HL-LHC-UK
Plenary meeting
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Crab cavity simulations

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On behalf of
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The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Motivation

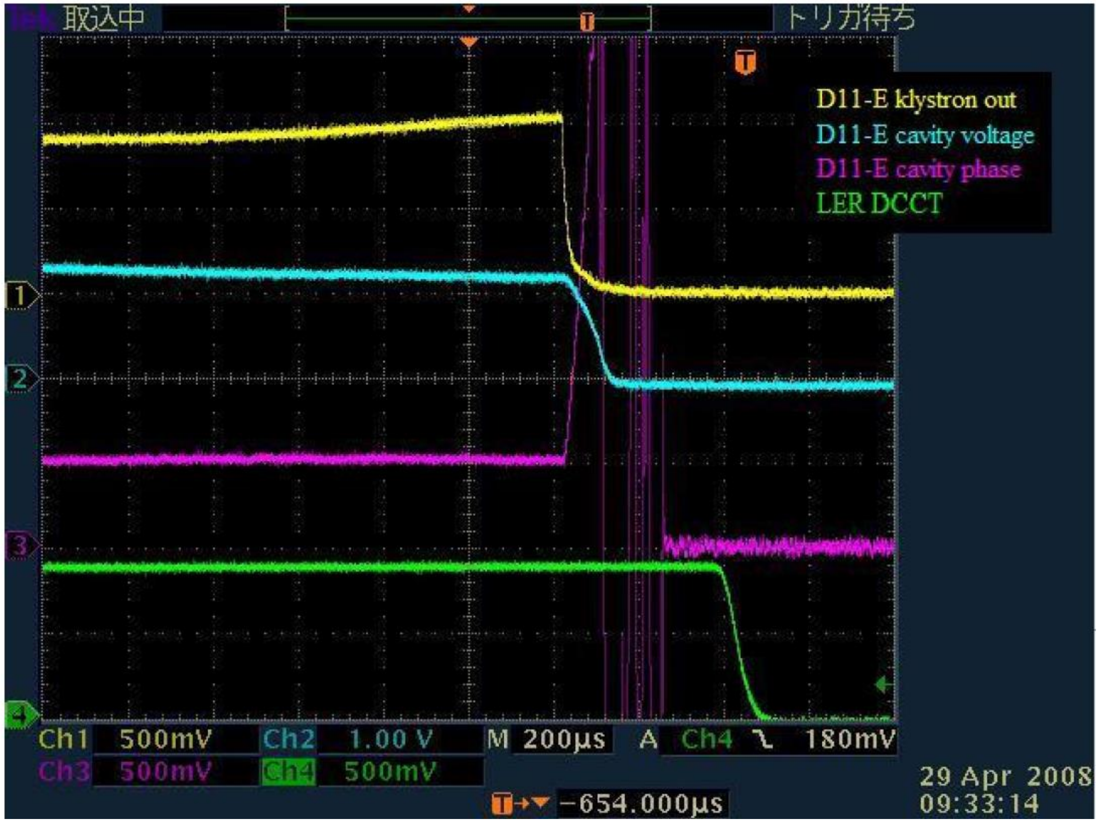
- KEKB crab cavities showed it was possible to get fast phase shifts during a quenches
  - Such failures could severely damage HL-LHC
- Motivation to study crab cavity failures in HL-LHC
  - What causes fast phase shifts in KEKB crabs?
  - Could it happen to HL-LHC crabs?
  - What would happen if it does happen to HL-LHC?

Overview

- Cavity failure measurements from KEKB
  - Results and operational procedure
  - Comparison of KEKB and HL-LHC parameters
- Simulations
  - Brief outline of code
  - Results
- Conclusions

Results from KEKB

- RF switched off when quench detected (yellow)
  - Approx. 700 µs after start of quench.
  - 50º phase shift in 50 µs (magenta) before cavity voltage significantly drops (cyan)
  - Beam finally dumped approx. 400 µs after quench detected (green)
- The important factor for KEKB CCs is that the RF is switched off **BEFORE** the beam is dumped
  - Protects RF system and klystron but at the cost of beam stability…



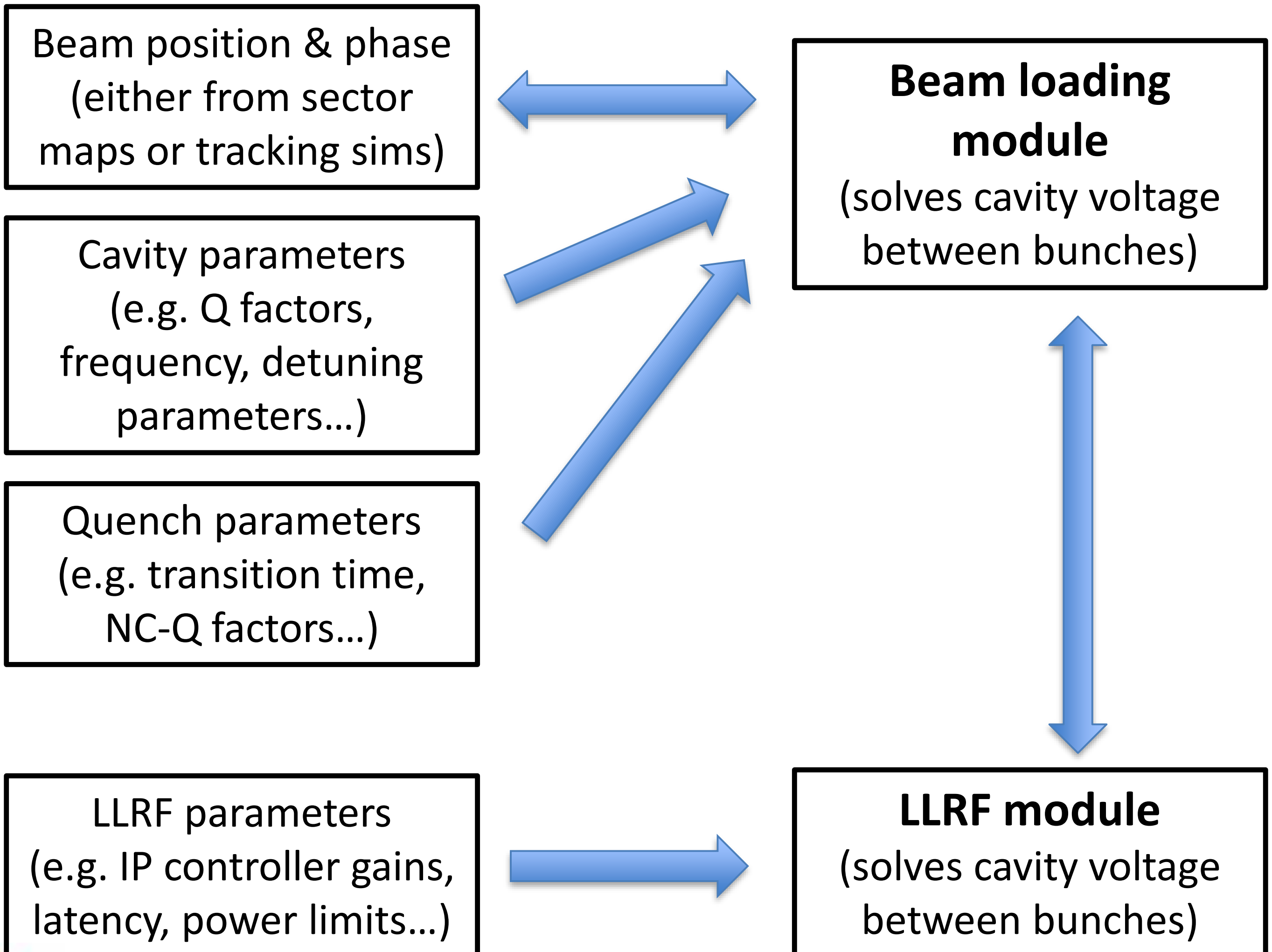
KEKB and HL-LHC parameters

	KEKB	HL-LHC
Transverse Voltage [MV]	1	3
R/Q [Ω]	50	400
External Q	1×10^5	5×10^5
Q_0	1×10^9	
Proportional coefficient	6.06	30.3
Integral coefficient	6.94×10^{-7}	3.47×10^{-6}
Beam energy [GeV]	8	7000

Simulation code

- Simulate interplay between beam and cavities
  - Beam jitter leads to beam loading in cavity
    - Changes cavity phase and amplitude
    - Simulated LLRF system reacts to changes in cavity
  - Cavity fluctuations give jitter to beam
    - Track macro-particles round the ring
      - 1st & 2nd order sector maps currently used
      - Tracking with SixTrack

Schematic of beam loading/LLRF code



Cavity detuning mechanisms

- Resistive detuning: $\delta f = f_0\left(\sqrt{1-\frac{1}{4Q_L^2}}-1\right)$
  - ~1 μHz when SC
  - ~100 Hz during quench
- Lorentz detuning: $\delta f = -K_L(|V_{actual}|^2 - |V_{nominal}|^2)$
  - $K_L \approx 10^2 - 10^3$ Hz MV^{-2}
- Pressure detuning
  - Modelled as a discrete step in frequency shortly after the start of the quench
  - ~100 Hz if T(LHe) < 2.17°K (superfluid)
  - 1-5 kHz if T(LHe) > 2.17°K (non-superfluid)

Simulation results

- KEKB simulation under normal operating procedure (RF off before beam dump)
- HL-LHC under same conditions
- Comparison of KEKB and HL-LHC results with and without RF and beam loading considered

NB: All these simulations use 1^{st} & 2^{nd} order sector maps to track the particles, integration between Matlab and SixTrack is nearly complete and we are also looking to integration with SAMM for benchmarking.

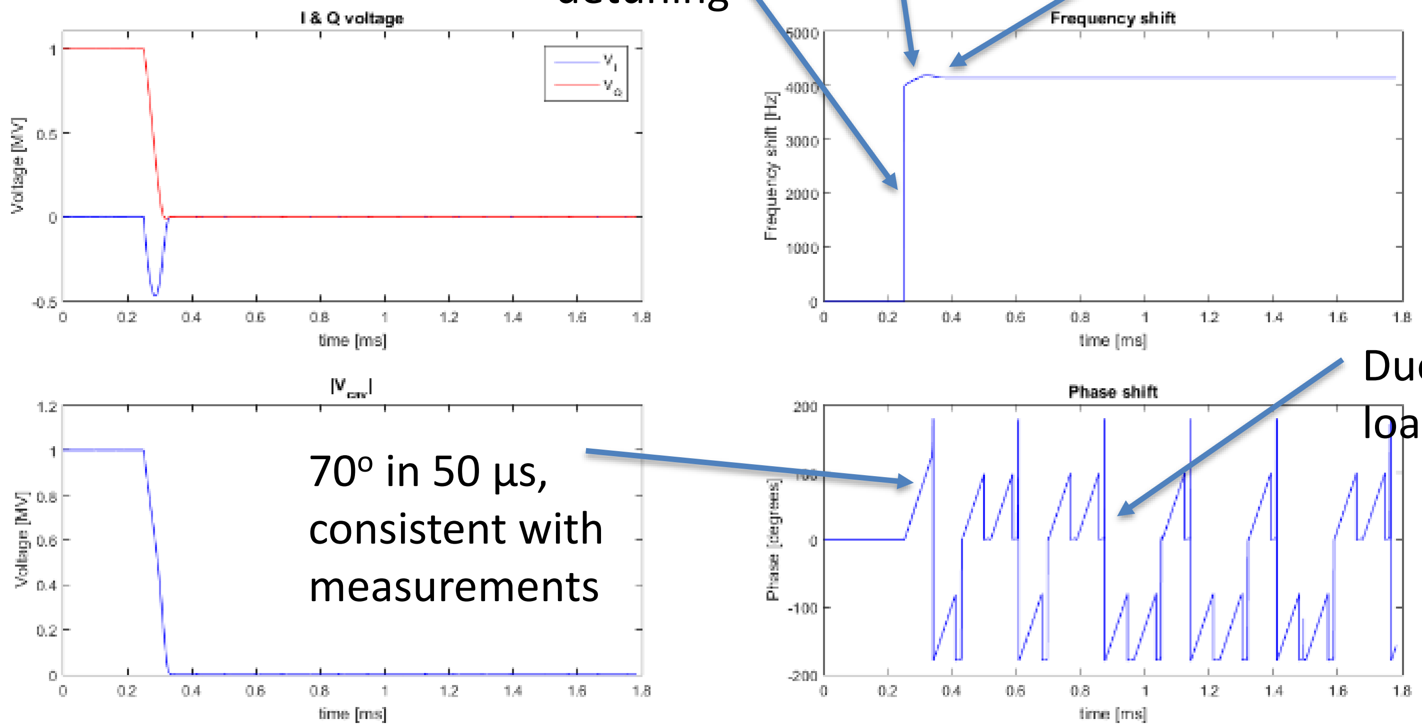
KEKB results under nominal conditions

RF off just after quench "detected", LHe @ 4^{o}K

Pressure detuning

Lorentz detuning

Resistive detuning

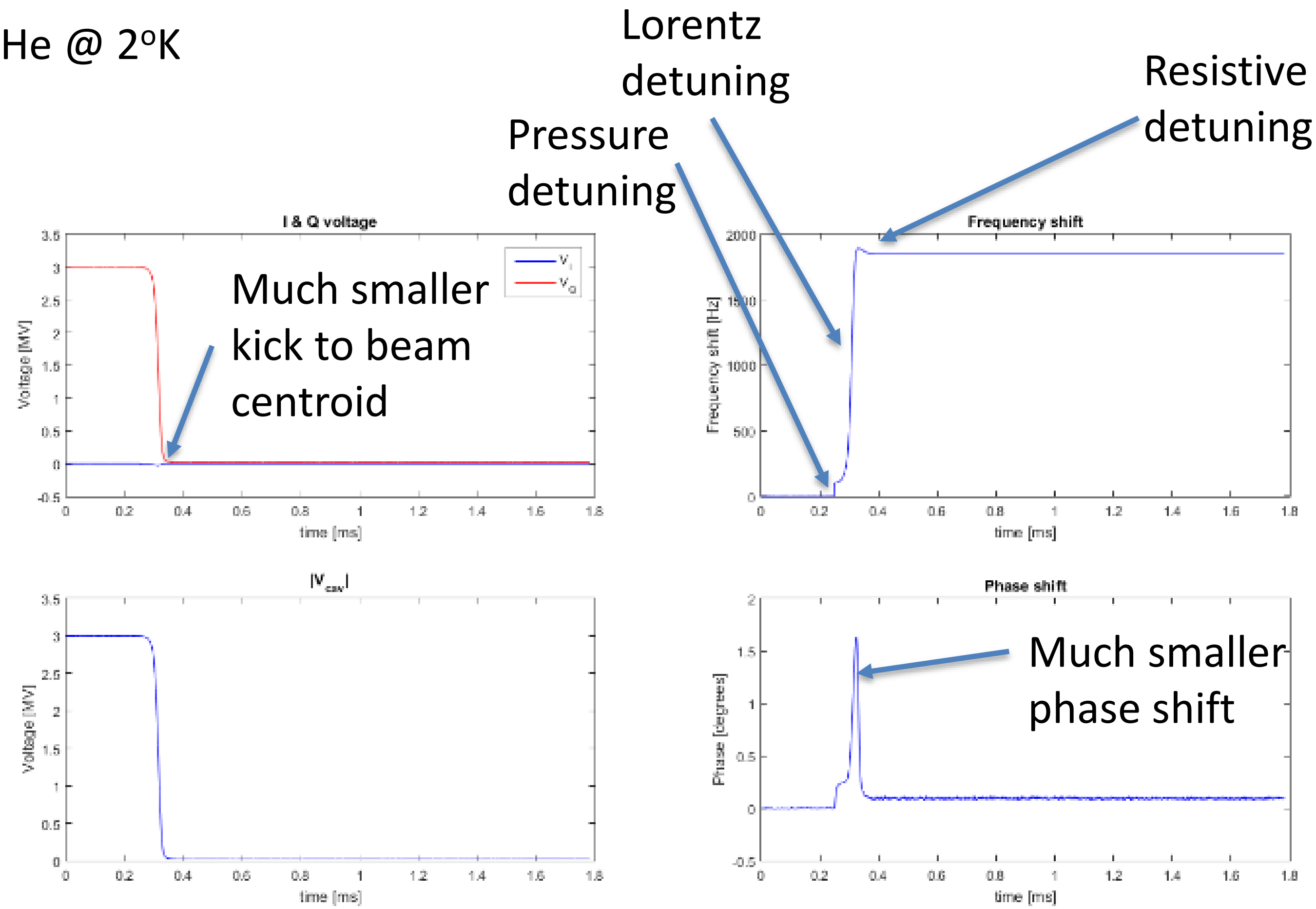


Due to beam loading

70^{o} in 50 μs, consistent with measurements

HL-LHC results under HL-LHC conditions

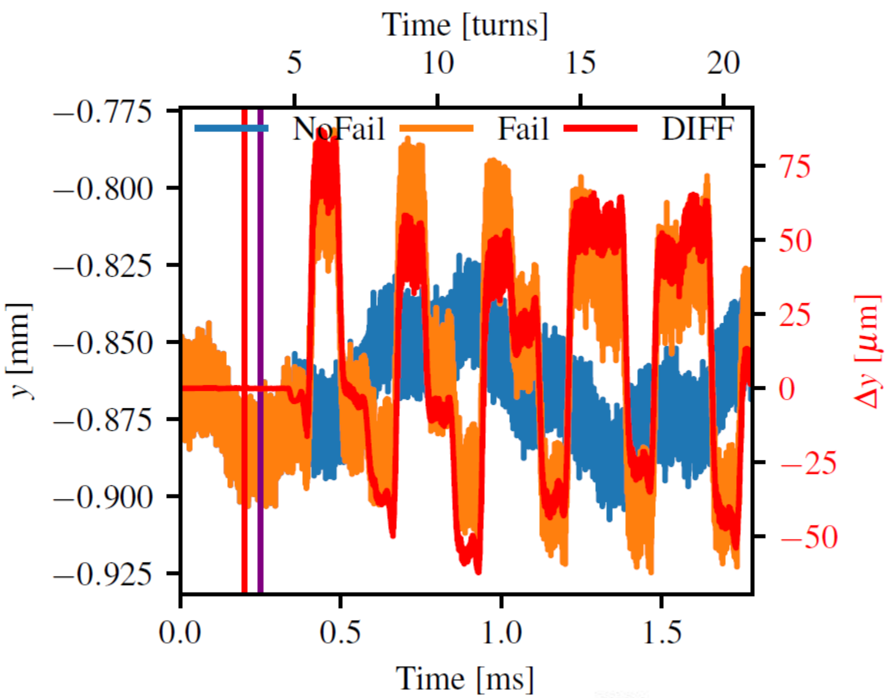
RF kept on, LHe @ 2°K

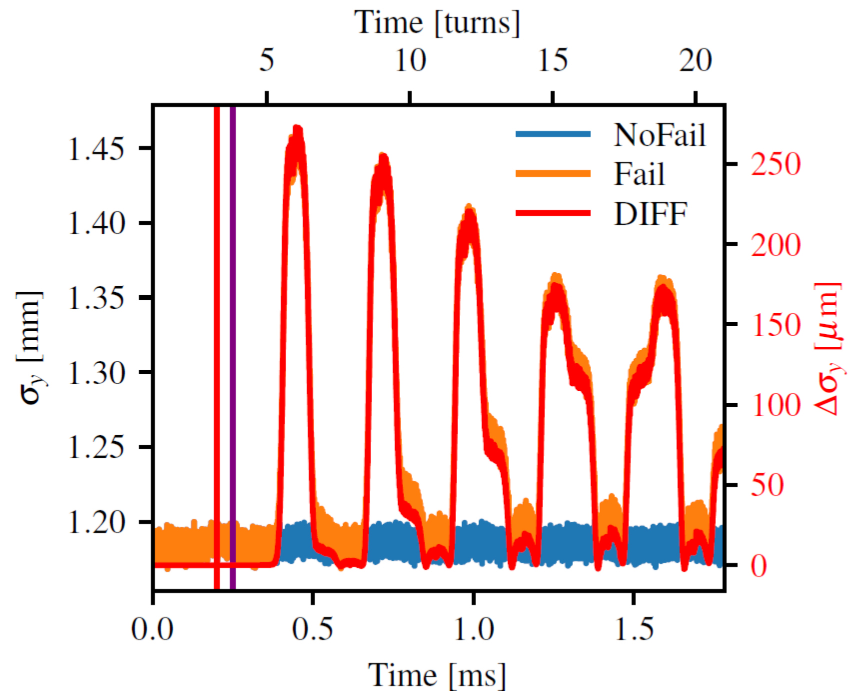


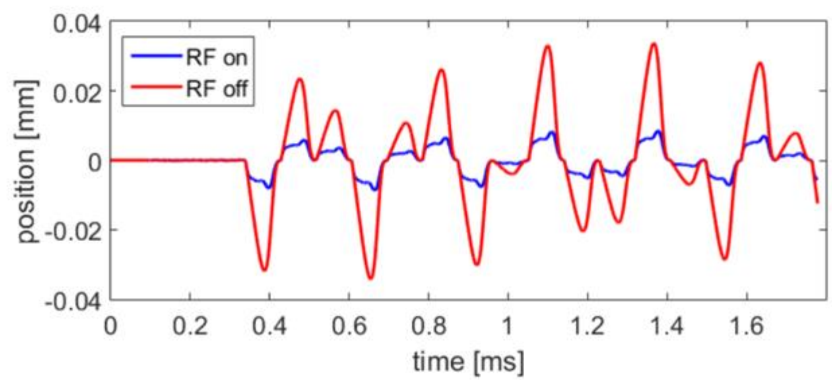
Which parameters affect stability?

- From previous simulation studies:
  - Temperature
    - Below 2.17^{o}K, LHe is superfluid → pressure detuning significantly reduced
  - RF on/off during the quench
    - For HL-LHC keeping RF on during the quench improves stability
    - For KEKB it doesn't matter as the beam is lost too quickly

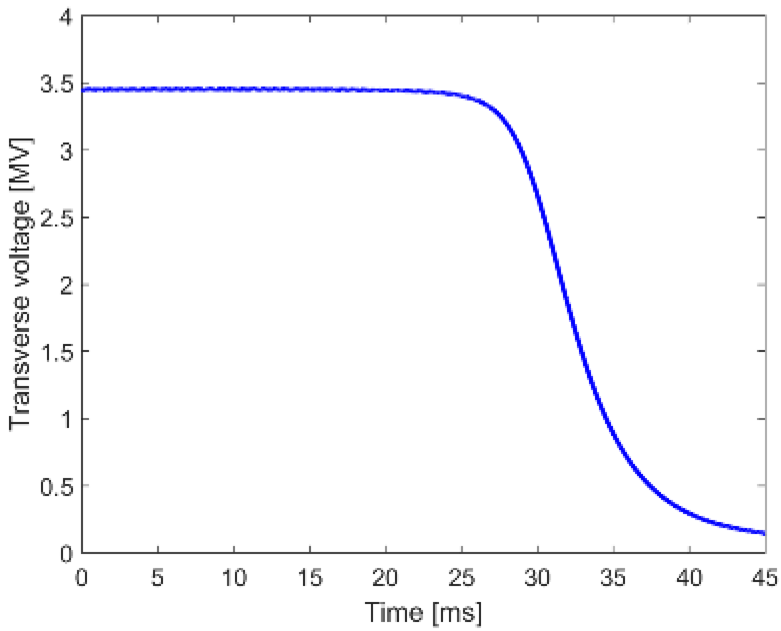
SixTrack vs transfer map studies

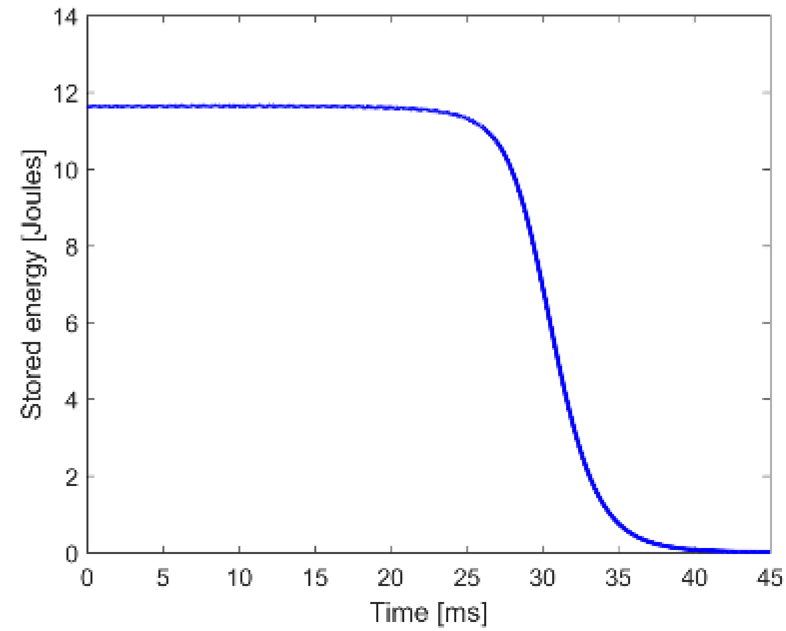




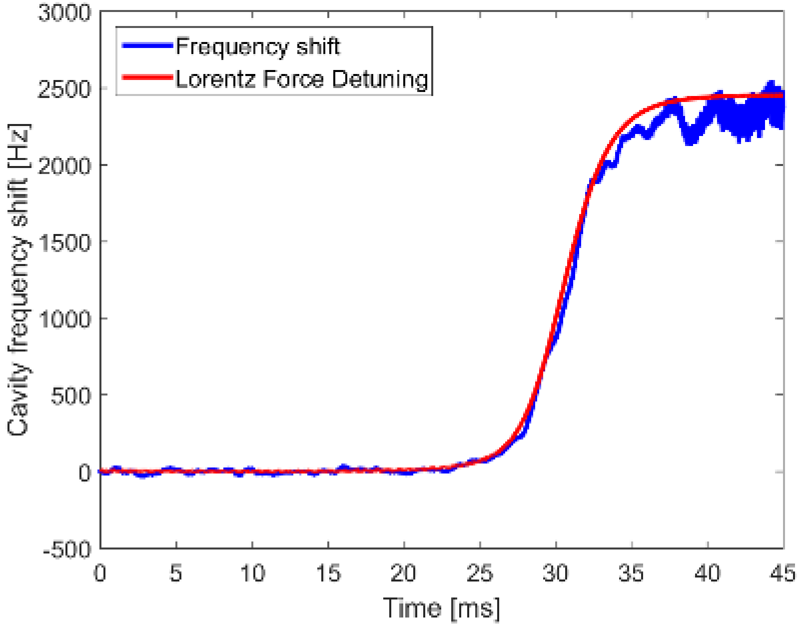


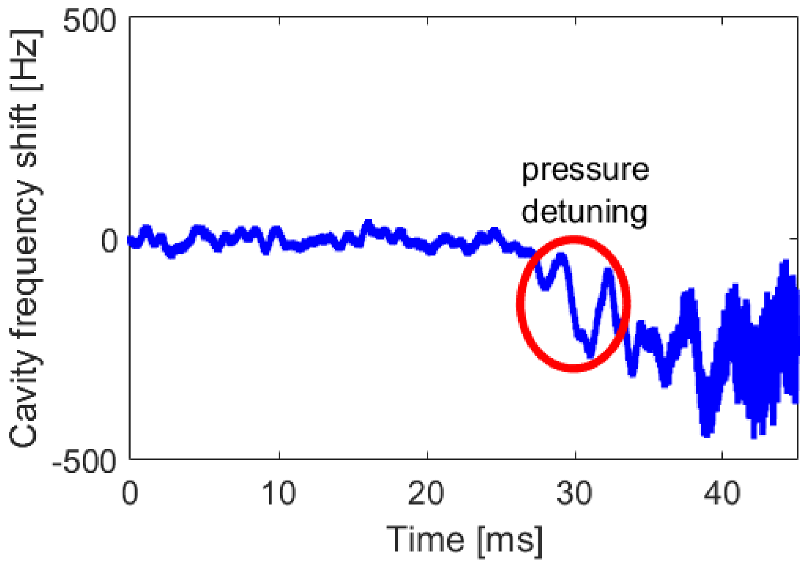
Quench dynamics measurements [1]



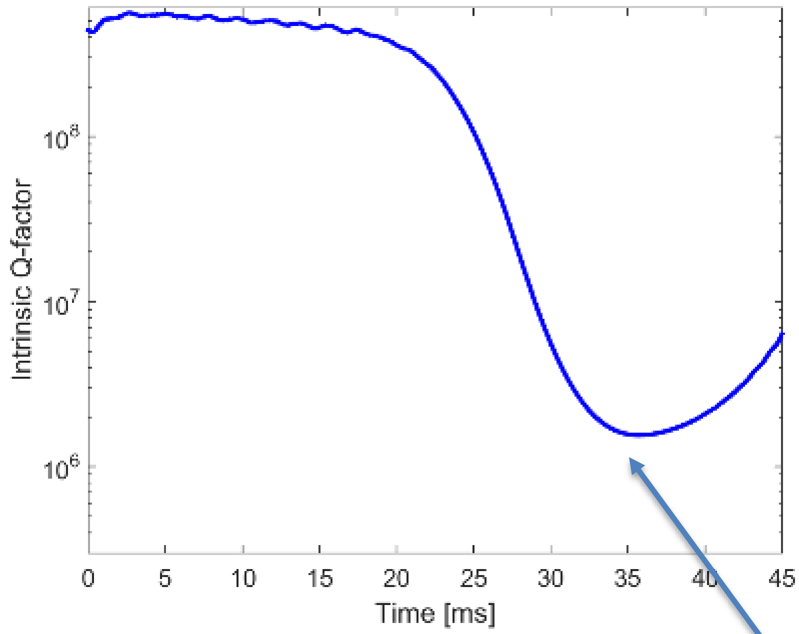


Quench dynamics measurements [2]





Quench dynamics measurements [3]



Quench recovers before becoming fully normal-conducting

Conclusions

- Simulations qualitatively agree with KEKB results
  - Suggests that HL-LHC will have much less impact
    - Due to HL-LHC operation: T(LHe) = 2^{o}K, RF on during quench
  - Measurements in good agreement with simulations of quench dynamics
    - Frequency shift, Lorentz and pressure detuning
    - Aiming to submit paper to PRAB in next few weeks

High
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