RF operation with fixed Pks

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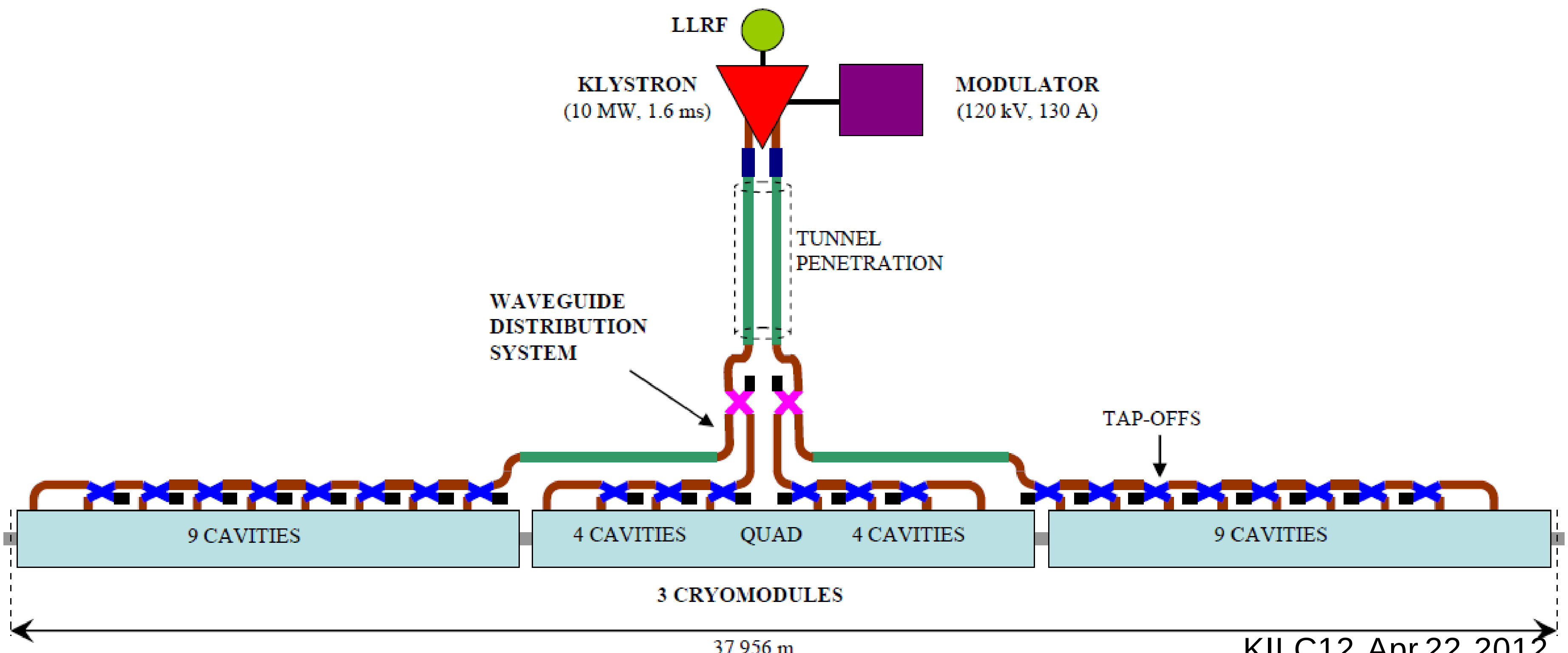
- Solution (1); Ql proportional to Ib
- Simulation configuration –rectangular distribution
- Solution (2); Ql optimization with 20% gradient distribution
- Solution (3); Ql optimization with 10% gradient distribution

RF distribution system (RDS)

- RDR: 1 klystron drives 26 same gradient cavities (31.5MV/m).
- TDR: 1 klystron drives 39 cavities with gradient variation (25 MV/m ~ 38 MV/m).
  1) PkQl control is proposed.
  2) new: semi-fixed Pks were proposed to reduce the RDS cost.

-> Pks are optimized at some beam current and are not changed during various beam operation. **-> Is it reasonable to fix Pks for near-quench-limit operation?**



Solution (1) –Ql proportional to Ib

PkQl control

$$V_{cav} = 2\frac{r}{Q}Q_L\mathrm{Igen}\cdot(1-\exp\left(-\frac{T_{inj}}{\tau}\right))$$

If we select Ql to be proportional to beam current (so Igen) and select filling time also proportional to Ql (or Ibeam), we can keep Vcav with various beam current.

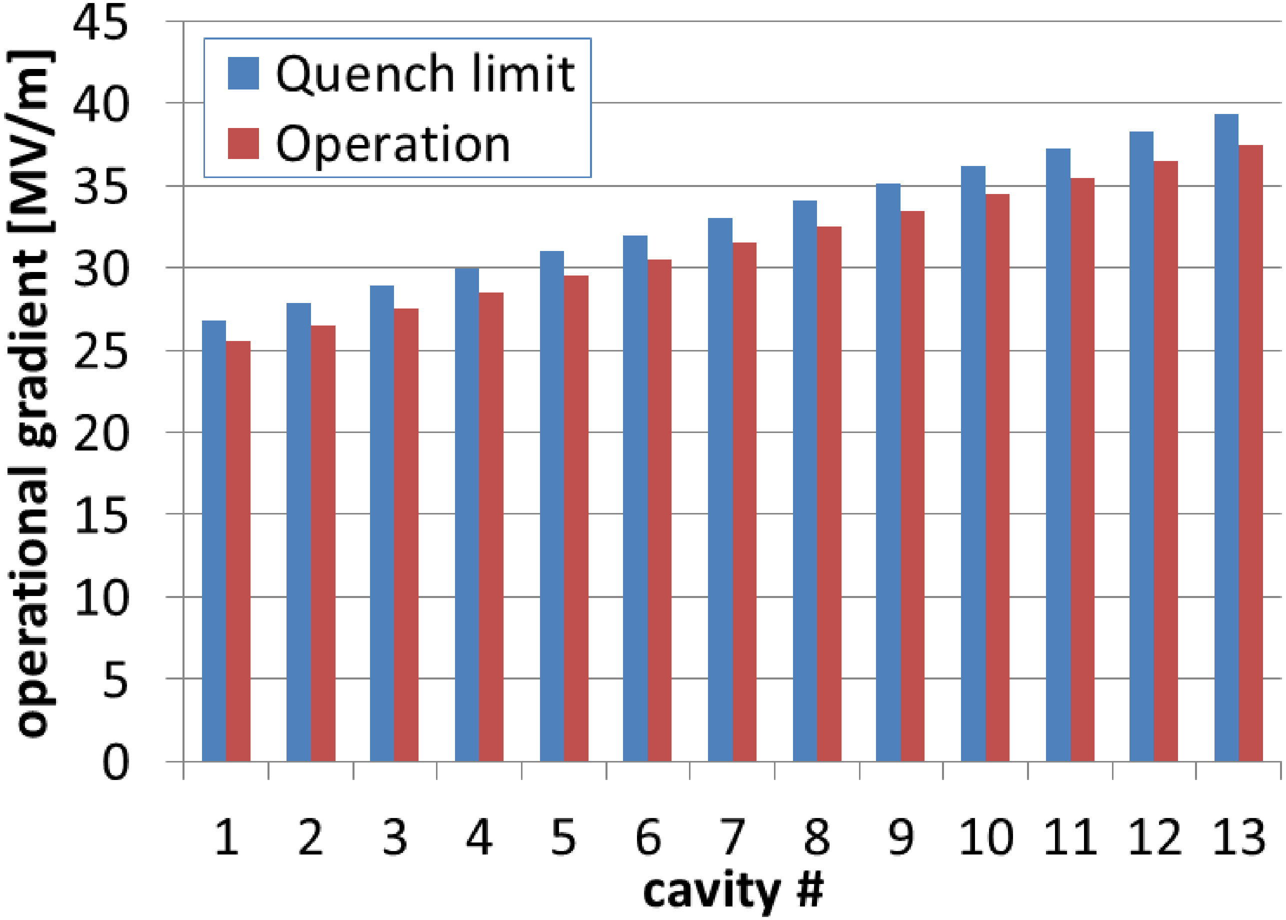
$$Q_L = \frac{\mathrm{Igen0}}{\mathrm{Igen}}Q_{L0} = \frac{\mathrm{Ibeam0}}{\mathrm{Ibeam}}Q_{L0}$$

$$T_{inj} = \frac{\tau}{\tau_0}T_{inj0} = \frac{\mathrm{Ibeam}}{\mathrm{Ibeam0}}T_{inj0}$$

$$\mathrm{Pk} = \frac{1}{4}\frac{r}{Q}Q_L(\mathrm{Igen})^2 = \frac{1}{4}\frac{r}{Q}Q_{L0}Igen0\ Igen = \frac{\mathrm{Ibeam}}{\mathrm{Ibeam0}}\mathrm{Pk0}$$

Configuretion:QIs with 20% Vcav variation

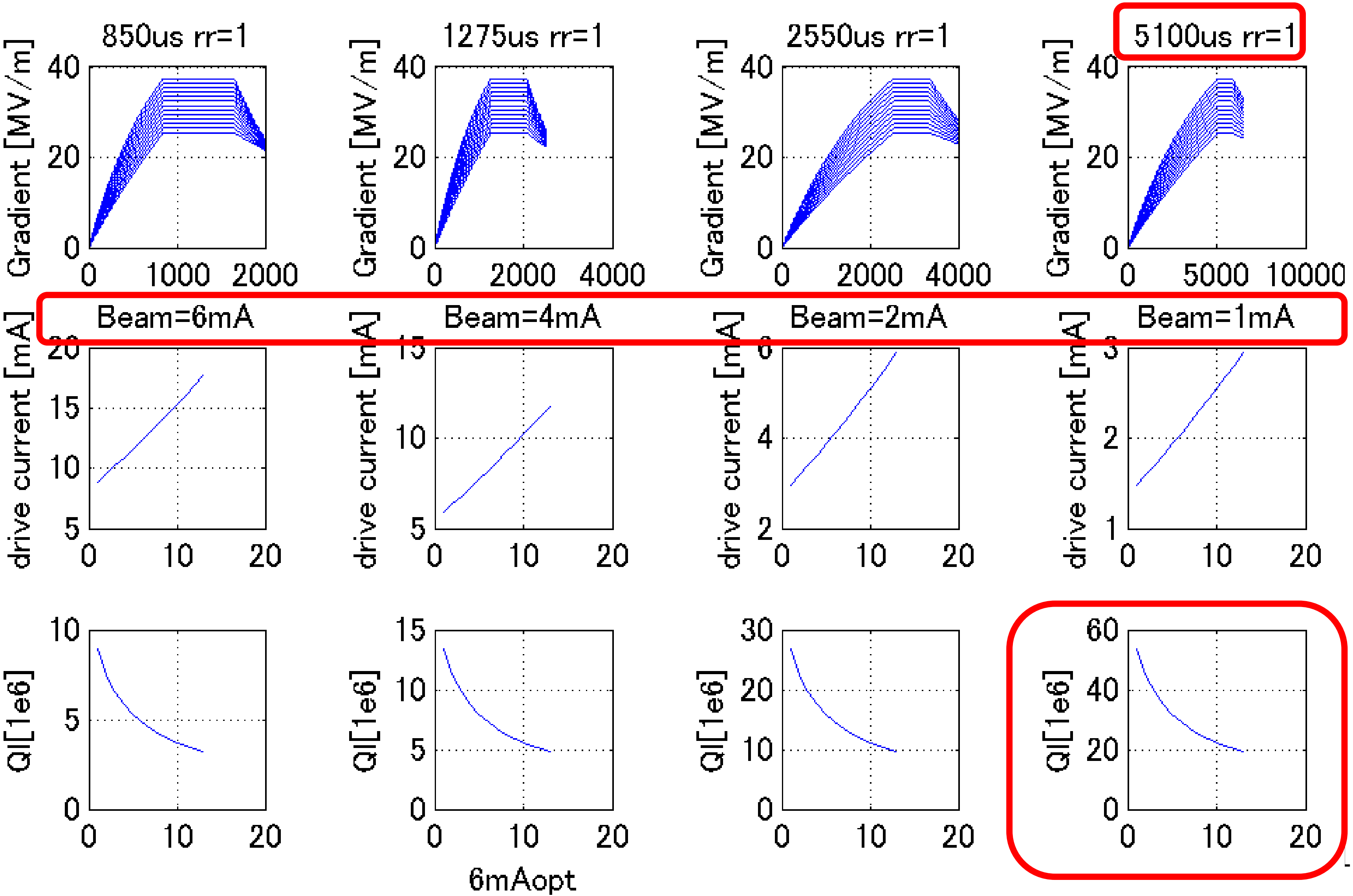
- 13 cavities having the operational gradient from 25.5 MV/m to 37.5 MV/m.
- Gradient spread is ~ rectangular distribution.



Suppose operational gradients (25.5 MV/m~37.5MV/m) are 5% lower than quench limit.

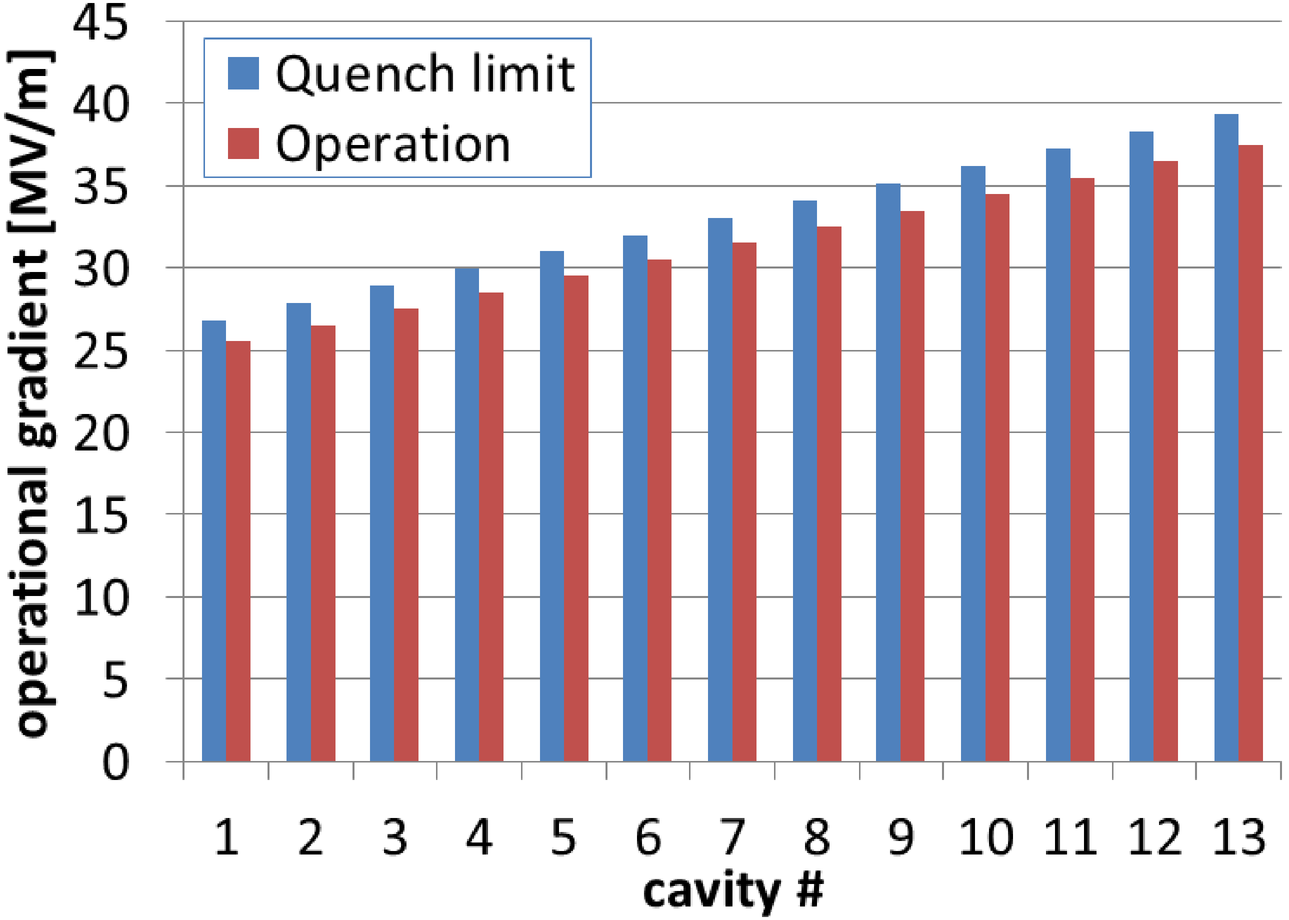
Solution (1) –Ql proportional to Ib

Cavity gradient can keep the same value with various beam current.
However, filling time (and Qls) becomes too large (~5ms filling time at 1mA beam).



Solution (2) -Qls with 20% Vcav variation

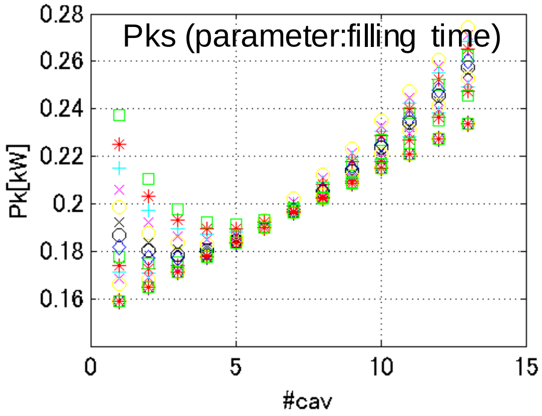
- 13 cavities having the operational gradient from 25.5 MV/m to 37.5 MV/m.
- Gradient spread is ~ rectangular distribution.

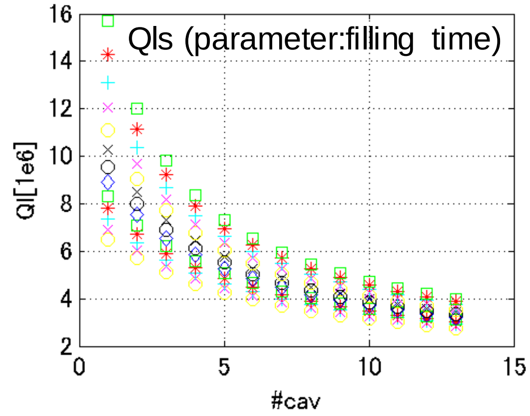


Suppose operational gradients (25.5 MV/m~37.5MV/m) are 5% lower than quench limit.

Simulation procedure

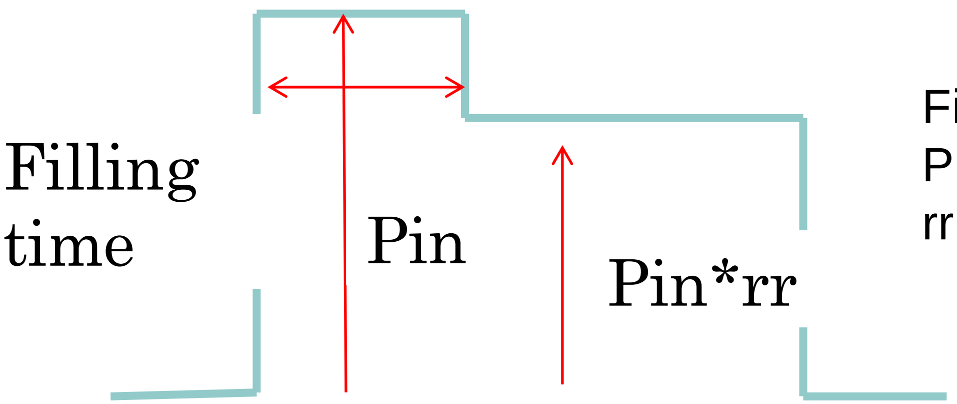
1. Optimize the Pks for 6mA beam operation





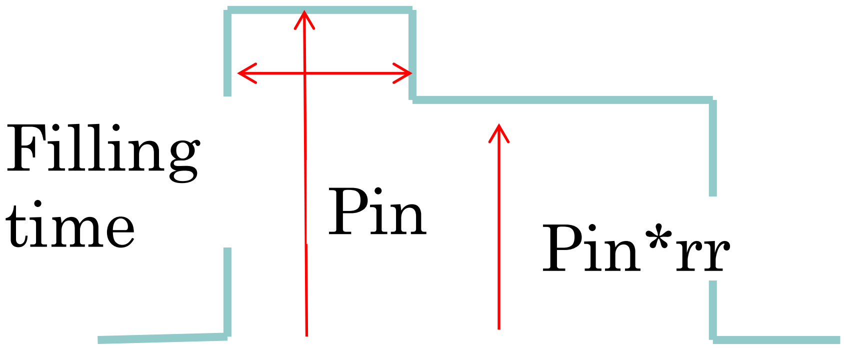
I select 850us filling time. (lowest rf power =2.677MW(~4.9% higher than beam loading(= optimized same Ql, Vacc control))
Qls are 8.9e6(24.5MV/m) ~3.2e6(37.5MV/m)

2. Under these Pks, optimize filling time, Pin, step ratio (rr) and Qls.



Filling time: 750us~950us
Pin: 0.8~1.0
rr:0.6~1.0

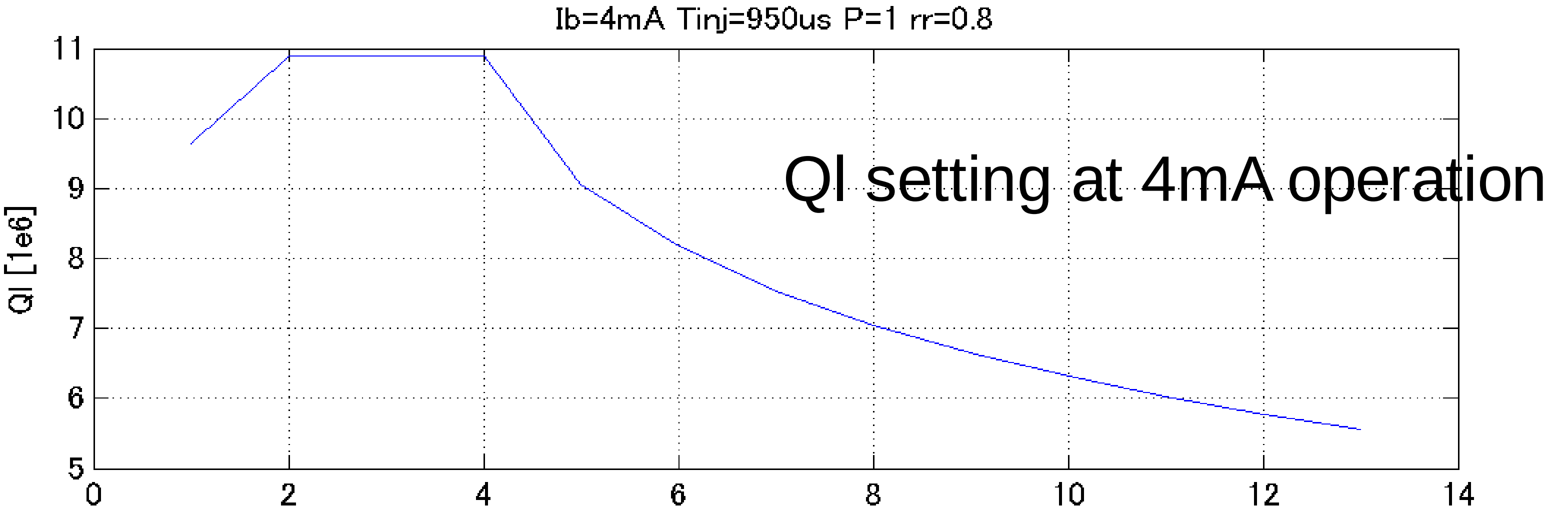
Performance at various Ibeam

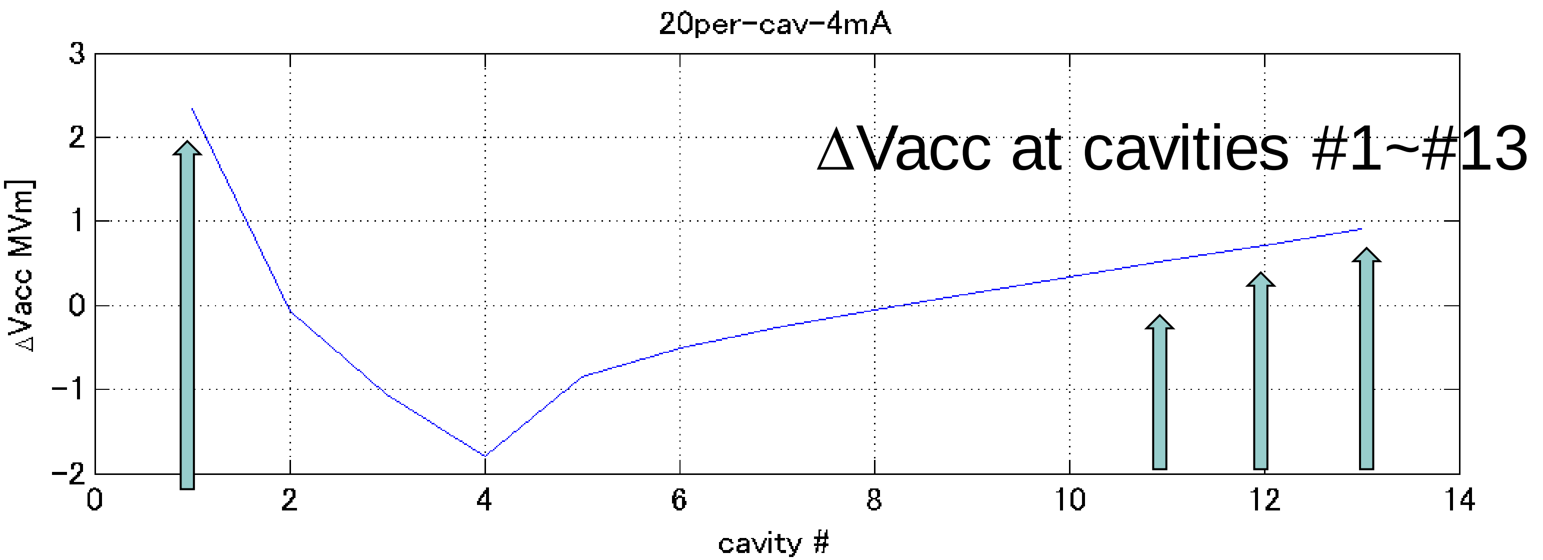


Ibeam [mA]	Filling [us]	Pin	rr	Additional Vacc [MV/m]	Additional Vacc [%]
6	850	1	1	0	0
4	950	1	0.8	2.35	9.2
2	870	1	0.6	3.63	14.2
0	800	1	0.9	4.03	15.8

Low gradient cavity shows the gradient ~10% higher.

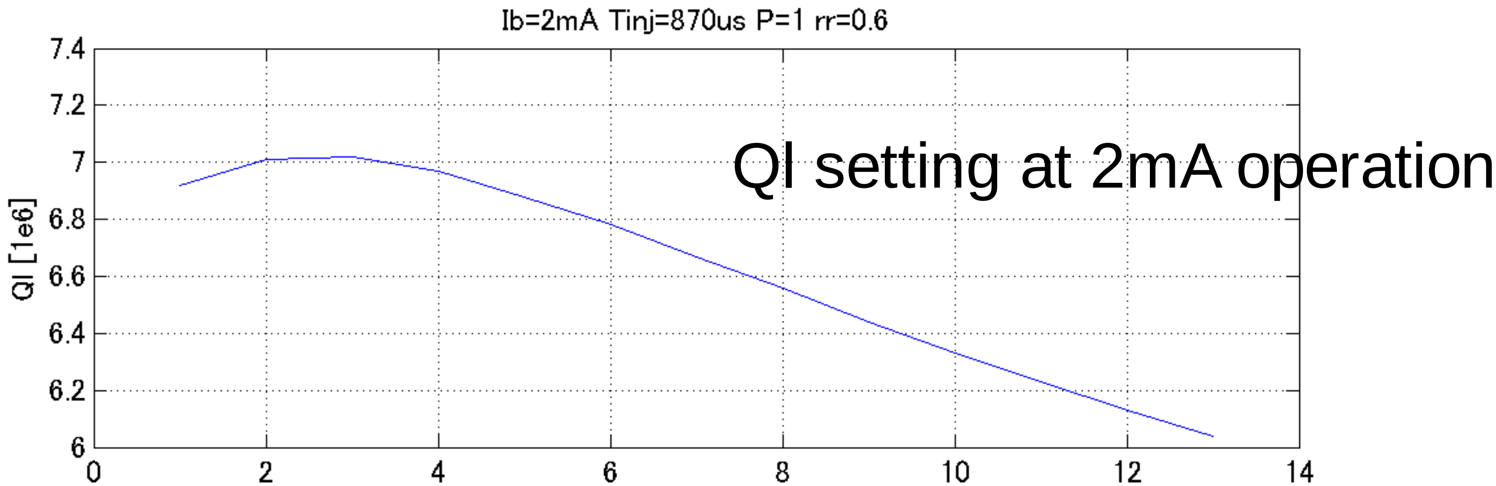
Performance at 4mA

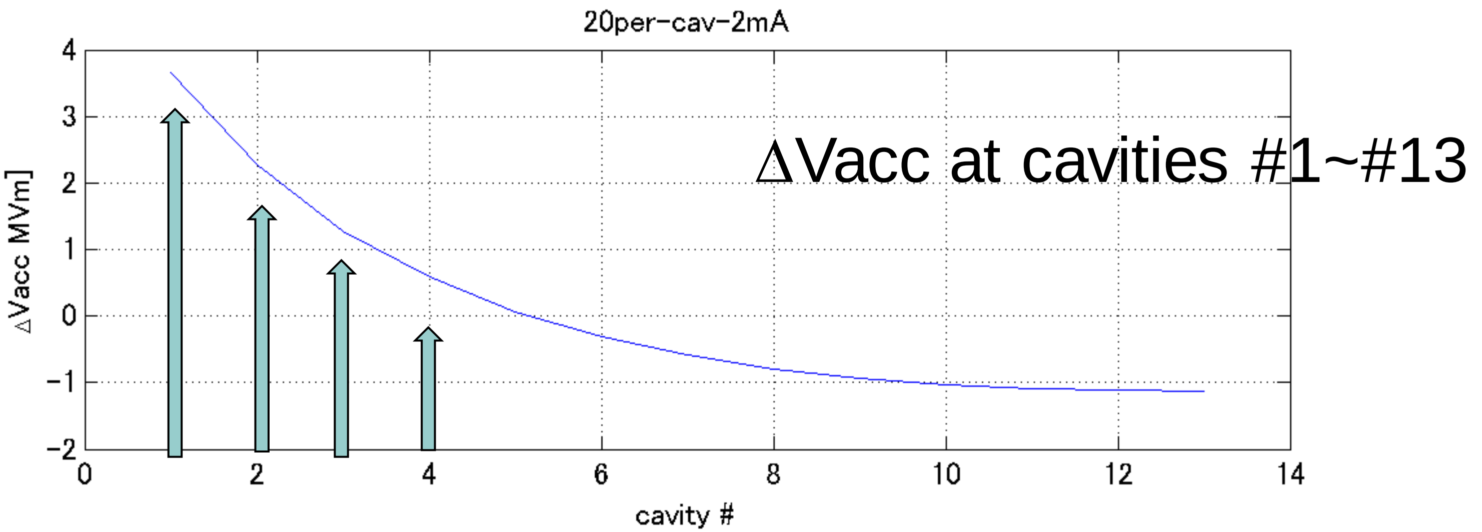




Lowest gradient cavity exceeds the 6mA operated gradient.

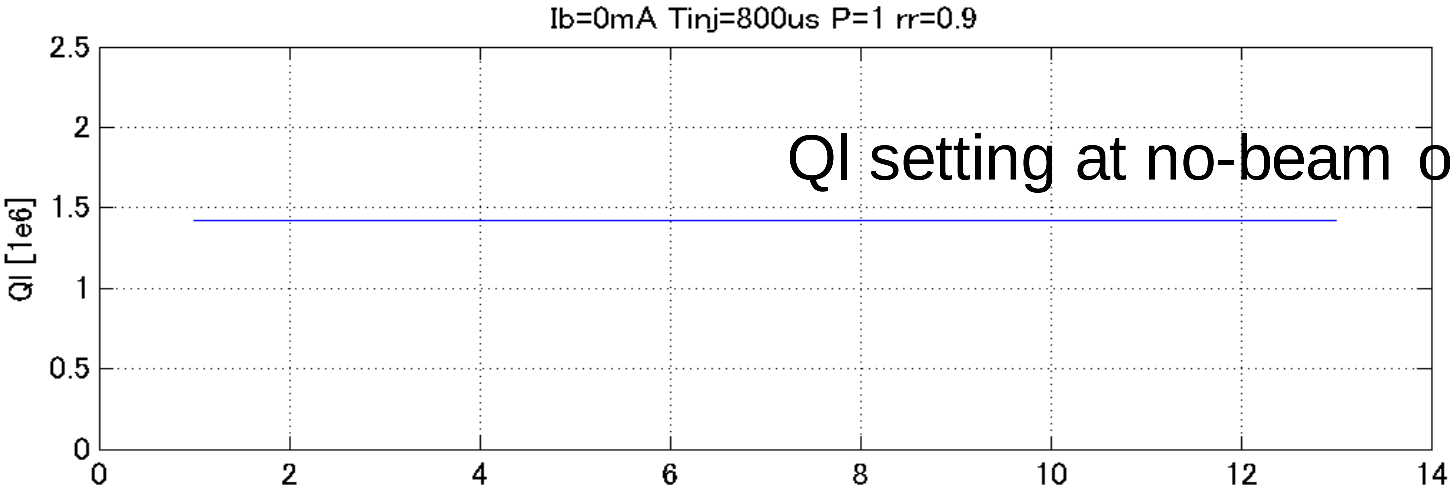
Performance at 2mA

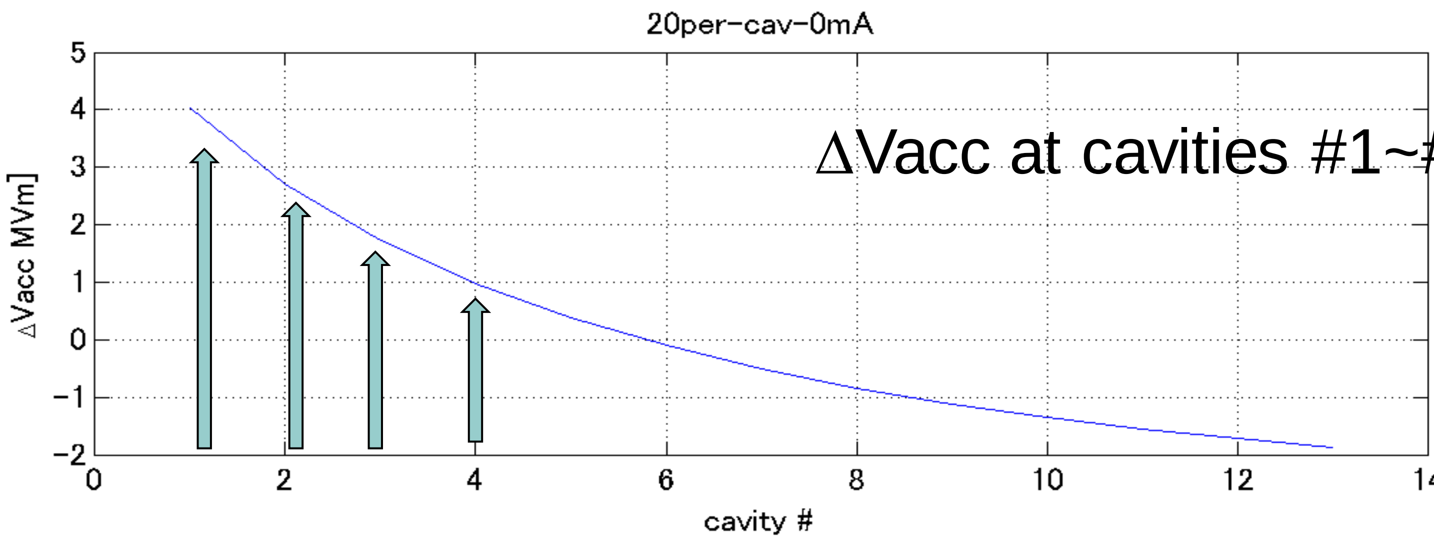




Lower 4 cavities exceed their Vacc value at 6mA.

Performance at 0mA



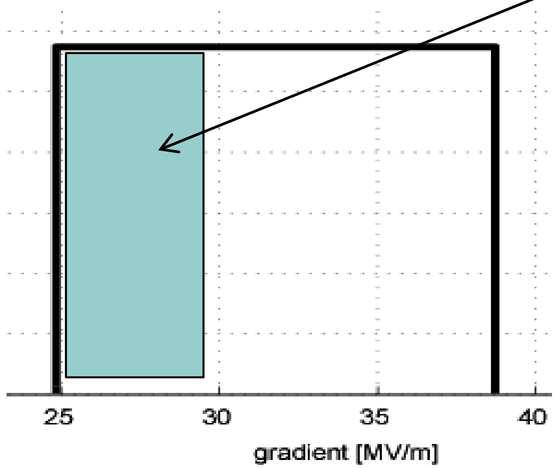


Lower 4 cavities exceed their Vacc value at 6mA.

Performance at various Ibeam

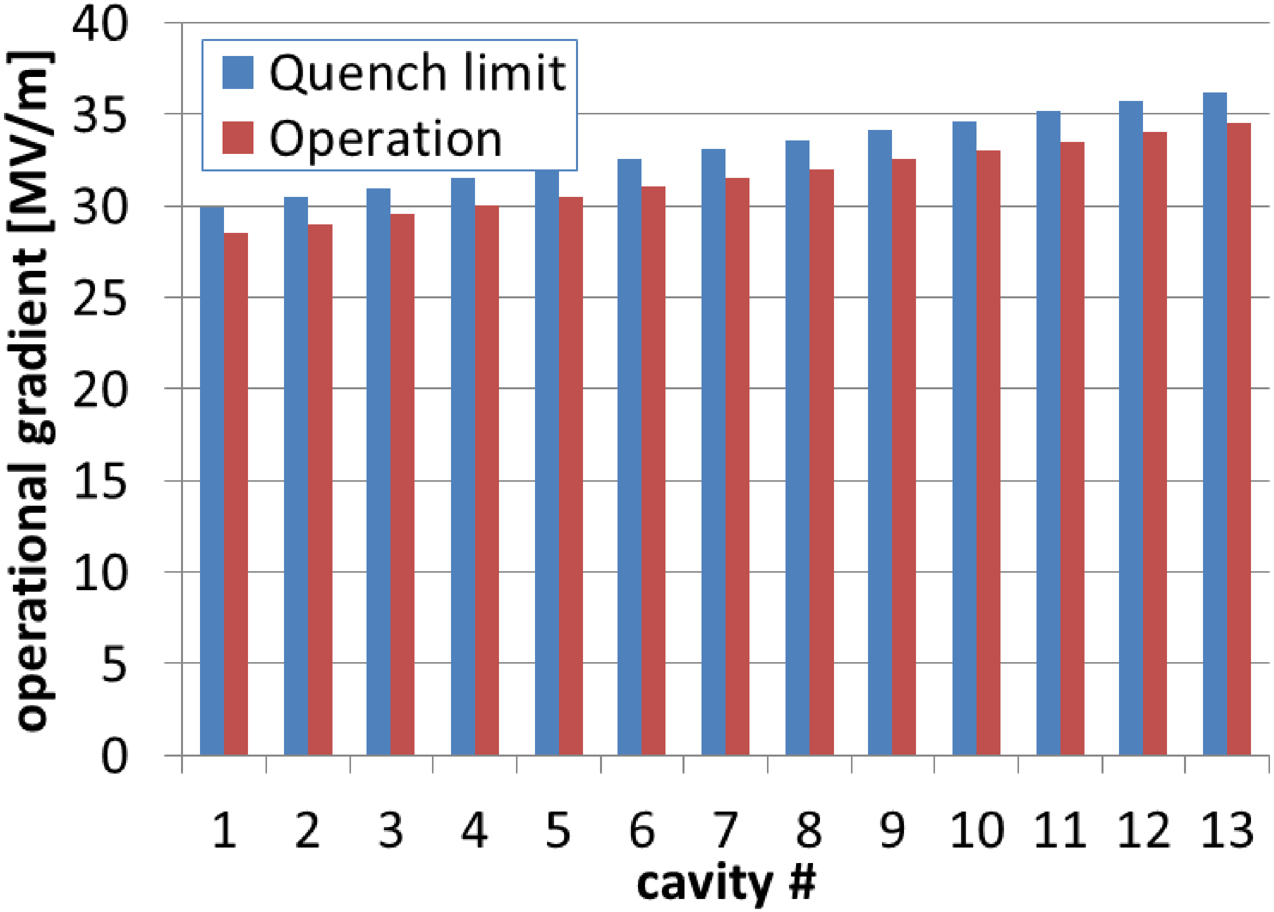
Ibeam [mA]	Filling [us]	Pin	rr	Additional Vacc [MV/m]	Additional Vacc [%]
6	850	1	1	0	0
4	950	1	0.8	2.35	9.2
2	870	1	0.6	3.63	14.2
0	800	1	0.9	4.03	15.8

25MV/m~30MV/m cavities should be operated <20% than quench limit.
-> In case of the rectangular gradient variation, 25~30MV/m cavities are 5/13(=38%)
Average gradient of 25-30MV/m=27.5MV/m
15% more margin than nominal cavities; 27.5*0.15*0.38/31.5=0.0503 (=5%)
Total accelerating energy decrease ~5% in case of the semi-fixed Pks configuration.



Solution (3) -Qls with 10% Vcav variation

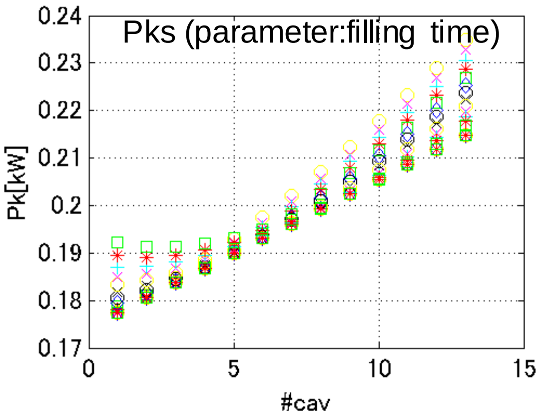
- 13 cavities having the operational gradient from 28.5 MV/m to 34.5 MV/m.
- Gradient spread is ~ rectangular distribution.

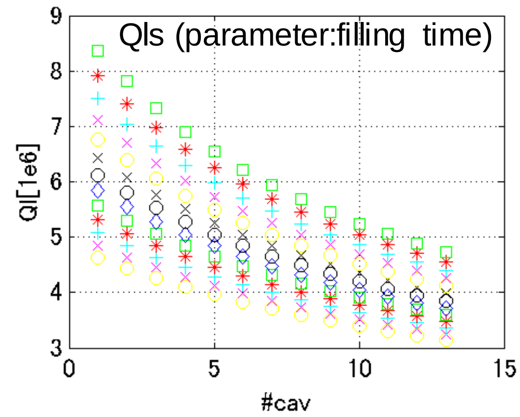


Suppose operational gradients (28.5 MV/m~34.5MV/m) are 5% lower than quench limit.

Simulation procedure

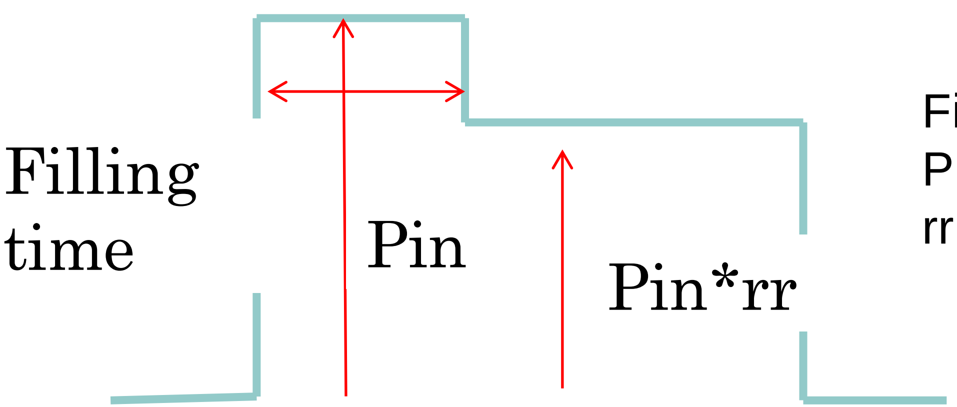
1. Optimize the Pks for 6mA beam operation





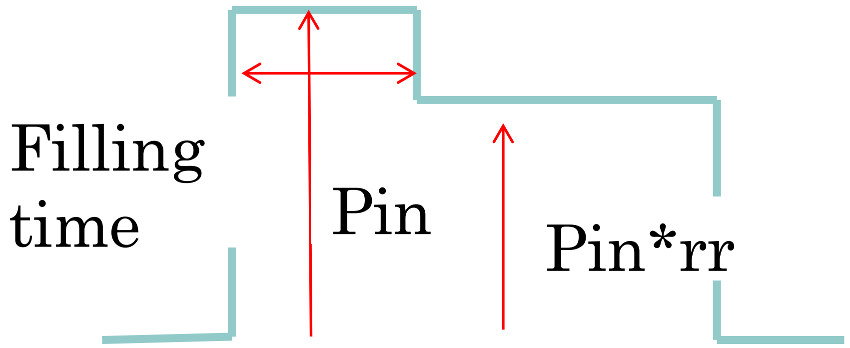
I select 850us filling time. (lowest rf power =2.58MW(~1.2% higher than beam loading(= optimized same Ql, Vacc control))
Qls are 6.77e6(28.5MV/m)~4.11e6(34.5MV/m).

2. Under these Pks, optimize filling time, Pin, step ratio (rr) and Qls.



Filling time: 750us~950us
Pin: 0.8~1.0
rr:0.6~1.0

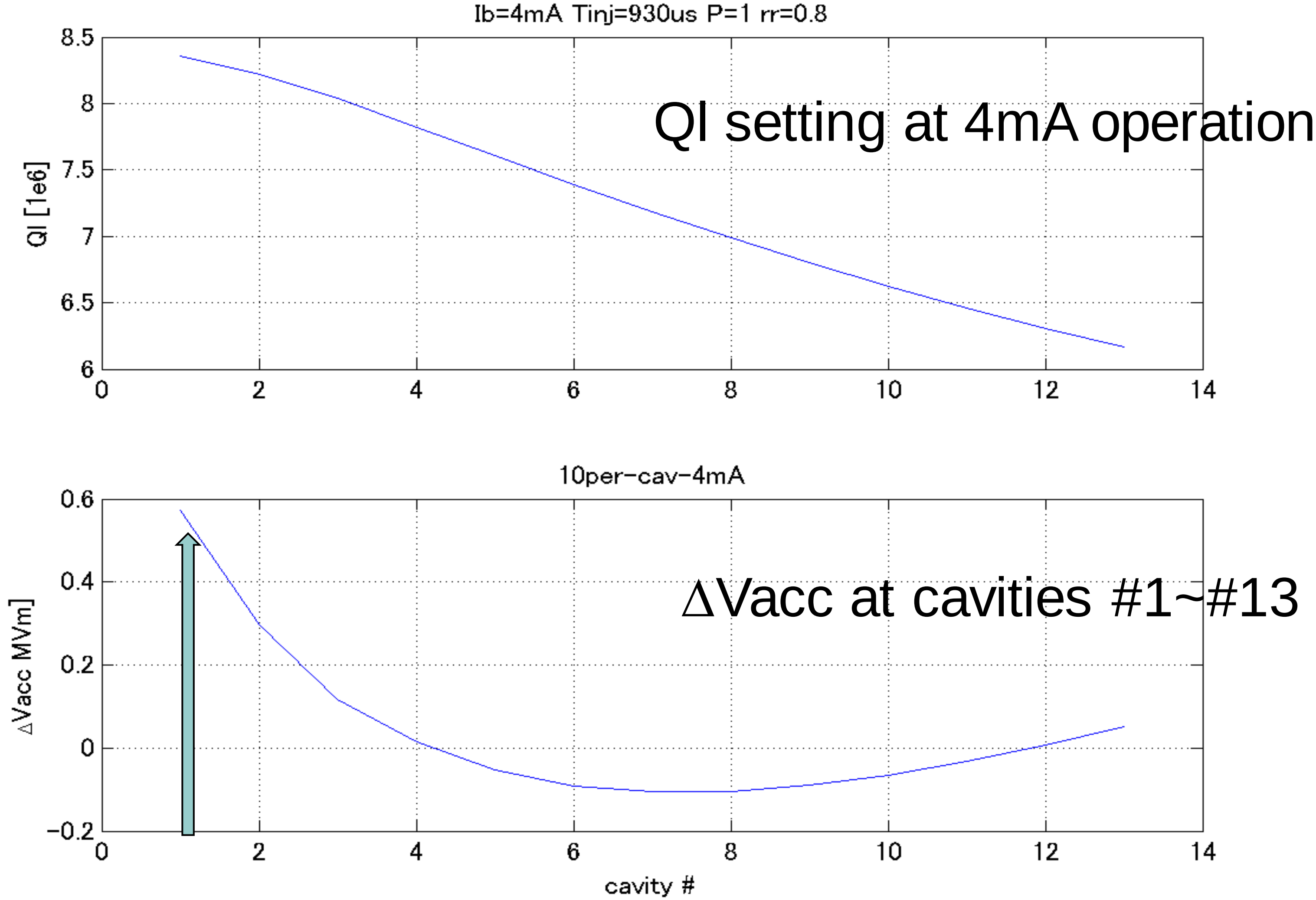
Performance at various Ibeam



Ibeam [mA]	Filling [us]	Pin	rr	Additional Vacc [MV/m]	Additional Vacc [%]
6	850	1	1	0	0
4	930	1	0.8	0.57	2.00
2	980	1	0.6	1.42	5.00
0	780	1	0.6	1.75	6.15

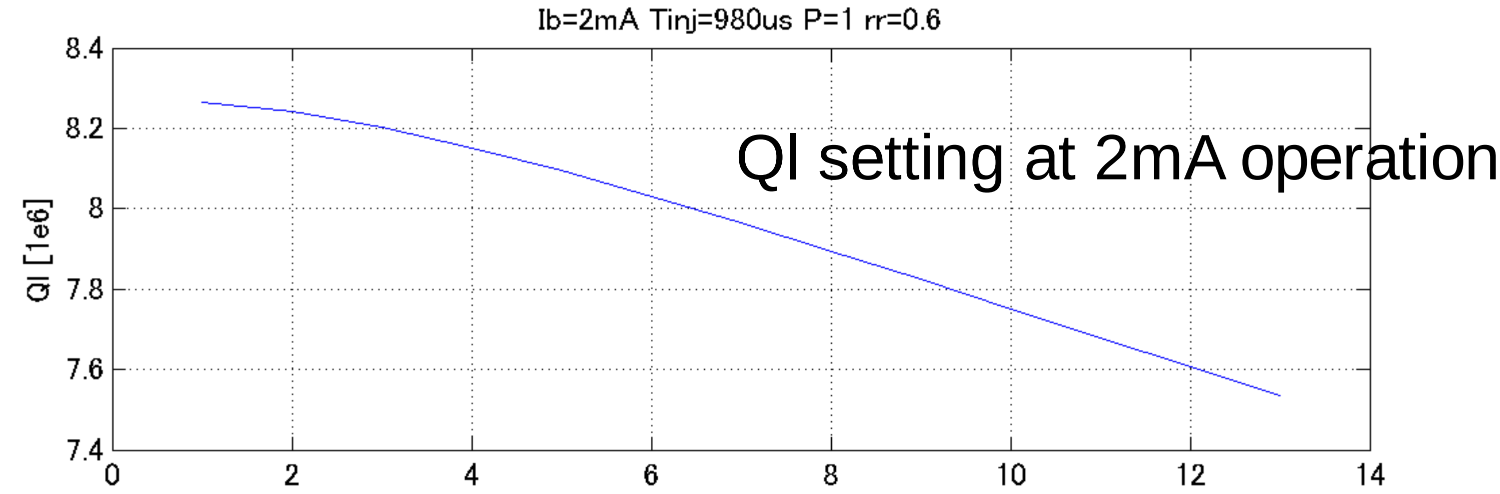
Low gradient cavity shows the gradient ~5% higher.

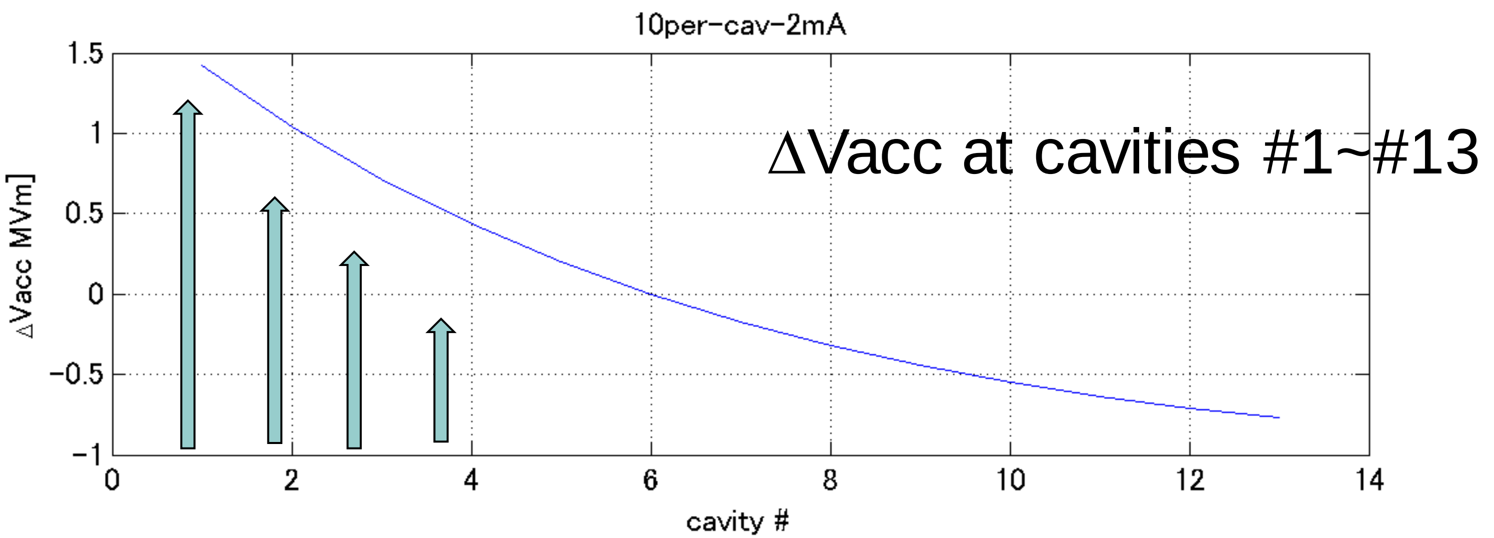
Performance at 4mA



Lowest gradient cavity slightly exceeds the 6mA operated gradient.

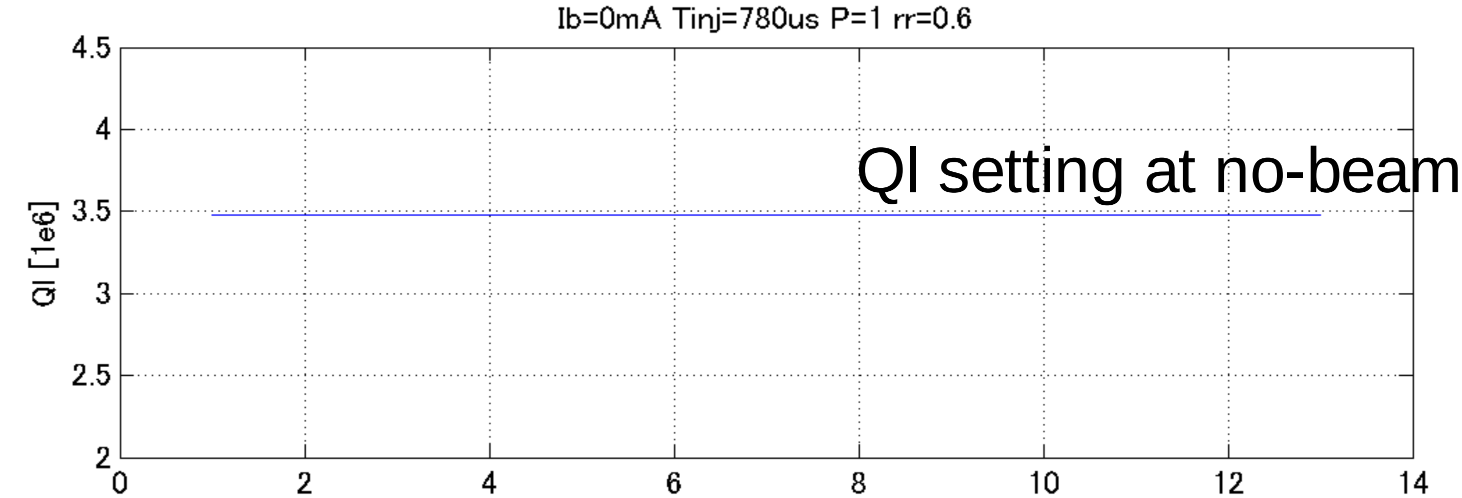
Performance at 2mA



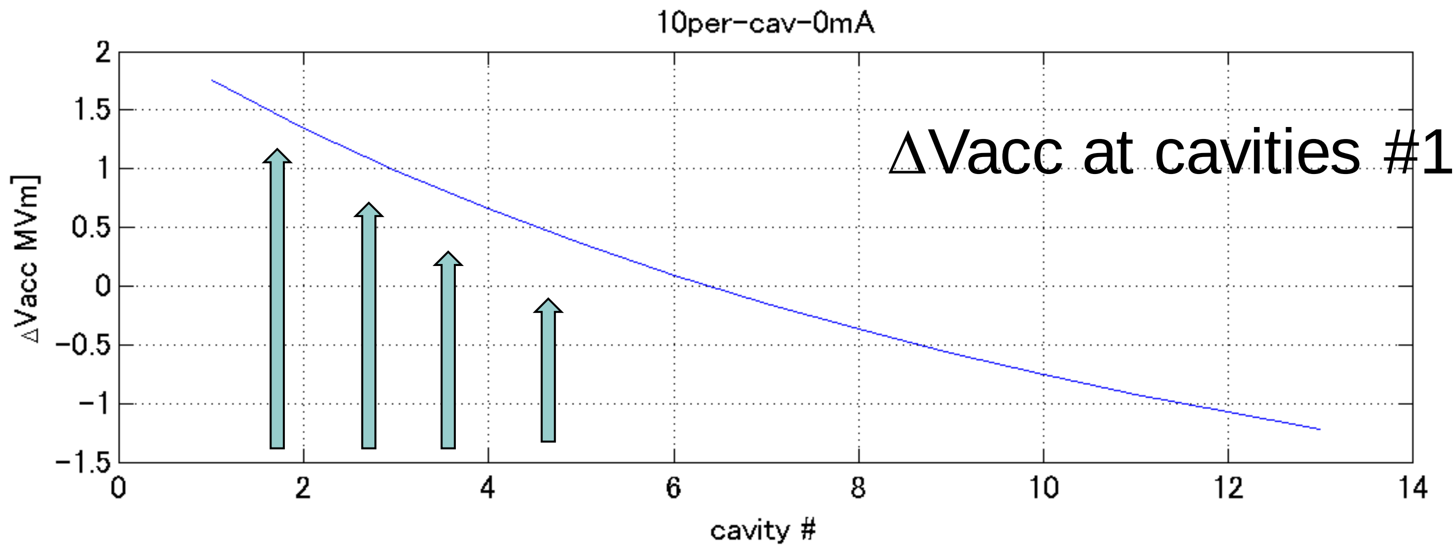


Lower 4 cavities slightly exceed their Vacc value at 6mA.

Performance at 0mA



Ql setting at no-beam operation



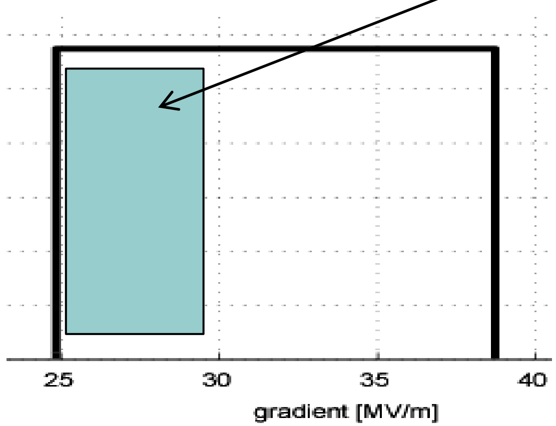
ΔVacc at cavities #1~#13

Lower 4 cavities slightly exceed their Vacc value at 6mA.

Performance at various Ibeam

Ibeam [mA]	Filling [us]	Pin	rr	Additional Vacc [MV/m]	Additional Vacc [%]
6	850	1	1	0	0
4	930	1	0.8	0.57	2.00
2	980	1	0.6	1.42	5.00
0	780	1	0.6	1.75	6.15

28.5MV/m~30MV/m cavities should be operated <10% than quench limit.
-> In case of the rectangular gradient variation, 28.5~30MV/m cavities are 4/13(=31%)
Average gradient of 28.5-30MV/m=29.25MV/m
5% more margin than nominal cavities; 29.25*0.05*0.31/31.5=0.014 (=1.4%)
Total accelerating energy decrease ~1.4% in case of the semi-fixed Pks configuration with 10% gradient variation..



Summary

- Semi-fixed Pks are simulated.
- Solution (1); Ql proportional to beam current
  - Perfect cavity gradient with any beam current
  - Huge filling time (and huge Ql (~7e7)) is required at low current (such as 1mA).
- Solution (2); Filling time,Ql adjustment to minimize the difference in operational gradient under 20% cavity gradient variation.
  - 15% gradient increase at lower gradient cavity.
  - Such cavities should be operated at lower gradient at 6mA.
  - Rough estimate indicates **we lose 5% acc. energy** (or 5% longer ML is required.)
- Solution (3); Filling time,Ql adjustment to minimize the difference in operational gradient under 10% cavity gradient variation.
  - 5% gradient increase at lower gradient cavity.
  - Such cavities should be operated at slightly lower gradient at 6mA.
  - Rough estimate indicates **we lose 1.5% acc. energy** (or 1.5% longer ML is required.)
- In addition to these difference in cavity gradient with various beam current, we should include the tolerance of the Pks.

Thank you for your attention