Comments from LLRF

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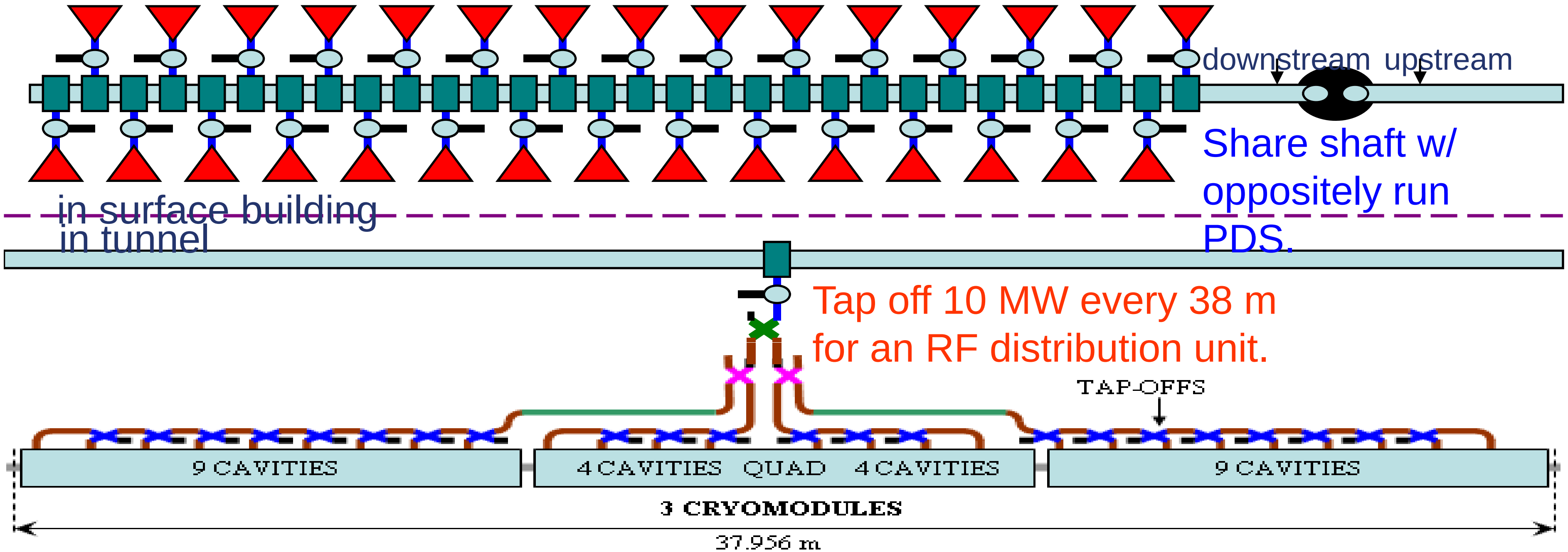
- LLRF performance under large dead time
- Questionnaire

Klystron cluster

- The configuration of klystron cluster introduces total 10~15us latency.
  -> larger latency than our current model (<1us)
  - 3.5us (rf transmission)
  - 1us (ADC detection at each 26 cavities in the tunnel and conversion to optical signal of 26 vector sum)
  - 6us (optical transmission)
  - 1us (conversion and vector sum of 27 units)
  - 1us (DAC outputs to 27units)
- LLRF detectors will be located in the tunnel (and process each 26 cavities).
  -> risks of high availability and maintenability



With extra transmission loss, feeds ~27 RF units = 1.026 km. (shaft serves 2.052 km)

Background (required stability)

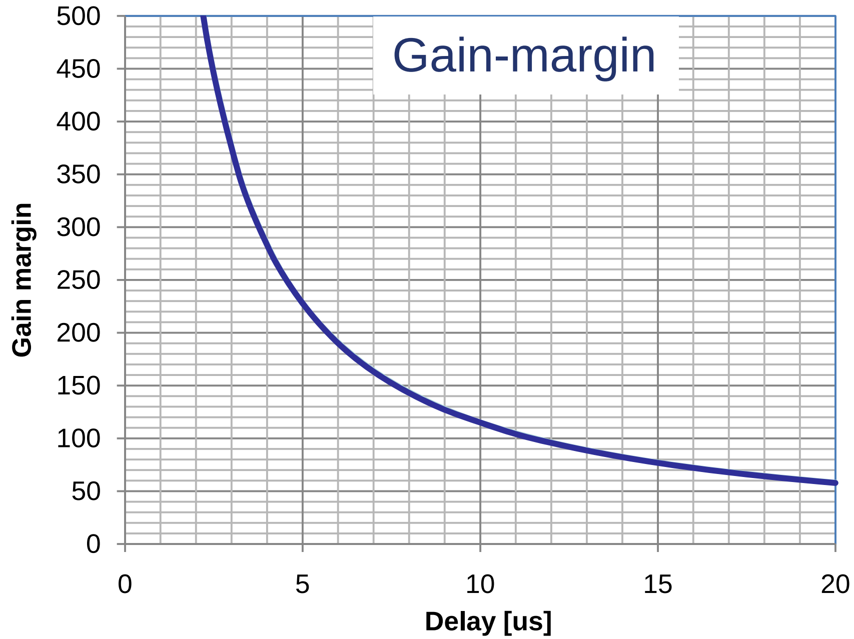
- Llrf stability requirements (@ ML and BC) are < 0.07%, 0.24deg.
- In order to satisfy these requirements, FB with proper FF control will be carried out.
- Each error source should be <1/3 of requirements (<0.02%, 0.08deg.)

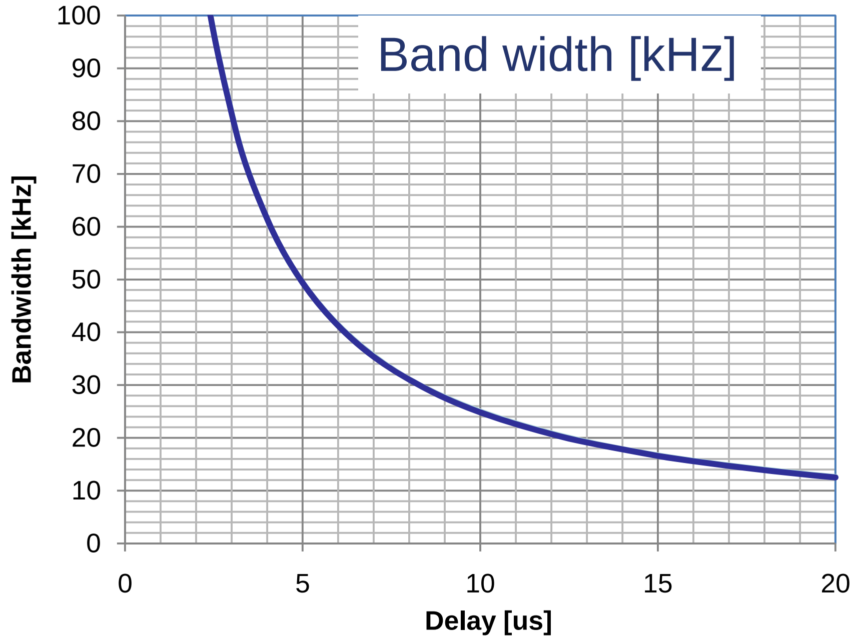
TABLE 3.9-1
Summary of tolerances for phase and amplitude control. These tolerances limit the average luminosity loss to <2% and limit the increase in RMS center-of-mass energy spread to <10% of the nominal energy spread.

Location	Phase (degree)		Amplitude (%)		limitation
	correlated	uncorr.	correlated	uncorr.	
Bunch Compressor	0.24	0.48	0.5	1.6	timing stability at IP (luminosity)
Main Linac	0.35	5.6	0.07	1.05	energy stability $\leq$0.1%

Operational gain and bandwidth

- Error is only compressed by a factor of gain
- Current proportional (P) control + FF is not sufficient due to lower gain
- PI (proportional and integral) control will be necessary
- Gain margin is calculated from Bode-plot.



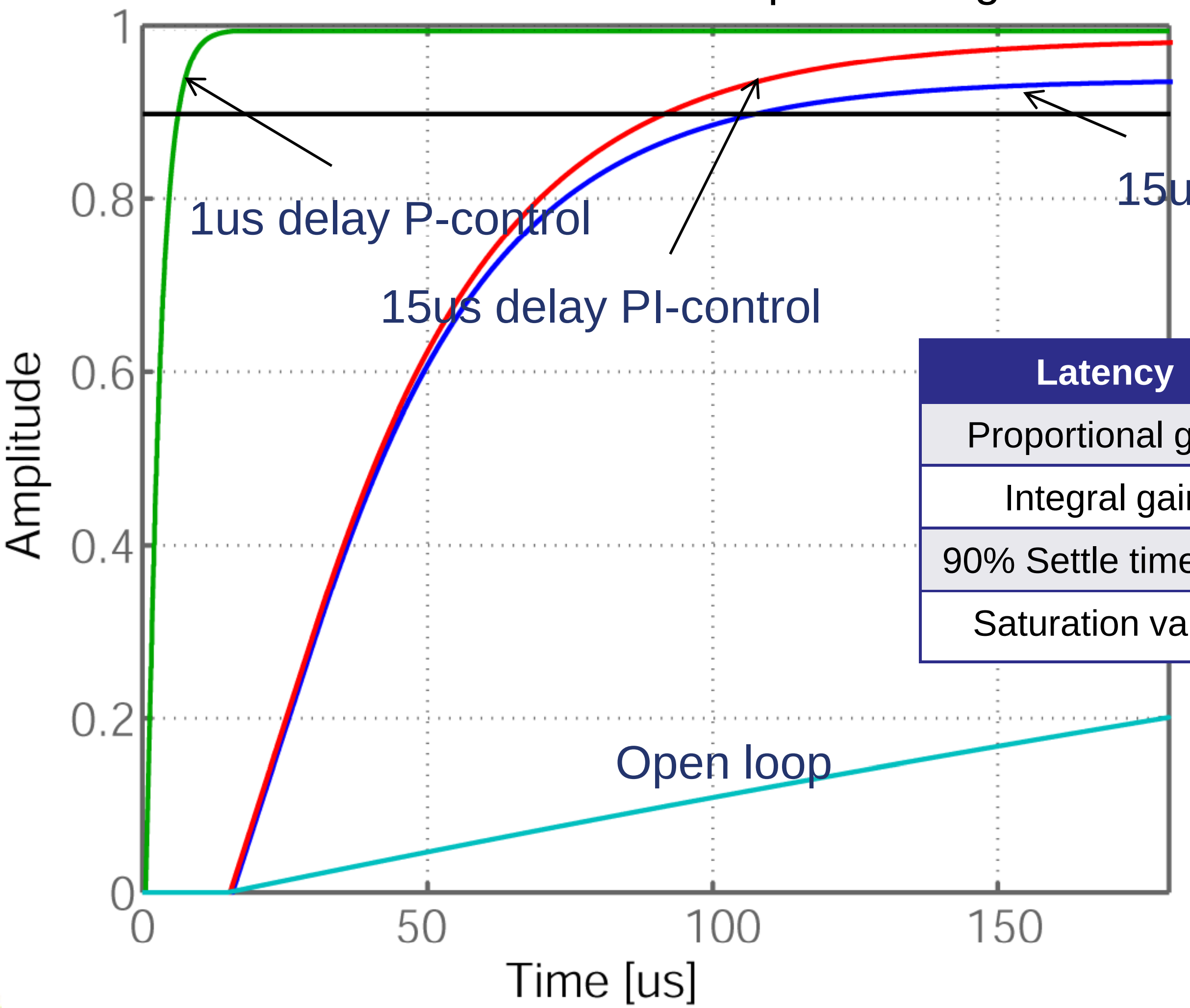


Latency	1us	10us	15us	15us PI
Maximum gain	200	25	15	15
Bandwidth [kHz]	230	25	17	17

Maximum operational gain is defined as 1/5 of gain margin. (taking account of the FLASH's gain margin (200) and operational FB gain (40))

Step response of llrf control

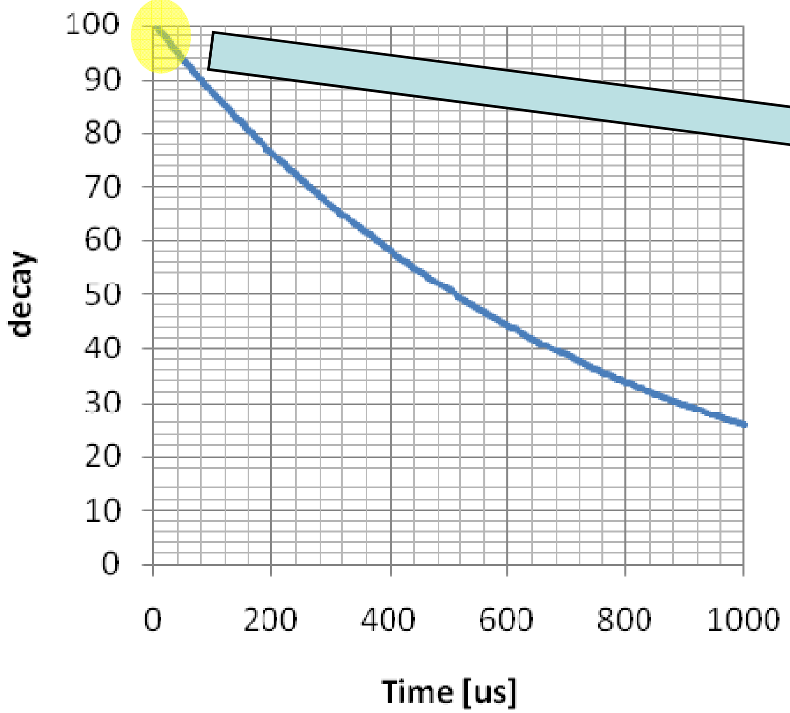
- 15us delayed system has slower response.
- Blind time of 15us and slower response degrades the total FB performance.

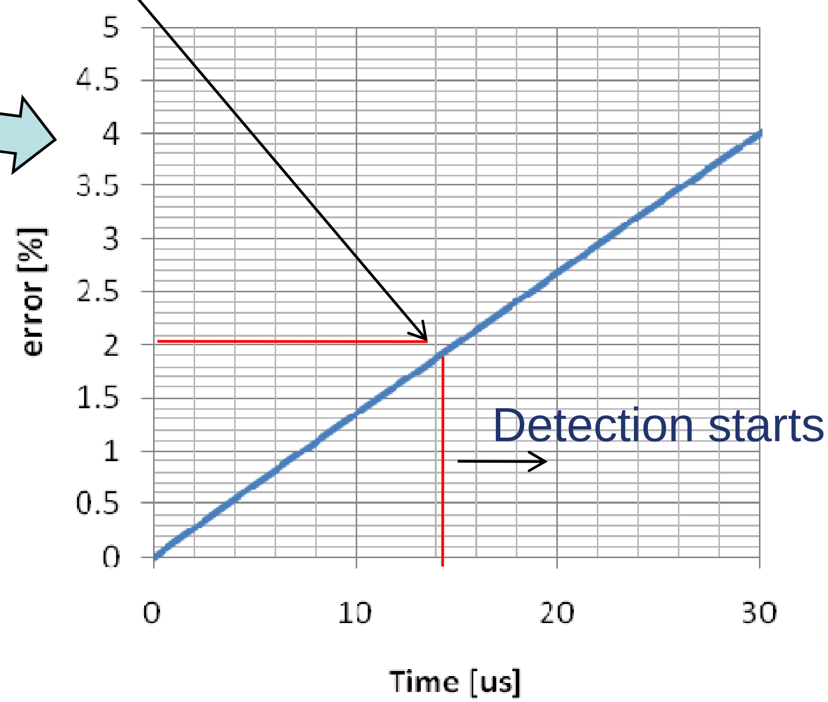


Latency	1us	15us	15us PI
Proportional gain	200	15	15
Integral gain	0	0	15,000
90% Settle time [us]	6	100	80
Saturation value	99.5%	93.3%	100%

External perturbations

- Assumption
  - Cavity Q:3e6 -> decay time constant=462us and f1/2=217Hz
  - All signals change in this time constant
  - After 15us of blind time, system changes 2% of perturbation (still large even though the time constant is slow).
  - Rough estimated delay would be 30us dead time (4%) including the slow response time.
- Example 1: Detuning changes (microphonics or Lorentz force) by 20Hz (5 deg in phase) during rf operation.
  - Cavity phase changes by 0.2deg. (=5 deg.*4%) and all the error budget is used for this.



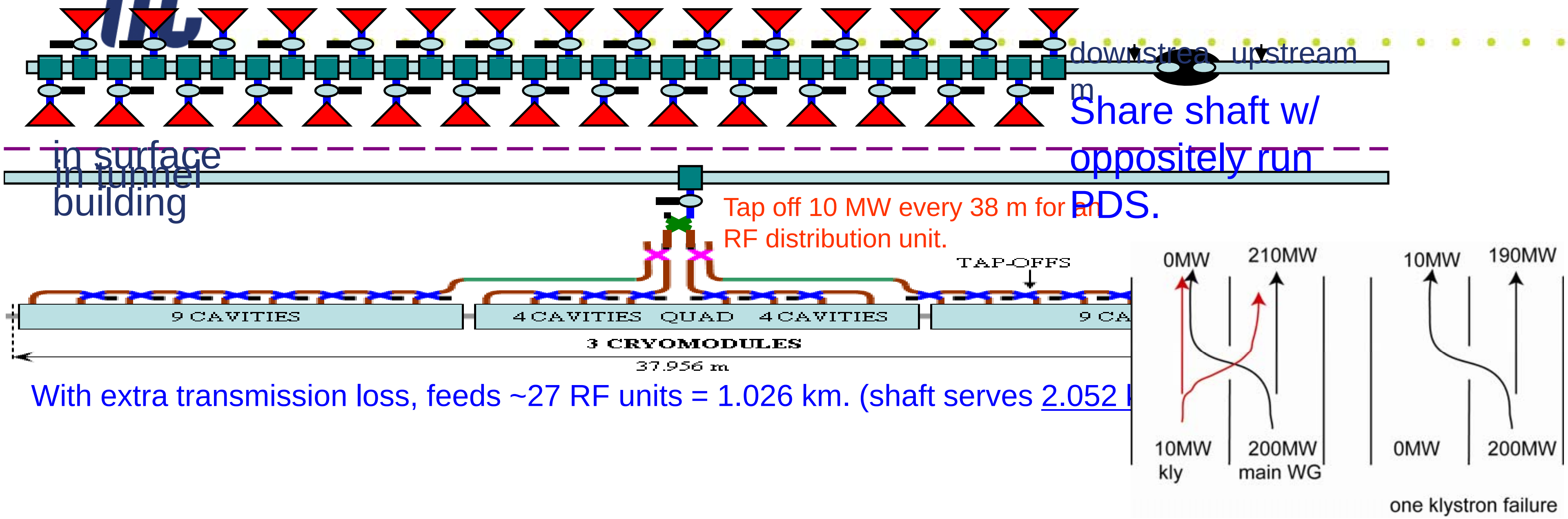


FB latency and llrf performance (2)

- Example 2: Kly HV change (1%, ~1.25% in amplitude) during rf operation.
  - Cavity amplitude changes by 0.034 % (=1.25%*4%).
- Example 3: Kly HV change (1%, 12 deg. in phase) during rf operation.
  - Cavity phase changes by 0.48 deg. (=12*4%) far from our goal of <0.1deg.

- We can not know the perturbation for first 15us and we need another 1us to detect error and >15us to recover. So total performance is poorer in case of 15us delay.)
- Despite slow rf time constant of SC cavity, blind time of 15us is large enough for the difficulties in field regulation.

Questionnaire



(1) What kind of power combiner is used?

- Hybrid-type power combiner lose 20MW in case of one klystron failure.

(2) Strategy of cavity configuration

- How will you locate the cavities of lower quench limits?
- How much the residual errors of loaded Q and tap-off control (<+/-3%?)?

(3) Upstream rf distribution is not suitable for the beam loading compensation.

- because rf and beam timing is not synchronized (7us difference).
- vector sum is not correct due to the different beam timing.

Comments from LLRF(1)

1. Field regulation

- field regulation worse but may be still ok
- higher stability of all subsystems required
- robust against perturbations or parameter changes significantly reduced
- operational field/current limits will be lower
- difficulties with feedforward due to delay between rf and beam (upstream rf distribution)
- should use fast klystron loops to reduce HLRF errors.

Comments from LLRF(2)

2. Availability

- exception detection and handling severely limited
- hot spare concept cannot be implemented

3. Operational

- Cannot simply turn on-off (or by-pass or manipulate) individual rf stations for commissioning, operational or diagnostic purposes.
- Setting up linac cannot be done by incrementally adding or controlling rf stations
- Operation close to performance limit (cavity quench, field emission, klystron saturation) will become much more challenging.