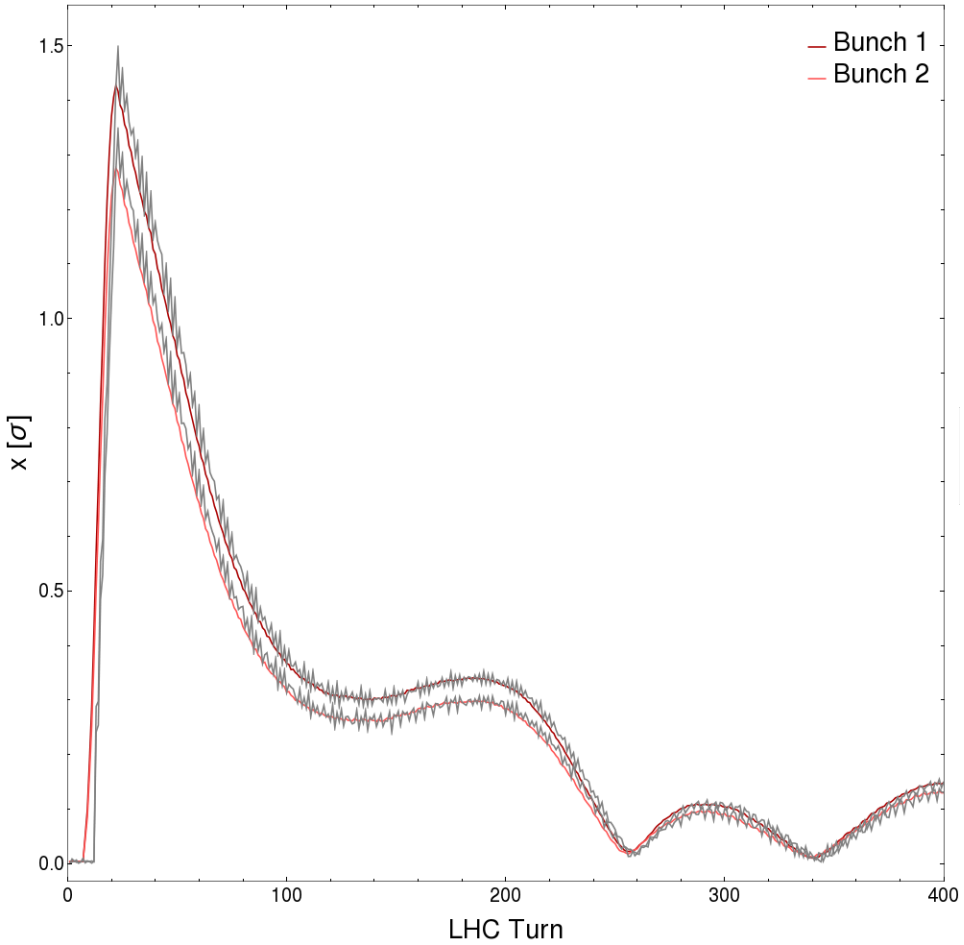
- **Parameters of Interest:**
  - Kick amplitude/Excitation speed (voltage, number of turns, bandwidth of excitation signal)
    - Time from detection until potential damage
  - Reproducibility of excitation (hor / ver, pilot /INDIV, re-excitation)
  - Intensity/number of bunches

- MD committed on 21/5/2017

Measured orbit excursion examples

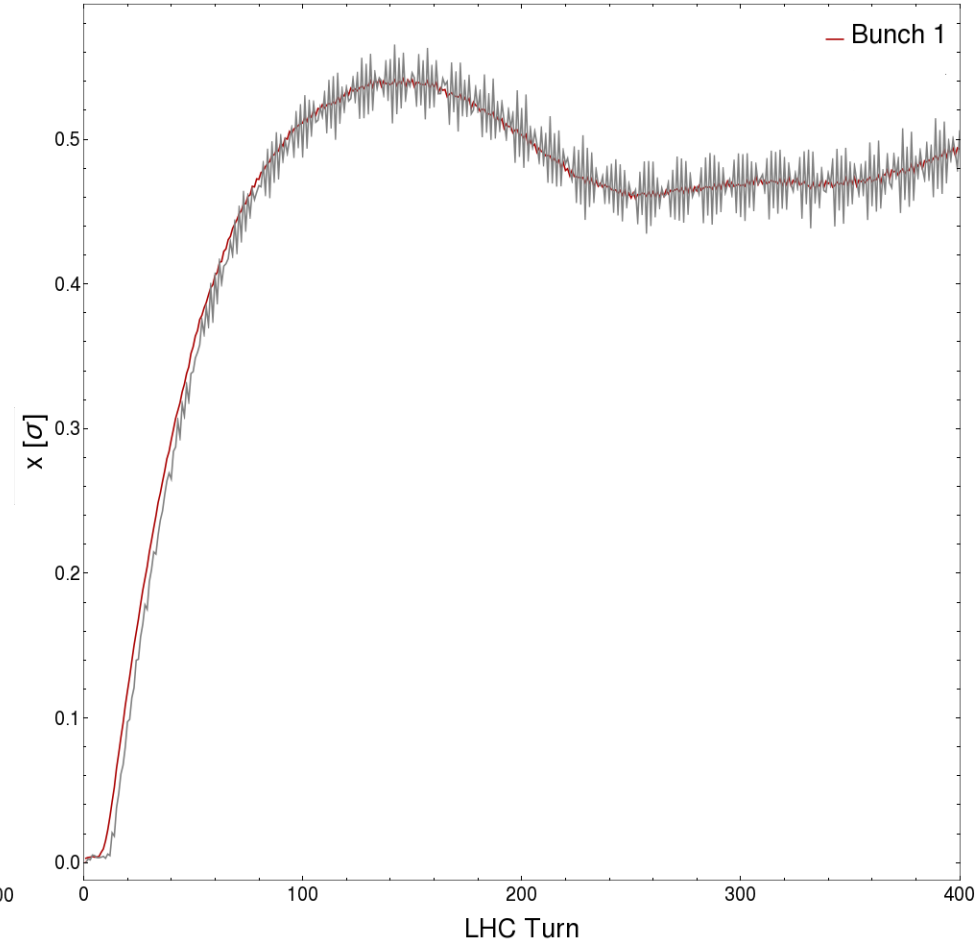
Excitation using 3 kV, for 10 turns

450 GeV



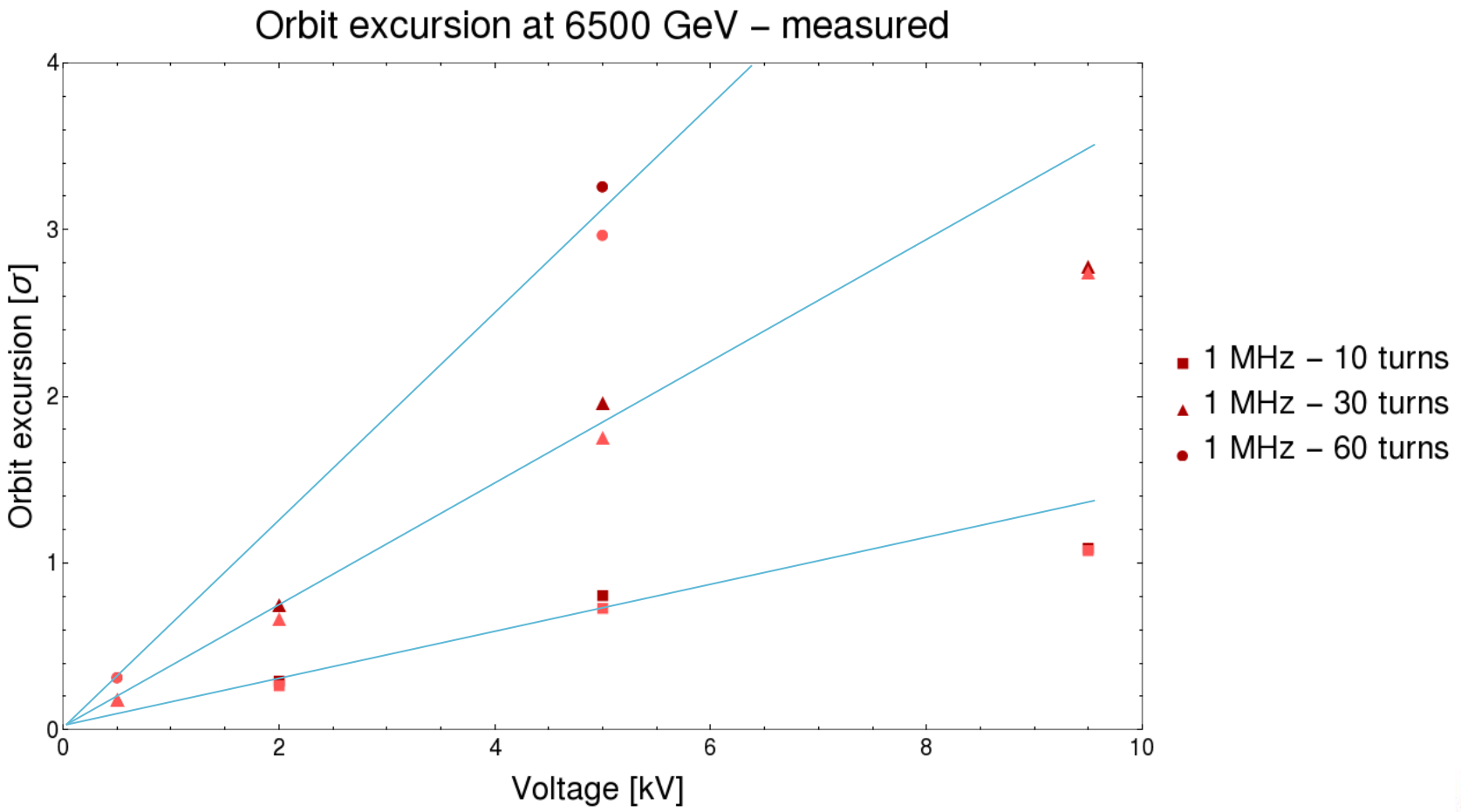
Excitation using 0.25 kV, for 1000 turns

450 GeV



Voltage Dependence

- Kick strength is proportional to voltage
  - Measurements agree except for highest voltage (9.5 kV)
  - Power supply believed to be saturated – actual max voltage around 7.5 kV

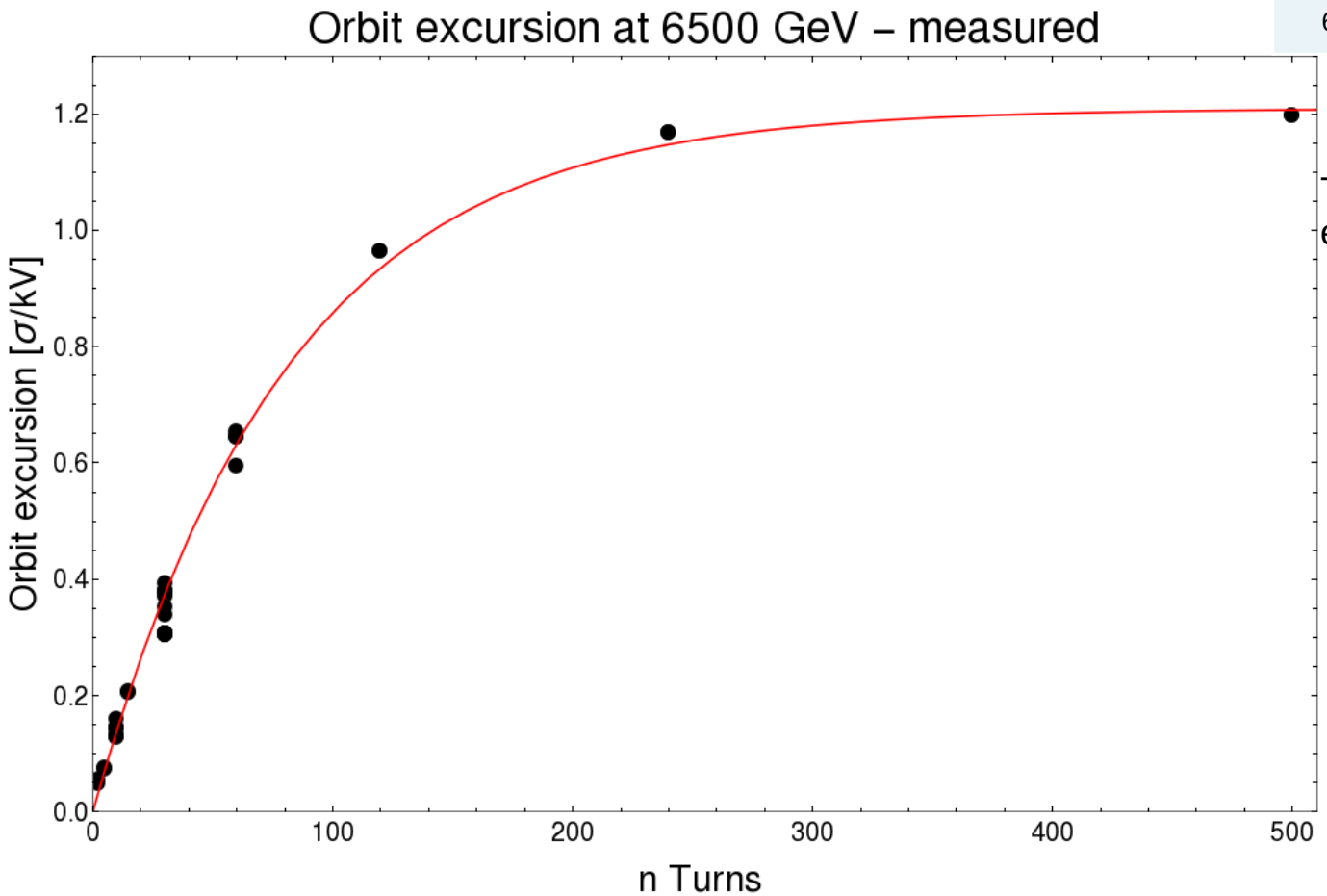


Turn dependence

- Analytical formula: $OrbEx_{norm}\left[\frac{\sigma}{kV}\right] = a(1 - e^{-b \cdot n})$,

  where $OrbEx_{norm}$ is the voltage-normalized orbit excursion vs n number of turns

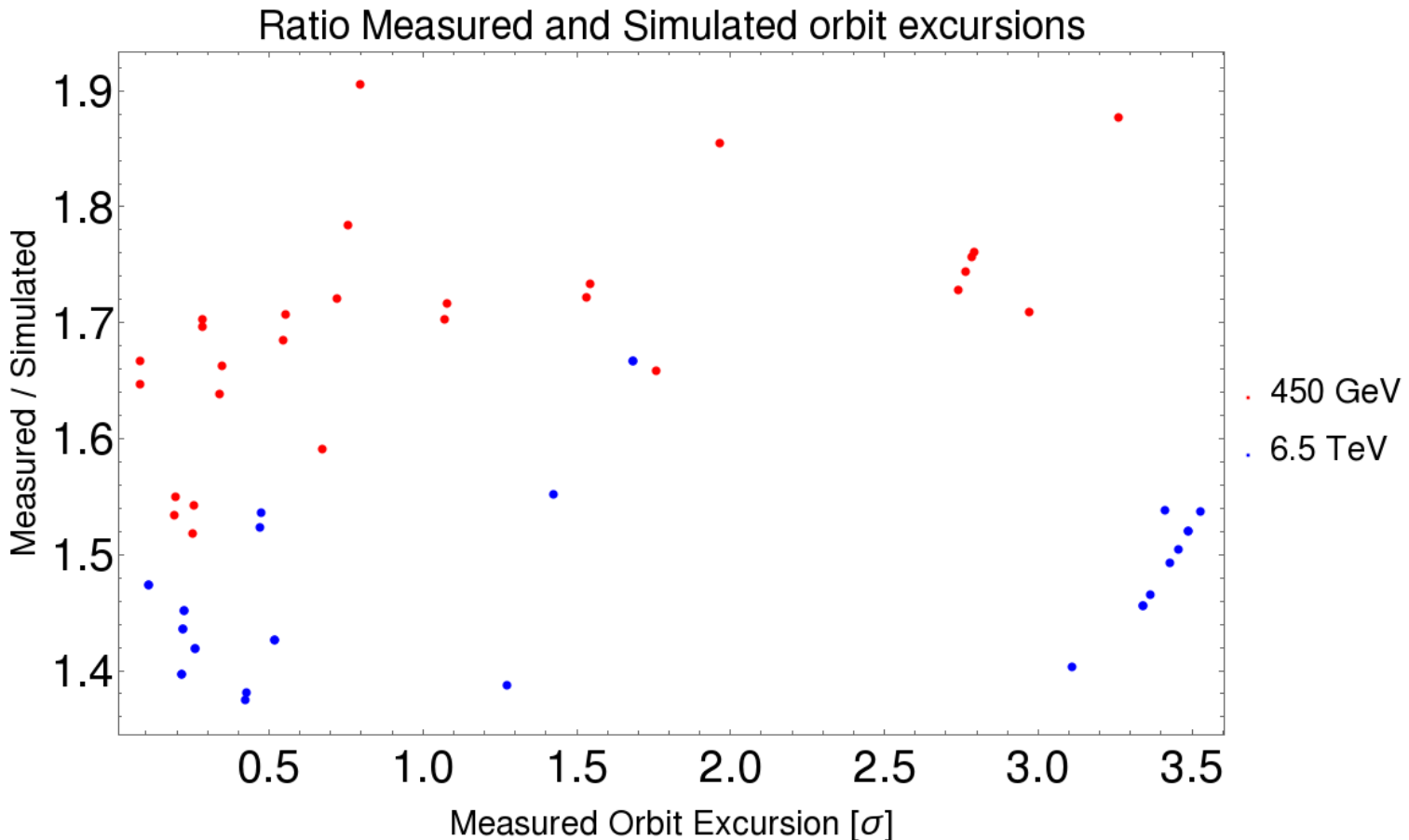
Fit Parameters	a	b
450 GeV	3.742	-0.01245
6.5 TeV	1.209	-0.01237



These fits assume a normalized emittance of 3.5 µm.

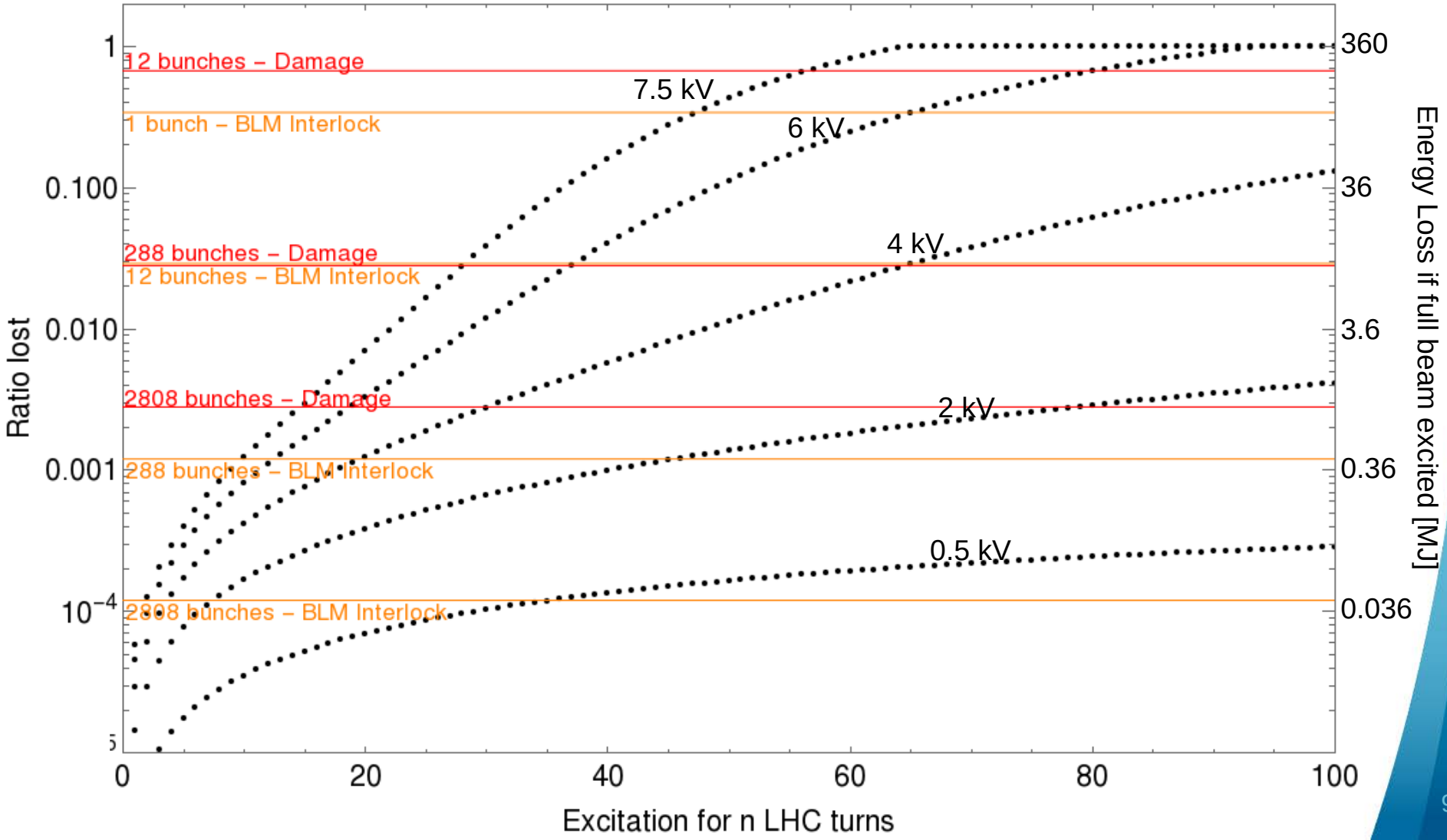
Measurements vs Simulations

- Simulations currently underestimate the orbit excursion
  - To be understood
- For now, ADT parameters can be derived directly from the measurements instead



Beam Losses and Excitation Limits

- Losses (as ratio of the excited bunches) are summarized with damage limits and BLM thresholds (TCPC / TCPD, 9.3 Gray/s)
- Different voltage curves from 0.5 kV to 7.5 kV
- 6.5 TeV



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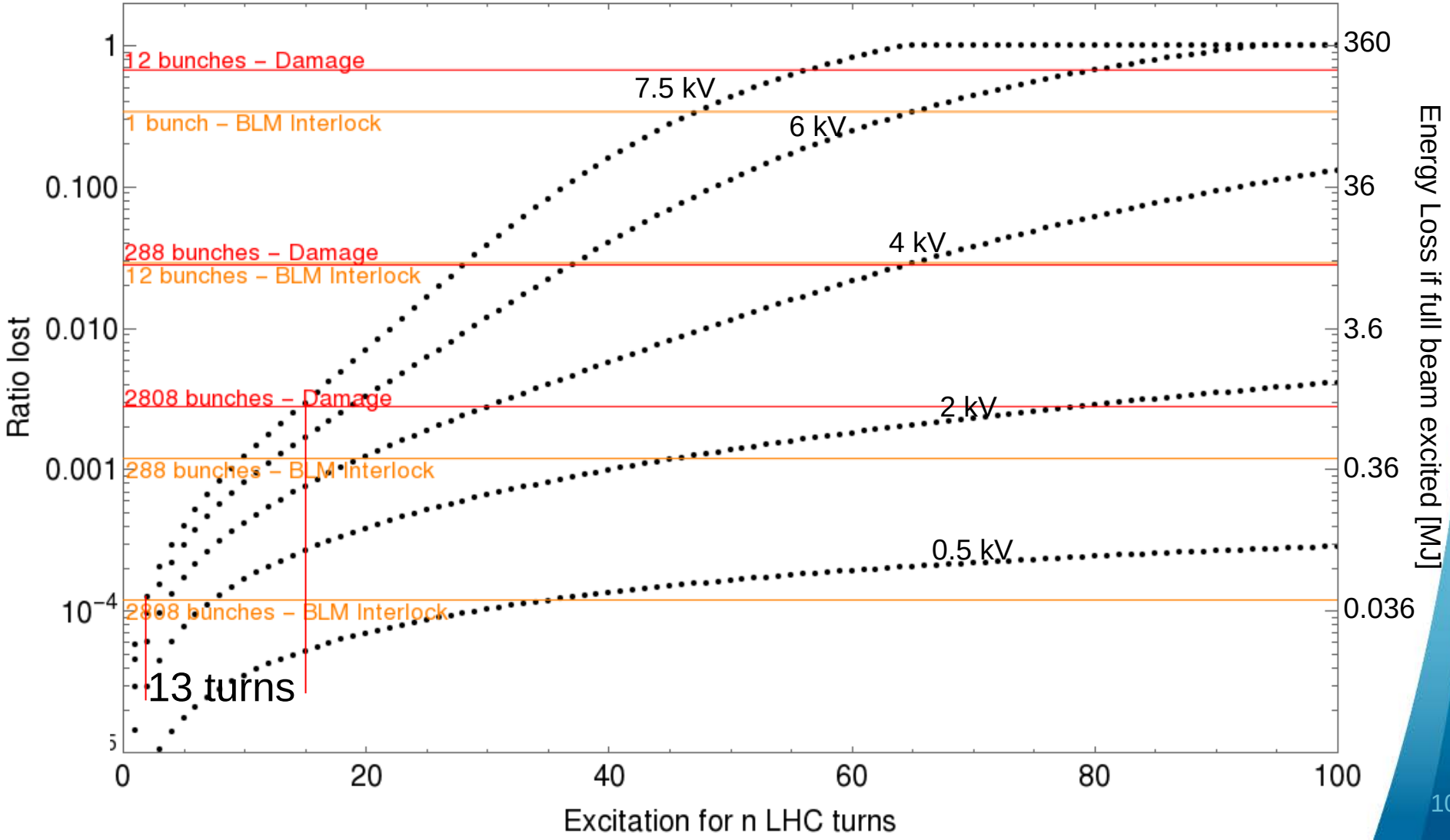

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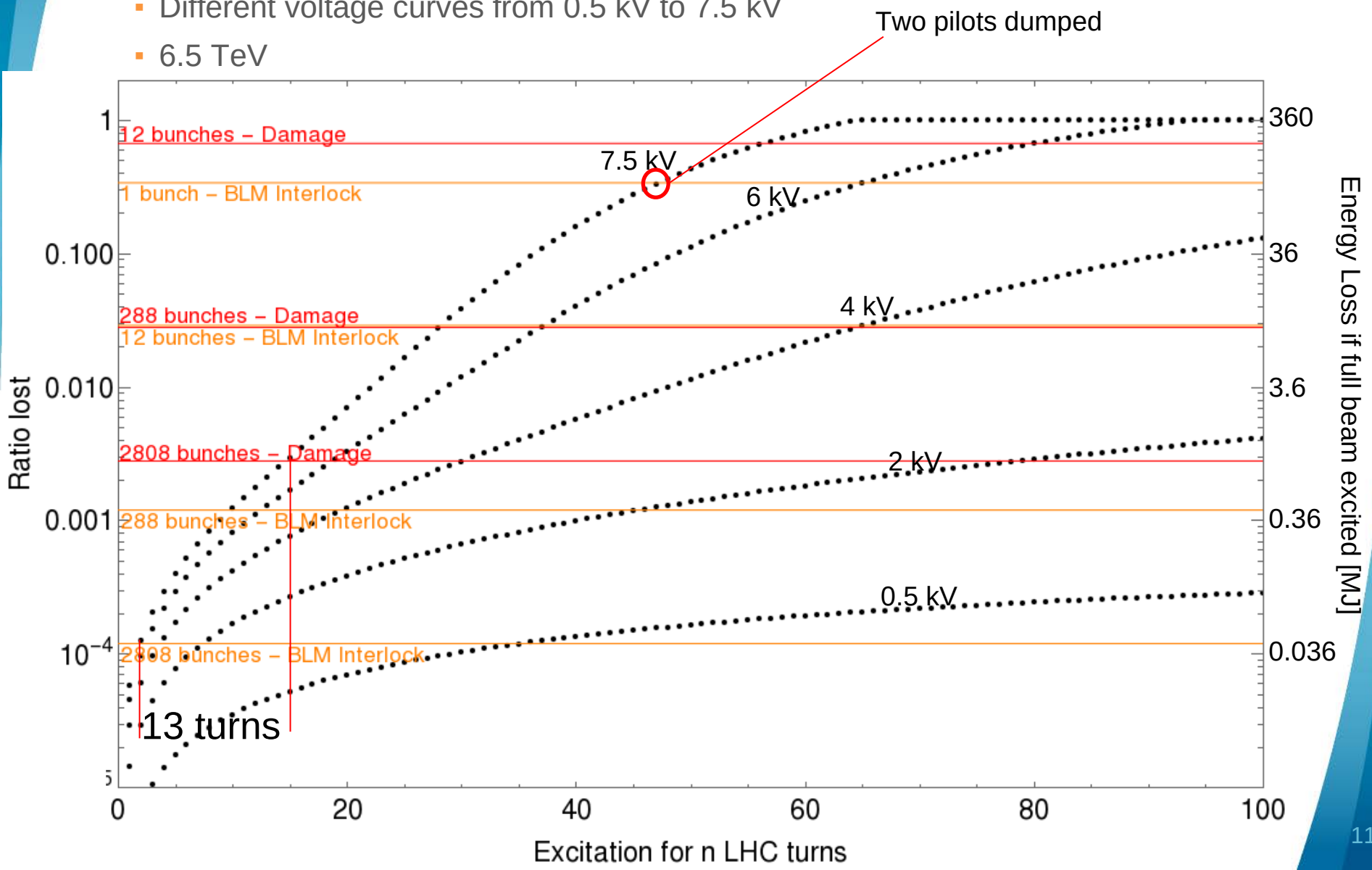
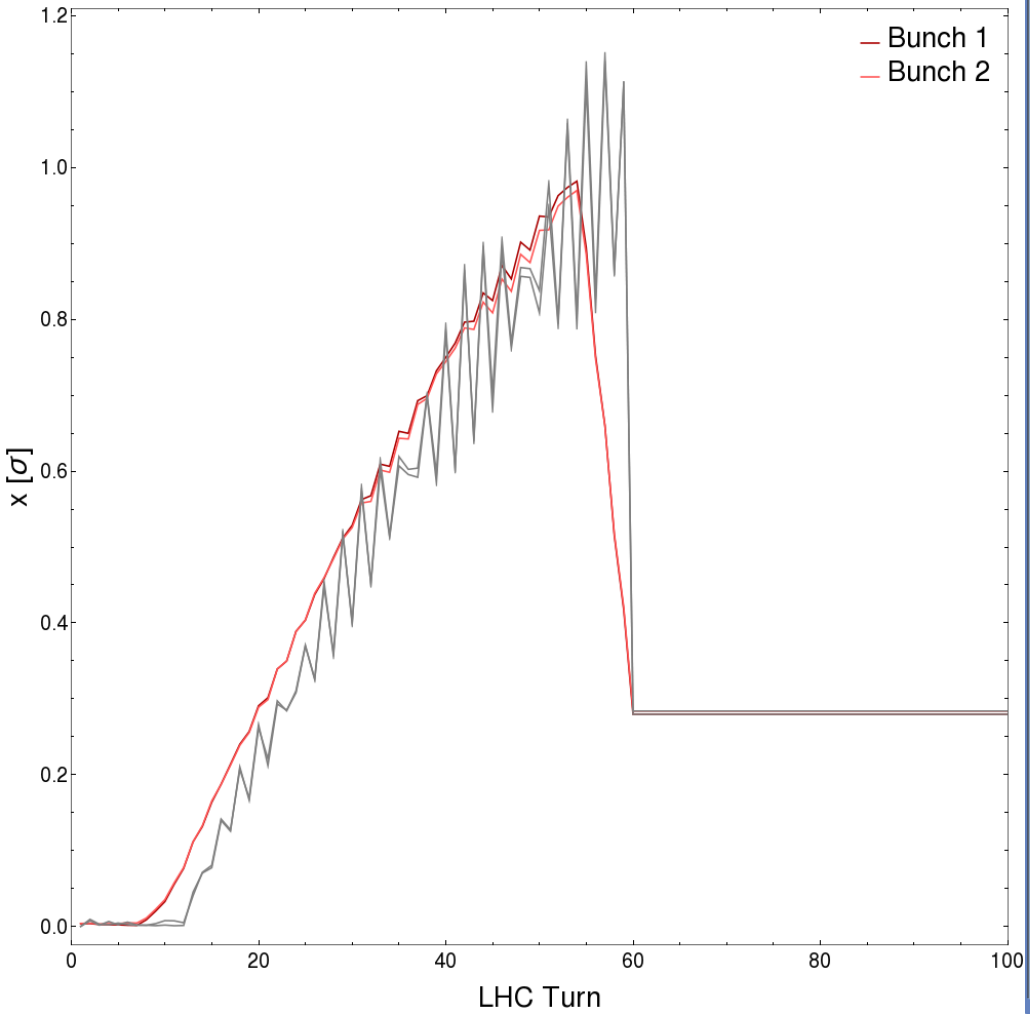
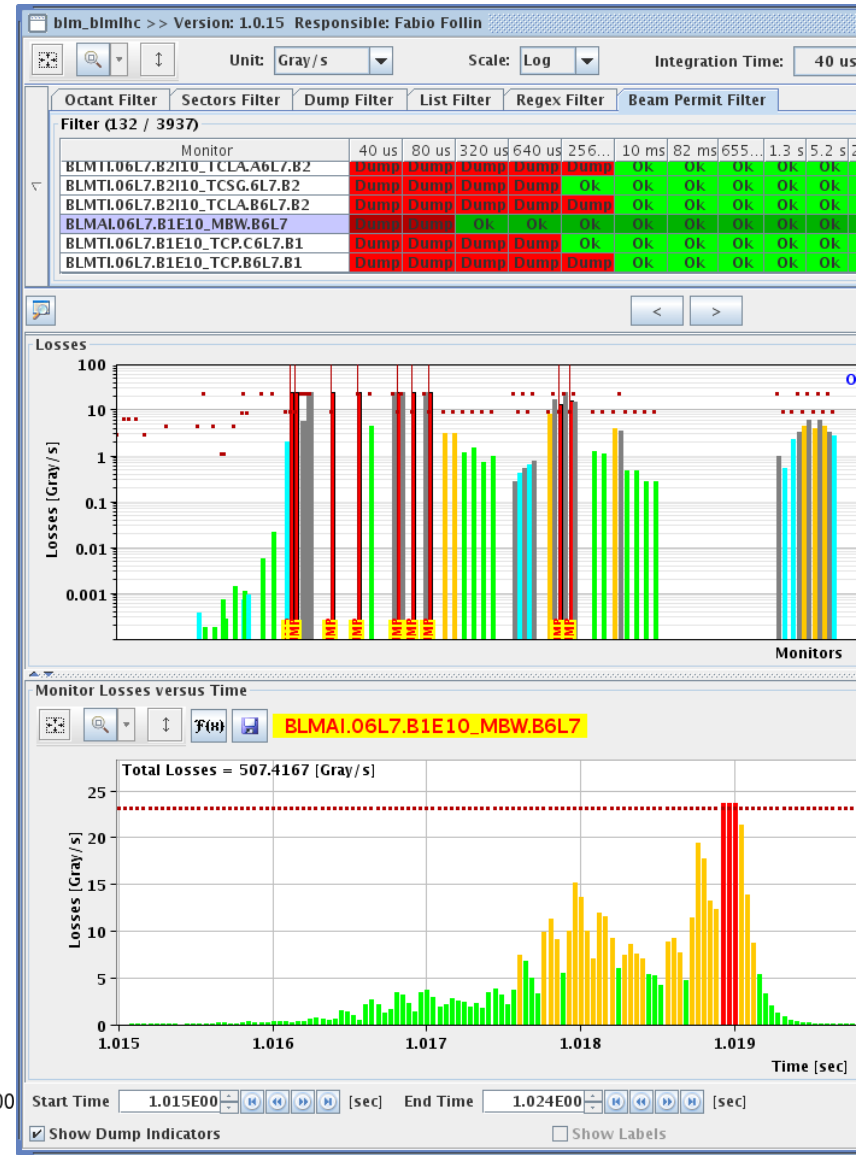


Loss-induced dump

- Dump caused by losses at 6.5 TeV (7.5 kV excitation, dump on turn 47, two pilots)





Requested Parameters

- Normalized emittance 2.5 µm
- Horizontal/Vertical excitation
- 450 GeV, 6.5 TeV

- **Coupling measurements**:
  - 50, 100 or 200 µm displacement (beta=174 m)
  - 1x INDIV excitation
  - 10000's turns (equilibrium)

- **Tune measurements**:
  - 100 µm displacement (beta=174 m)
  - 1-3 x INDIV excitation in parallell
  - 3-10 turns

ADT Settings Proposal

Measurement type	Version	Displacement (μm)	Voltage* (kV)	Turns	Expected orbit excursion (sigma)	Expected losses** (# protons per nominal bunch)
Tune, 450 GeV	1	100	0.8	10	0.4	1.4e6 ± 20 %
	2		2.5	3		
Tune, 6.5 TeV	1	100	2.4	10	0.4	6.7e6 ± 20 %
	2		7.5	3		
Coupling, 450 GeV	1	50	0.045	>400	0.2	5.6e5 ± 20 %
	2	**100**	0.09		0.4	1.4e6 ± 20 %
	3	200	0.18		0.8	4.5e6 ± 30 %
Coupling, 6.5 TeV	1	50	0.15	>400	0.2	2.8e6 ± 20 %
	2	**100**	0.3		0.4	6.7e6 ± 20 %
	3	200	0.6		0.8	2e7 ± 30 %

** During the MD a ~13 % stronger excitation was measured in the vertical plane, is possibly due to a lower damping*

*** Error margin derived from measurements, emittance increase not taken into account*

Conclusions

- The ADT AC-Dipole mode verification measurements were performed successfully
- Voltage and excitation length dependence as expected
  - => Orbit excursion can be extrapolated from the ADT settings
- From the MD, parameters for the tune and coupling measurements have been derived, pending approval by the MPP
- Excitation speed slow enough that dump should occur before losses reach dangerous levels
- Damping gives an inherent safety measure
  - => If damping lost for one bunch, coupling measurement would quickly excite the bunch into aperture
- Measurements show good reproducibility
- No apparent dependence on intensity was observed
- Emittance was blown up for all excited bunches – by how much not known *(BSRT was not calibrated) → to be taken into account for coupling and tune measurements*
- No difference was observed between on-tune and off-tune measurements (off-tune was 1.01*Q_frac), since the precision in the ADT excitation is not better than this

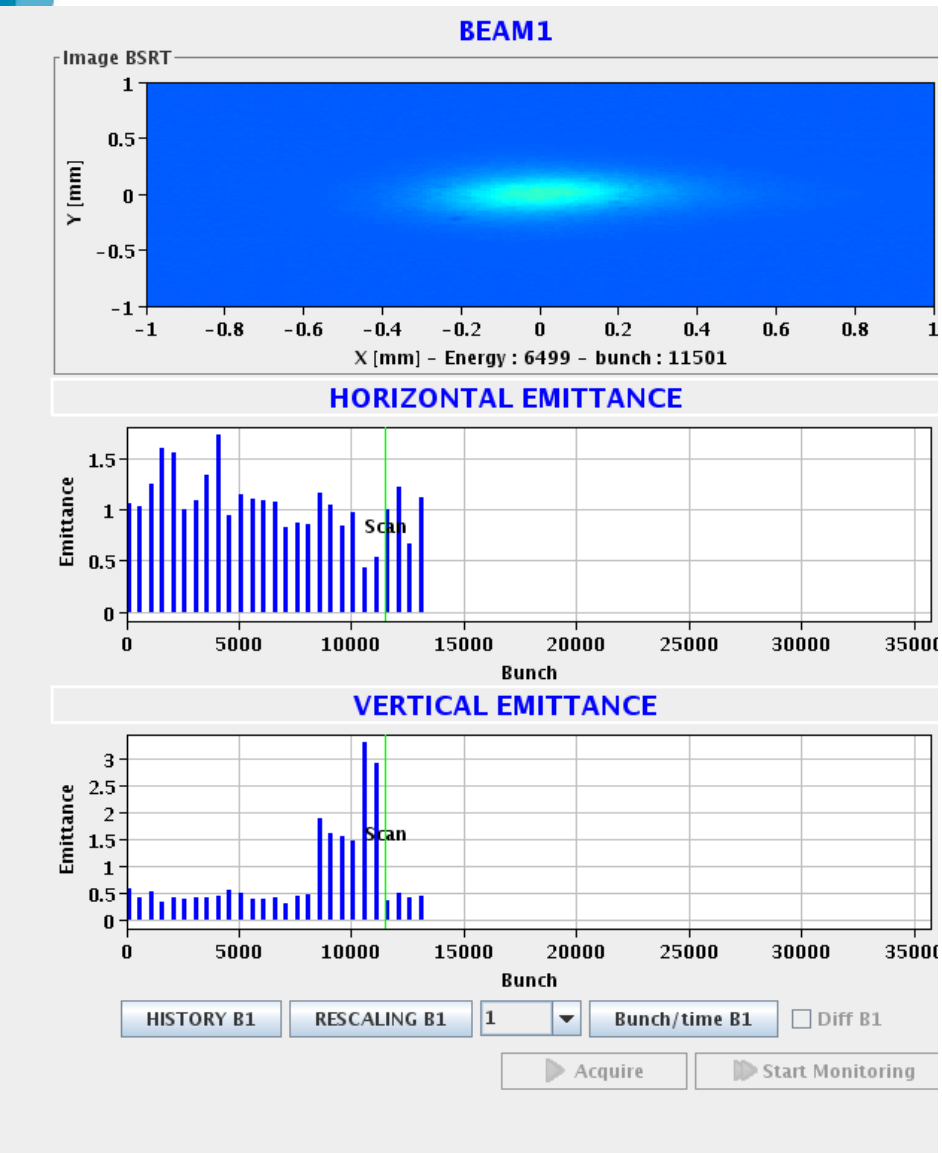
Unresolved Question

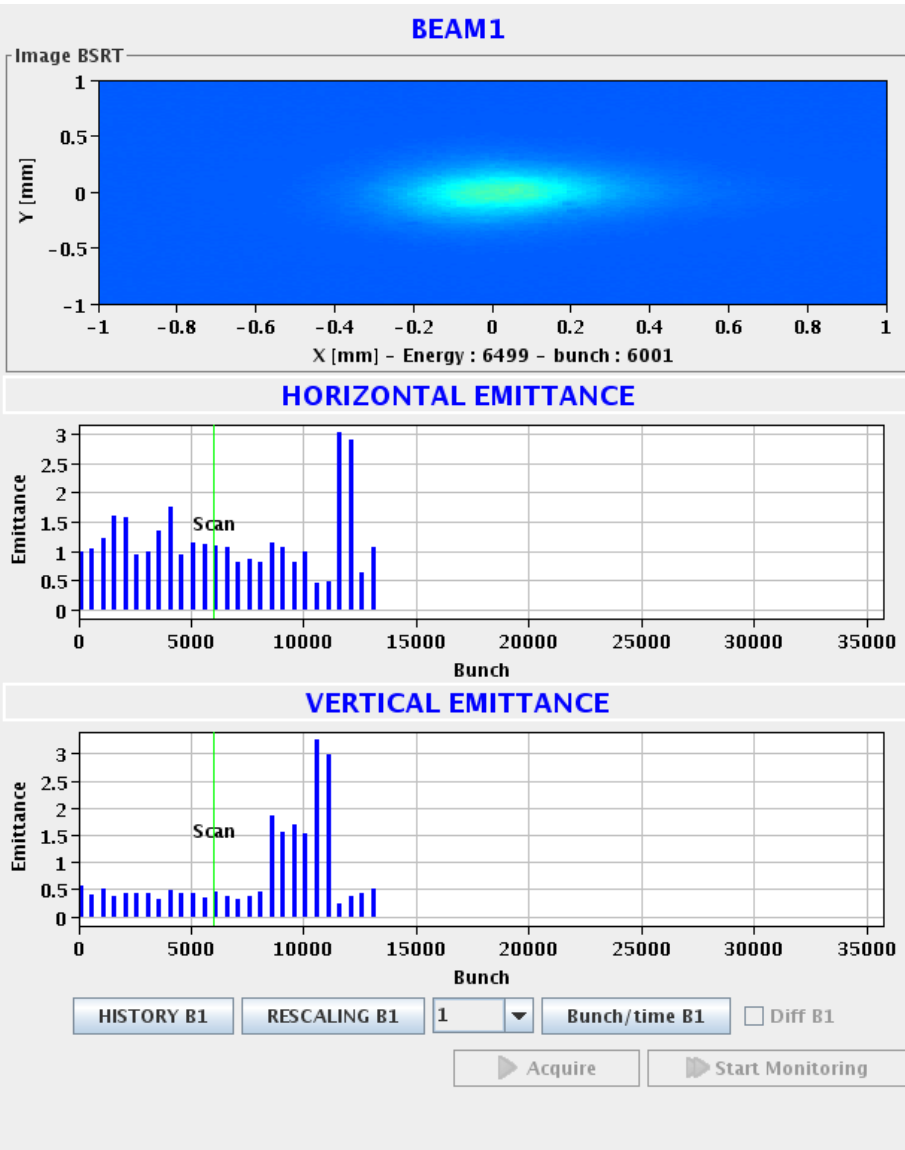
- Discrepancy between simulations and measurements (~factor 1.6)

Extra Slides

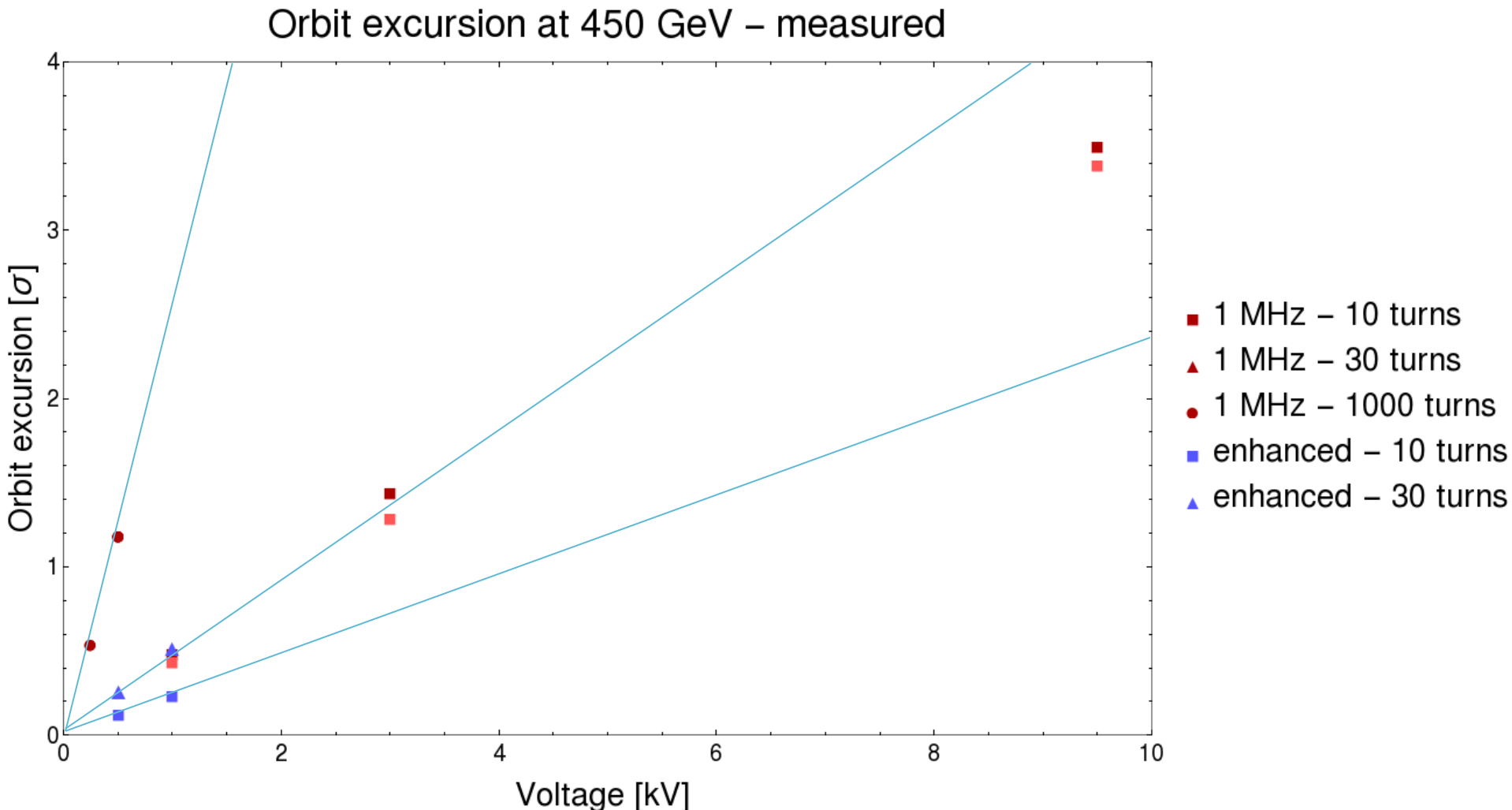
Emittance Growth

- Example of emittance growth, exciting with 5 kV for 60 turns horizontally

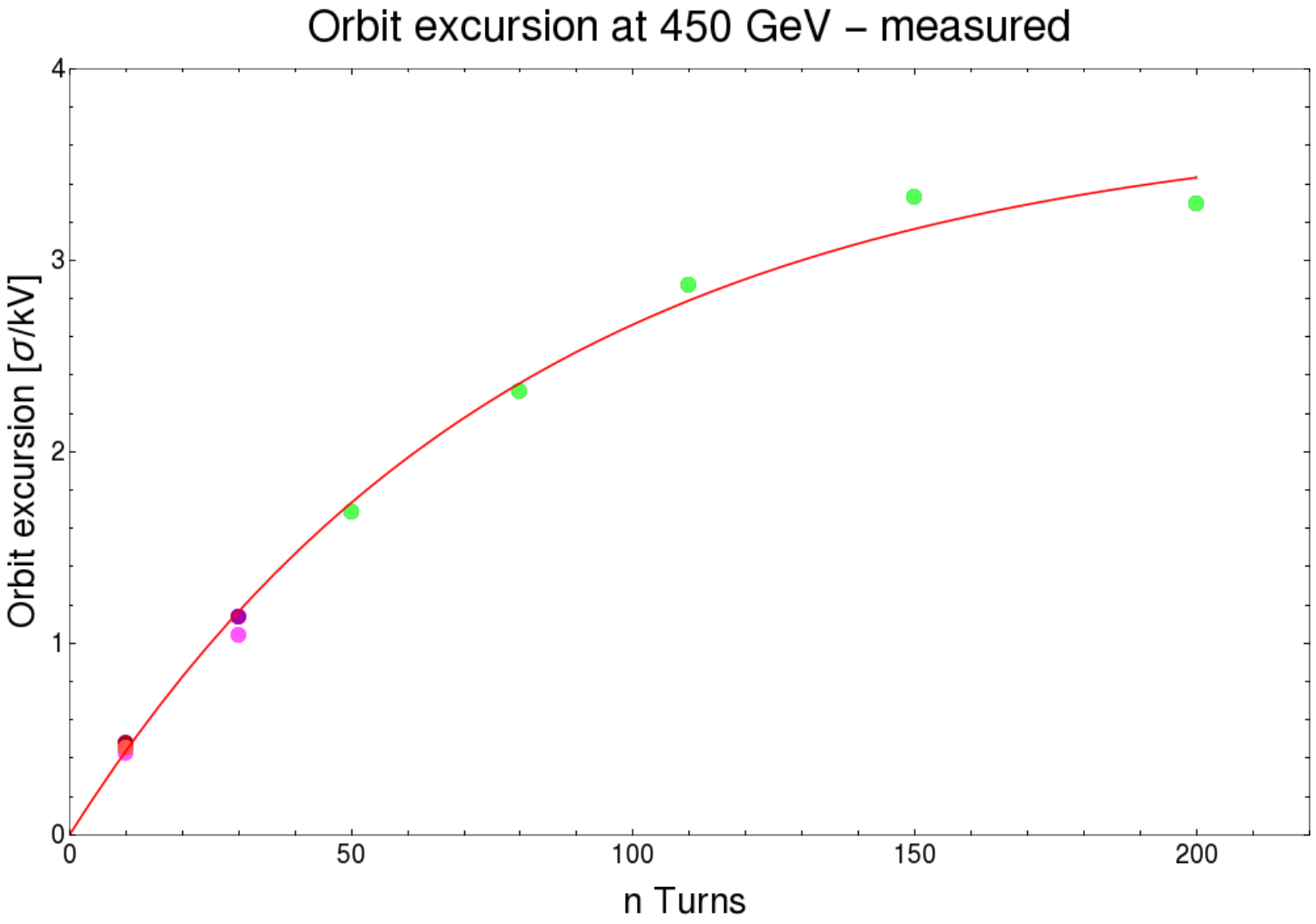




Voltage dependence 450 GeV



Fit of 450 GeV measurements



Beam Losses and Excitation Limits

- Losses (as ratio of the excited bunches) are summarized with damage limits and BLM thresholds (TCP.C / TCP.D, 9.3 Gray/s)
- Different voltage curves from 0.5 kV to 8 kV
- 450 GeV