Fast and beta-beating free optics transitions

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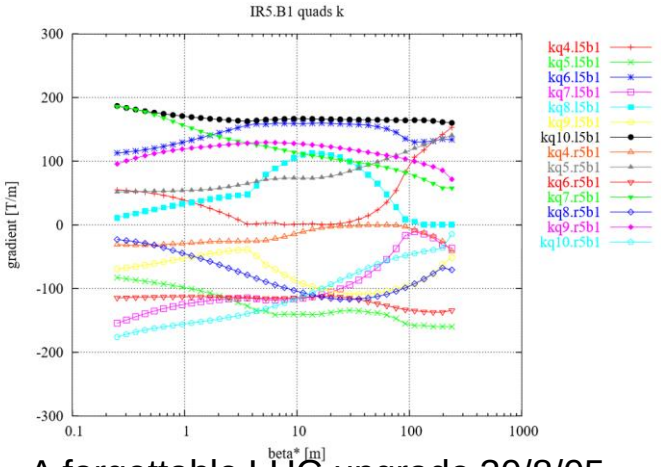
Optics transitions

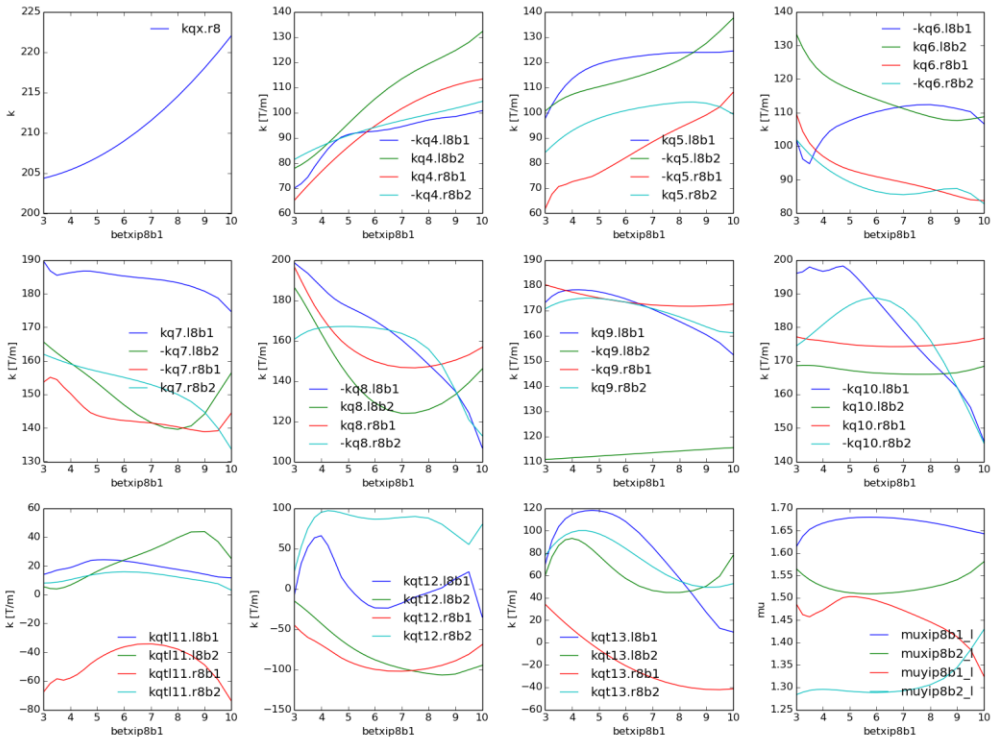
- During an operation cycle (HL-)LHC needs very different optics conditions driven by experiment needs (e.g. β*) and constrained by aperture, magnet currents, phase advances, …
- Today
  - We prepare a bunch of intermediate optics files (set of normalized strengths) close enough such that when linearly interpolated the mismatch (β-beat, tune error etc) are below a certain threshold.
  - OP converts them into currents (through LSA using a simplified Fidel model), generates a set of parabolic-linear-parabolic time-current series which respect circuit (approximately) constraints and iterate driving the circuits during dry-runs tests
- This works however:
  - Time is lost during the parabolic fractions (up to 50%)
  - Machine is mismatched in several points and loss spikes are observed
  - The whole procedure involves manual testing and iterations: ABP-OP-PC
- Therefore we could try to improve, because:
  - It is possible to generate smooth optics transitions: arbitrarily finely spaced matched points up to spline or polynomial interpolated functions with negligible mismatch.
  - Realistic magnet circuit response can be simulated fairly well using more realistic models.
  - One can try to use all information to generate directly k(t) or I(t) and hand them to OP.

Smooth Optics transitions

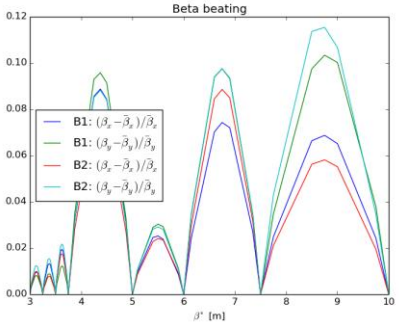
- In many practical cases it is possible to find optics transitions that smooth in one parameter: e.g. by using Jacobian matching method in MadX on the full parameter space (increasing the parameter space linearize the system of constraints).



A forgettable LHC upgrade 30/8/05



IR8 squeeze Run 2015-16



β-beating sorely appearing after down-selection

Smooth Optics transitions

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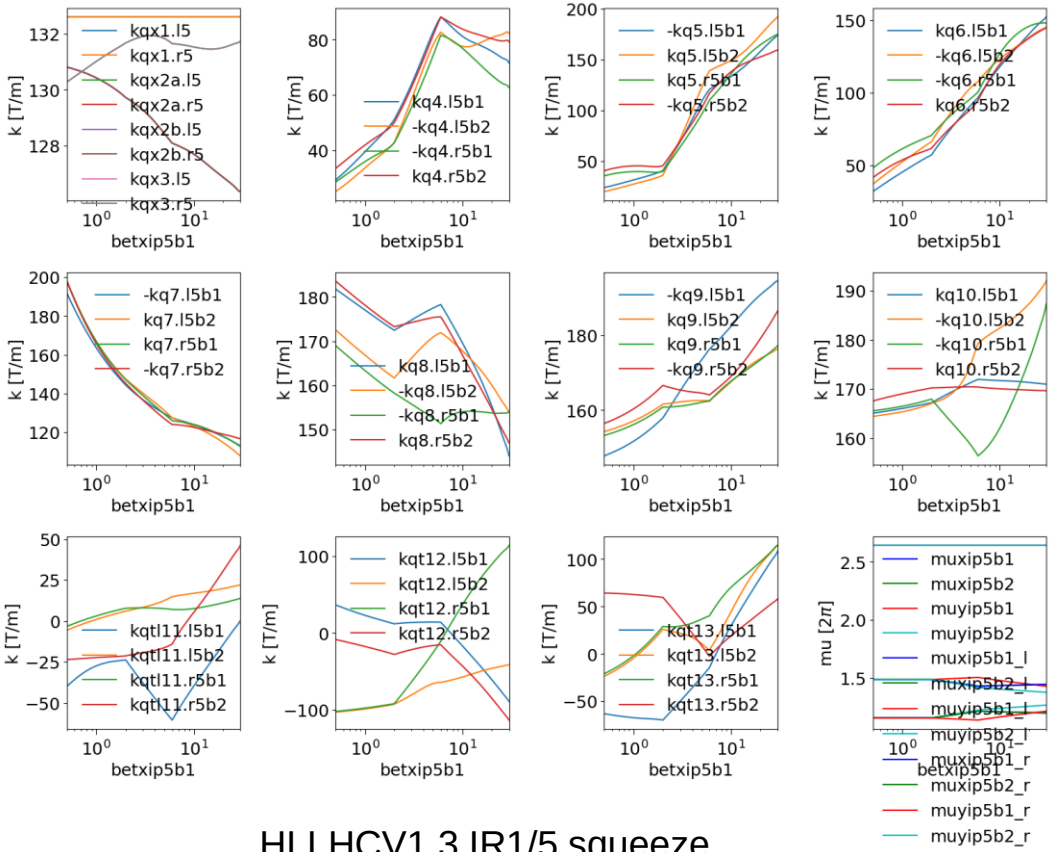
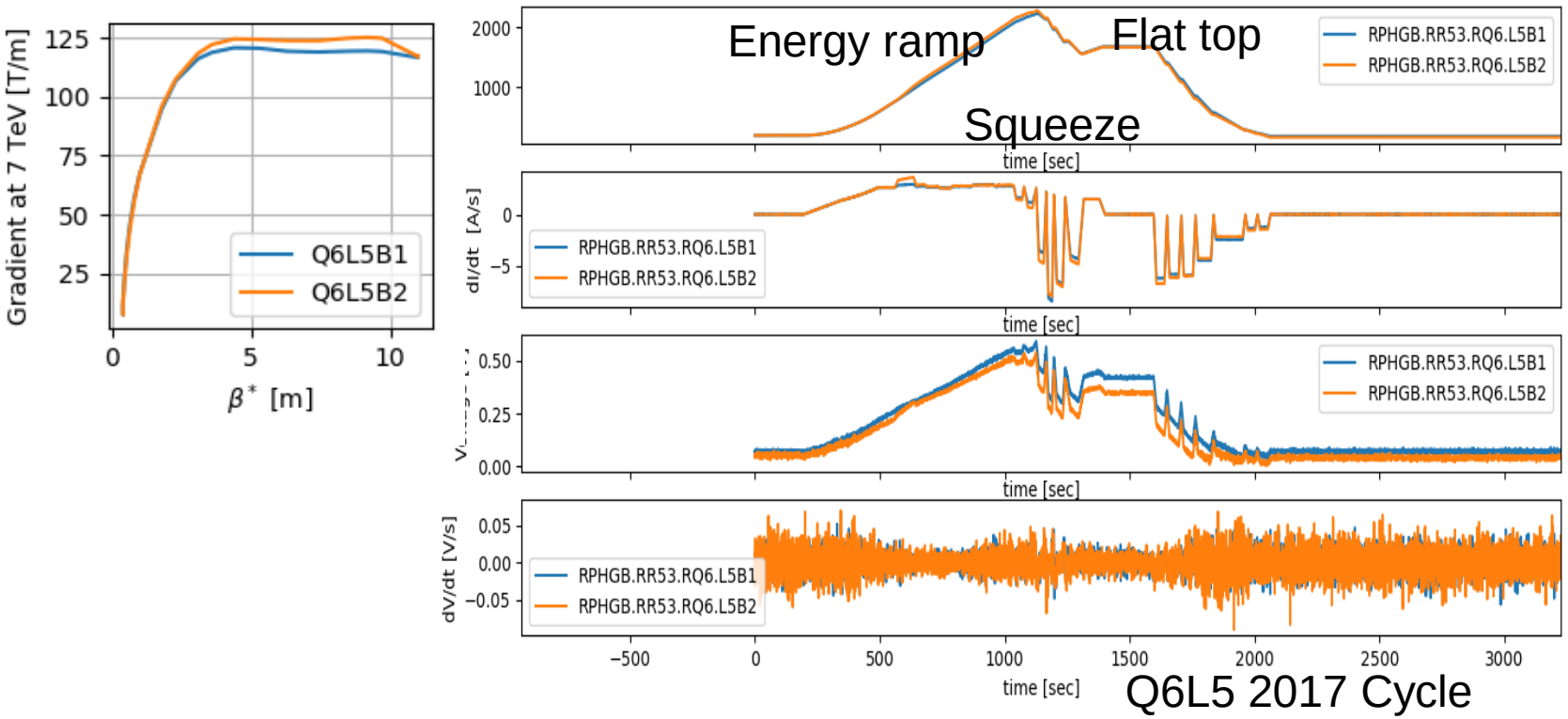


HLLHCV1.3 IR1/5 squeeze

Each function can be interpolated by 3 piecewise continuous 5th order polynomial in β* resulting in >10^{-4} β-beating.

Example Ramp&Squeeze Run 2017

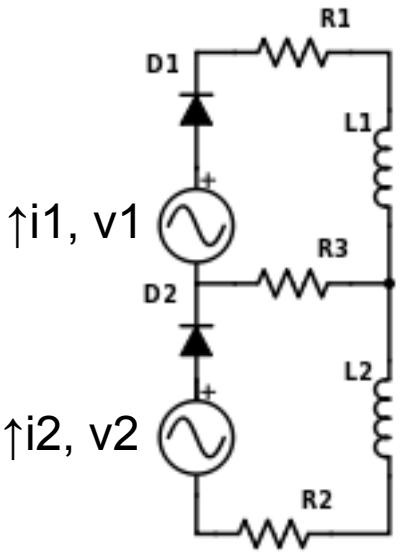


- Real constraints are V>0 and dV/dt<~100mV/s and not dI/dt or d^2I/dt^2
- dI/dt (and V) have unnecessary spikes
- V could be lowered in some part to speed-up
- Some parts needed manual stretching to avoid negative voltages

Voltage prediction

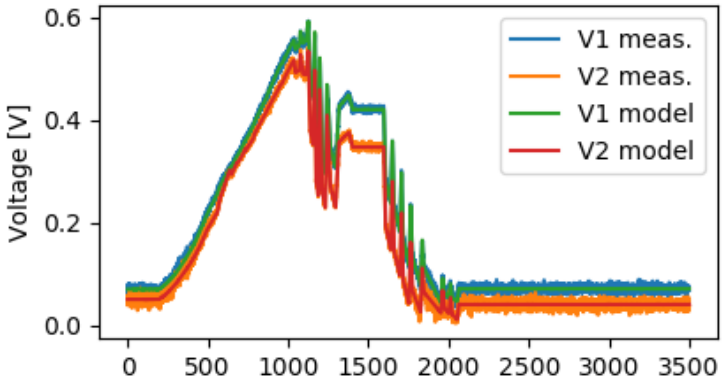
Expected voltages from imposed currents can be predicted fairly well:

- by taking into account interaction between currents
- and solving more realistic circuits (e.g. 2-in-1 with 2 inductances 5 resistances and 2 voltage source).



L1=21.1 mH
L2=21.3 mH
R1=236 μΩ
R2=203 μΩ
R3=202 μΩ
D1=22.8 mV
D2=0.9 mV
Fit from measurements

Q6 L5 normal cycle

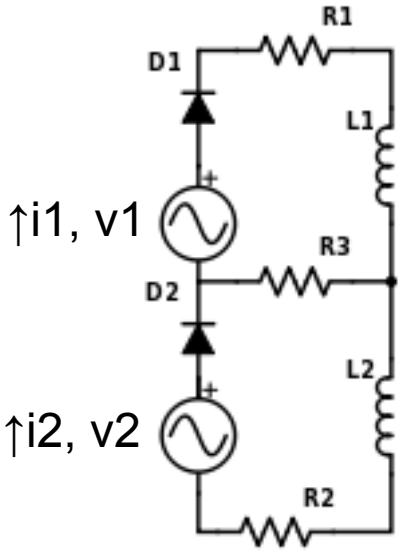


V calculated from I(t)

“Diodes” are indeed in parallel, but coarsely modeled as a constant voltage drop.
They determine the voltage at low current or negative dI/dT and are important because we are often optimal when V~0.

Voltage prediction

Circuit parameter taken from a cycle perform fairly well on other cycles:



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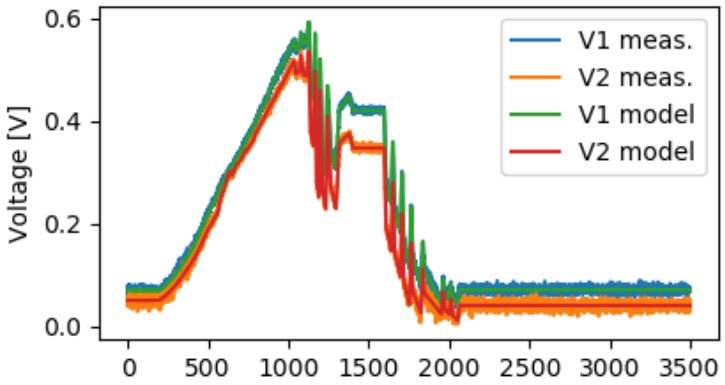
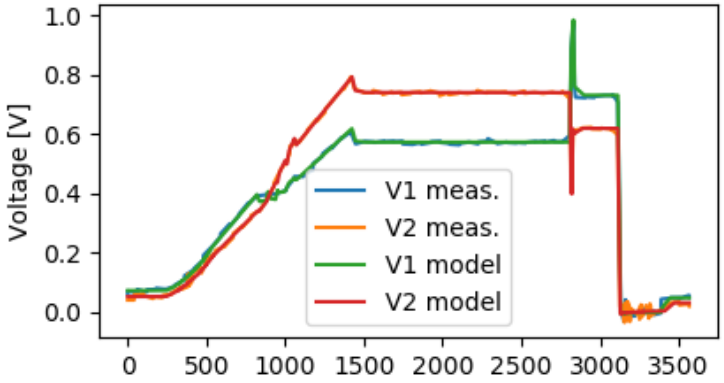
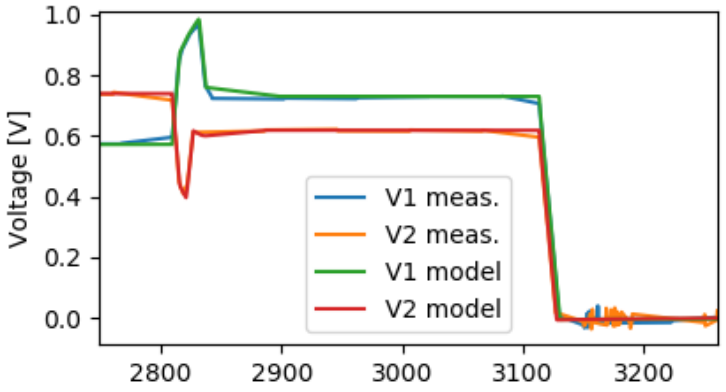




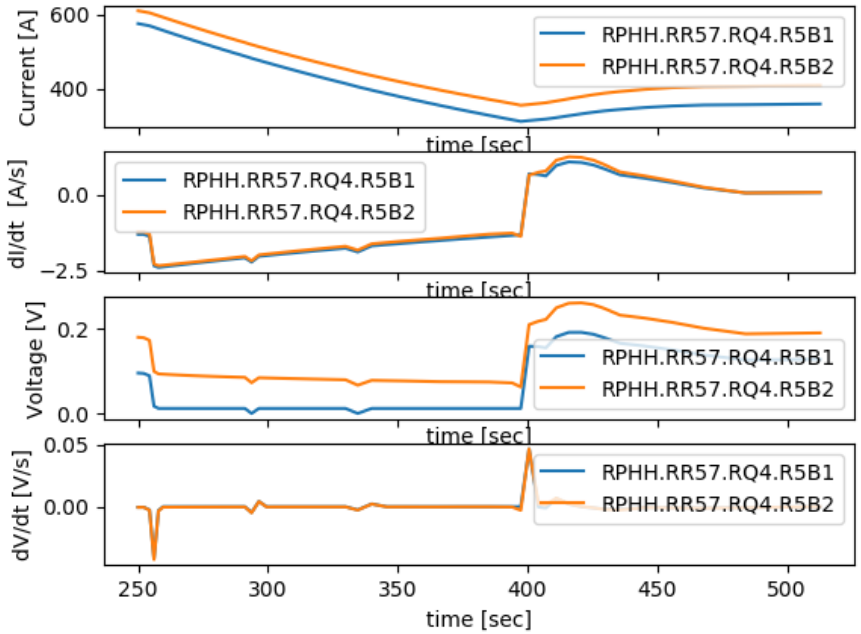


Q6 L5 VDM cycle

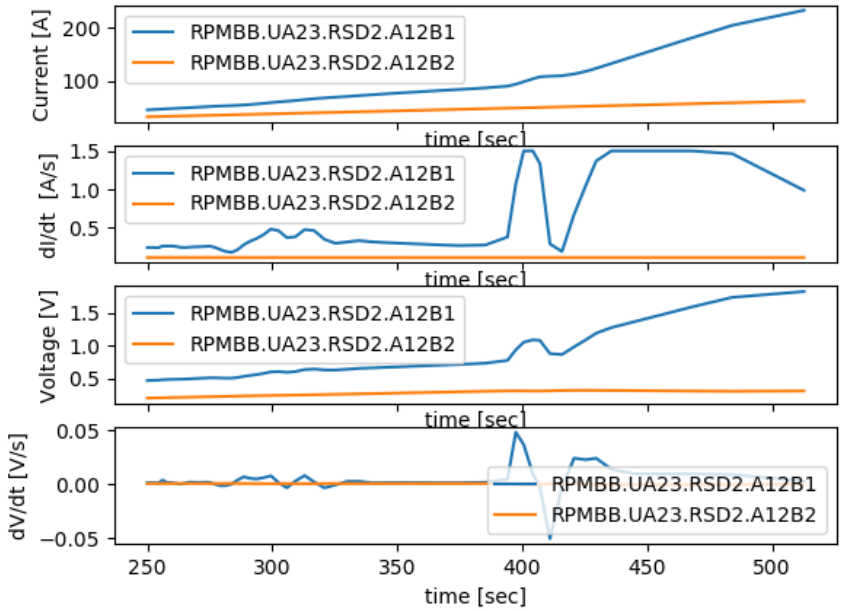
Smooth and fast continuous squeeze

- It is then possible to use smooth strength and convert it in smooth currents fulfilling V and dV/dt constraints.

Q5R5 using Q4R5 LHC model



RSD2 A12 limiting the squeeze speed



Example Ramp&Squeeze: 1.6 Tev → 3.1 Tev using the new PPLP ramp:

- realistic for PC but too fast for aperture and LRBB separation!
- IR8 slows squeeze down by 0.3 TeV if included, needs to be in the model

Next steps

- Prepare a set of I(t) for a ramp and squeeze: Q4, Q5, Q6 and MS and make an hardware test to prove the principle:
  - Test predicted V and dV/dt vs measurement and verify well behaving PC and QPS.
  - One can use HL-LHC optics (just being aware that some circuits may not reach nominal 7 TeV currents since not routinely excited).
  - Import t,I tables in LSA and send them to the PC (M. Solfaroli),
  - Possible date December 4th,
- Prepare a set of k(t) to be imported in LSA (M. Solfaroli) to enable a real test with beam in an MD:
  - One could use the present optics and profit to test a ramp&squeeze down to lower β* values or
  - Other HL optics scenarios worth testing