Optimal Q_L and P_k Settings for all Beam Currents

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Problem Statement

Different cavities within a cryomodule will have different quenching gradients and will operate at different gradients.

Assuming a certain gradient spread, we want to :

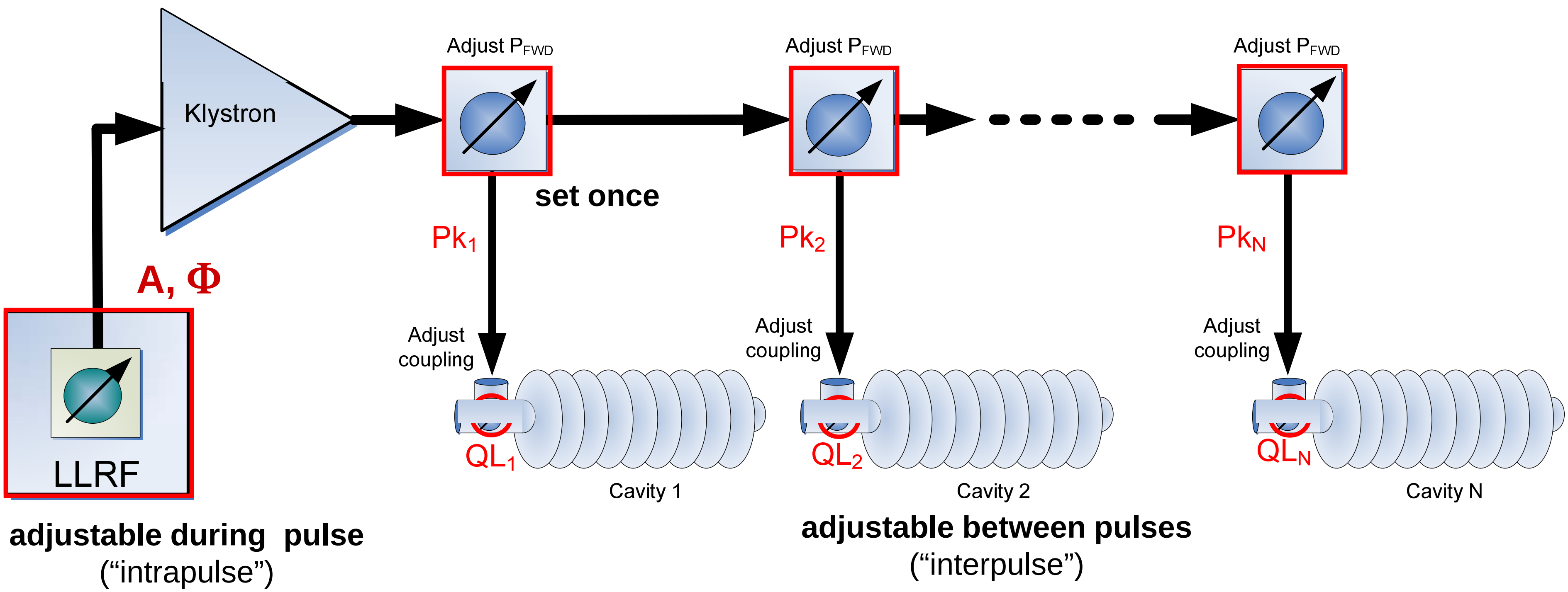
- Have a constant vector sum gradient
- Maintain that gradient for a 1 ms flat top
- Operate from 0 to full beam current

This study has been performed with a nominal gradient of 28 MV/m and a nominal current of 9 mA.

The typical gradient spread considered here is 13 cavities ranging from 22 MV/m to 34 MV/m

Problem Statement (cont'd)

3 knobs:
- LLRF (intrapulse)
- cavity power coupler (interpulse)
- waveguide power coupler (once)



Assume we can adjust both Q_L ($\approx Q_e$) and P_k for each cavity.

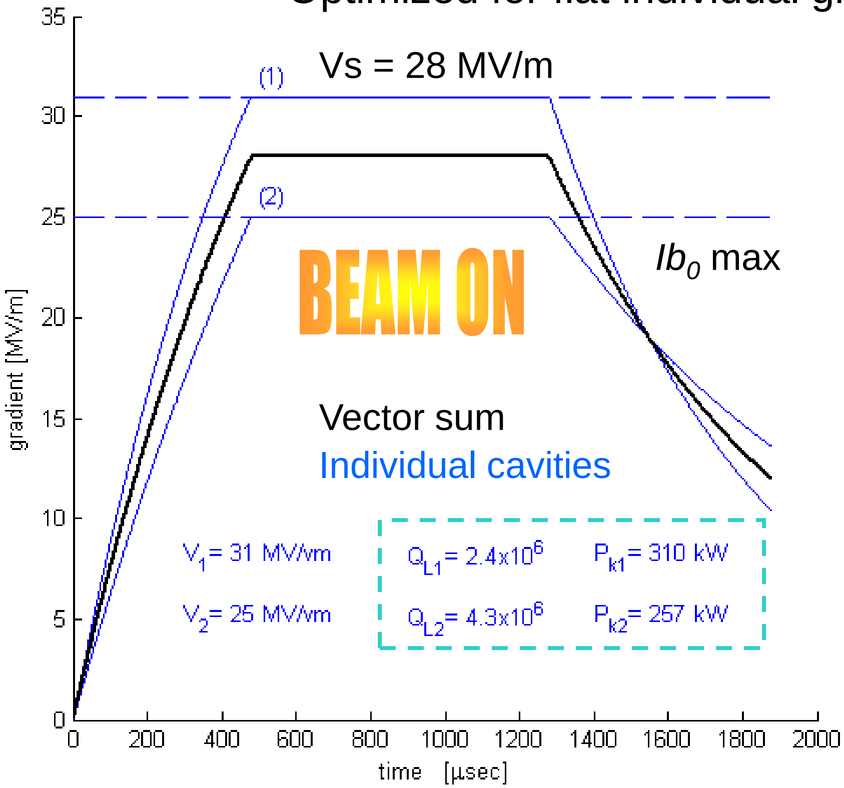
1st approach: individual Q_L, individual P_k

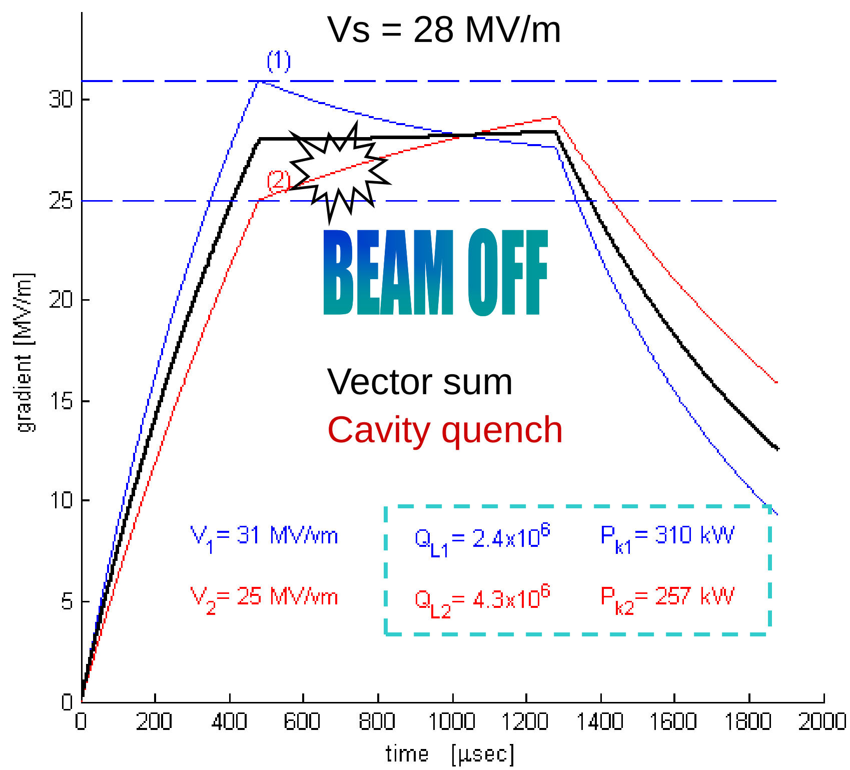
SLAC: "RF distribution optimization in the main linac of the ILC"

K.Bane, C.Adolphsen, C.Nantista (PAC07)

$$\frac{V}{V_0} = \frac{Q_L}{Q_{L0}}\left(2^{\frac{Q_{L0}}{Q_L}} - 1\right) \qquad \frac{P_k}{P_{k0}} = \frac{Q_L}{Q_{L0}} 4^{\left(\frac{Q_{L0}}{Q_L} - 1\right)}$$

Optimized for flat individual gradient under maximum beam current

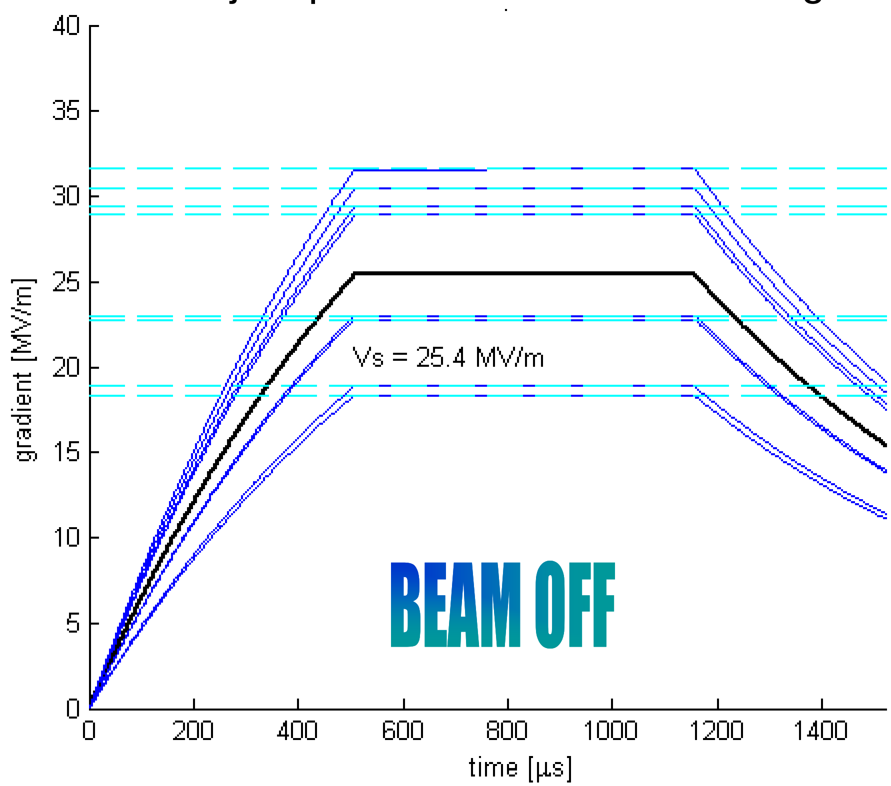


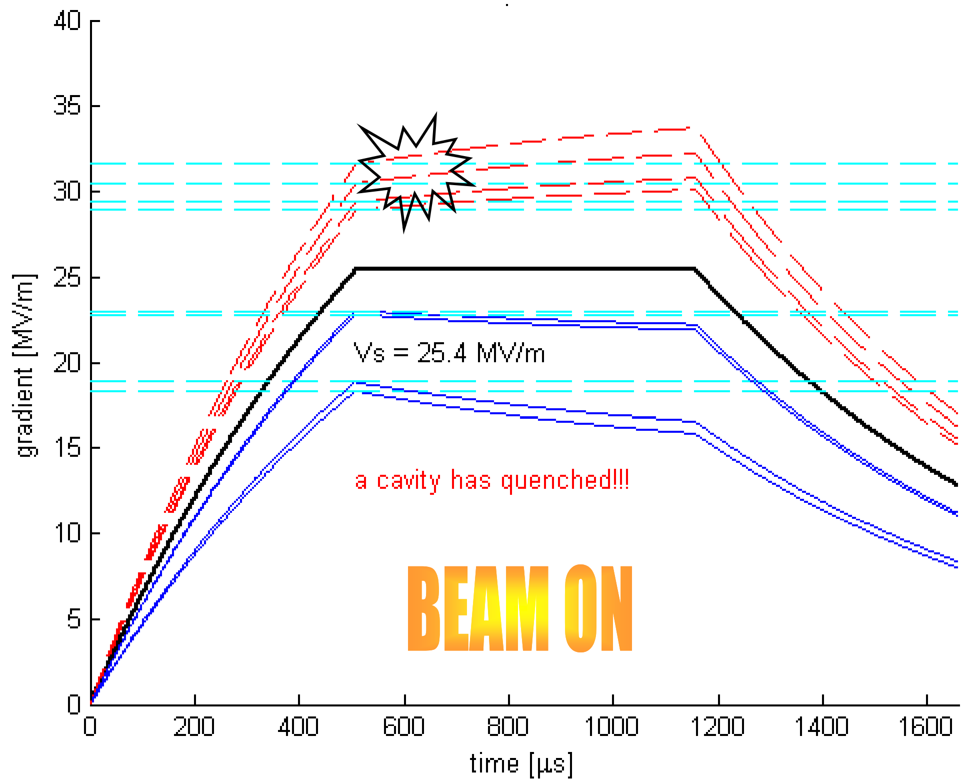


2nd approach: individual P_k, same Q_L (optimized for no beam)

DESY: "XFEL waveguide distribution and more", V. Katalev

- Same Q_L for all cavities (Q_L=3 x 10^6)
  ACC6 : [30.48 31.59 29.41 28.91 18.32 18.84 23.04 22.80] MV/m
  Ibo = 5 mA
- Adjust power to flatten individual gradient without beam





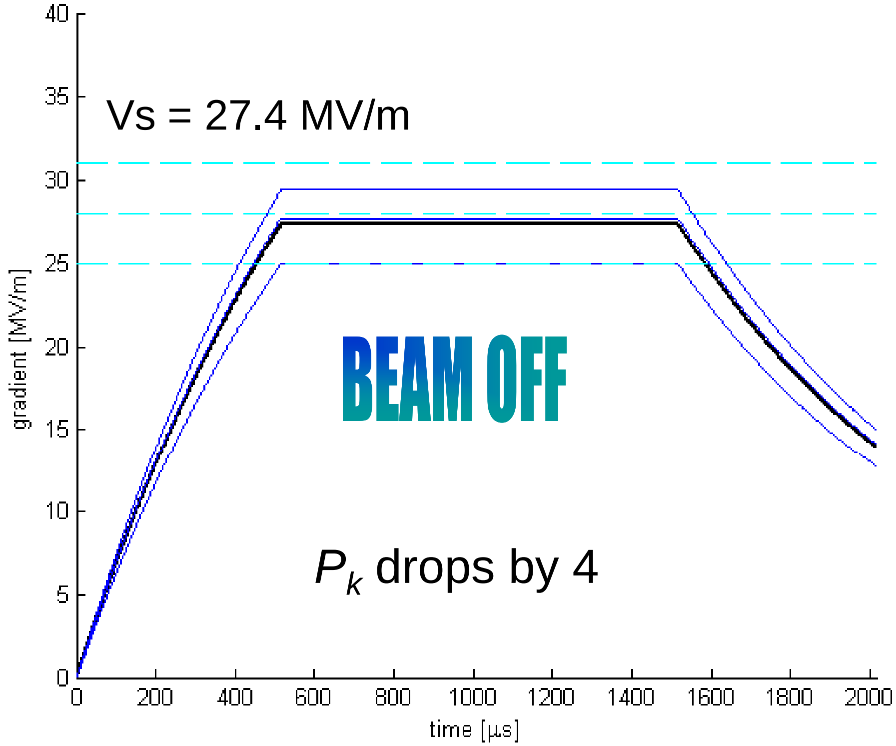
This approach: individual P_k, same Q_L (optimized for beam)

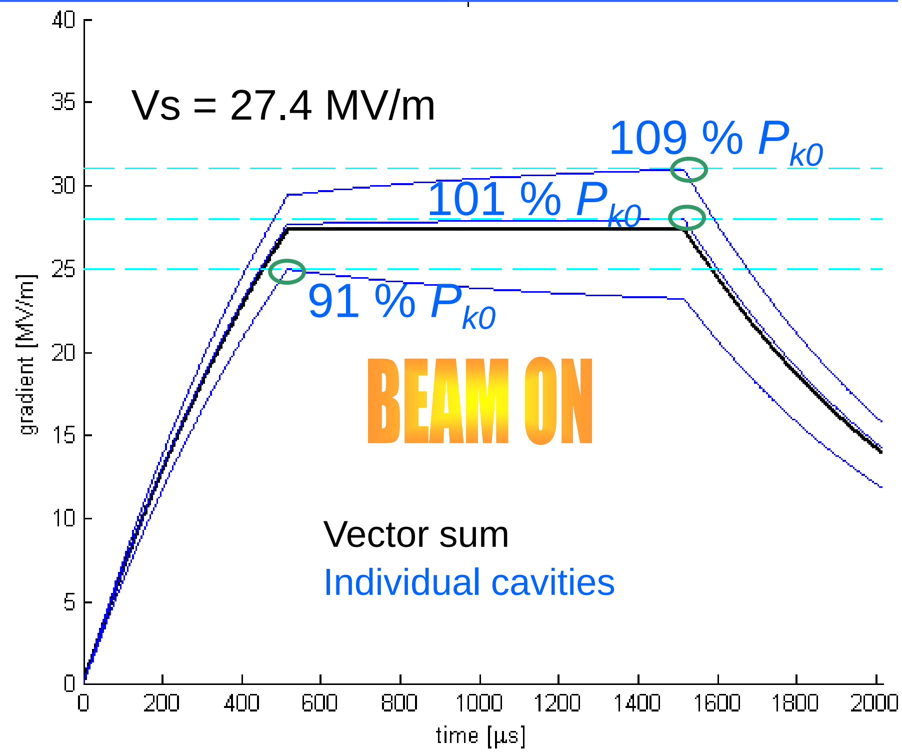
1 - choose Q_L → sets $\tau = 2Q_L / \omega_0$

2 - choose $t_{inj} = \tau \ln 2$ → guaranties flat top when beam is OFF

3 - distribute power so that $\frac{1}{N}\sum_i I_{gi} = 2I_{b0}$ → guaranties flat top when beam is ON

4 - check if cavity exceeds limit → new Q_L for maximum Vs (optimization)

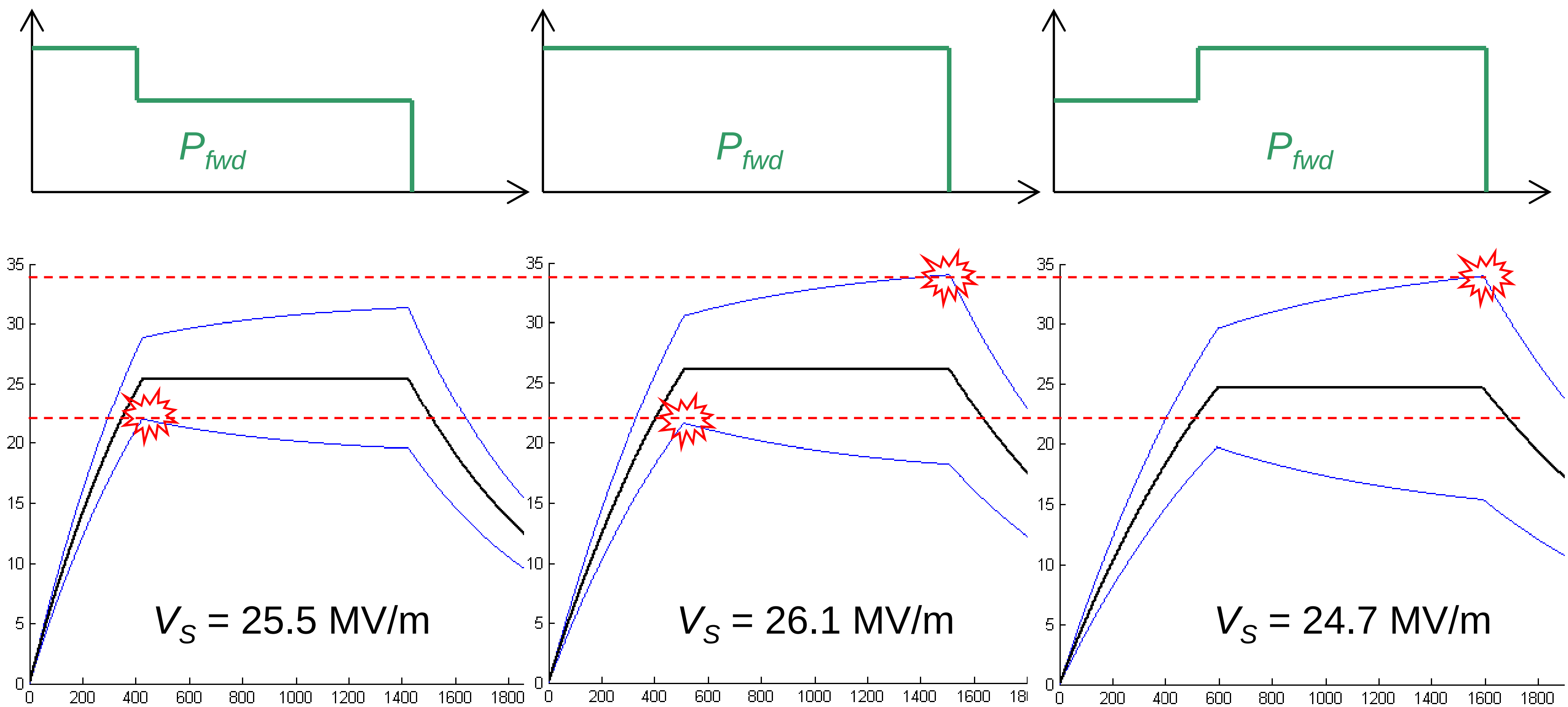




V_{q1} = 22 MV/m

V_{q2} = 34 MV/m

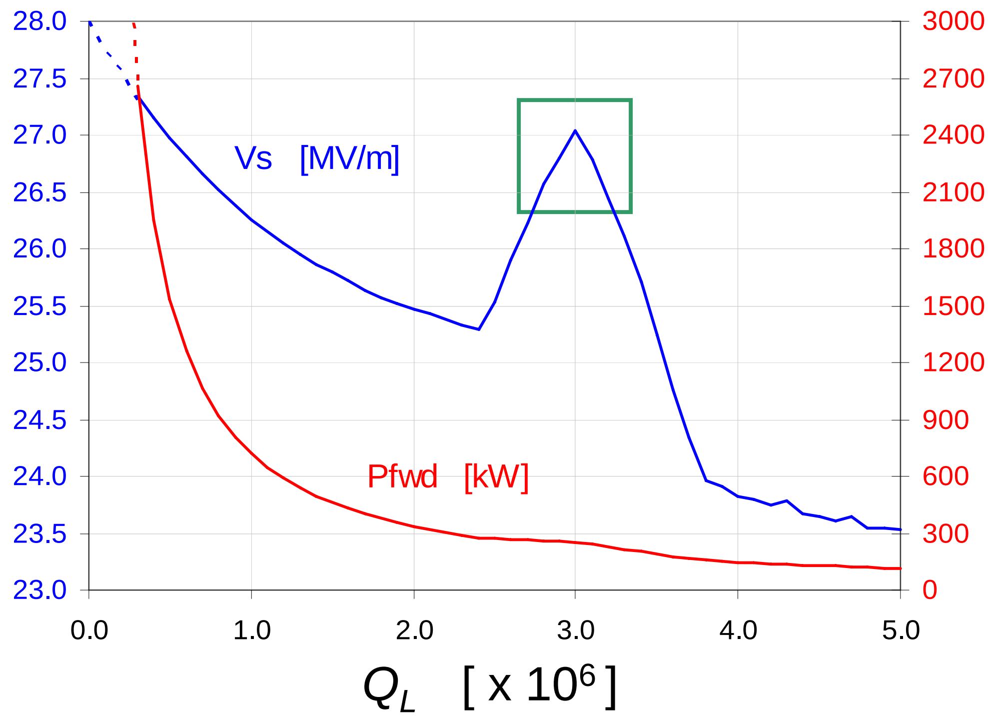
finding the optimal $Q_L \Leftrightarrow$ finding maximum V_S

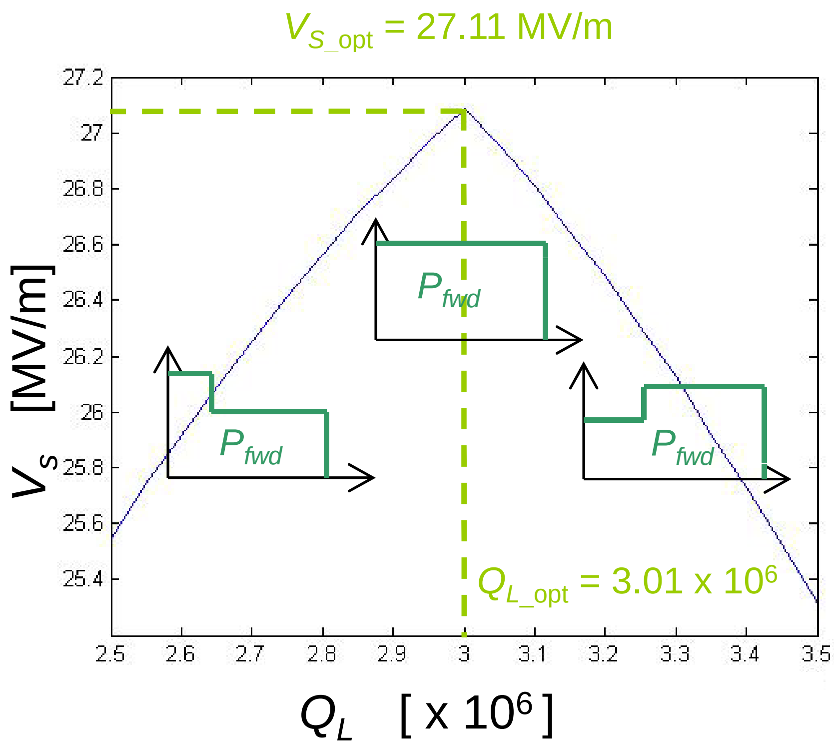


Q_L = 2.5 x 10^6 Q_L = 3.0 x 10^6 Q_L = 3.5 x 10^6

For a given cavity maximum gradient distribution, find optimal Q_L (maximum V_S)

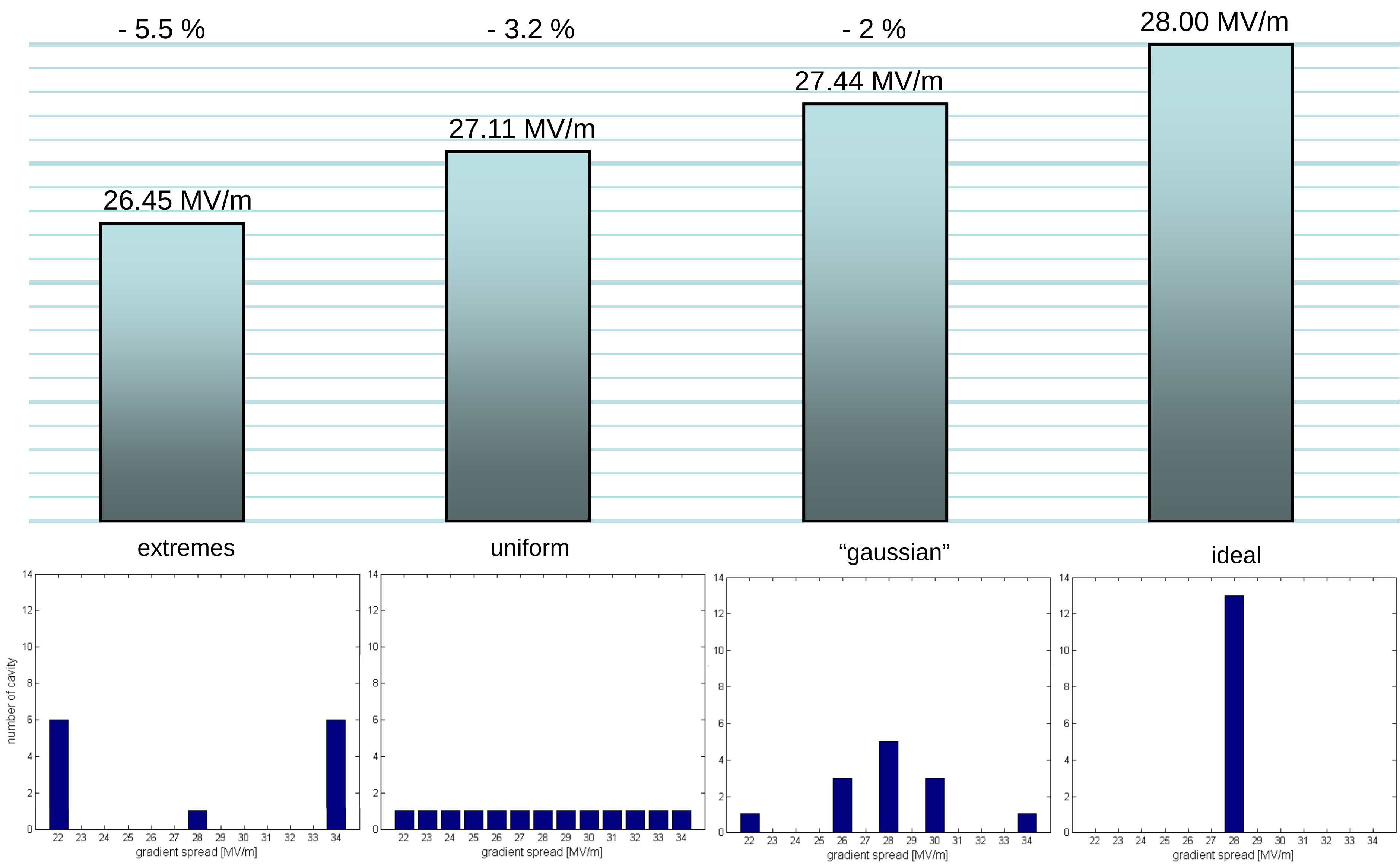
13 cavities [22 – 34] MV/m



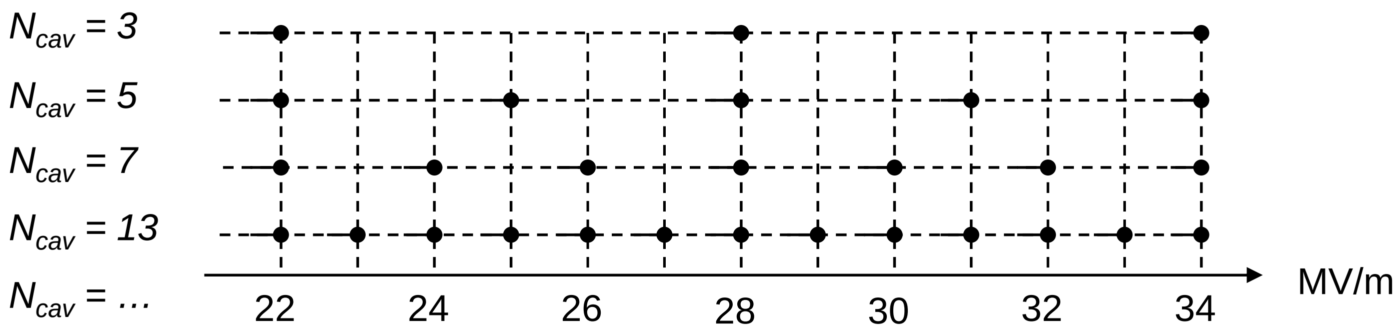


quench gradients = 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 33, 33, 34 MV/m

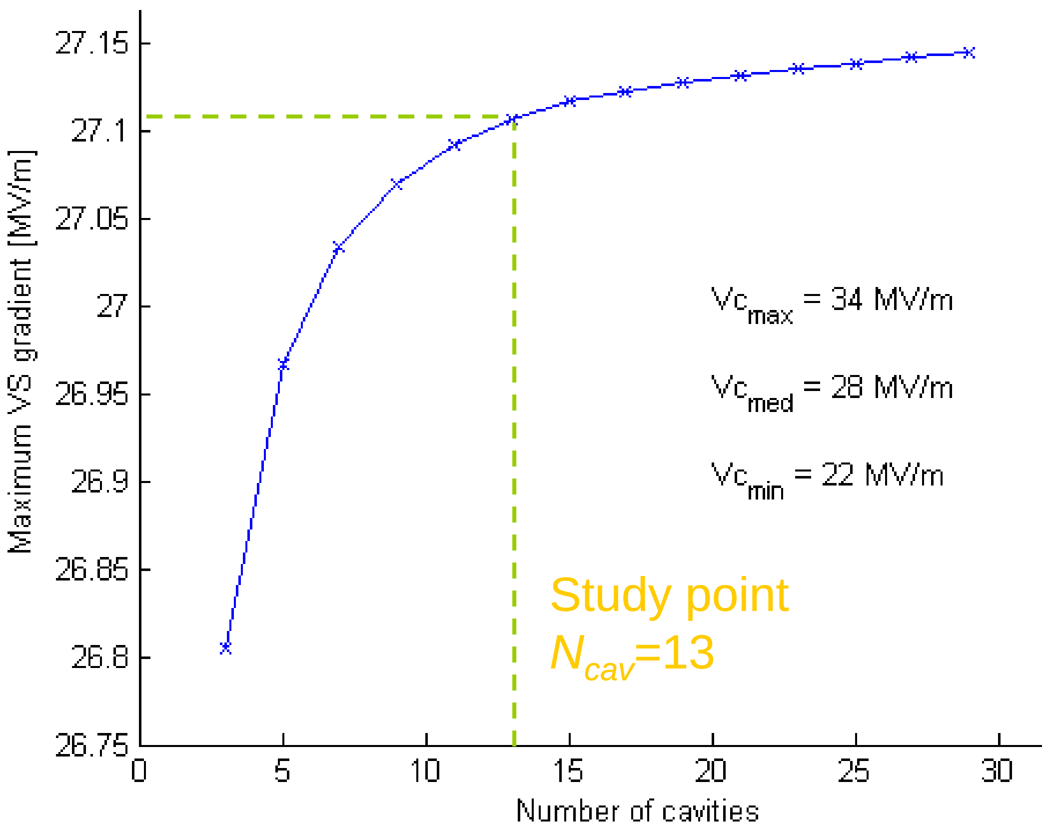
Impact of the **cavity gradient distribution** for a fixed 22-34 MV/m spread



Increasing the **number of cavities** (*Ncav*) for a range of quenching gradients

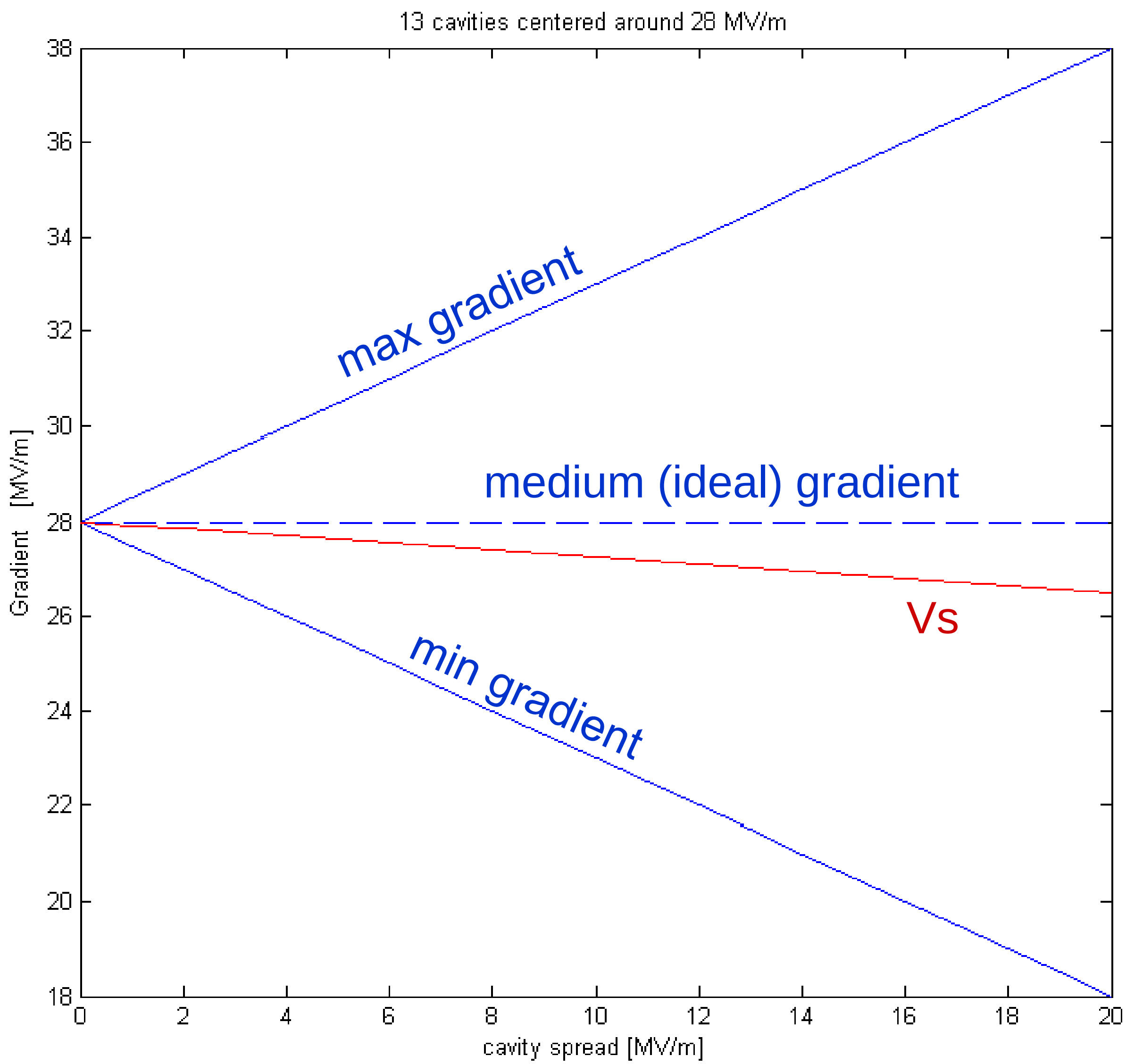


N_{cav} cavities ranging from 22 to 34 MV/m



Fermilab

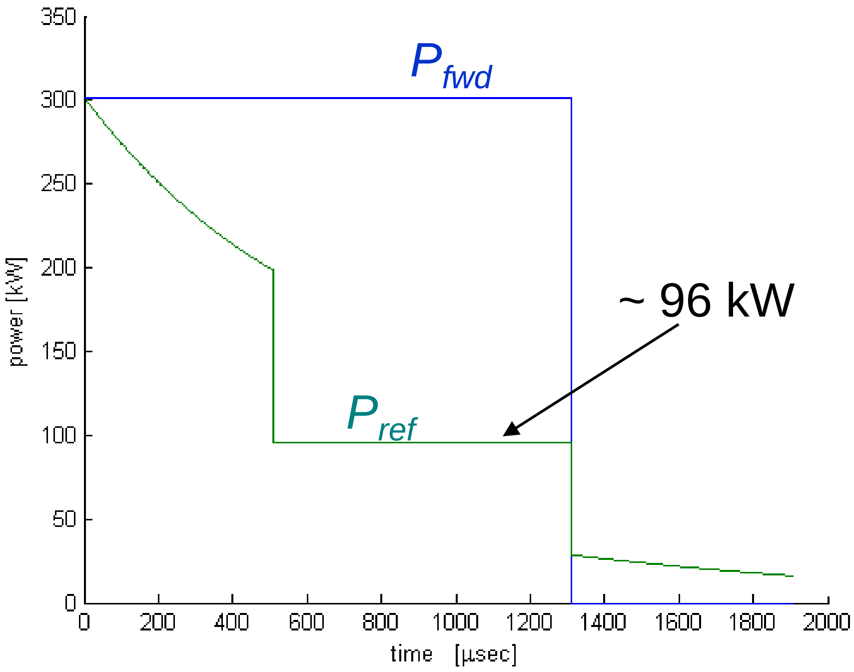
Impact of the **cavity gradient spread** for a uniform distribution



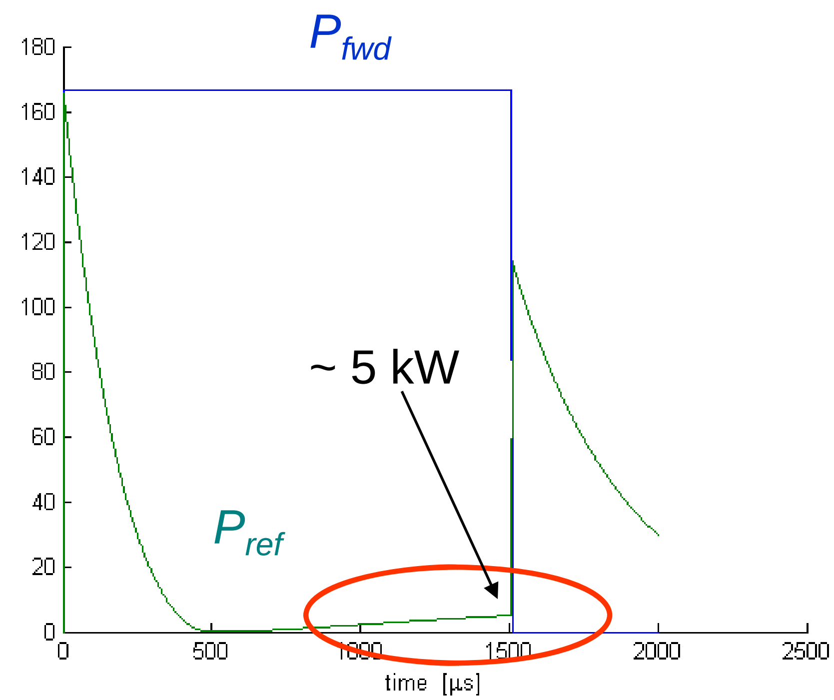
Approach comparison

Reflected power

indiv. Q_L indiv P_k
(SLAC)



same Q_L indiv P_k
(this approach)



Lowest cavity (22 MV/m) ➔ maximum reflected power

Approach comparison - Conclusion

Approach	indiv. Q_L, indiv. P_K	same Q_L, indiv. P_K
Maximum gradient	28 MV/m	27.1 MV/m
P_{FWD} (total 13 cavities)	3.7 MW	3.3 MW
P_{REF} (total 13 cavities)	270 kW	20 kW
Operate at any beam current	No	Yes
Operate without tunable coupler	No	Yes

for a uniform gradient spread ranging from 22 MV/m to 34 MV/m

Conclusions

With the current approach:

- **+** We can maintain a constant vector sum for the entire flat top duration and for any beam current
- **-** We operate at a gradient below the maximum gradient (nom. ~ -2%)
- **+** The reflected power during beam is reduced by a factor of 14
- **+** All cavities operate with the same loaded Q and will therefore all have a similar control response