Preliminary outline for BAW presentation: “Experience from FLASH experiments” “Discussion on overheads”

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Outline...

- Experience at FLASH
  - **FLASH machine layouts 2009 and 2010**
  - **Max operating gradients, comparison with ILC**
  - **Observed quench events**
  - **Gradient tilts under beam loading**
  - **Piezo compensation of LFD**

…Outline

- Discussion on gradient overhead
  - **Factors determining max usable gradient**
    - Practical/technical issues
    - Fundamental issues
  - **Impact of gradient spread on operating margins**
  - **Cavity sorting**
  - **Measurement uncertainties**
  - **RF/LLRF Control**
    - DRFS
    - Propagation delays in KCS
    - RDR ‘prime’ (one-tunnel RDR solution)

Experience from FLASH

Specific objectives for the 9mA study

- Long bunch-train high beam loading (9mA) demonstration
  - 800μs pulse with 2400 bunches at 3MHz, 3nC per bunch
  - Vector Sum control of up to 24 cavities
  - +/- 0.1% energy stability
  - Cavity gradients approaching quench limits
  - Beam energy 700-1000MeV

Demonstrate ILC-like beams

- Characterize operational limits
  - Energy stability limitations and trade-offs
  - Cavity gradient overhead needed for LLRF control
  - Klystron power overhead needed for LLRF control
  - HOM absorber studies (cryo-load)

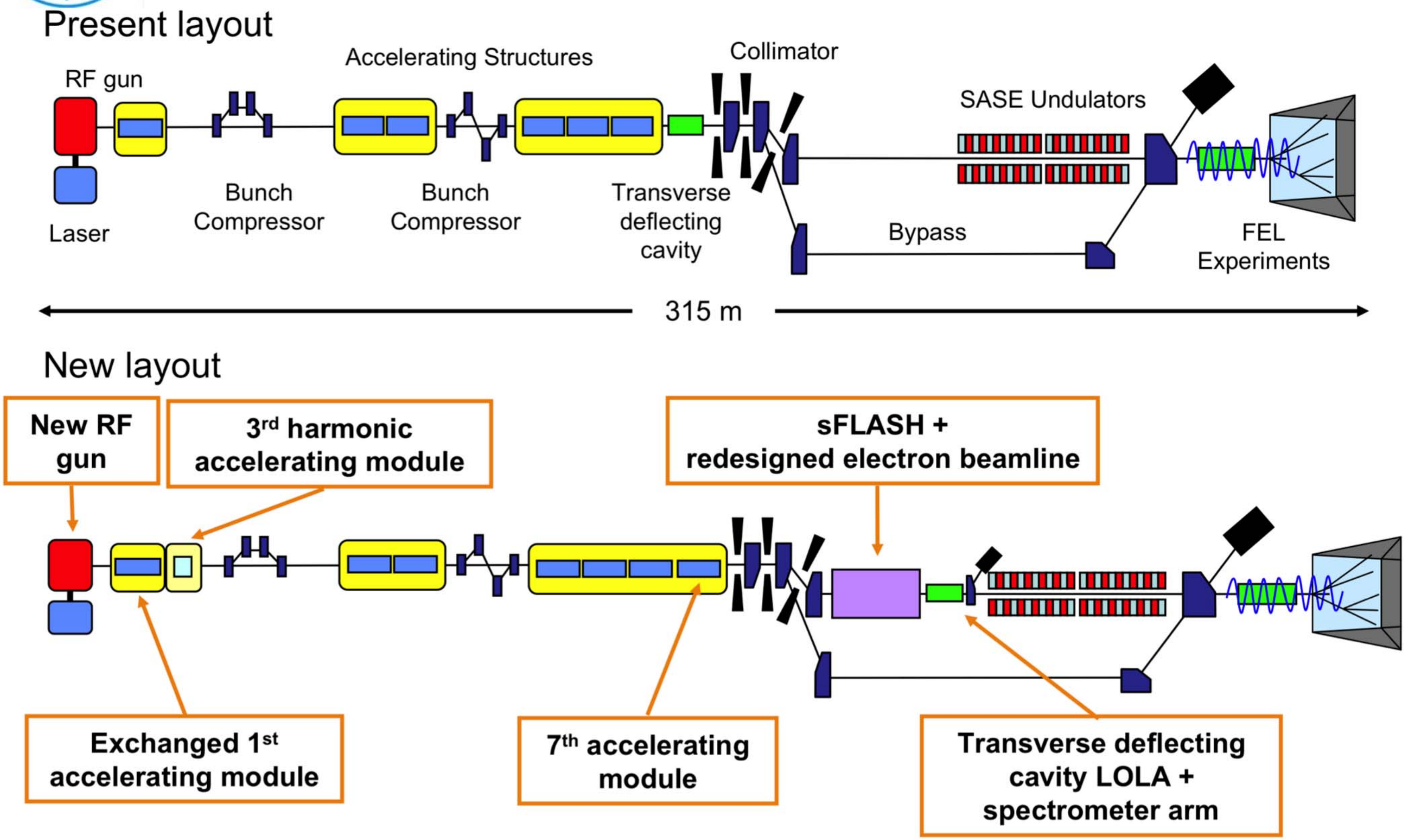
Studies requiring ILC-like beams

- Operation close to limits, eg
  - Robust automation of tuning, etc
  - Quench detection/recovery, exception handling
  - Beam-based adjustments/optimization

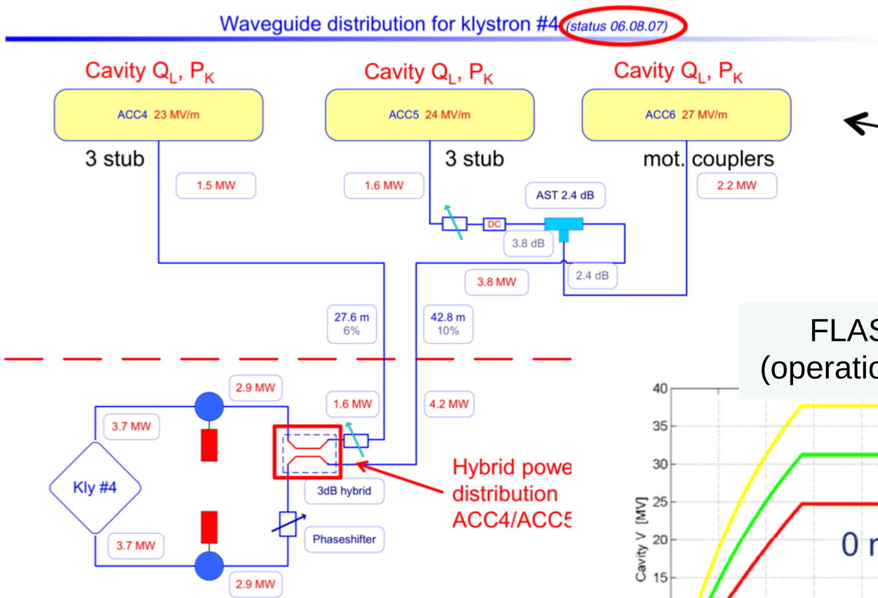
Operational challenge for FLASH

(well beyond typical beam parameters for photon users)

FLASH Upgrade 2009/10



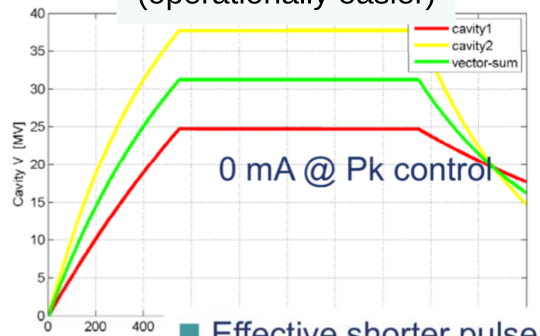
Cavity gradient tilts: RF distribution setups

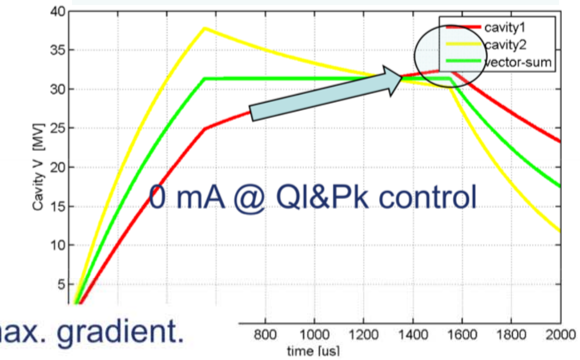


Cavity Q_L & P_K are set up for flat gradients at a particular beam current

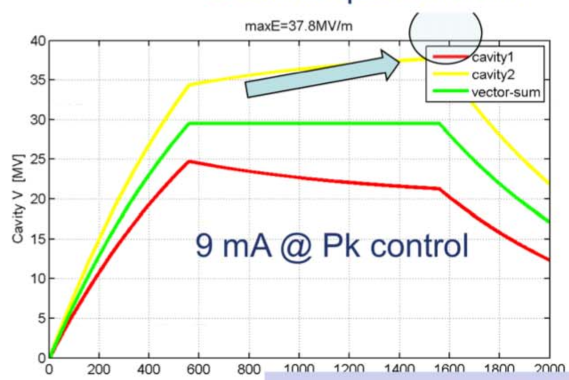
FLASH setup (operationally easier)

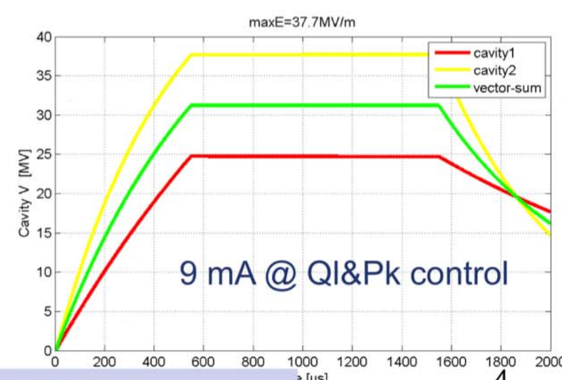
ILC Reference Design (higher average gradient)





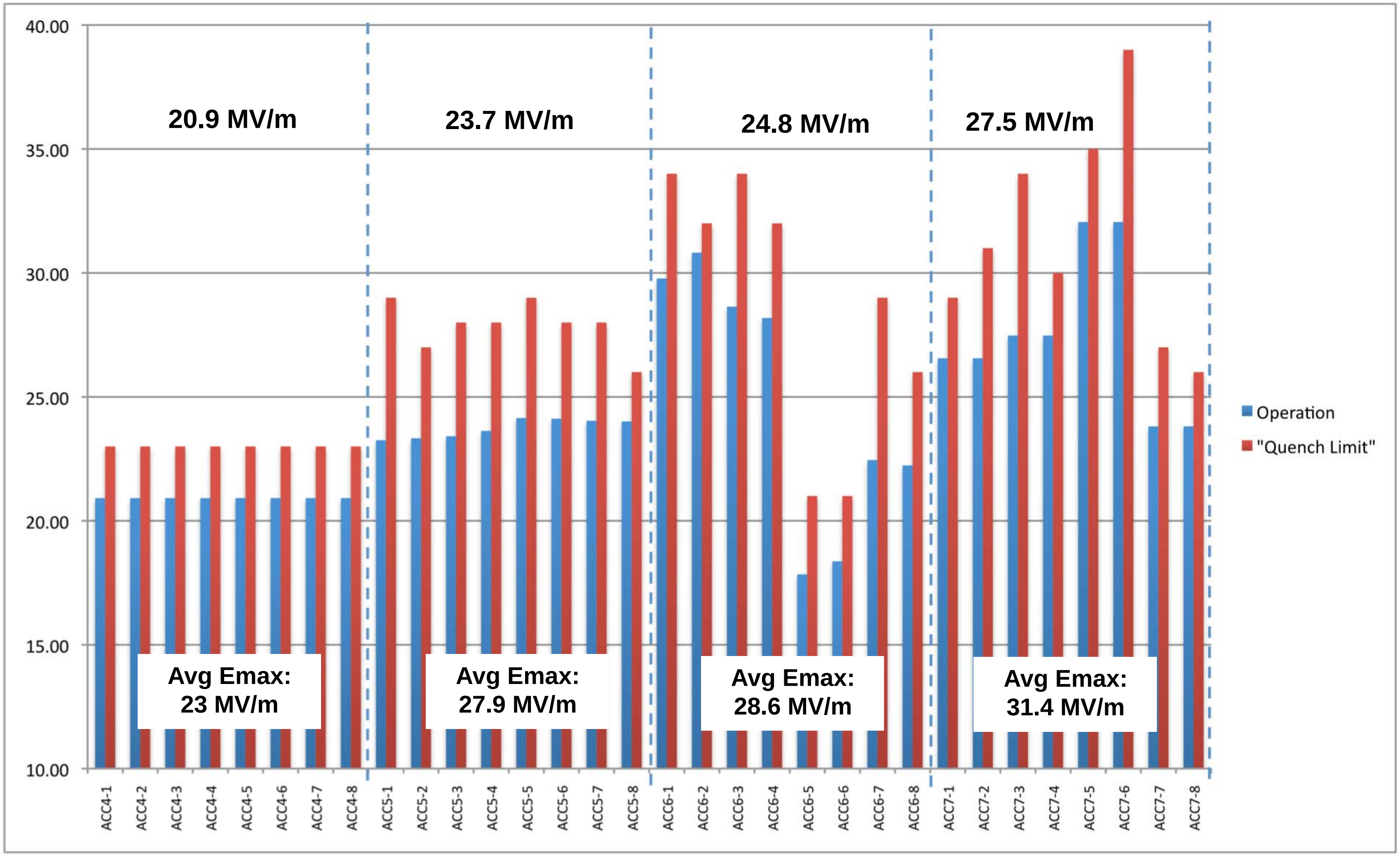
- Effective shorter pulse at max. gradient.
- Same quench limit?





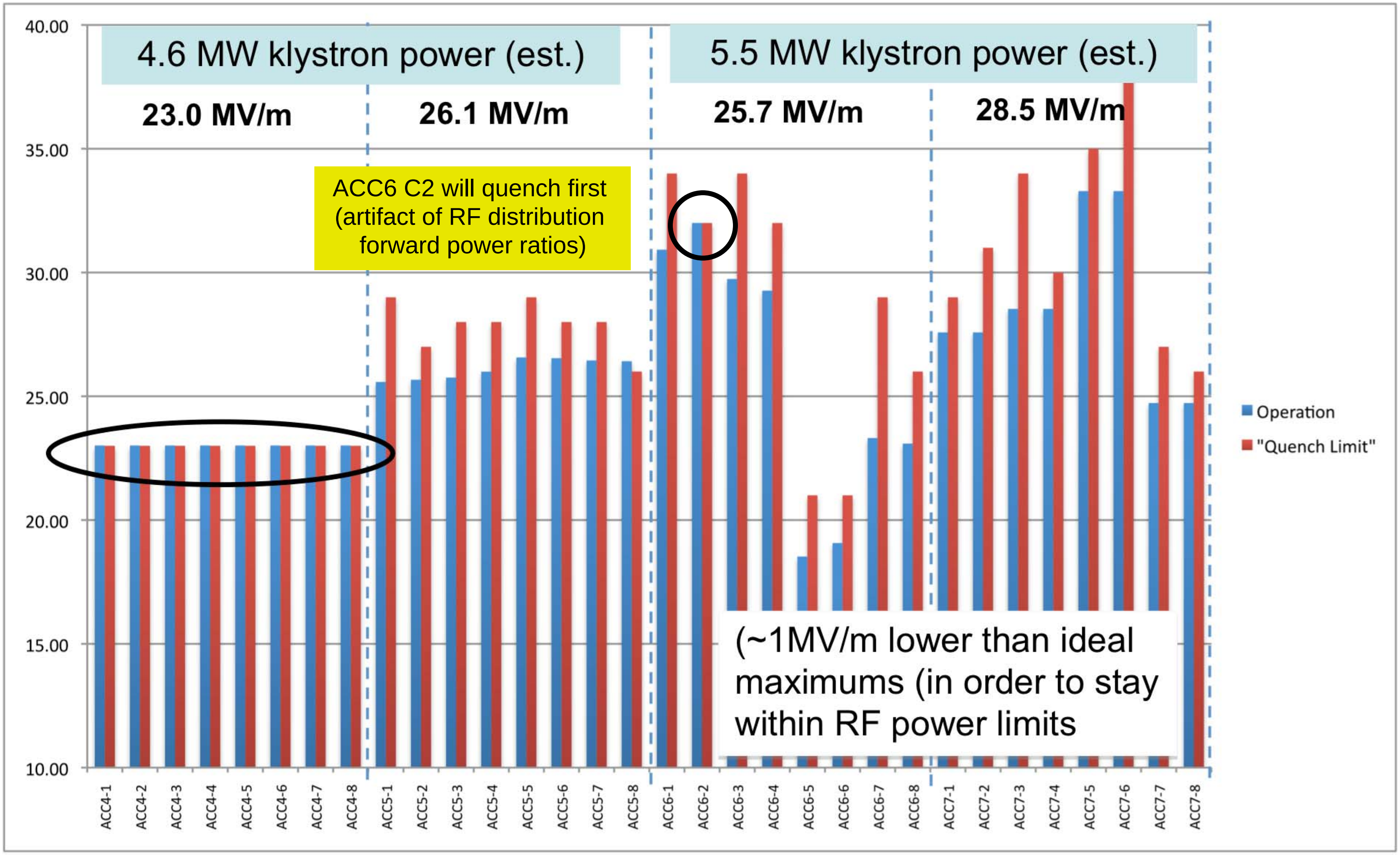
Simulation for 38 MV/m & 25 MV/m cavities

ACC4-6 average operating gradients for a final linac energy of 1.3GeV



There are other factors in addition to quench limits, eg RF power limits on waveguides and cavity circulators

The maximum possible gradient on ACC67 is limited by ACC6 cavity 2…



RF distribution configuration for flat gradients without beam

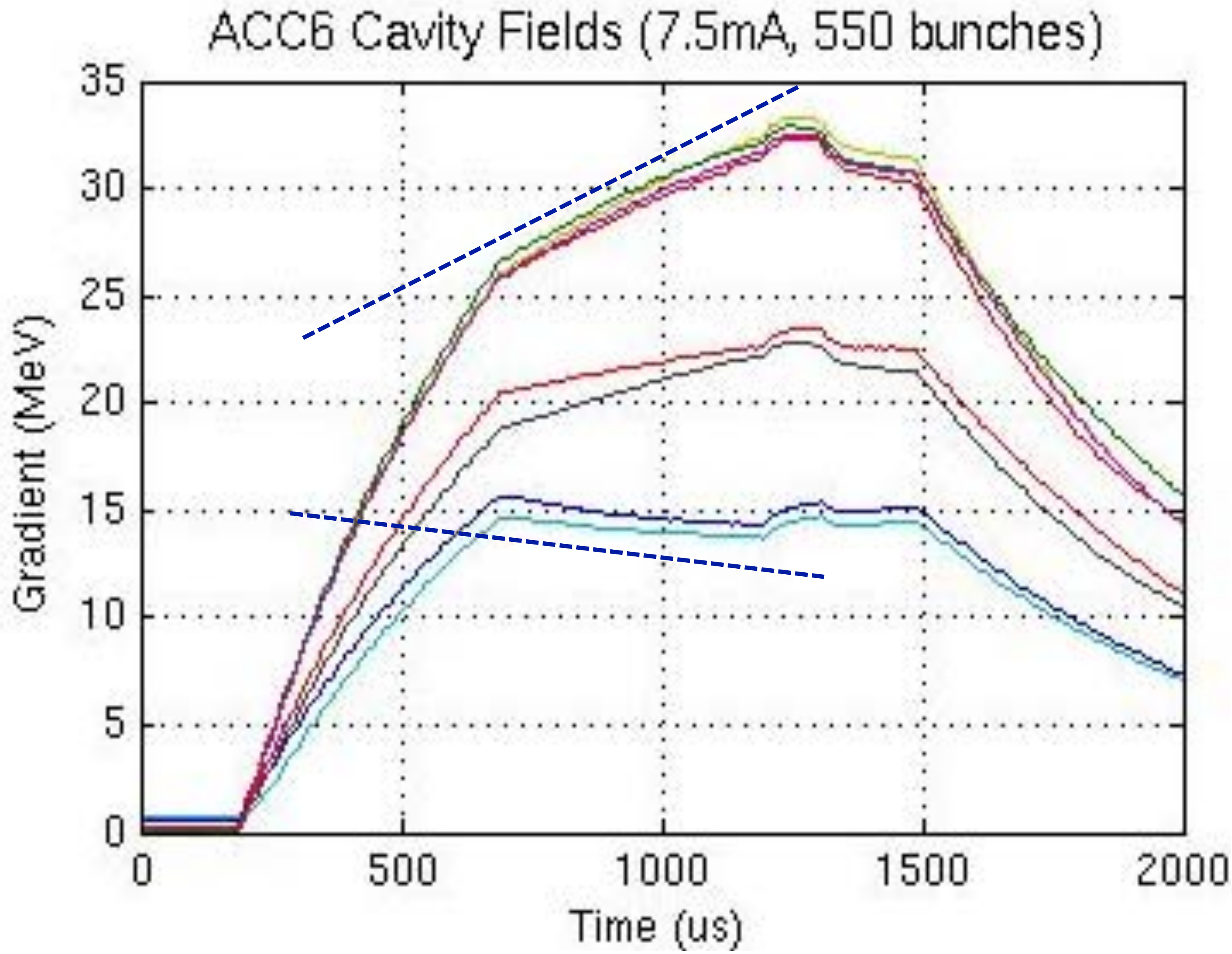
Characterize operating gradient margins

- **Demonstrate operation with gradient tilts of better than ~% on all cavities over 800us pulse with spread of gradients and 9mA beam**

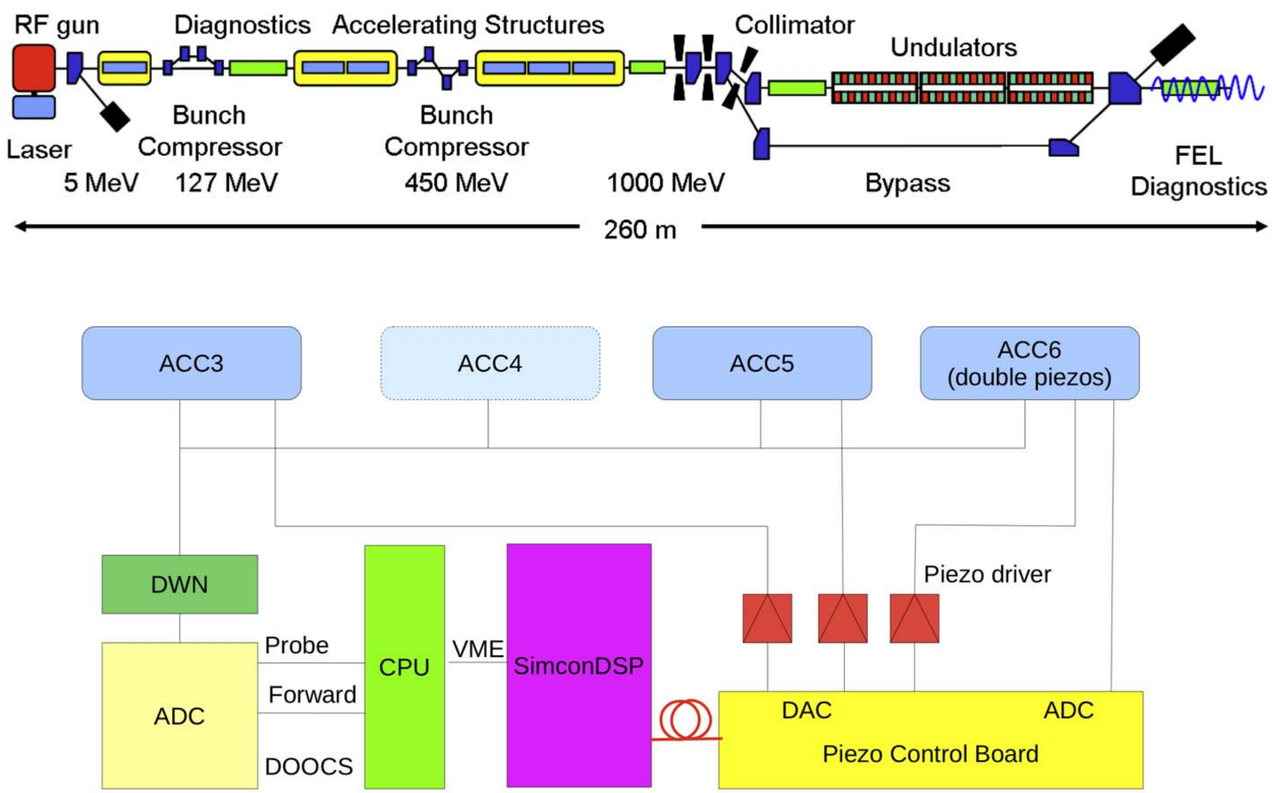
- Pk/Qext studies to minimize gradient tilts at nominal gradient & current
- Piezo LFD compensation optimization studies
- Procedure for ramping to full current, pulse length, maximum gradients
- Characterize and understand operating margins needed, eg…
  - **Random pulse to pulse fluctuations, eg microphonics**
  - **Residual uncorrected LFD**
  - **LLRF tuning – initial turn-on transients,…**
  - **Calibration errors/uncertainties: cavity to cavity; absolute**
- Other factors
  - **RF power limits, eg max power on cavity circulators**
  - **Measurement uncertainties in quench limits**

- Behavior of cavities operating close to quench for long period… eg
  - **Stability, shapness of the quench 'knee'**
  - **Do all cavities behave the same?**
  - **How does beam loading change things?**

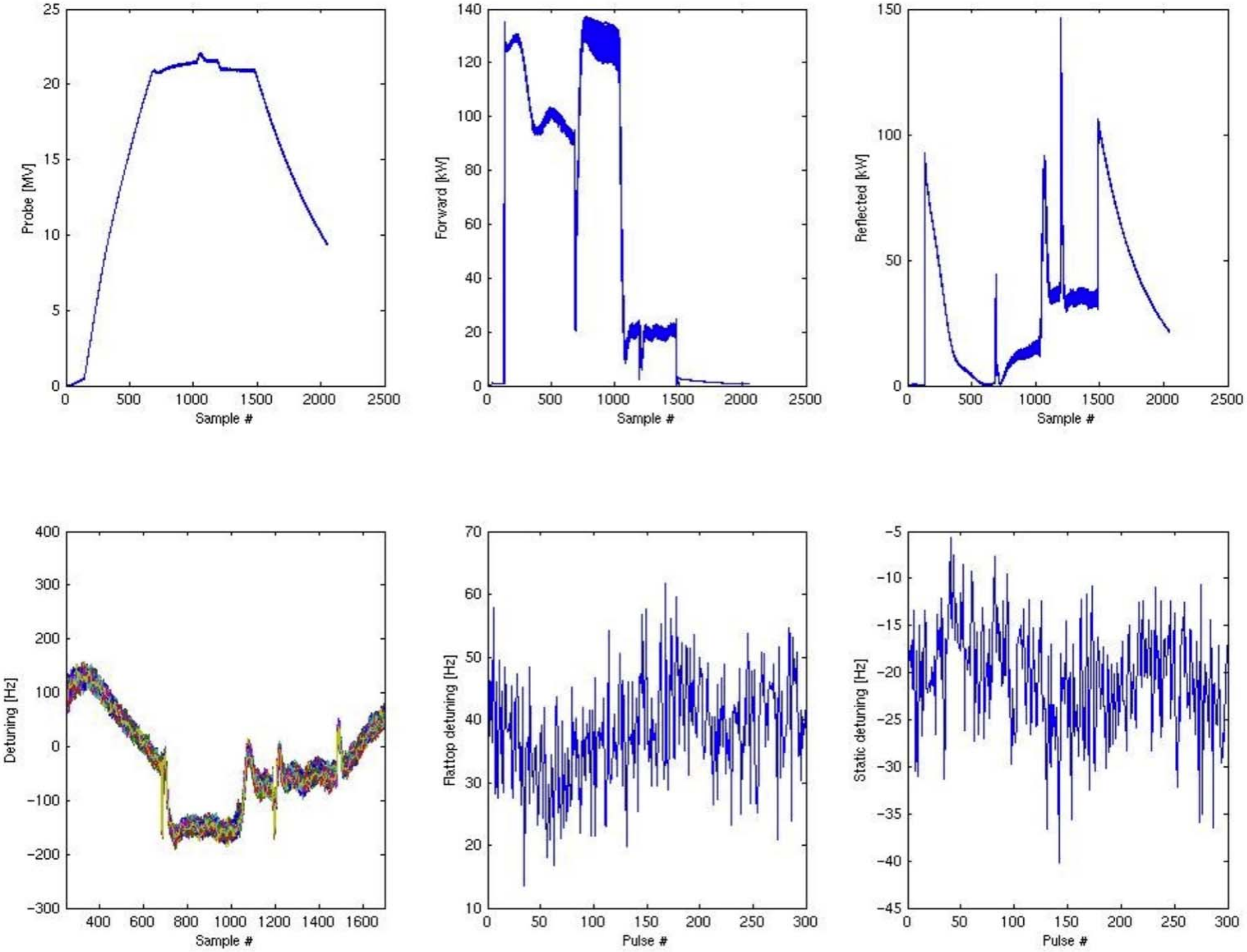
Example of gradient tilts and different LFD features



Piezo tuners at FLASH

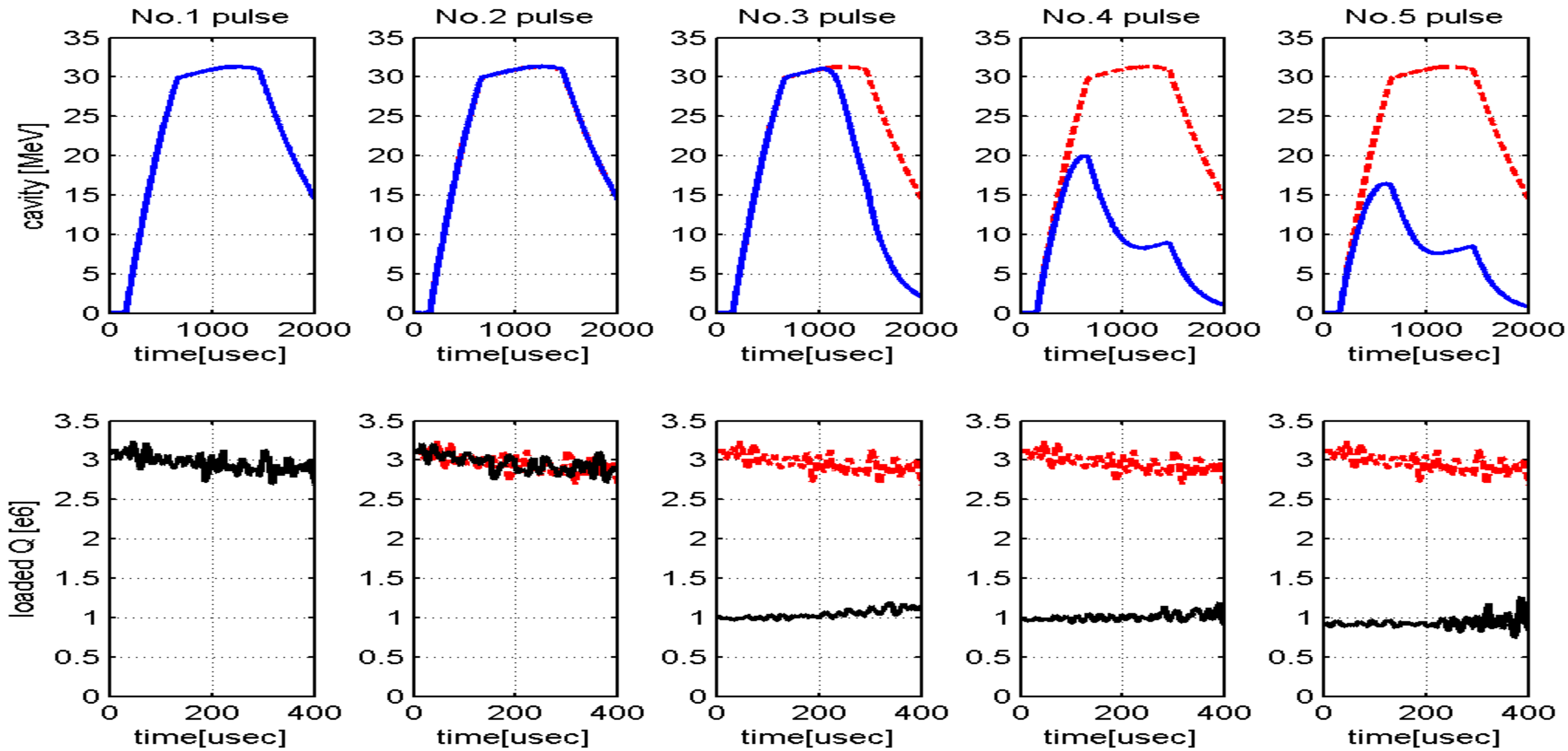


ACC3 cav 1 with piezos (with beam)



Quenches during 800us RF pulses, no beam

I will also show examples from other operating conditions



- At longer pulse (~800 us flattop), "quasi-quenches" were not observed.
- Once a quench took place, there was not a quick recovery, probably due to the larger energy deposited in the quenched area.

Future R&D studies at FLASH…

- Still a long list to be done from the original topic list
- New items… eg simulation of LLRF control for KCS

Discussion on overheads

Outline

- Discussion on gradient overhead
  - **Factors determining max usable gradient**
    - Practical/technical issues
    - Fundamental issues
  - **RF/LLRF Control**
    - DRFS
    - Propagation delays in KCS
    - RDR ‘prime’ (one-tunnel RDR solution)
  - **Measurement uncertainties in gradient limits**
  - **Cost/performance trade-offs**
  - **Cavity sorting**

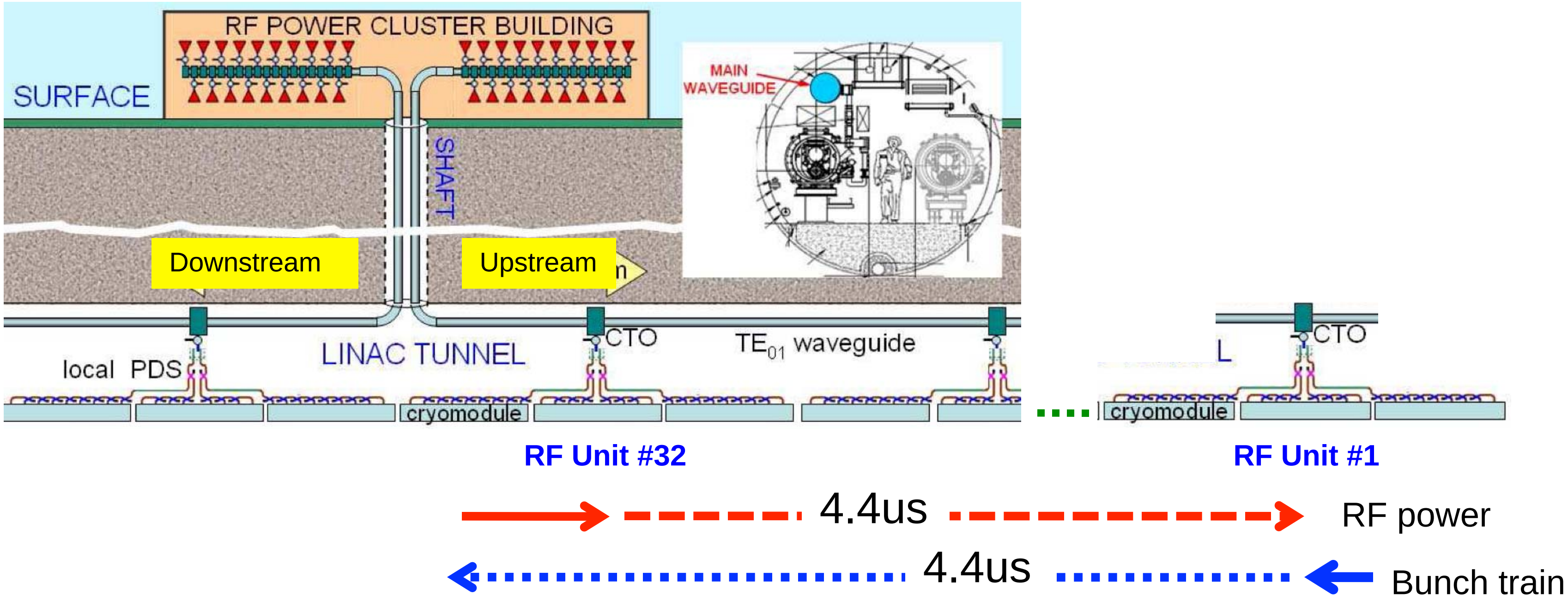
Operating gradient margins

- Operating margins needed for various effects, eg…
  - **Random pulse to pulse fluctuations, eg microphonics**
  - **Residual uncorrected LFD**
  - **LLRF tuning – initial turn-on transients,…**
  - **Calibration errors/uncertainties: cavity to cavity; absolute**
- Other factors
  - **Measurement uncertainties in quench limits**

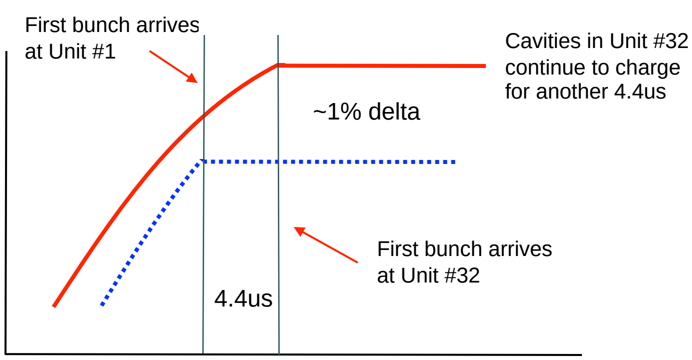
- Behavior of cavities operating close to quench for long period… eg
  - **Stability, shapness of the quench 'knee'**
  - **Do all cavities behave the same?**
  - **How does beam loading change things?**

Fundamental vs practical issues wrt TDP proposal…
Practical issues limit what we could demonstrate today

KCS propogation delays



Cavity field amplitude during fill (upstream side)



Transit delays also apply to vector sum readbacks and therefore impact LLRF feedback performance

- If LLRF regulated using only RF Unit #1 vector sum, the 4.4us delay would limit bandwidth to a couple of kHz
- Conversely, regulating using only RF Unit #32 vector sum would give a much wider closed loop bandwidth
- (Should explore a MIMO-optimizing feedback design)

Trade-offs

- RF power overhead vs gradient overhead
- Cavity sorting vs spread in operating gradients
  …in each hybrid cavity pair, across entire RF unit
  - **(hybrids vs circulators?)**
  - **(range of adjustment of Pk and Qext?)**
- Environmental (vibration => microphonics)
  - **Influences LLRF regulation requirements**
  - **We should use consistent assumptions for the three RF schemes**
- The three HLRF alternatives have different optimizations: RDR-prime, KCS, DRFS
- [Try to give numbers rather than qualitiative statements]

Cavity sorting by quench limits

- Present model assumes random distribution of cavity gradient limits with +/-20% spread (26MV/m to 38MV/m)

- Cost penality of using a wide spread of operating gradients?

- Two contexts for sorting:
  - **Minimize the difference in gradient limits for the two cavities in each hybrid pair. Ideally, we operate both cavities at the same gradient**
  - **Minimize the spread of gradient limits in a given rf unit**

- Trade off between the cost of warehousing cavities for sorting vs smaller operating gradient spread across each rf unit

- ‘Trivial’ sorting: Sorting into two groups (<31.5MV/m and >31.5MV/m) would come essentially at no cost in any practical production chain

Gradient sorting makes things easier

- *Matching cavity operating gradients allows operation closer to quench*
  - **Matching operating gradients in each cavity hybrid pair**
  - **Matching operating gradients of all cavities in an RF unit**

- Same operating gradients in hybrid pair = same forward power
  - **No rf power overhead penalty**
  - **Gradient penalty from difference in quench limits**

- Same operating gradients in an RF unit => similar lorentz-force detuning => all cavities behave in similar manner
  - **Common-mode components appear on the vector sum and can be removed using RF feed-forward**

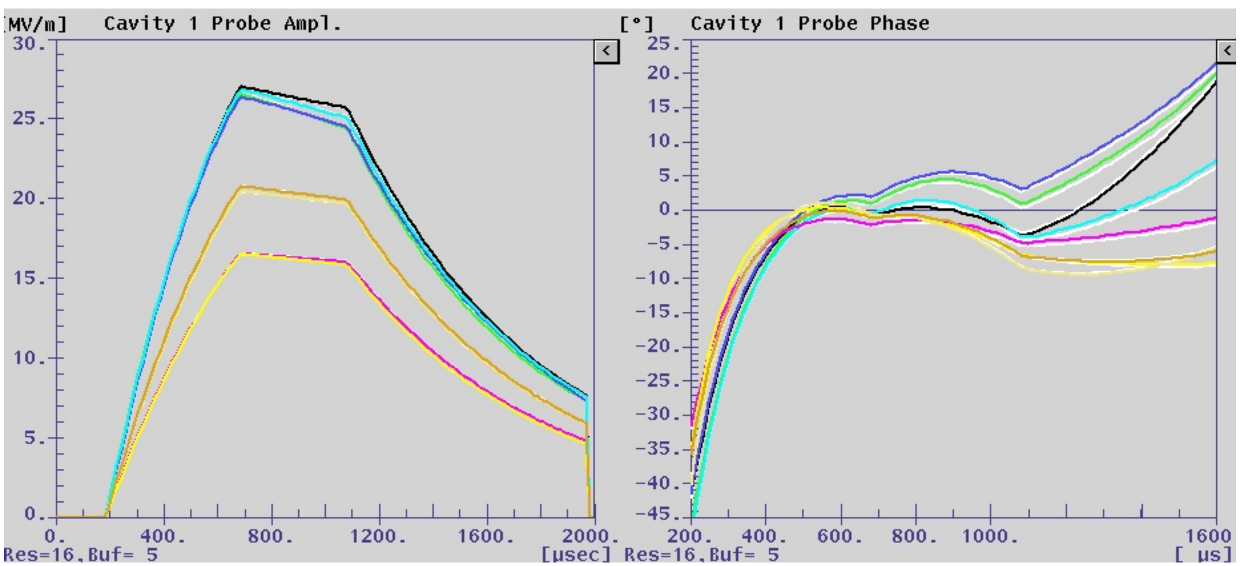
“Conclusions”

- The cost of the ILC would be cut by 7% (460M) if we increased the operating gradient to 35MV/m end

Cavity gradient tilt studies

- Flattening cavity field amplitudes and phases without beam is not trivial
  - **Optimization of mechanical tuners, Qext, piezo feedforward,…**
- Even rf-only studies could be used to make meaningful progress towards understanding how to obtain flat gradient tilts

- Random example from the 9mA studies (25 Aug 2009, ACC6 cavities phase & amplitude, no beam)



Vertical tests: uncertainty of quench limits

- Absolute calibration, precision, and repeatability of cavity quench limit measurements
  - **On the same cavity…?**
  - **On different cavities…?**
  - **From test stand to test stand…?**
- How to account for the uncertainty in measurement of quench limits?
- Experience from the tight loop program?