for the Simple
Highest Gradient Operation

Part – I

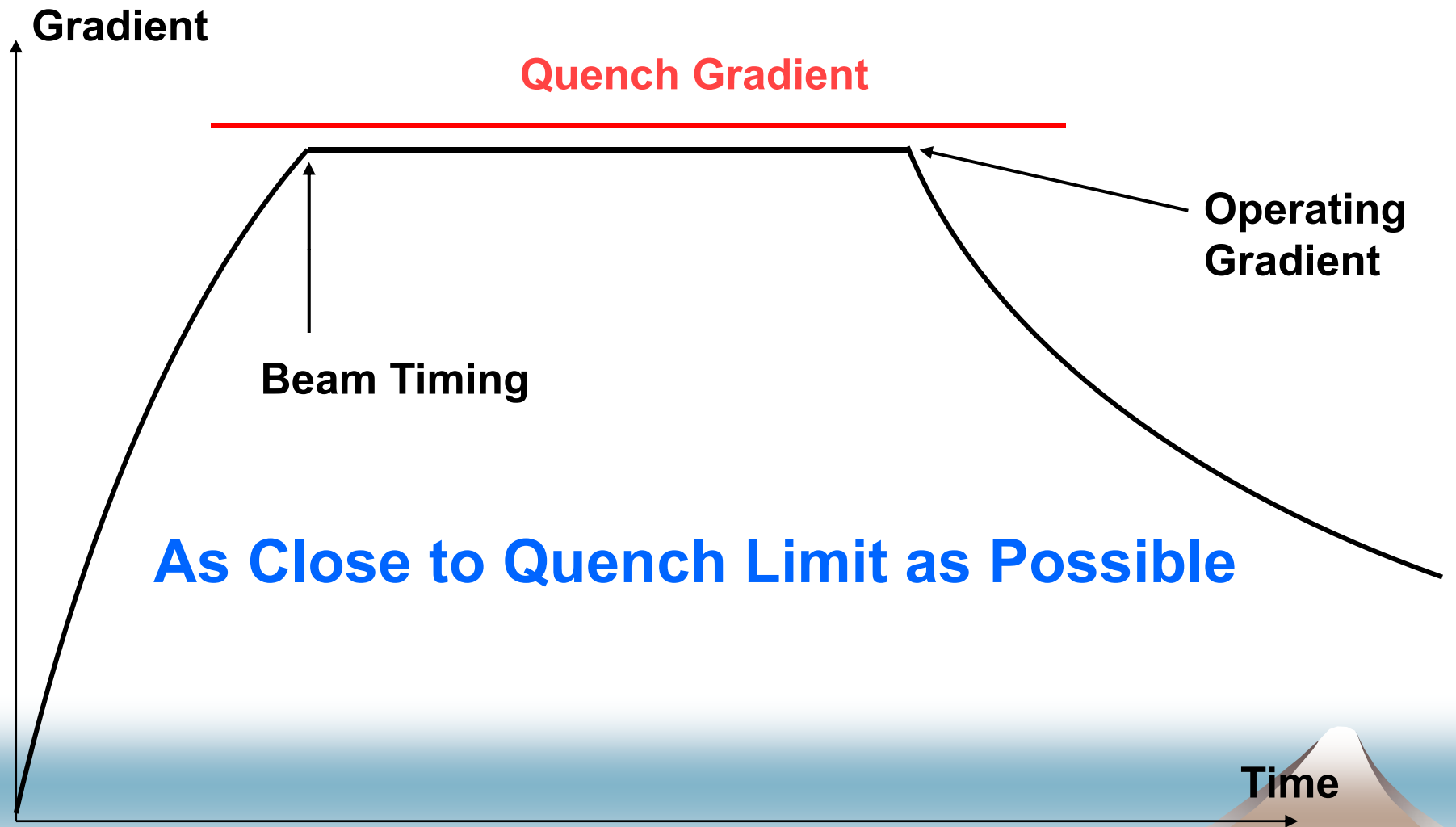
Grouping Concept

for Scattered Cavity Gradient.

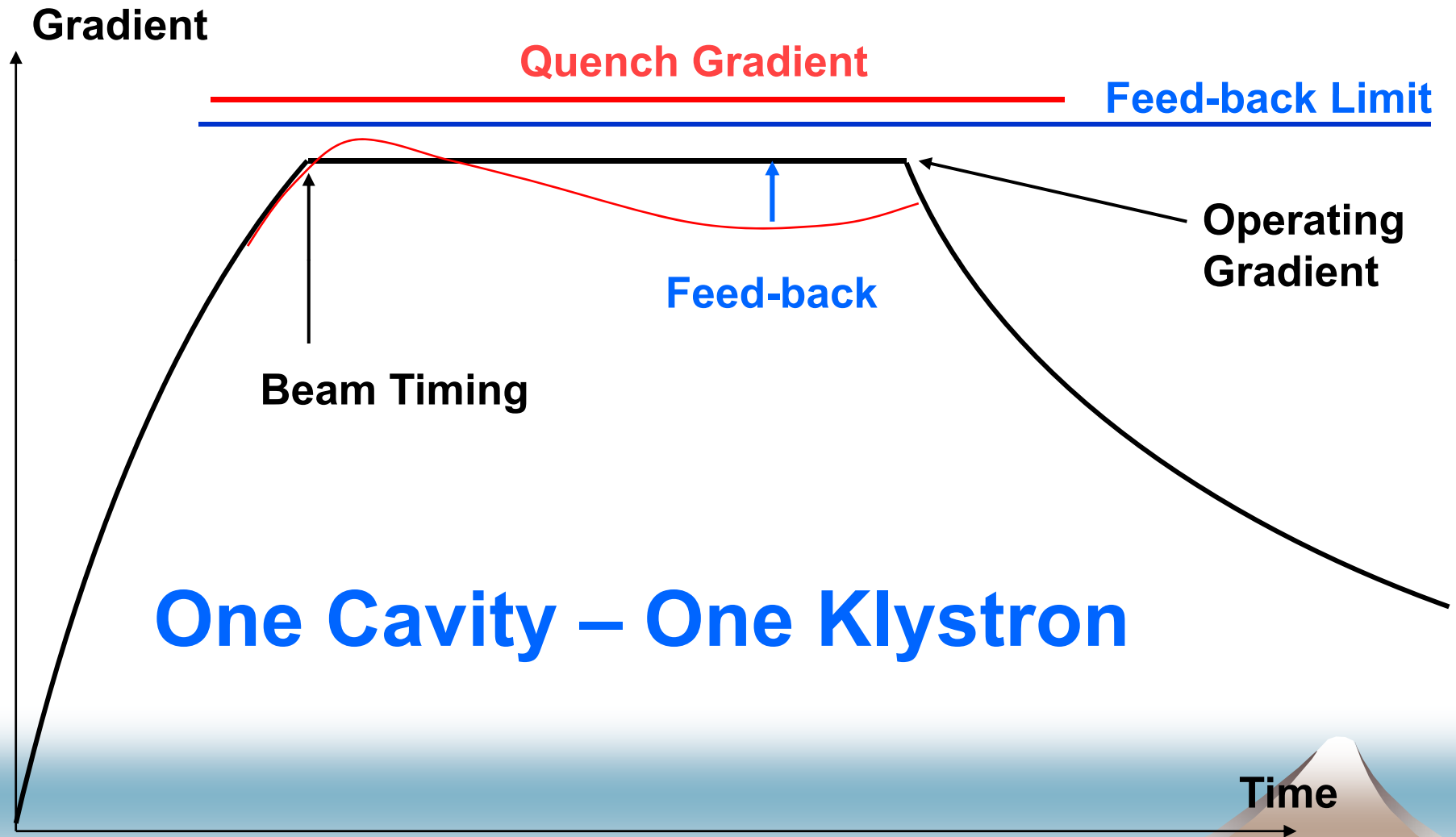
Part – II

Fixed Coupling.

Highest Gradient Operation



Highest Gradient Operation

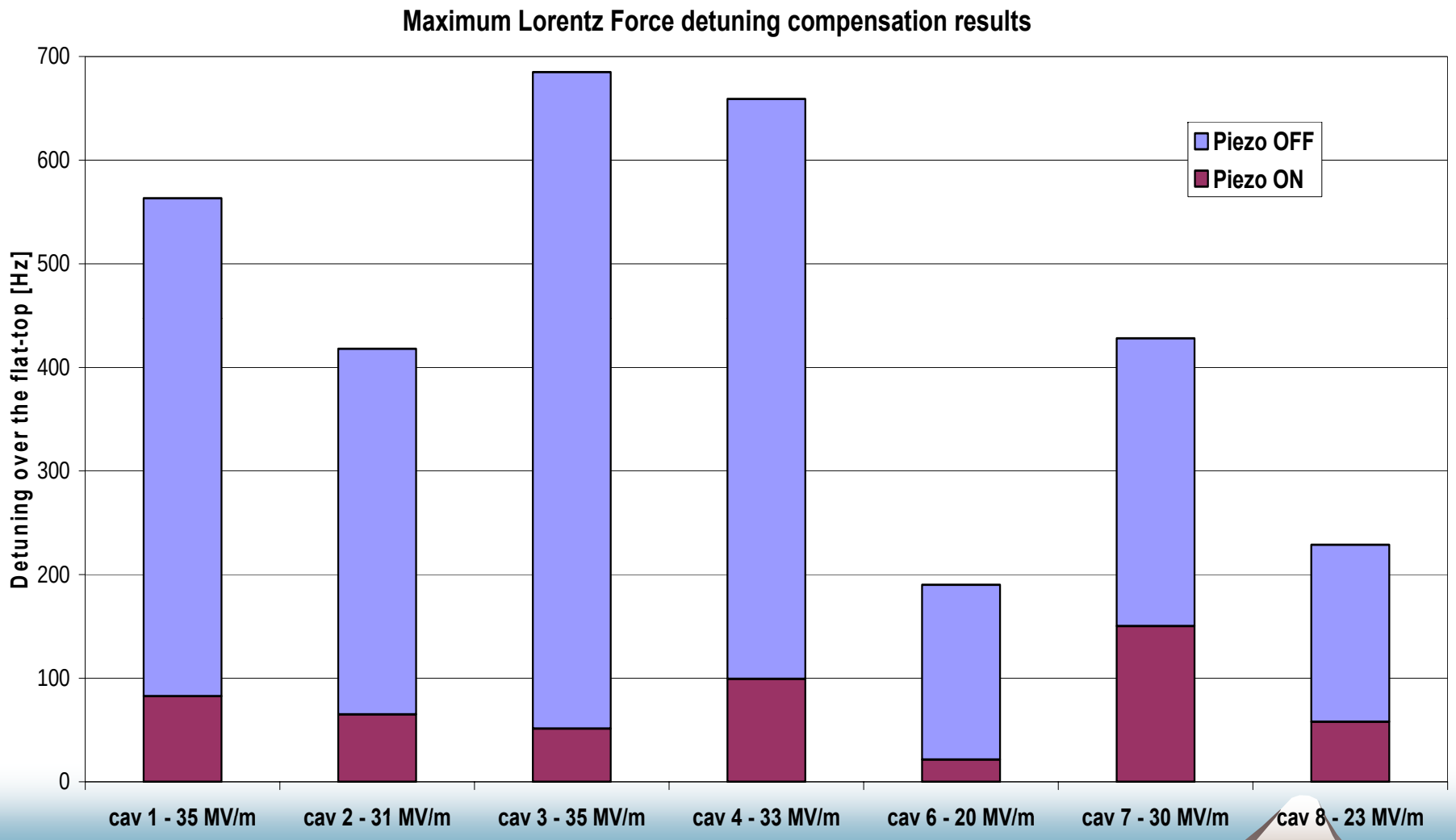


One Cavity – One Klystron

Error Souses of Operating Gradient

Error Souse	Error	Effect on Energy Gain	
Input Coupling Geometric + Field Flatness	15%	+1.9, -2.3%	Fixed
Power Dividing Ratio	2%	+1.5, -1.6%	Fixed
Input Power Phase	3 deg.	-0.14%	Fluctuation
Lorentz Detuning Compensation Error	50 Hz 13 deg.	-5.1%	Some Fluctuation

DLD Compensation Error

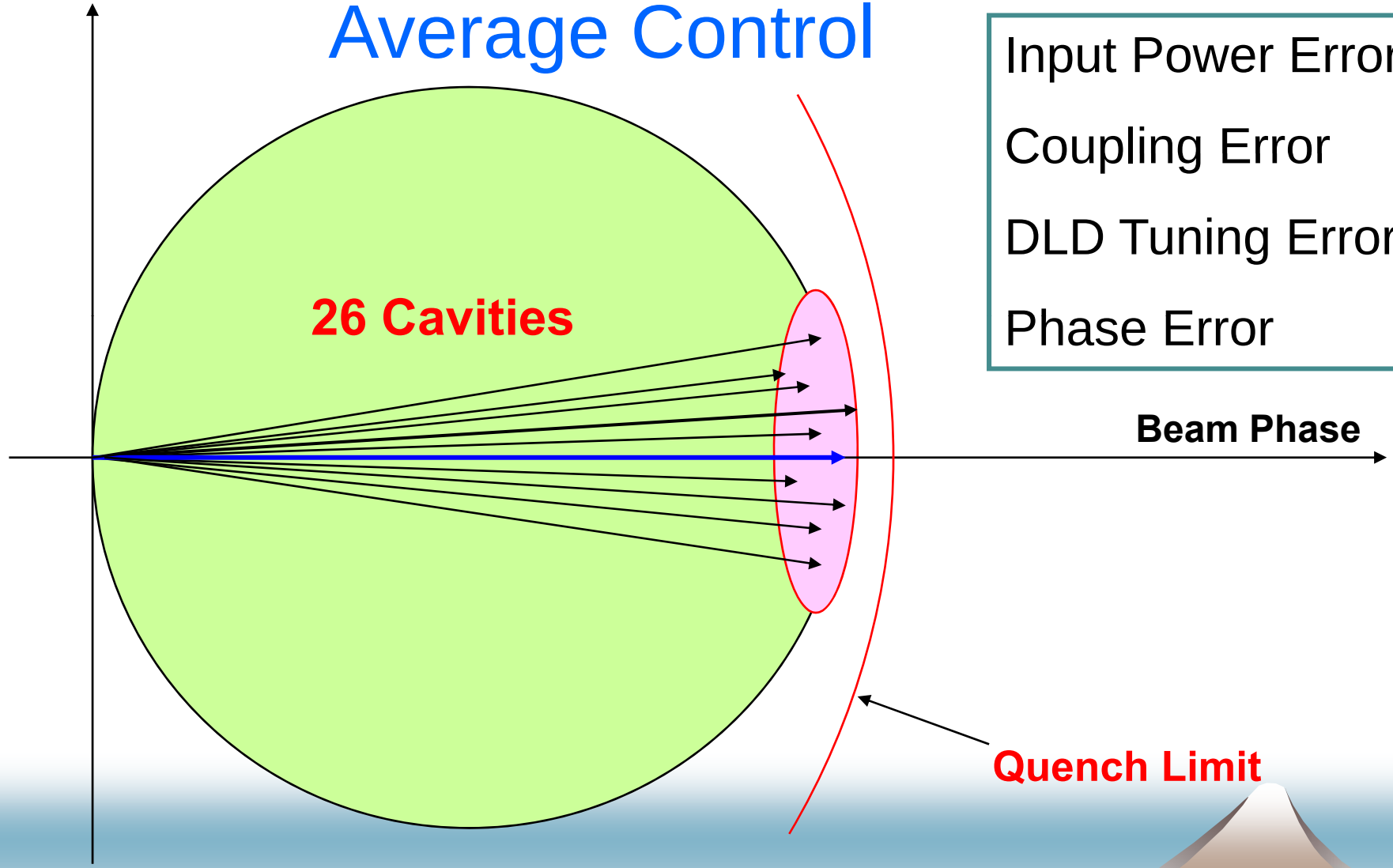


Operating Condition in ILC - ML

- 26 Cavities are Driven by One Klystron.
- Scatter of Cavity Gradient Performance.
- Design Maximum Klystron Power is
  8 MW + Feed-back Margin (15 %).
- Maximum Pulse Width is 1.6 msec.
- Cavities above 150 GeV are used in
  Deceleration Mode, also.
- Lower Beam Current Operation.

Vector Sum Control

Average Control



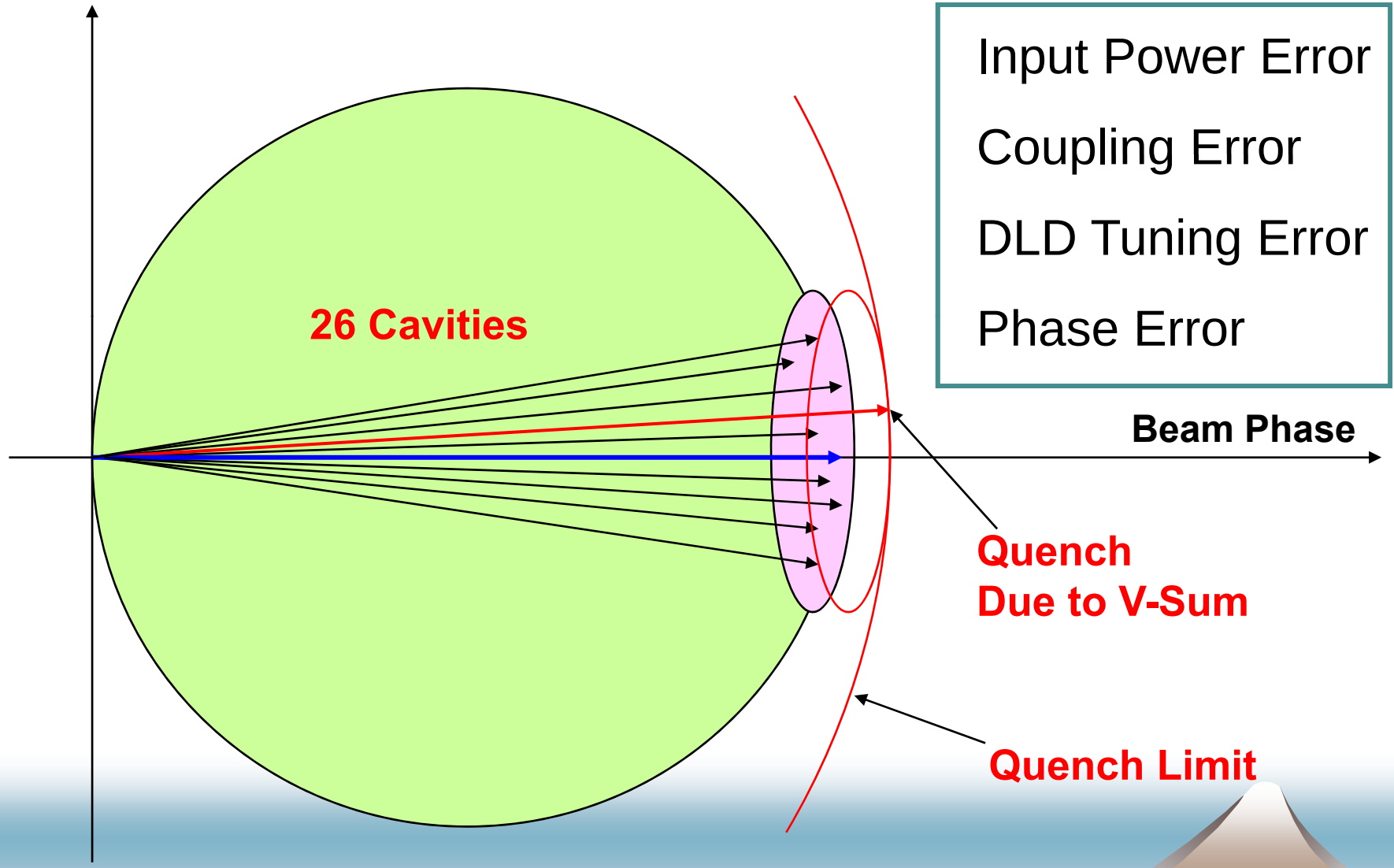
Input Power Error

Coupling Error

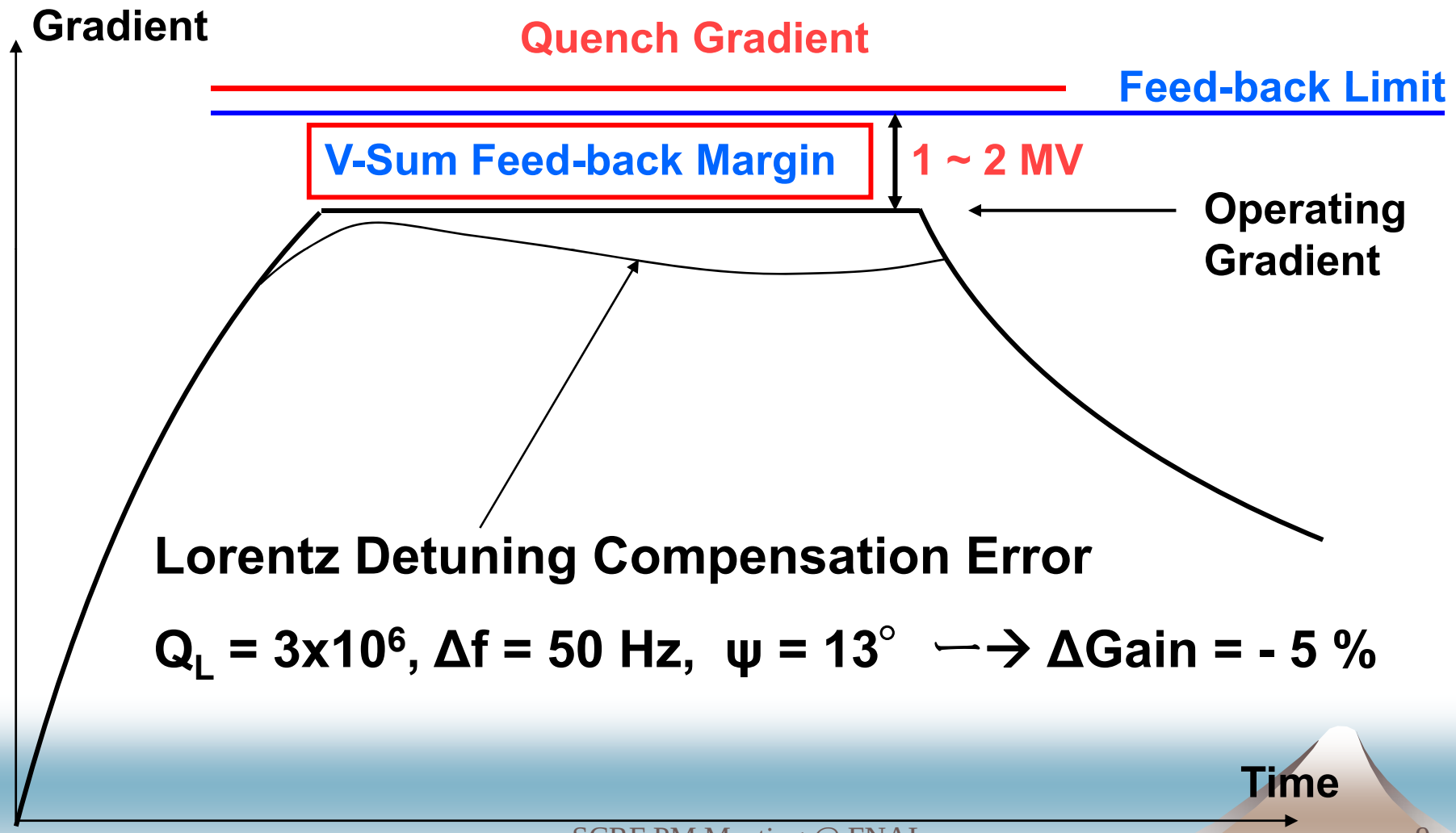
DLD Tuning Error

Phase Error

Vector Sum Control

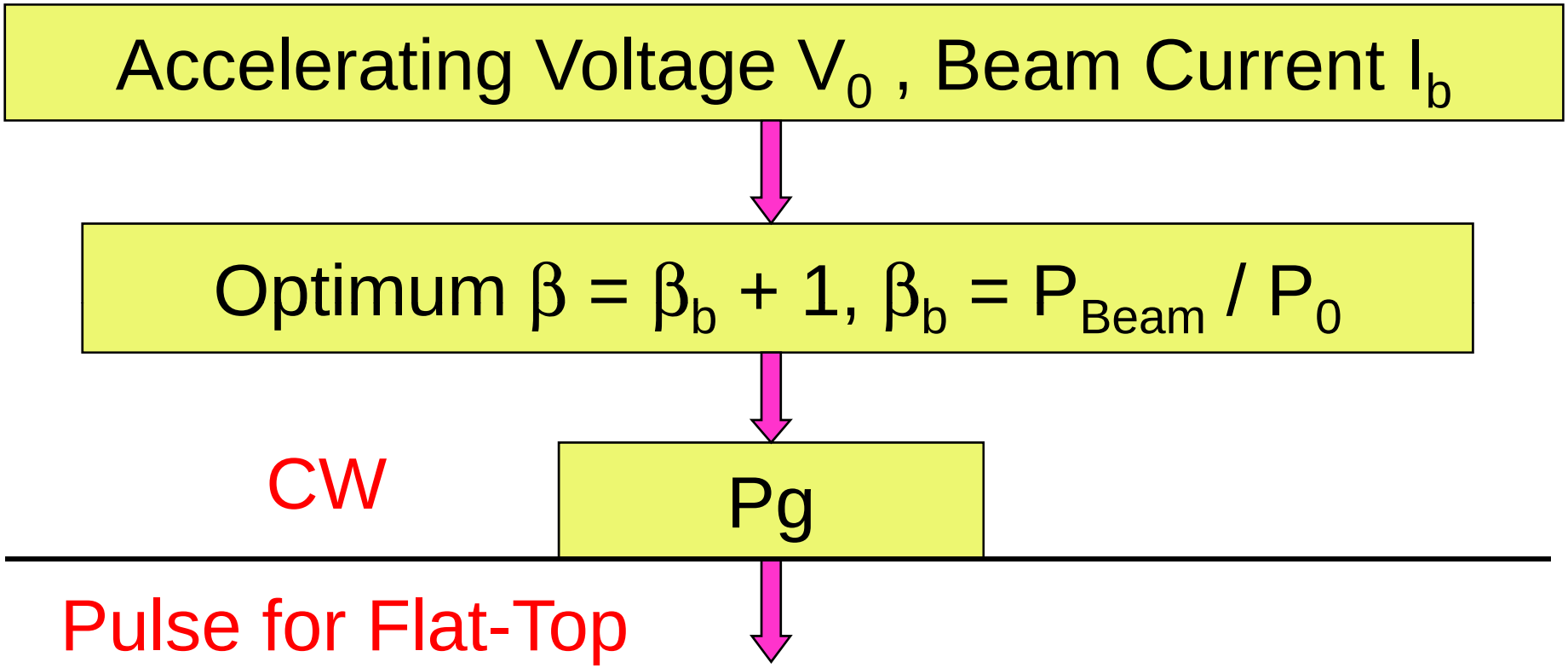


Highest Gradient Operation



Part – I
Grouping Concept

Parameter Setting for Flat-Top



Cavity Voltage

at the CW Limit

$$\vec{V} = \left[2\sqrt{P_g \left(\frac{R}{Q}\right) Q_o \frac{\beta}{(1+\beta)^2}} \exp(j\theta) - I_b \left(\frac{R}{Q}\right) Q_o \frac{1}{1+\beta} \right] \cos\psi \exp(j\psi)$$

Feedback works fine.

Cavity Voltage

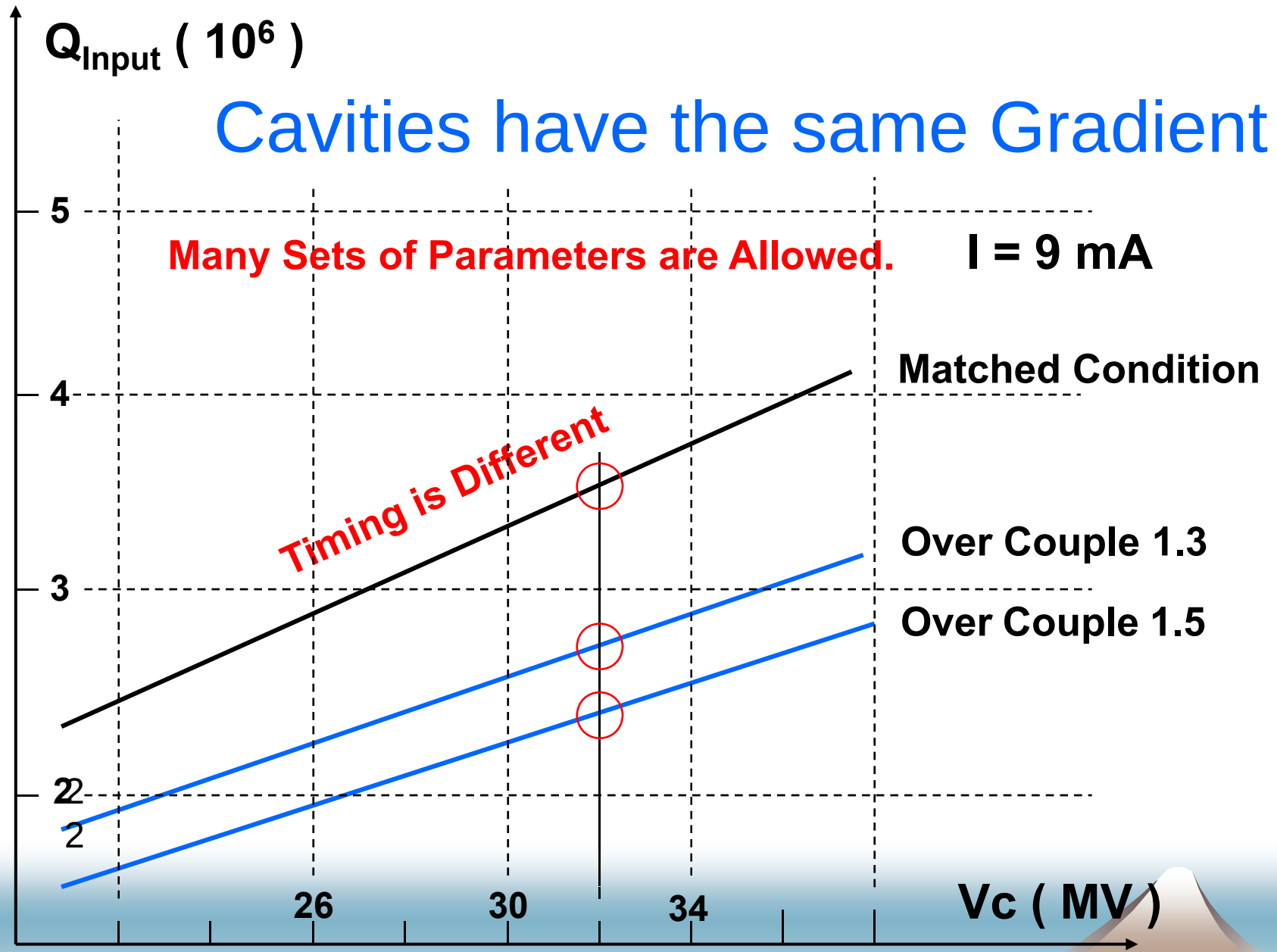
During Build-up

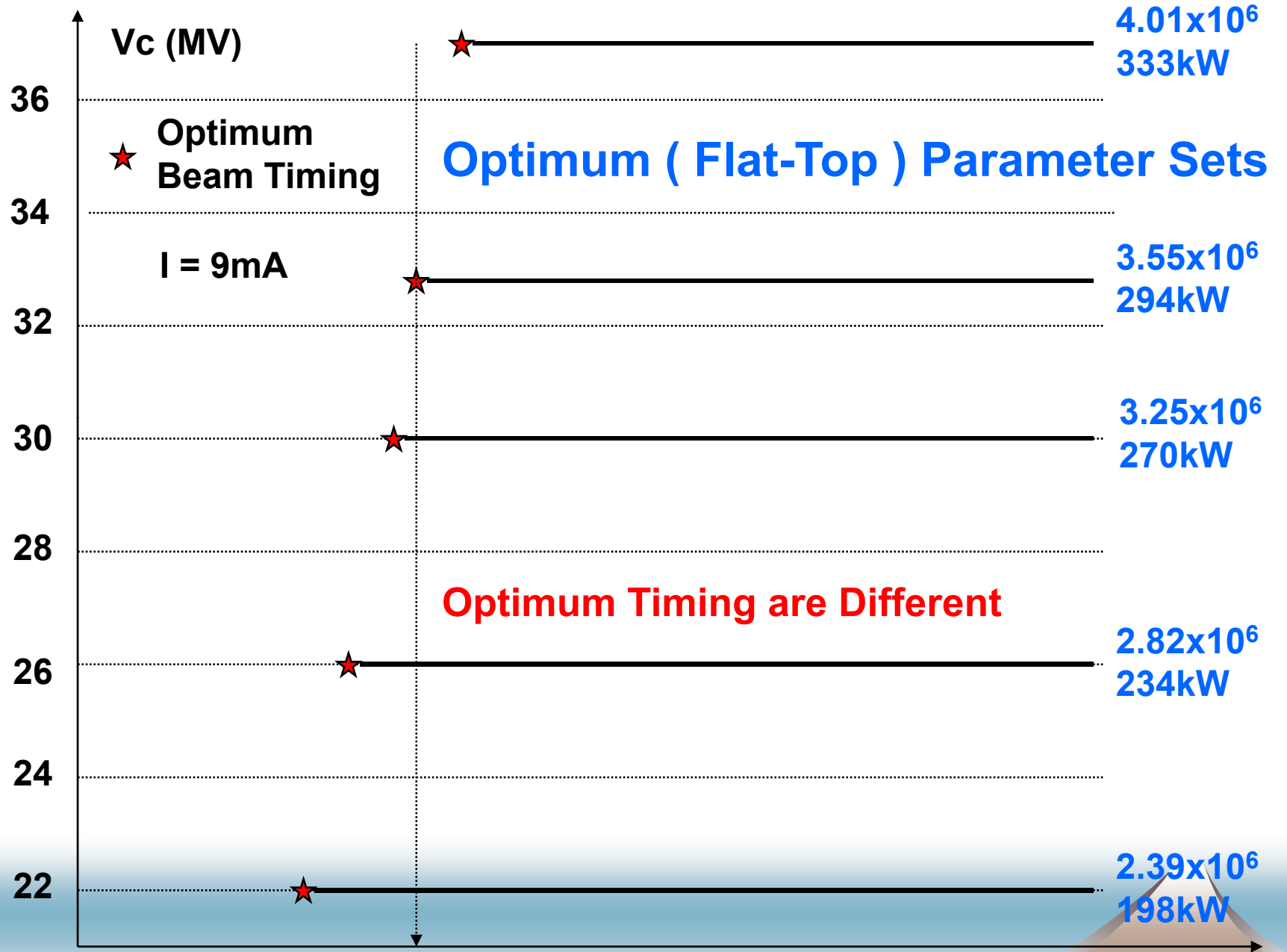
$$\vec{V} = V_d \left[1 - \exp\left(-\frac{t}{T_F} \right) \exp\left(j \frac{\tan\psi}{T_F} t \right) \right] \cos\psi \, \exp\{ j(\theta + \psi) \}$$

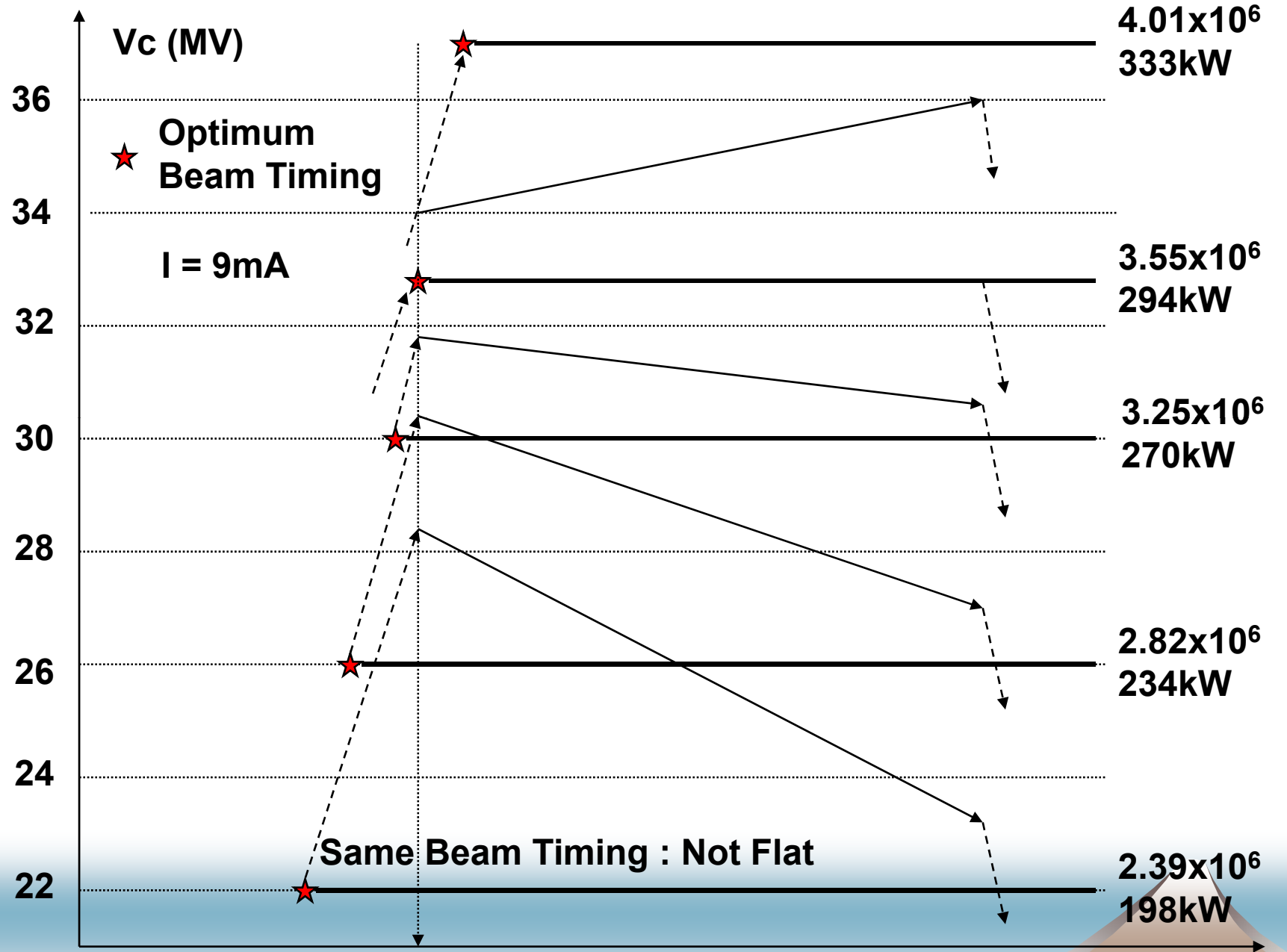
$$V_d = V_g = 2\sqrt{P_g \left(\frac{R}{Q} \right) Q_0 \frac{\beta}{(1+\beta)^2}}$$

$$\vec{V} = \vec{V}_{FlatTop} \quad \text{at Beam Timing } T_e = T_F \, \mathrm{In} \frac{1+\beta+\beta_b}{\beta_b}$$

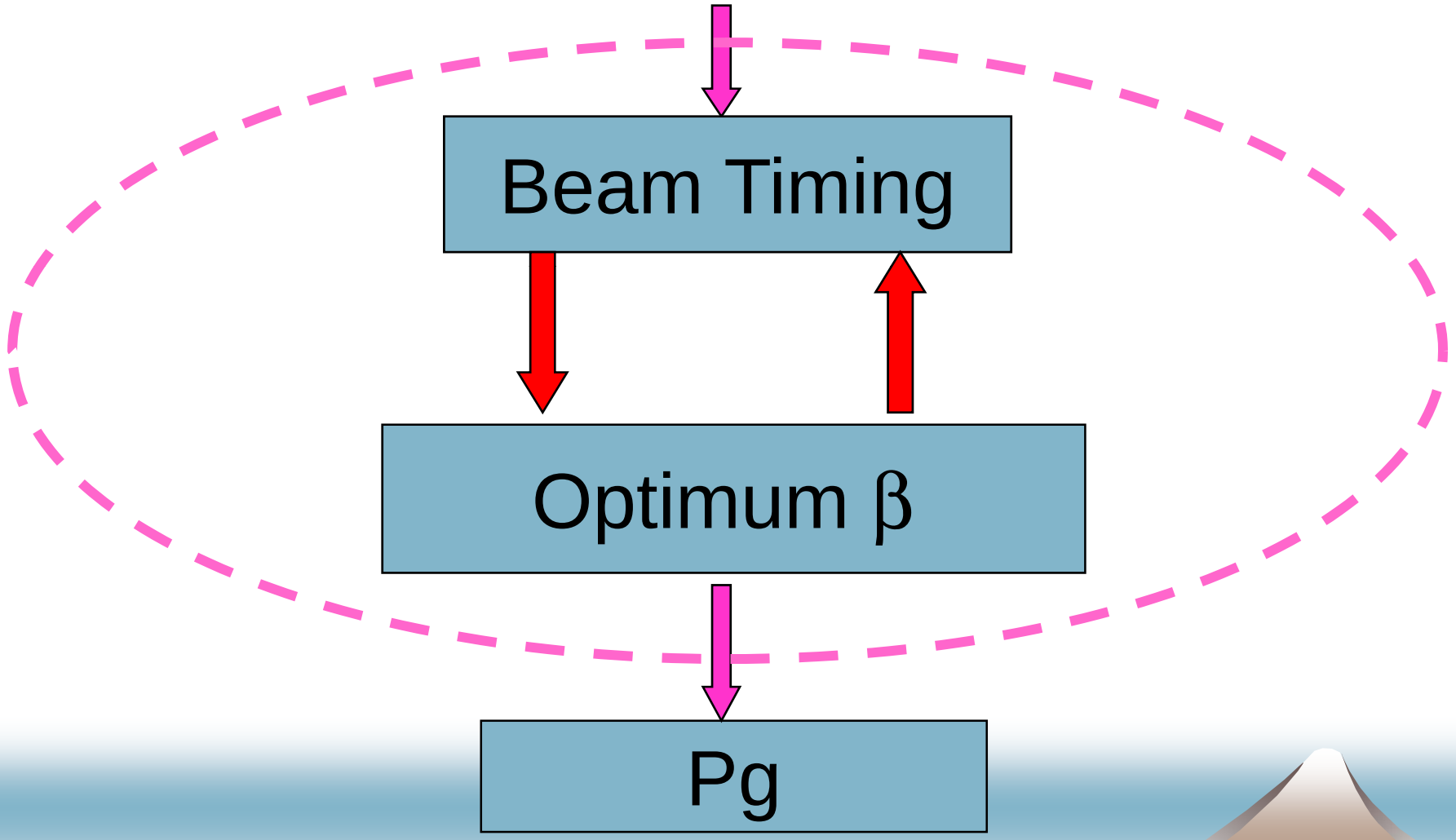
Cavities have the same Gradient

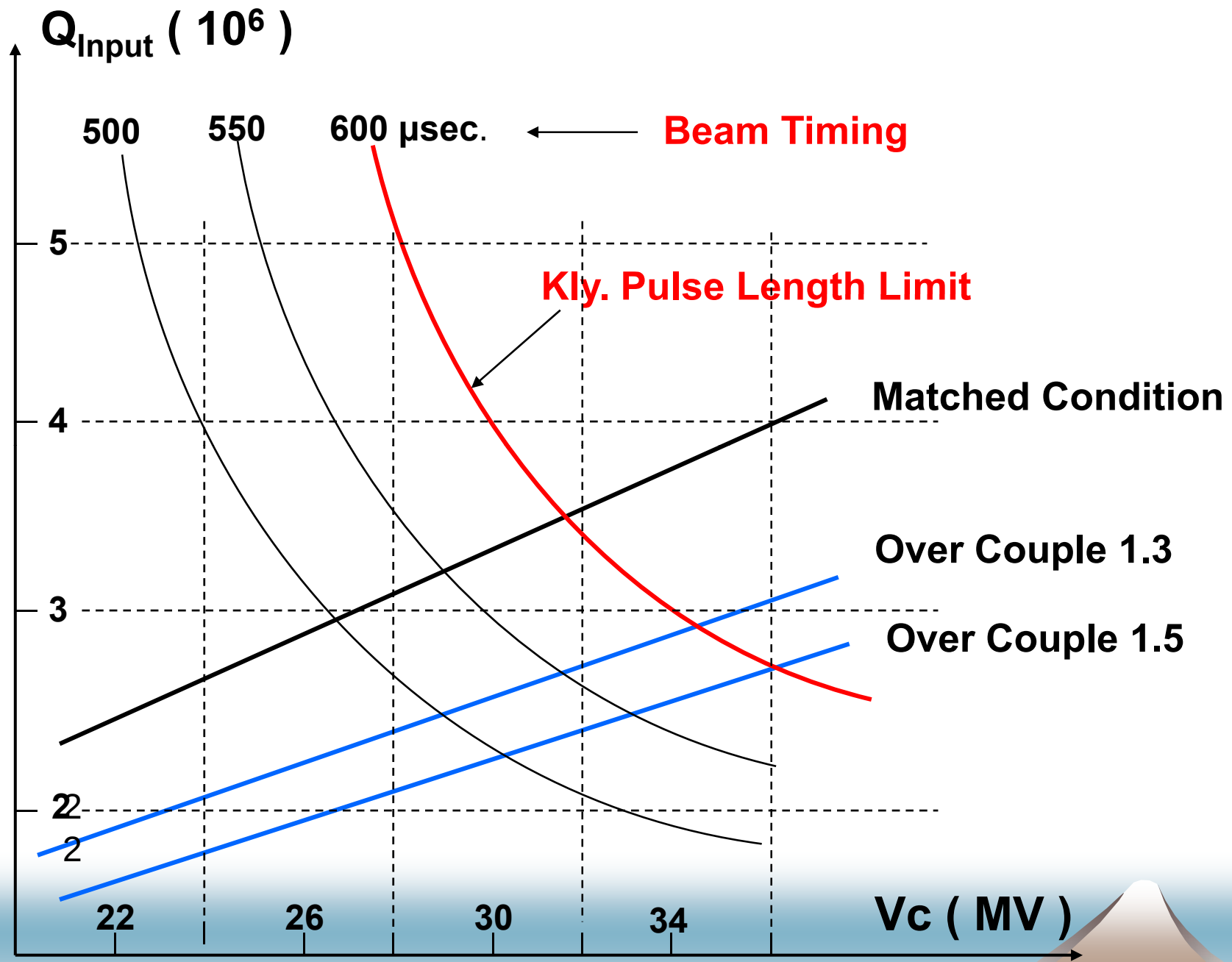


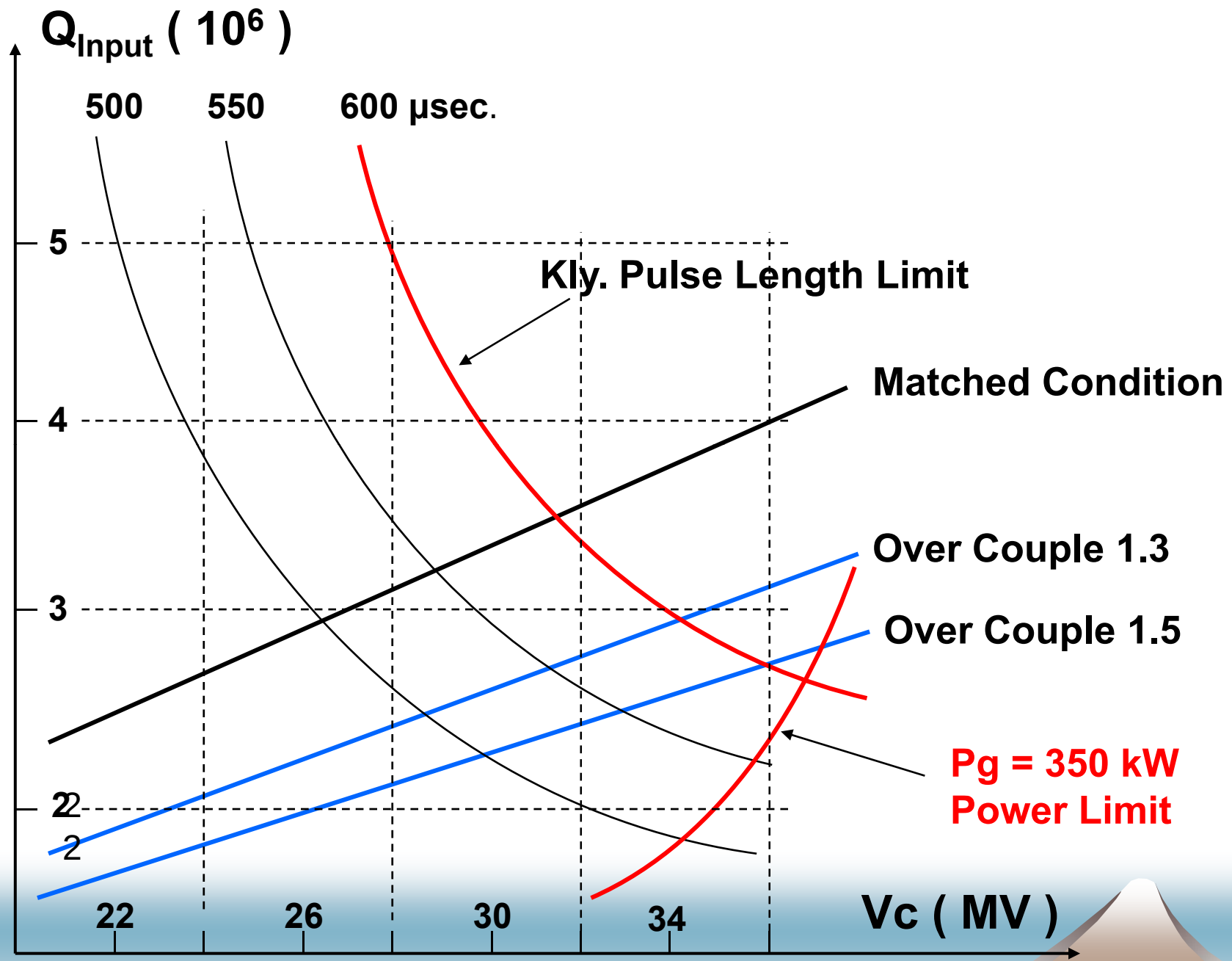

Vc (MV)
36
34
32
30
28
26
24
22
Optimum
Beam Timing
I = 9mA
Optimum (Flat-Top) Parameter Sets
4.01x10^6
333kW
3.55x10^6
294kW
3.25x10^6
270kW
Optimum Timing are Different
2.82x10^6
234kW
2.39x10^6
198kW
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Time (msec.)

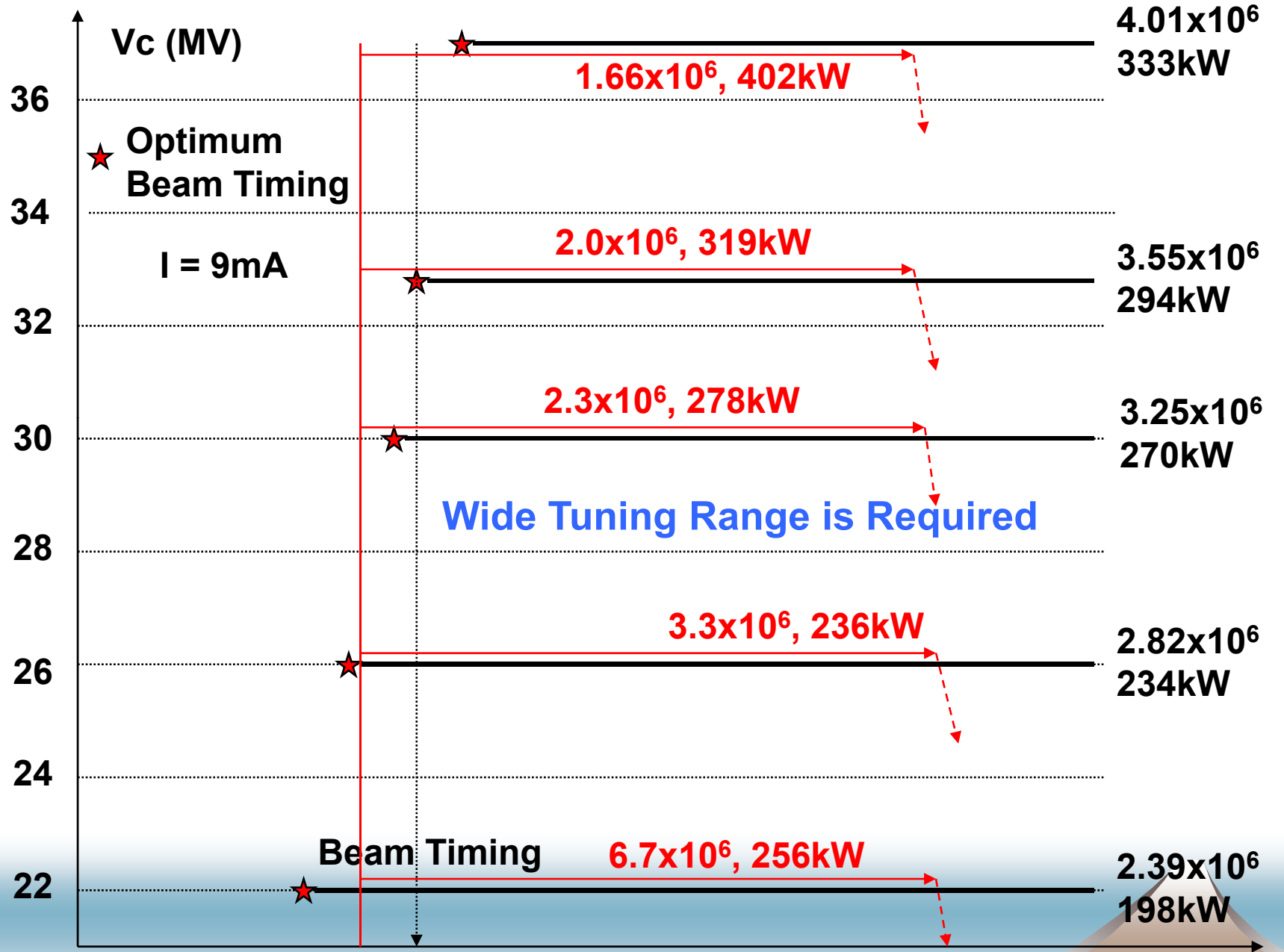

Vc (MV)
36
34
32
30
28
26
24
22
Optimum
Beam Timing
I = 9mA
4.01x10^6
333kW
3.55x10^6
294kW
3.25x10^6
270kW
2.82x10^6
234kW
2.39x10^6
198kW
Same Beam Timing : Not Flat
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Time (msec.)

Scattered Gradient, Beam Current I_b




Q_{Input} (10^6)
500
550
600 μsec.
Beam Timing
Kly. Pulse Length Limit
Matched Condition
Over Couple 1.3
Over Couple 1.5
5
4
3
2
2
22
26
30
34
Vc (MV)

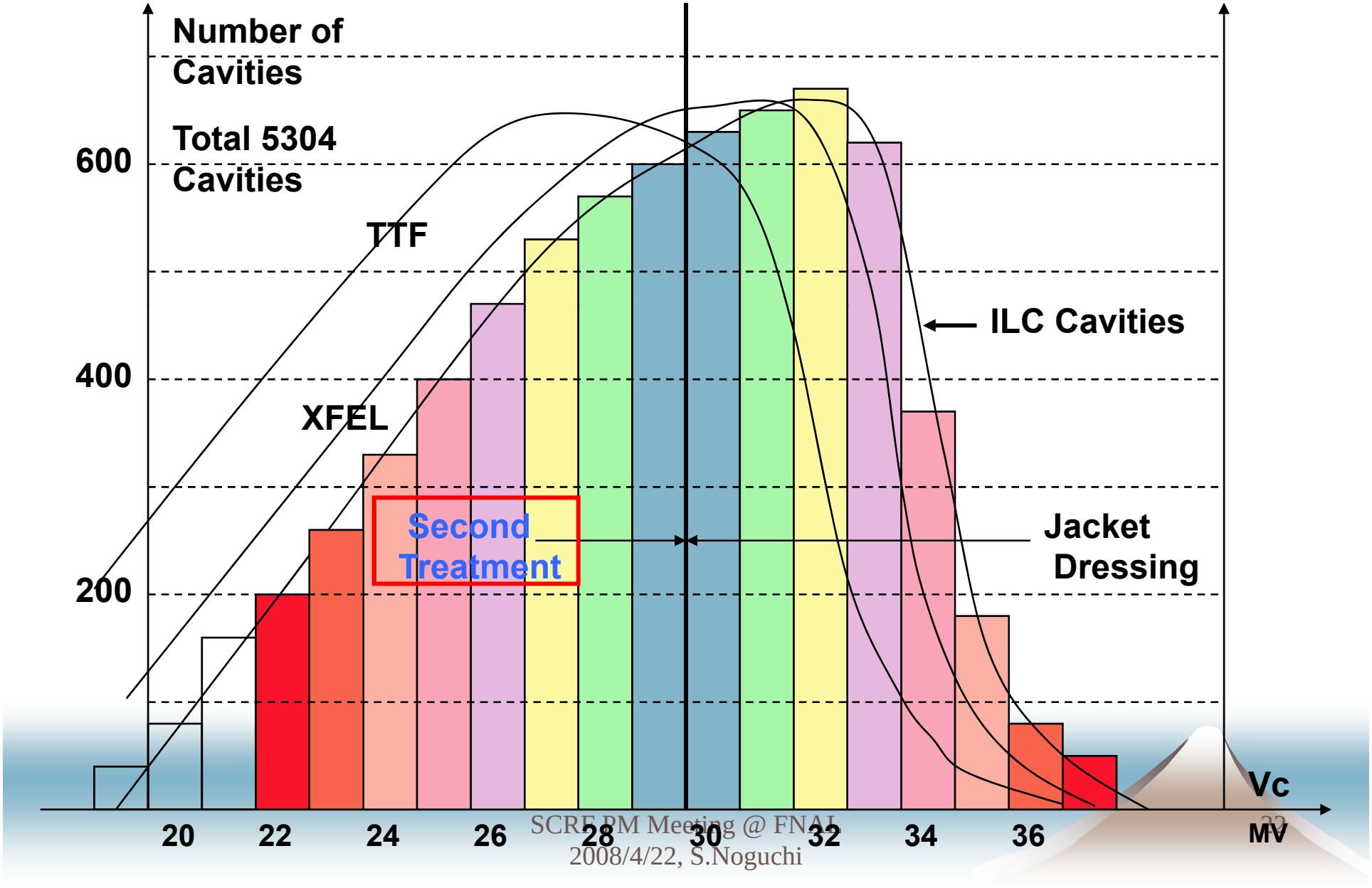

Q_{Input} (10^6)
500
550
600 μsec.
5
4
3
2
2
Kly. Pulse Length Limit
Matched Condition
Over Couple 1.3
Over Couple 1.5
Pg = 350 kW
Power Limit
22
26
30
34
Vc (MV)


Vc (MV)
36
34
32
30
28
26
24
22
Optimum
Beam Timing
I = 9mA
1.66x10^6, 402kW
4.01x10^6
333kW
2.0x10^6, 319kW
3.55x10^6
294kW
2.3x10^6, 278kW
3.25x10^6
270kW
Wide Tuning Range is Required
3.3x10^6, 236kW
2.82x10^6
234kW
Beam Timing
6.7x10^6, 256kW
2.39x10^6
198kW
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Time (msec.)

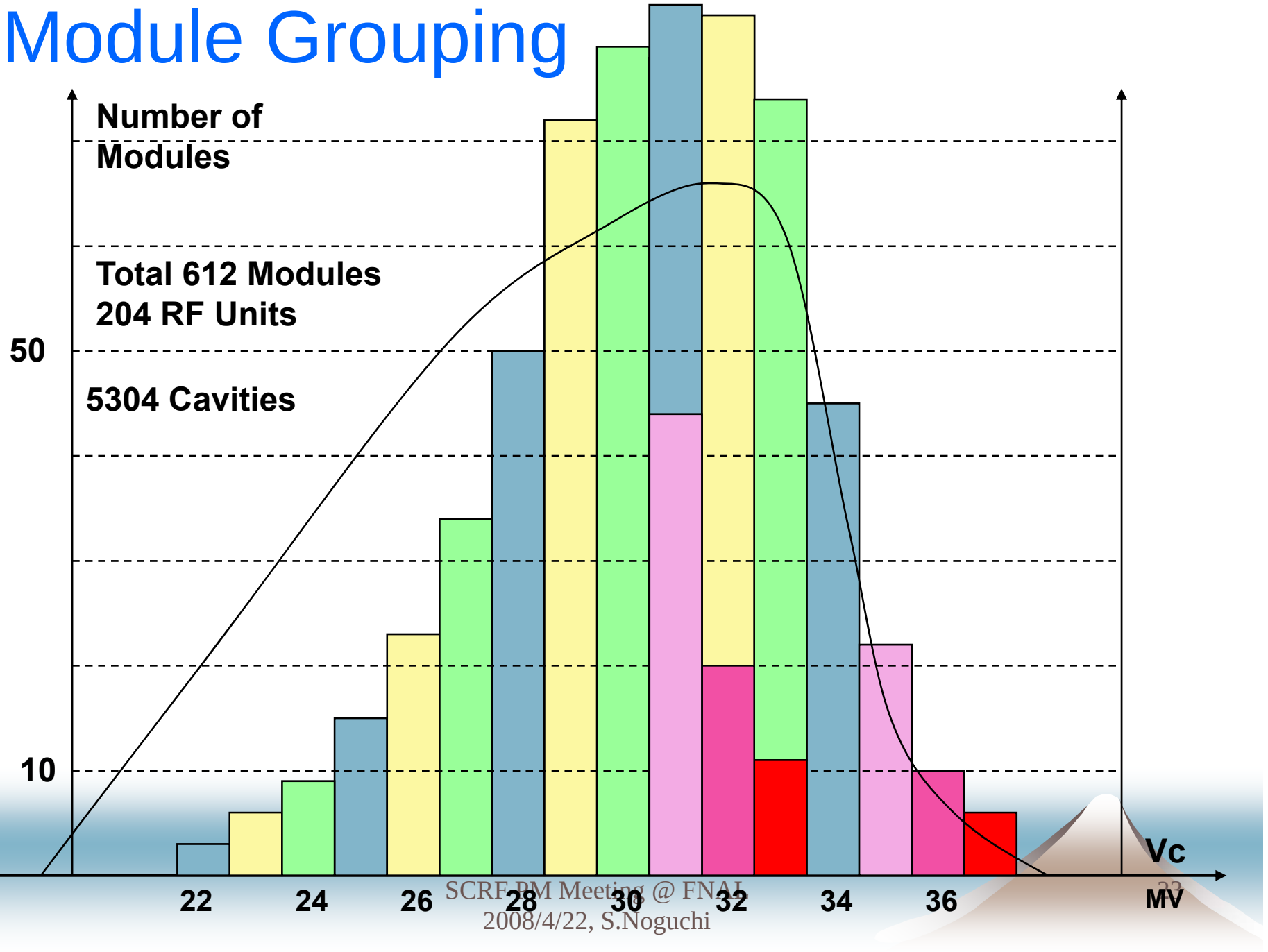
Cavity Grouping Concept

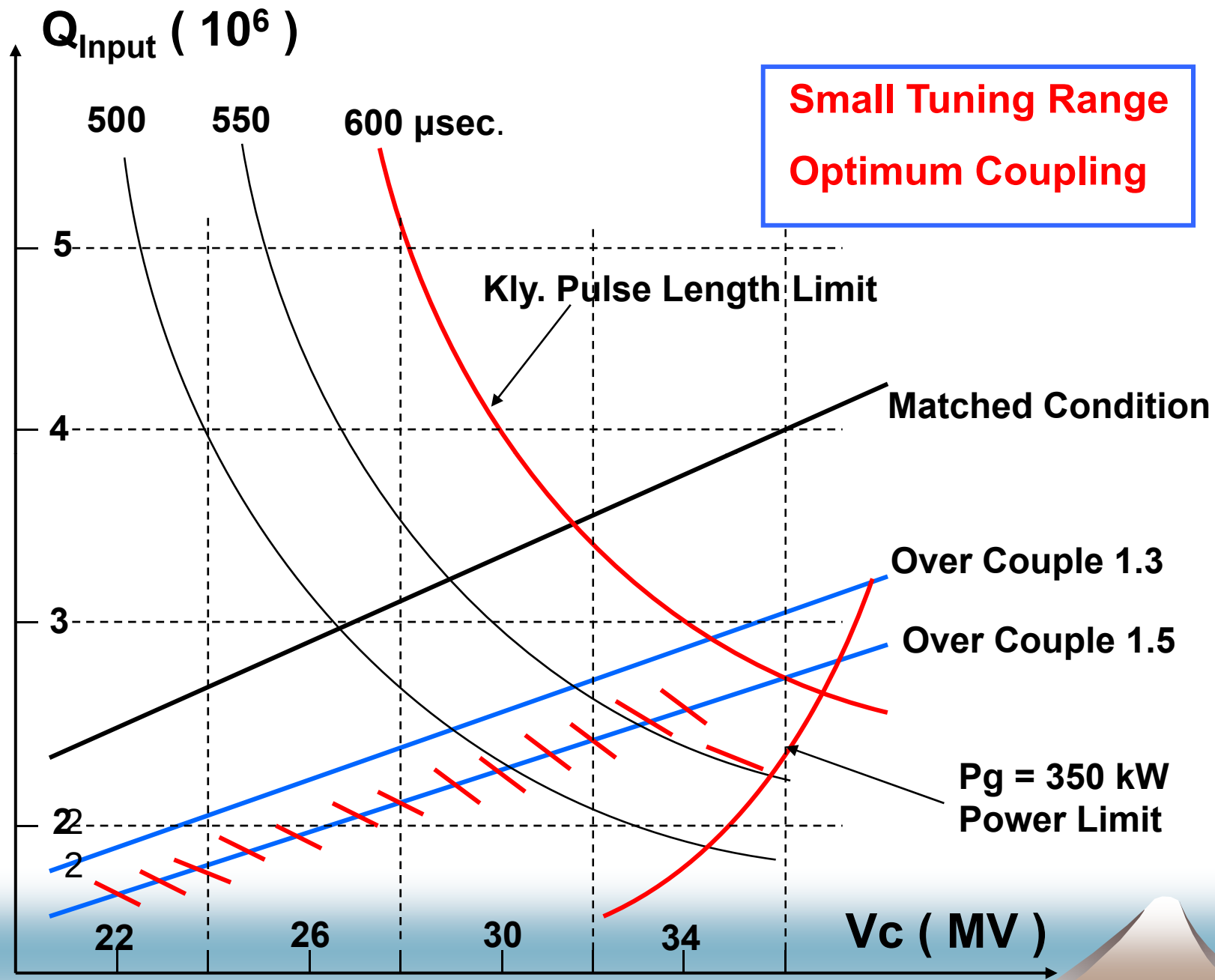
- Install the Cavities having nearly the same Maximum Gradient into the same Cryostat.
- Drive the same Gradient Cryomodules by one Klystron.
- Combine a high Gradient module with two other low Gradient Modules.

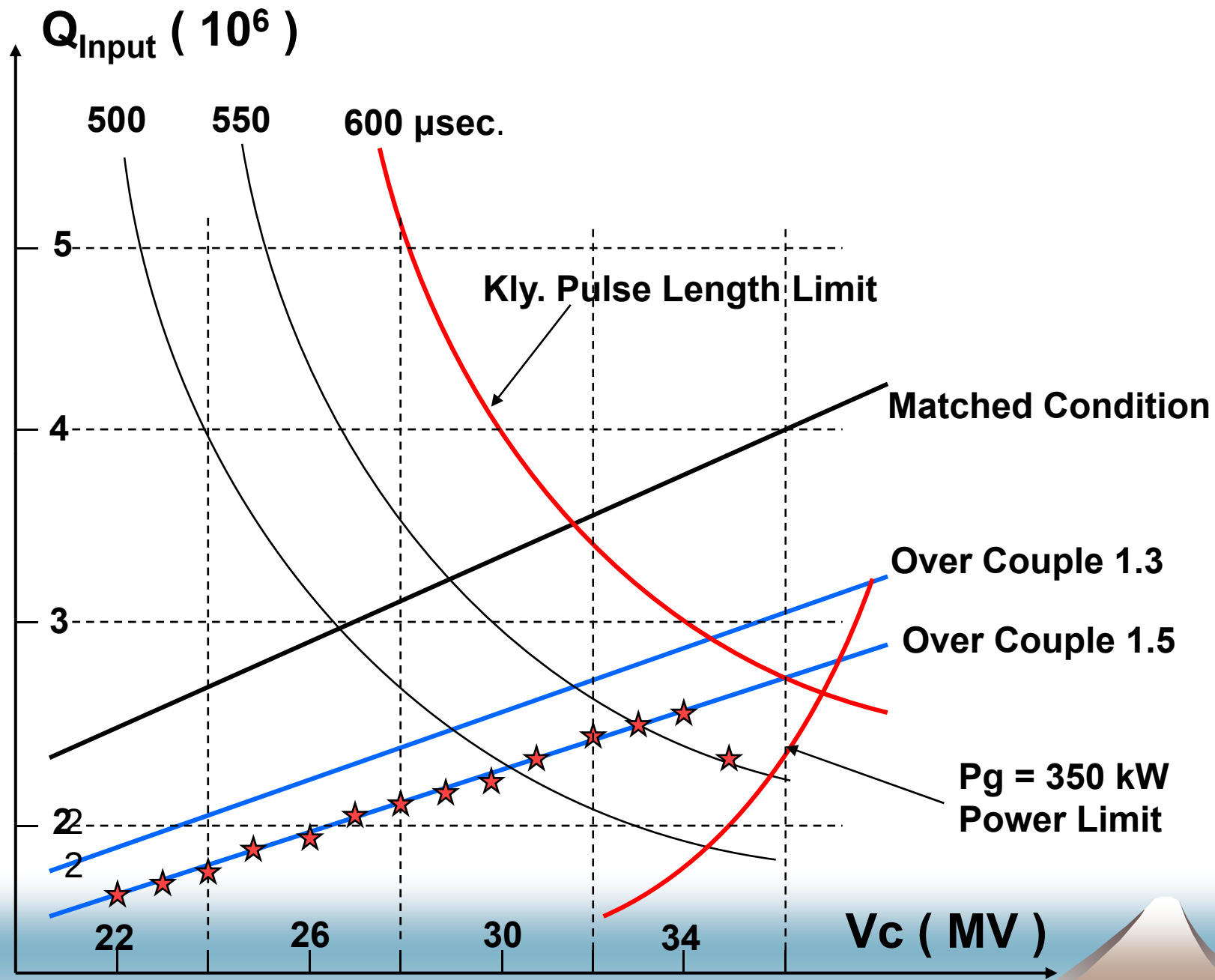
Cavity Grouping

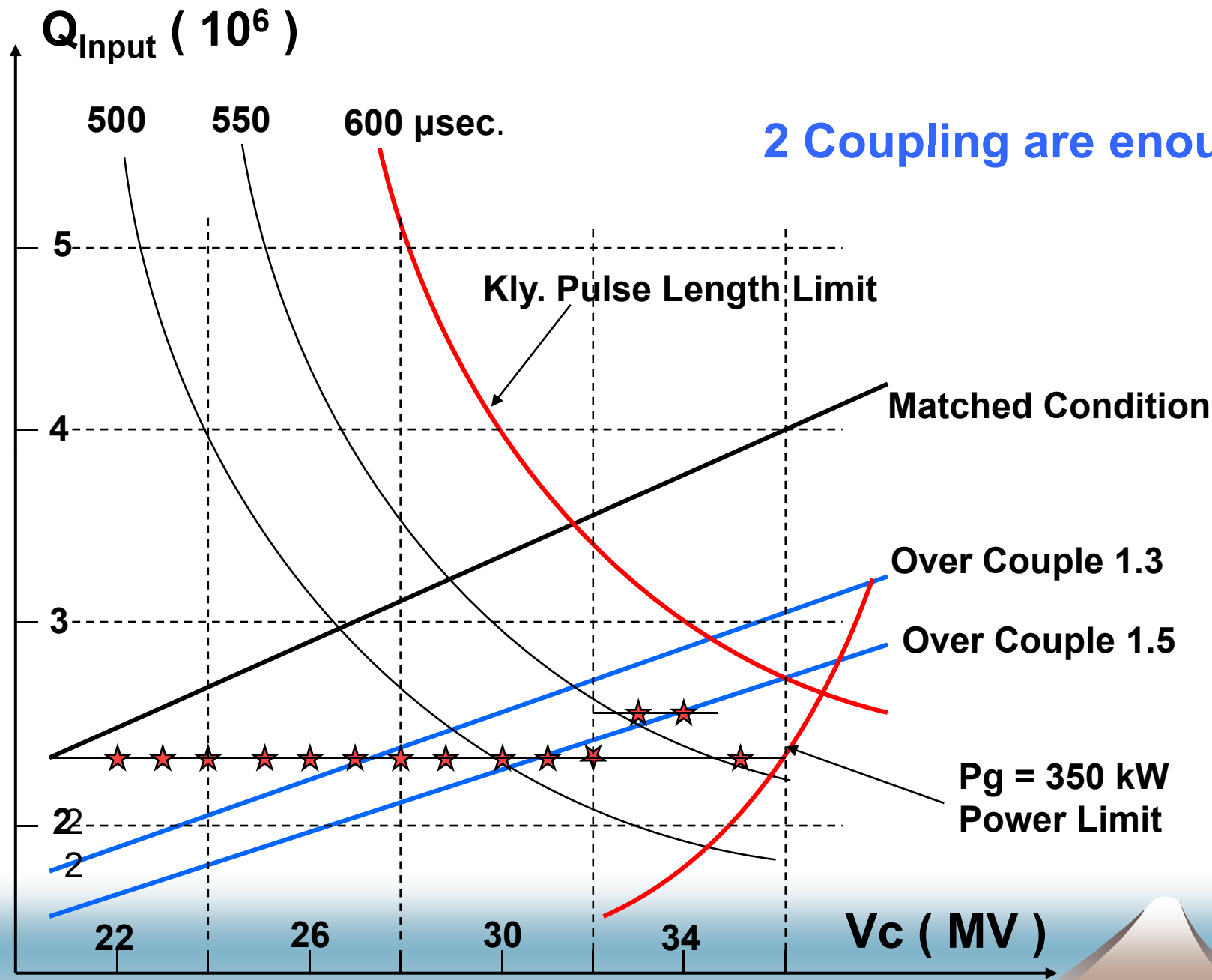


Module Grouping




Q_{Input} (10^6)
500
550
600 μsec.
Small Tuning Range
Optimum Coupling
5
4
3
2
2
Kly. Pulse Length Limit
Matched Condition
Over Couple 1.3
Over Couple 1.5
Pg = 350 kW
Power Limit
22
26
30
34
Vc (MV)


Q_{Input} (10^6)
500
550
600 μsec.
5
4
3
2
2
Kly. Pulse Length Limit
Matched Condition
Over Couple 1.3
Over Couple 1.5
Pg = 350 kW
Power Limit
22
26
30
34
Vc (MV)


Q_{Input} (10^6)
500
550
600 μsec.
2 Coupling are enough
5
4
3
2
Kly. Pulse Length Limit
Matched Condition
Over Couple 1.3
Over Couple 1.5
Pg = 350 kW
Power Limit
22
26
30
34
Vc (MV)

Part – II
Fixed Coupling

Tuning & Gradient Reduction in Grouped Cavities

- No Tuning
- Power Tuning
- Coupling Tuning
- Power & Coupling Tuning
- DLD Compensation Error is not Included.(Biggest Effect)

Error Souses of Operating Gradient

Error Souse	Error	Effect on Energy Gain	
Input Coupling Geometric + Field Flatness	15%	+1.9, -2.3%	Fixed
Input Power	1.8%	±1.4 %	Fixed
Input Power Phase	3 deg.	-0.14%	Fluctuation
Lorentz Detuning Compensation Error	50 Hz 13 deg.	-5.1%	Some Fluctuation

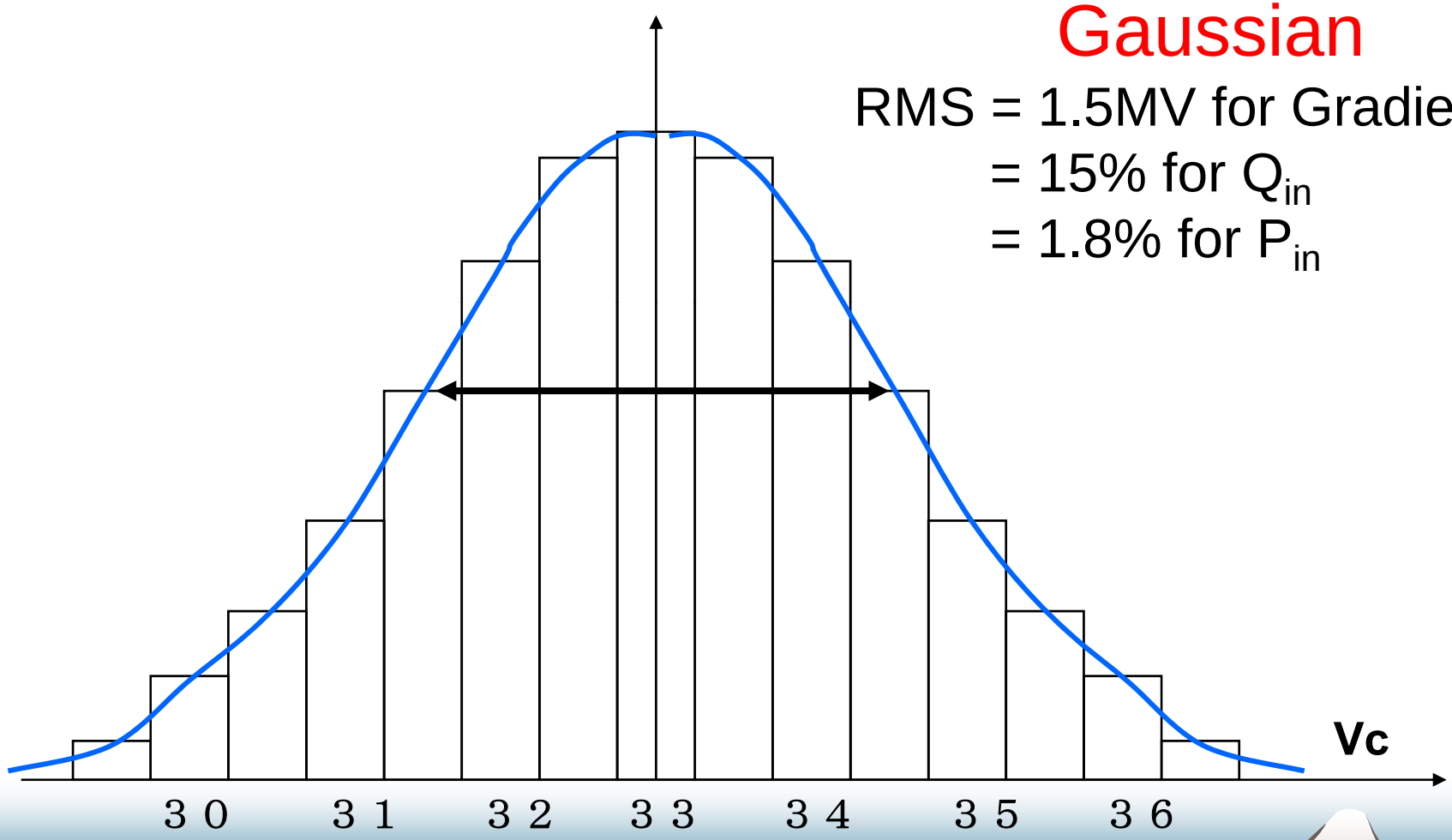
Realistic Gradient Distribution

Gaussian

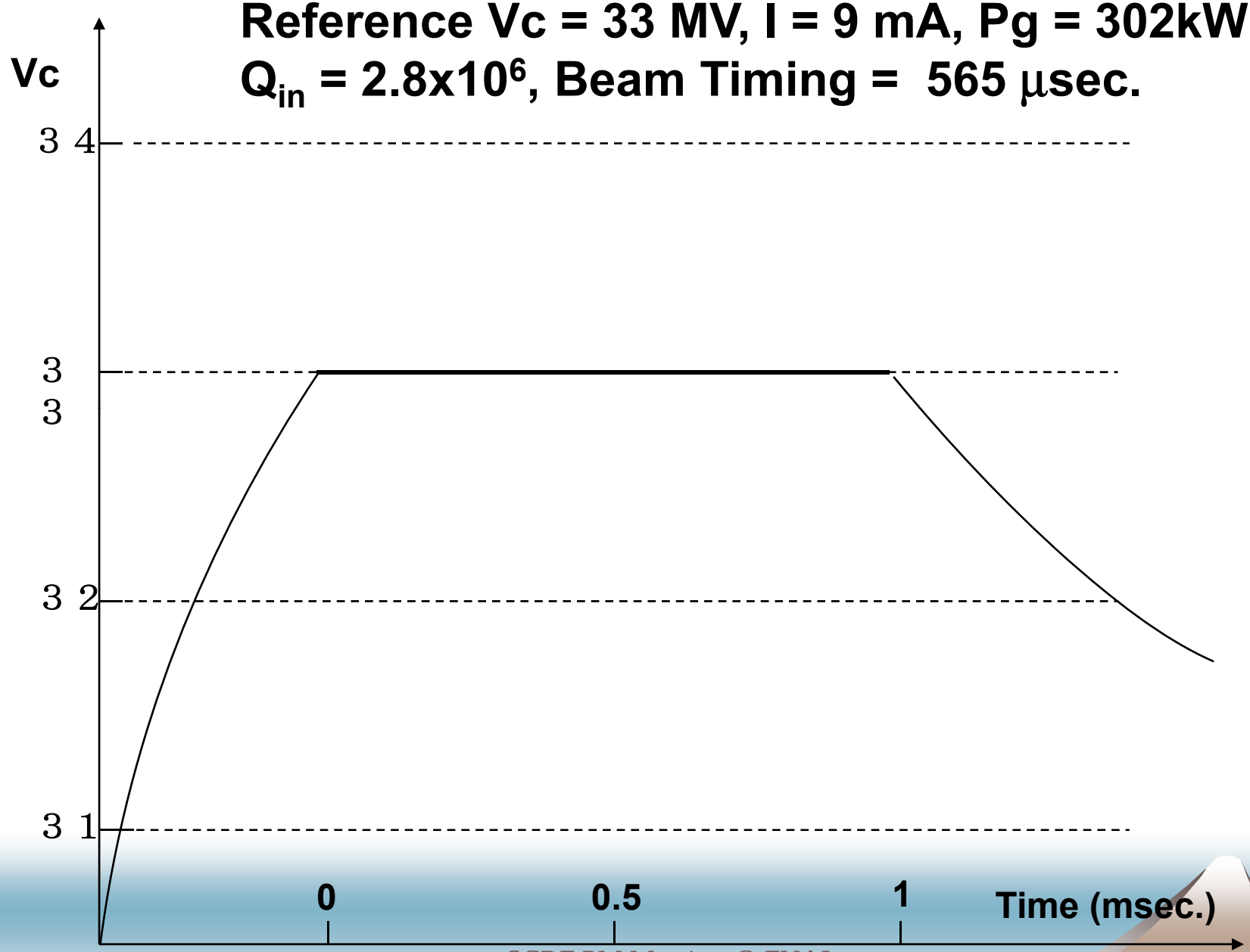
RMS = 1.5MV for Gradient

= 15% for Q_{in}

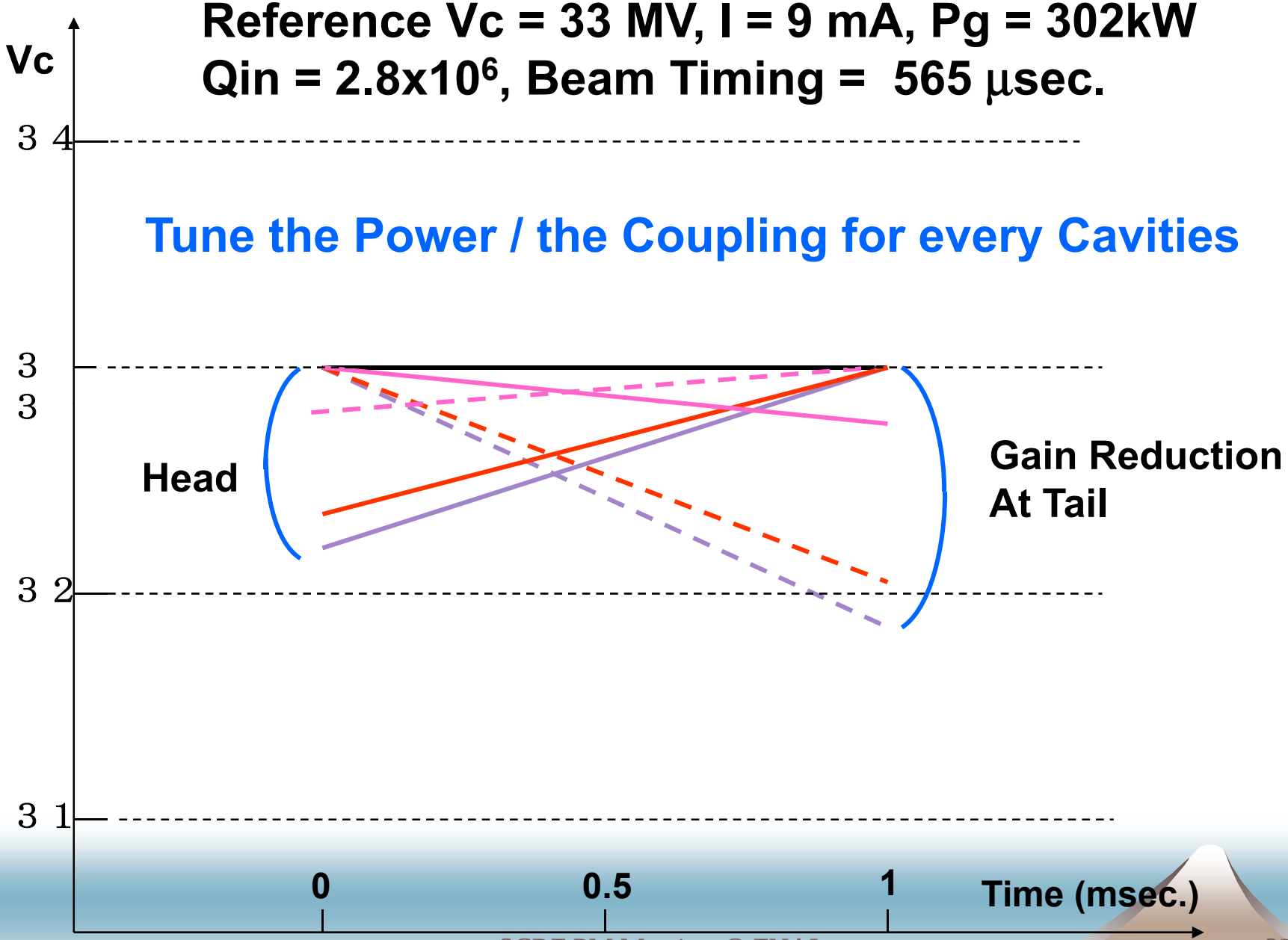
= 1.8% for P_{in}



Reference Vc = 33 MV, I = 9 mA, Pg = 302kW
Q_{in} = 2.8x10^6, Beam Timing = 565 μsec.

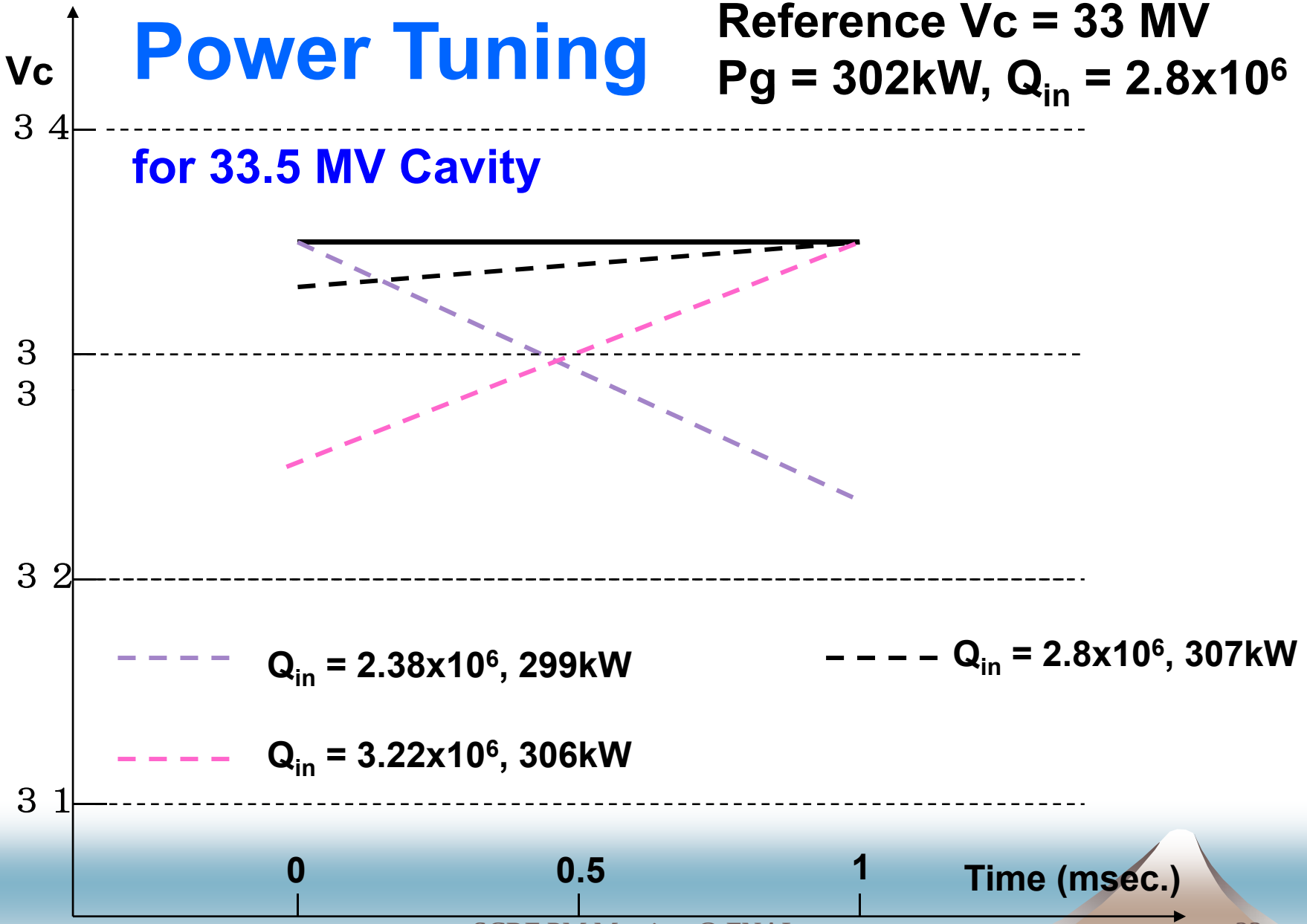


Reference Vc = 33 MV, I = 9 mA, Pg = 302kW
Qin = 2.8×10^6, Beam Timing = 565 μsec.



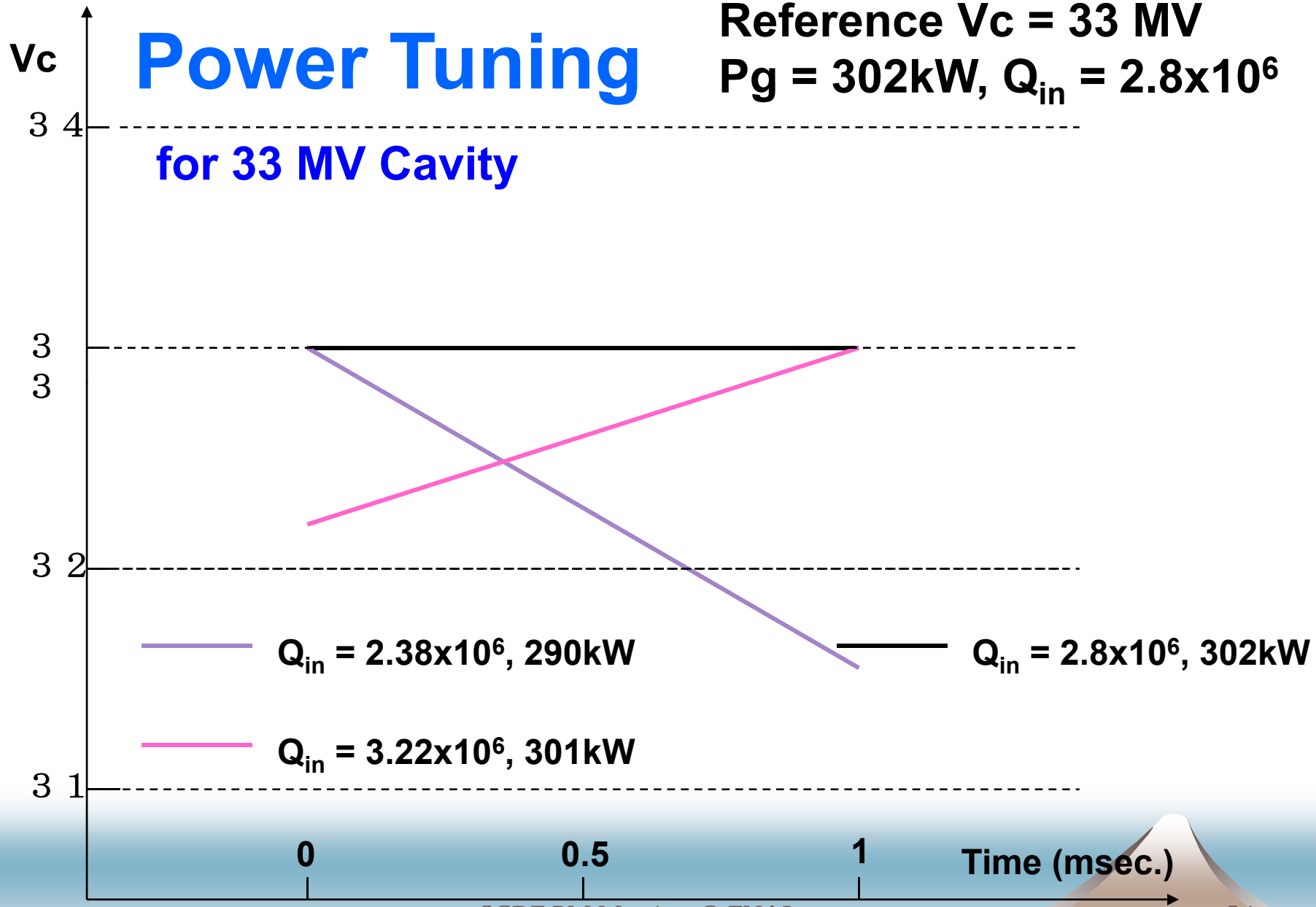
Power Tuning

Reference Vc = 33 MV
Pg = 302kW, $Q_{in} = 2.8 \times 10^6$



Power Tuning

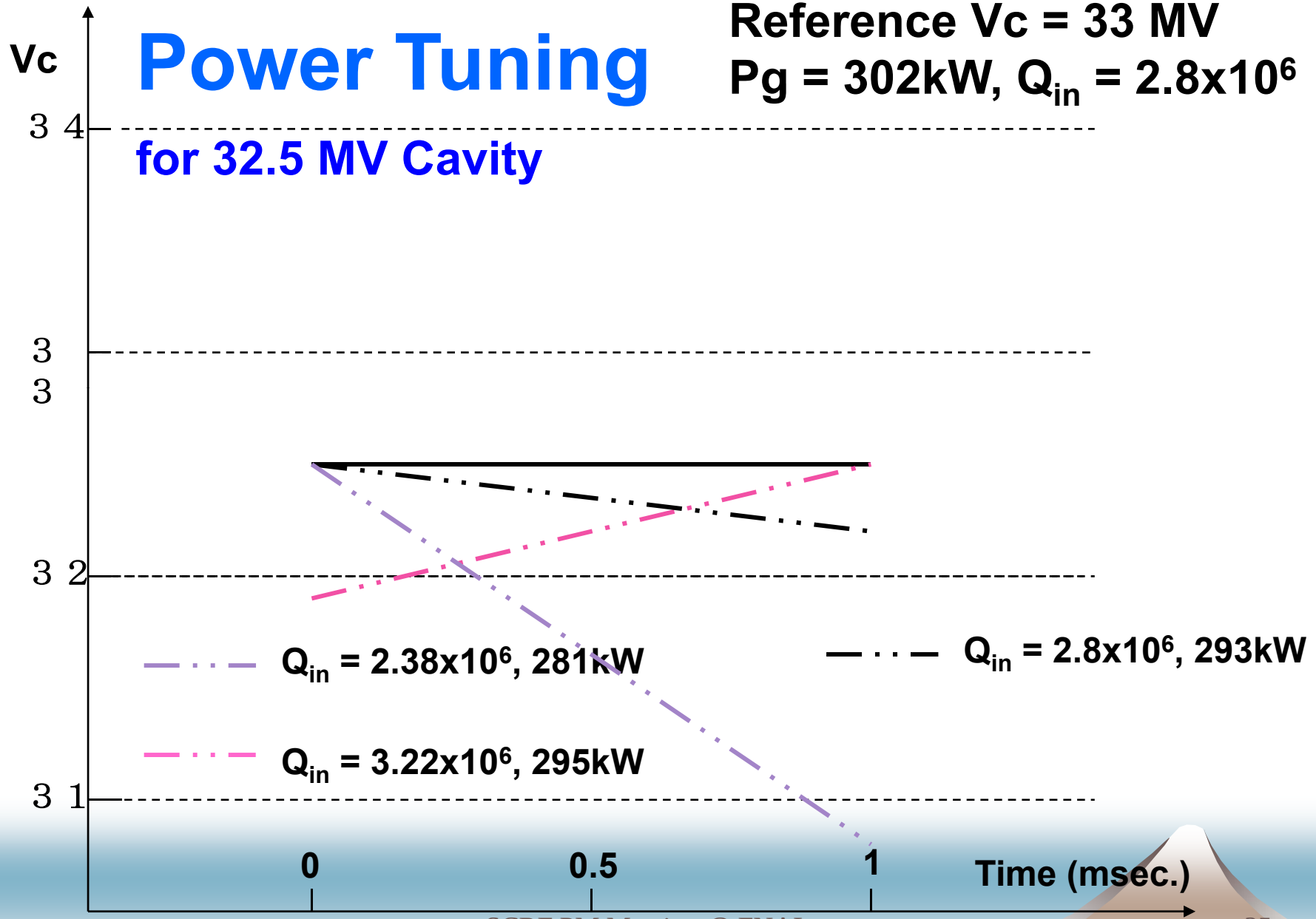
Reference Vc = 33 MV
Pg = 302kW, $Q_{in} = 2.8 \times 10^6$



Power Tuning

for 32.5 MV Cavity

Reference Vc = 33 MV
Pg = 302kW, $Q_{in} = 2.8 \times 10^6$



Power Tuning : 9 mA Head

	V														
Q	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5
1.96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.21
2.52	0	0	0	0	0	0	0	0	0	0	0	0.06	0.26	0.45	0.61
2.66	0	0	0	0	0	0	0	0	0	0.06	0.24	0.44	0.62	0.8	0.98
2.8	0	0	0	0	0	0	0	0	0.17	0.37	0.56	0.75	0.94	1.13	1.31
2.94	0	0	0	0	0	0	0.08	0.28	0.49	0.65	0.86	1.06	1.25	1.45	1.64
3.08	0	0	0	0	0	0.16	0.34	0.55	0.75	0.94	1.15	1.34	1.54	1.73	1.93
3.22	0	0	0	0	0.16	0.3	0.5	0.7	0.9	1.2	1.41	1.59	1.8	2.01	2.22

Power Tuning : 9 mA Head

	V														
Q	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5
1.96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0.002	0.006
2.52	0	0	0	0	0	0	0	0	0	0	0	0.016	0.041	0.039	0.025
2.66	0	0	0	0	0	0	0	0	0	0.039	0.119	0.148	0.126	0.089	0.053
2.8	0	0	0	0	0	0	0	0	0.153	0.282	0.323	0.293	0.223	0.145	0.082
2.94	0	0	0	0	0	0	0.076	0.28	0.464	0.52	0.522	0.436	0.312	0.196	0.108
3.08	0	0	0	0	0	0.122	0.306	0.523	0.675	0.716	0.663	0.524	0.365	0.223	0.121
3.22	0	0	0	0	0.079	0.249	0.441	0.646	0.766	0.785	0.699	0.534	0.367	0.222	0.119
3.36	0	0	0	0.05	0.15	0.305	0.493	0.648	0.739	0.733	0.632	0.486	0.326	0.195	0.103
3.5	0	0	0.019	0.072	0.163	0.29	0.435	0.549	0.617	0.597	0.509	0.384	0.257	0.152	0.08
3.64	0	0.005	0.025	0.068	0.136	0.229	0.33	0.409	0.446	0.425	0.36	0.269	0.178	0.105	0.055
3.78	0.001	0.007	0.022	0.051	0.098	0.157	0.216	0.267	0.285	0.273	0.225	0.168	0.111	0.065	0.034

Power Tuning : 9 mA Tail

	V														
Q	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5
1.96	4.29	4.09	3.92	3.7	3.51	3.32	3.13	2.95	2.75	2.55	2.35	2.16	1.97	1.76	1.57
2.1	3.93	3.71	3.52	3.28	3.07	2.87	2.66	2.44	2.22	2	1.78	1.57	1.36	1.13	0.93
2.24	3.58	3.32	3.11	2.85	2.63	2.41	2.16	1.94	1.71	1.47	1.24	1.01	0.77	0.54	0.29
2.38	3.19	2.93	2.69	2.45	2.17	1.94	1.7	1.45	1.19	0.94	0.69	0.45	0.21	0	0
2.52	2.81	2.58	2.28	2	1.74	1.49	1.24	0.98	0.67	0.38	0.14	0	0	0	0
2.66	2.45	2.17	1.89	1.62	1.32	1.03	0.77	0.45	0.19	0	0	0	0	0	0
2.8	2.1	1.77	1.49	1.17	0.9	0.59	0.29	0	0	0	0	0	0	0	0
2.94	1.77	1.43	1.14	0.82	0.49	0.16	0	0	0	0	0	0	0	0	0
3.08	1.4	1.07	0.73	0.43	0.1	0	0	0	0	0	0	0	0	0	0
3.22	1.08	0.73	0.38	0.03	0	0	0	0	0	0	0	0	0	0	0

Power Tuning : 9 mA Tail

	V														
Q	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5
1.96	0.024	0.047	0.083	0.129	0.18	0.225	0.251	0.25	0.22	0.173	0.121	0.075	0.042	0.02	0.009
2.1	0.042	0.082	0.143	0.22	0.303	0.375	0.41	0.398	0.342	0.261	0.176	0.105	0.055	0.025	0.01
2.24	0.067	0.127	0.22	0.332	0.453	0.548	0.58	0.55	0.459	0.334	0.213	0.118	0.054	0.021	0.005
2.38	0.094	0.177	0.3	0.45	0.588	0.694	0.718	0.647	0.503	0.336	0.187	0.083	0.023	0	0
2.52	0.117	0.222	0.361	0.522	0.671	0.758	0.745	0.623	0.403	0.193	0.054	0	0	0	0
2.66	0.132	0.24	0.385	0.544	0.654	0.674	0.595	0.368	0.147	0	0	0	0	0	0
2.8	0.131	0.228	0.353	0.457	0.519	0.449	0.261	0	0	0	0	0	0	0	0
2.94	0.116	0.194	0.284	0.337	0.297	0.128	0	0	0	0	0	0	0	0	0
3.08	0.087	0.138	0.173	0.168	0.058	0	0	0	0	0	0	0	0	0	0
3.22	0.058	0.081	0.077	0.01	0	0	0	0	0	0	0	0	0	0	0
3.36	0.032	0.031	0.003	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0.013	0.004	0	0	0	0	0	0	0	0	0	0	0	0	0
3.64	0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5 mA Head (0.6msec.,73% Power)

	V														
Q	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5
1.96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5E-04
2.8	0	0	0	0	0	0	0	0	0	0	0	0.043	0.055	0.045	0.029
2.94	0	0	0	0	0	0	0	0	0.123	0.208	0.23	0.21	0.16	0.104	0.059
3.08	0	0	0	0	0	0.069	0.198	0.342	0.441	0.472	0.438	0.348	0.244	0.149	0.081
3.22	0	0	0	0.044	0.134	0.268	0.425	0.564	0.634	0.628	0.55	0.417	0.283	0.169	0.09
3.36	0	0.01	0.043	0.107	0.216	0.361	0.511	0.635	0.685	0.656	0.551	0.413	0.273	0.161	0.084
3.5	0.007	0.023	0.059	0.125	0.225	0.354	0.477	0.576	0.604	0.565	0.469	0.345	0.226	0.132	0.069
3.64	0.009	0.024	0.055	0.108	0.188	0.282	0.376	0.44	0.459	0.423	0.348	0.254	0.165	0.096	0.049
3.78	0.007	0.019	0.041	0.078	0.131	0.194	0.254	0.295	0.304	0.278	0.226	0.164	0.106	0.061	0.031
3.92	0.005	0.012	0.026	0.048	0.08	0.117	0.151	0.174	0.177	0.161	0.13	0.094	0.061	0.035	0.018

5 mA Tail (0.6msec.,73% Power)

	V														
Q	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5
1.96	0.024	0.049	0.088	0.143	0.207	0.269	0.312	0.323	0.3	0.249	0.184	0.122	0.073	0.038	0.018
2.1	0.041	0.083	0.15	0.241	0.346	0.446	0.512	0.526	0.484	0.398	0.293	0.192	0.113	0.059	0.028
2.24	0.063	0.126	0.225	0.359	0.513	0.652	0.738	0.755	0.684	0.554	0.403	0.261	0.151	0.078	0.036
2.38	0.086	0.17	0.3	0.472	0.666	0.833	0.938	0.933	0.832	0.665	0.471	0.297	0.167	0.083	0.037
2.52	0.104	0.201	0.35	0.543	0.748	0.921	1.01	0.985	0.847	0.651	0.443	0.264	0.139	0.064	0.025
2.66	0.11	0.209	0.355	0.538	0.719	0.857	0.897	0.826	0.673	0.471	0.283	0.141	0.057	0.014	0
2.8	0.101	0.187	0.306	0.442	0.559	0.617	0.585	0.475	0.297	0.137	0.012	0	0	0	0
2.94	0.079	0.138	0.212	0.28	0.309	0.272	0.161	0	0	0	0	0	0	0	0
3.08	0.049	0.078	0.102	0.094	0.035	0	0	0	0	0	0	0	0	0	0
3.22	0.021	0.023	0.004	0	0	0	0	0	0	0	0	0	0	0	0
3.36	8E-04	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Coupling Tuning : 9mA Head

	V														
Power	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5
287.4	0.002	0.004	0.008	0.012	0.011	0	0	0	0	0.013	0.03	0.034	0.029	0.02	0.012
289.2	0.005	0.01	0.02	0.031	0.034	0.013	0	0	0	0	0.041	0.056	0.051	0.037	0.022
291	0.01	0.022	0.041	0.066	0.085	0.064	0	0	0	0	0.076	0.103	0.093	0.067	0.041
292.8	0.017	0.039	0.077	0.125	0.167	0.168	0.012	0	0	0	0.105	0.155	0.146	0.107	0.065
294.6	0.028	0.062	0.124	0.207	0.291	0.325	0.195	0	0	0	0.118	0.204	0.2	0.149	0.092
296.4	0.039	0.09	0.178	0.3	0.432	0.507	0.424	0	0	0	0.102	0.234	0.242	0.185	0.116
298.2	0.048	0.114	0.224	0.385	0.562	0.697	0.662	0.246	0	0	0.063	0.237	0.262	0.206	0.131
300	0.055	0.126	0.252	0.436	0.661	0.817	0.88	0.59	0	0	0.006	0.21	0.252	0.204	0.132
301.8	0.055	0.127	0.255	0.436	0.654	0.848	0.922	0.274	0	0	0	0.156	0.212	0.179	0.118
303.6	0.048	0.113	0.226	0.392	0.602	0.789	0.879	0.777	0.356	0	0	0.099	0.16	0.141	0.095
305.4	0.039	0.089	0.178	0.314	0.482	0.636	0.723	0.685	0.453	0	0	0.05	0.106	0.099	0.068
307.2	0.027	0.063	0.126	0.223	0.342	0.458	0.529	0.518	0.393	0	0	0.015	0.06	0.061	0.043
309	0.017	0.039	0.08	0.14	0.218	0.294	0.344	0.347	0.278	0.136	0	0	0.03	0.033	0.024
310.8	0.01	0.022	0.045	0.08	0.125	0.168	0.2	0.204	0.173	0.106	0	0	0.009	0.014	0.011
312.6	0.005	0.011	0.023	0.04	0.063	0.085	0.101	0.105	0.093	0.064	0	0	0.005	0.007	0.006

Coupling Tuning : 9mA Tail

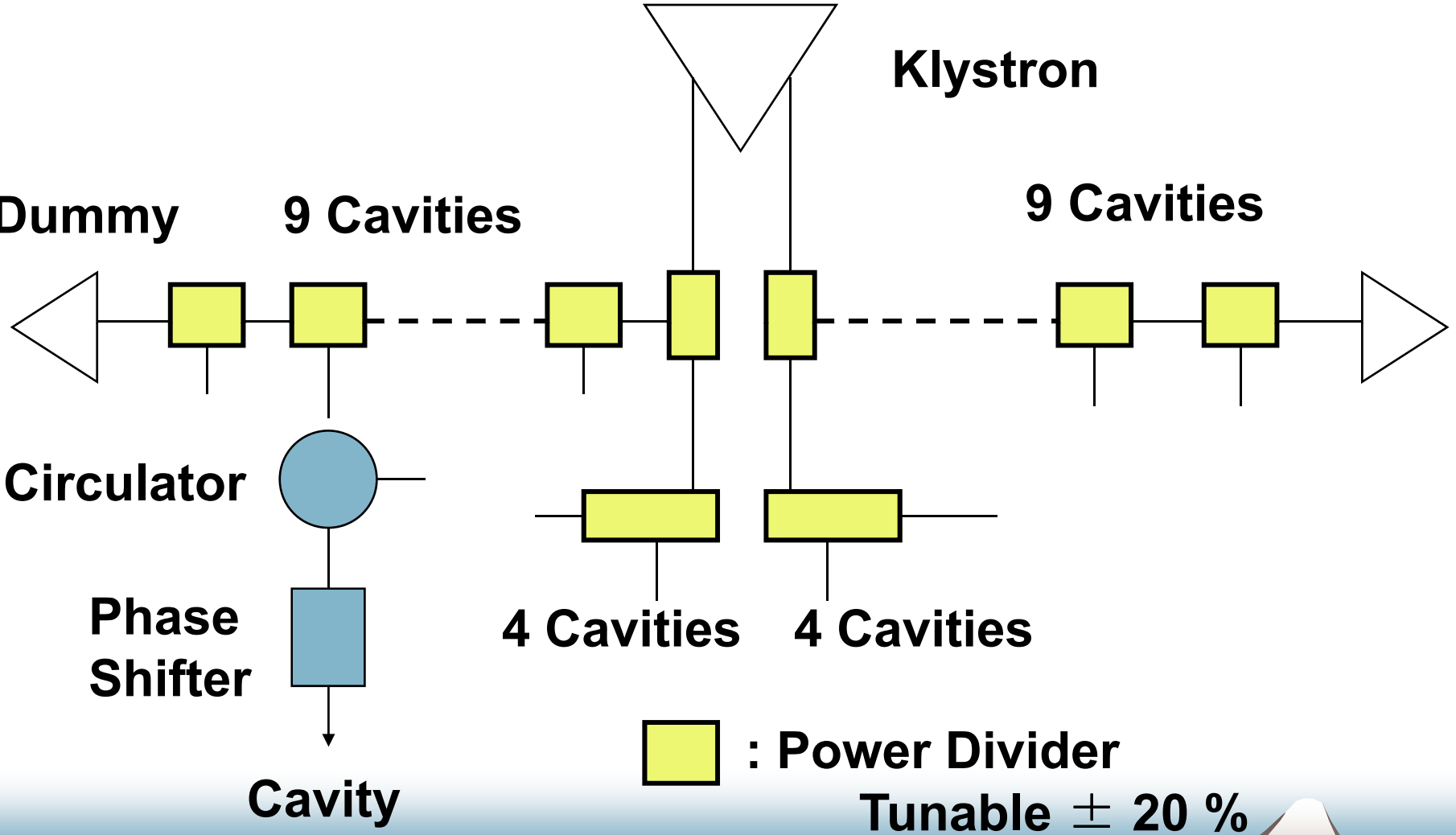
	V														
Power	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5
287.42	0	0	0	0	0	0.004	0.025	0.057	0.091	0.113	0.106	0.085	0.06	0.037	0.02
289.22	0	0	0	0	0	0	0.033	0.093	0.163	0.23	0.215	0.174	0.122	0.075	0.041
291.02	0	0	0	0	0	0	0.028	0.132	0.252	0.369	0.355	0.292	0.208	0.13	0.071
292.82	0	0	0	0	0	0	0	0.152	0.342	0.527	0.541	0.451	0.325	0.204	0.113
294.62	0	0	0	0	0	0	0	0.133	0.402	0.67	0.739	0.626	0.455	0.288	0.16
296.42	0	0	0	0	0	0	0	0.056	0.401	0.744	0.903	0.777	0.571	0.364	0.203
298.22	0	0	0	0	0	0	0	0	0.322	0.727	0.975	0.856	0.637	0.41	0.23
300.02	0	0	0	0	0	0	0	0	0.189	0.609	0.928	0.835	0.631	0.41	0.232
301.82	0	0	0	0	0	0	0	0	0.045	0.432	0.746	0.735	0.564	0.37	0.211
303.62	0	0	0	0	0	0	0	0	0	0.25	0.525	0.57	0.445	0.296	0.17
305.42	0	0	0	0	0	0	0	0	0	0.107	0.316	0.394	0.315	0.212	0.123
307.22	0	0	0	0	0	0	0	0	0	0.016	0.165	0.24	0.197	0.135	0.079
309.02	0	0	0	0	0	0	0	0	0	0	0.07	0.13	0.11	0.077	0.045
310.82	0	0	0	0	0	0	0	0	0	0	0.021	0.057	0.06	0.042	0.025
312.62	0	0	0	0	0	0	0	0	0	0	0.004	0.021	0.024	0.017	0.011

Cost Comparison

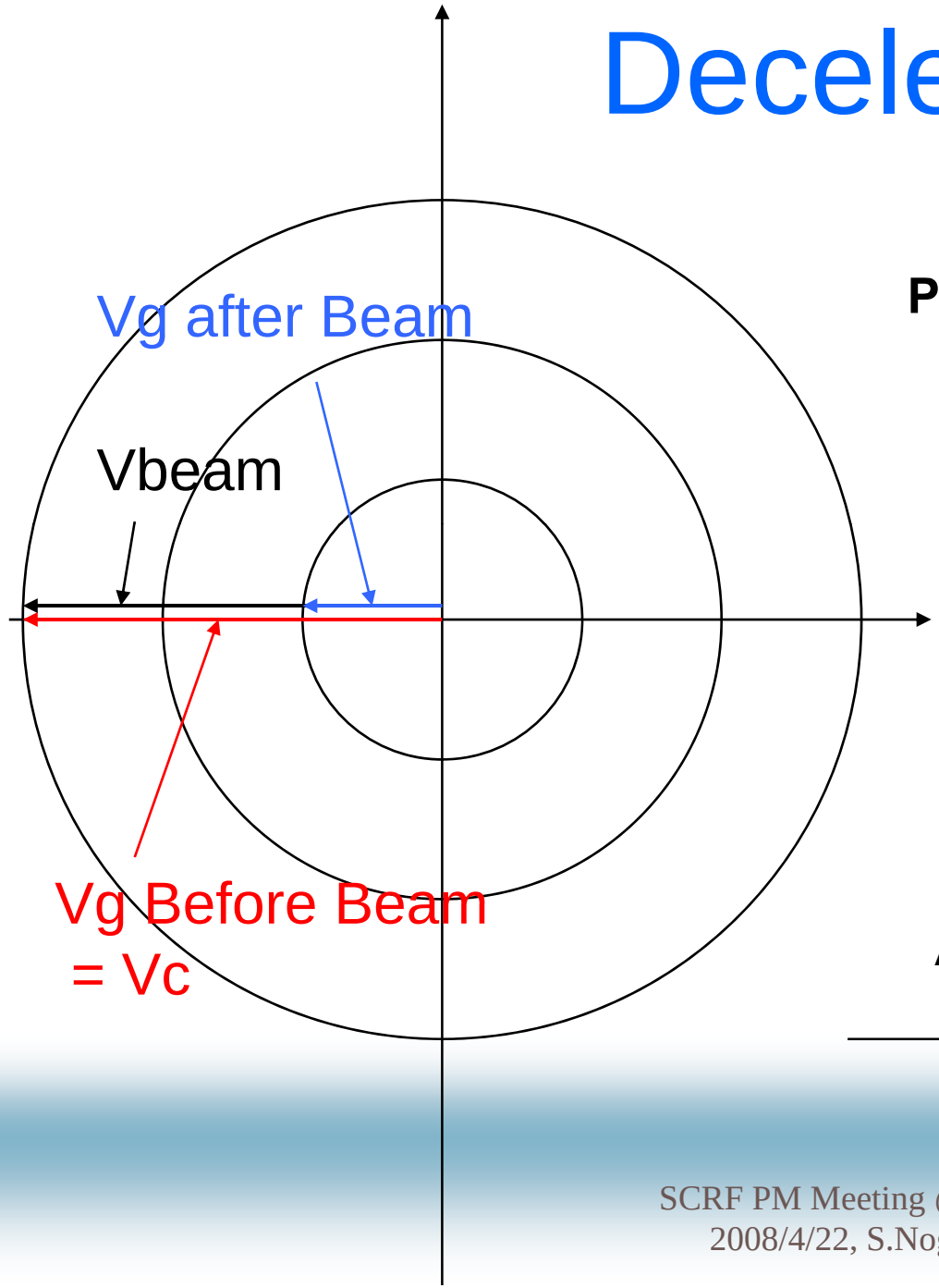
ML costs 4000 MILC, Assembly & Tuning Cost are not evaluated.

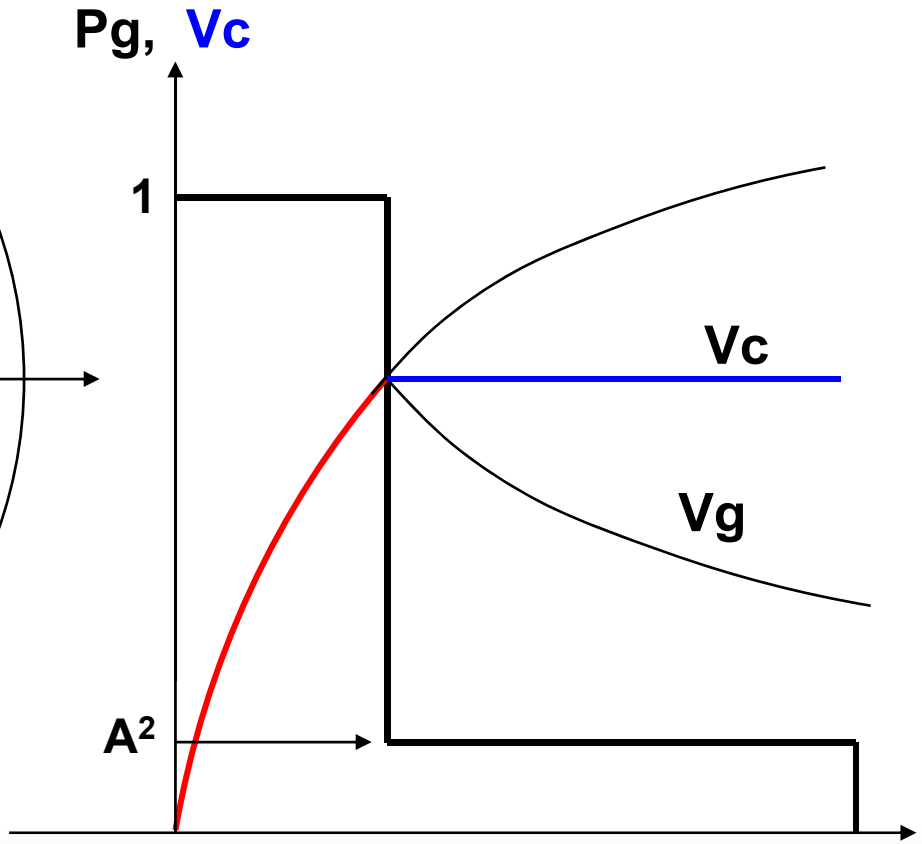
	Energy Reduction	Extra Cost	Devise Cost	Total Cost-Up
No Tuning	> 10 %	> 400	0	> 400
Full Tuning	0	0	60 + 60	120
Coupling $2.5 – 6.7 \times 10^6$	1.8 %	72	60	132
Power 227 – 347 kW	1.5 % 1.6 % (5mA)	60	60	120

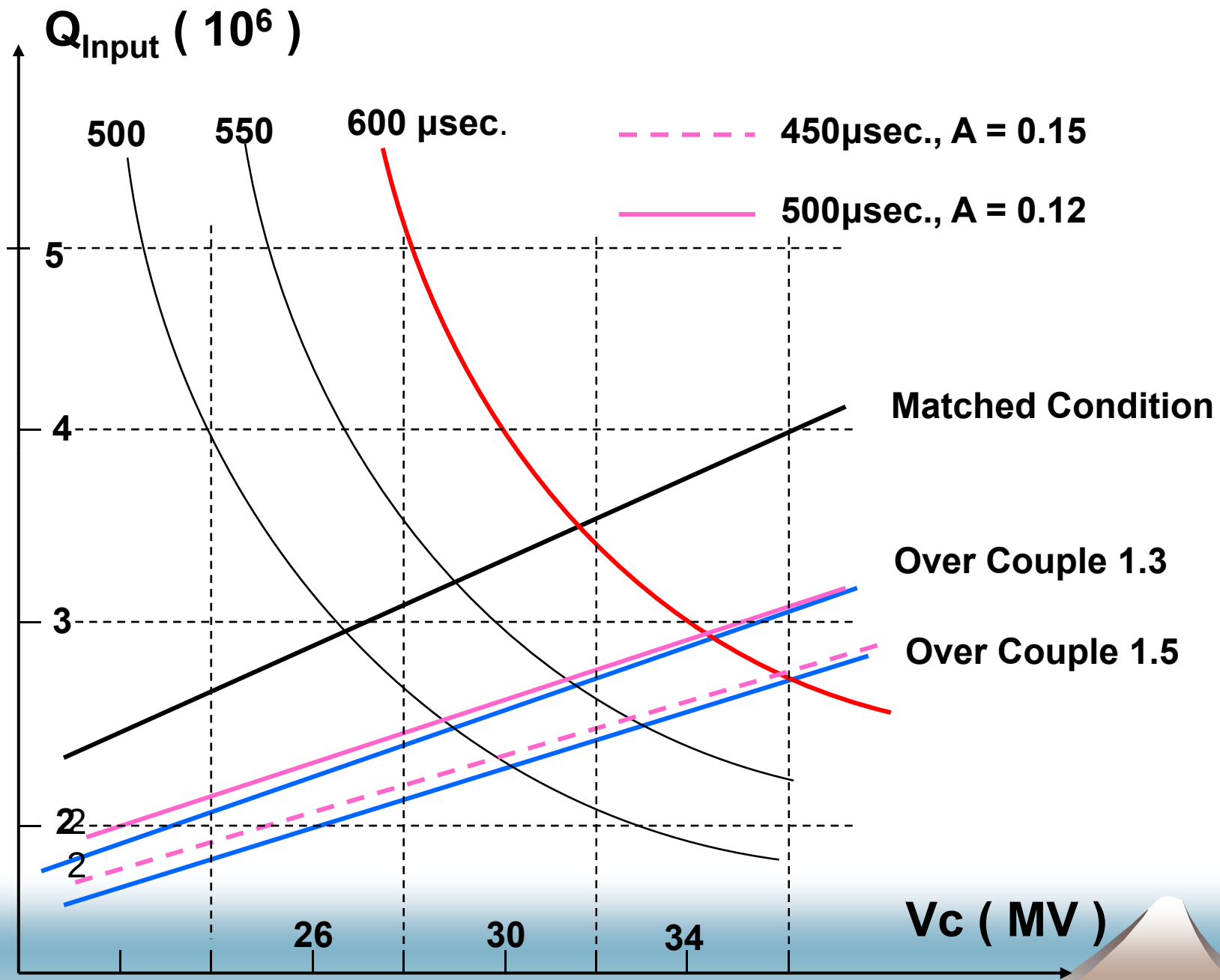
Power Distribution

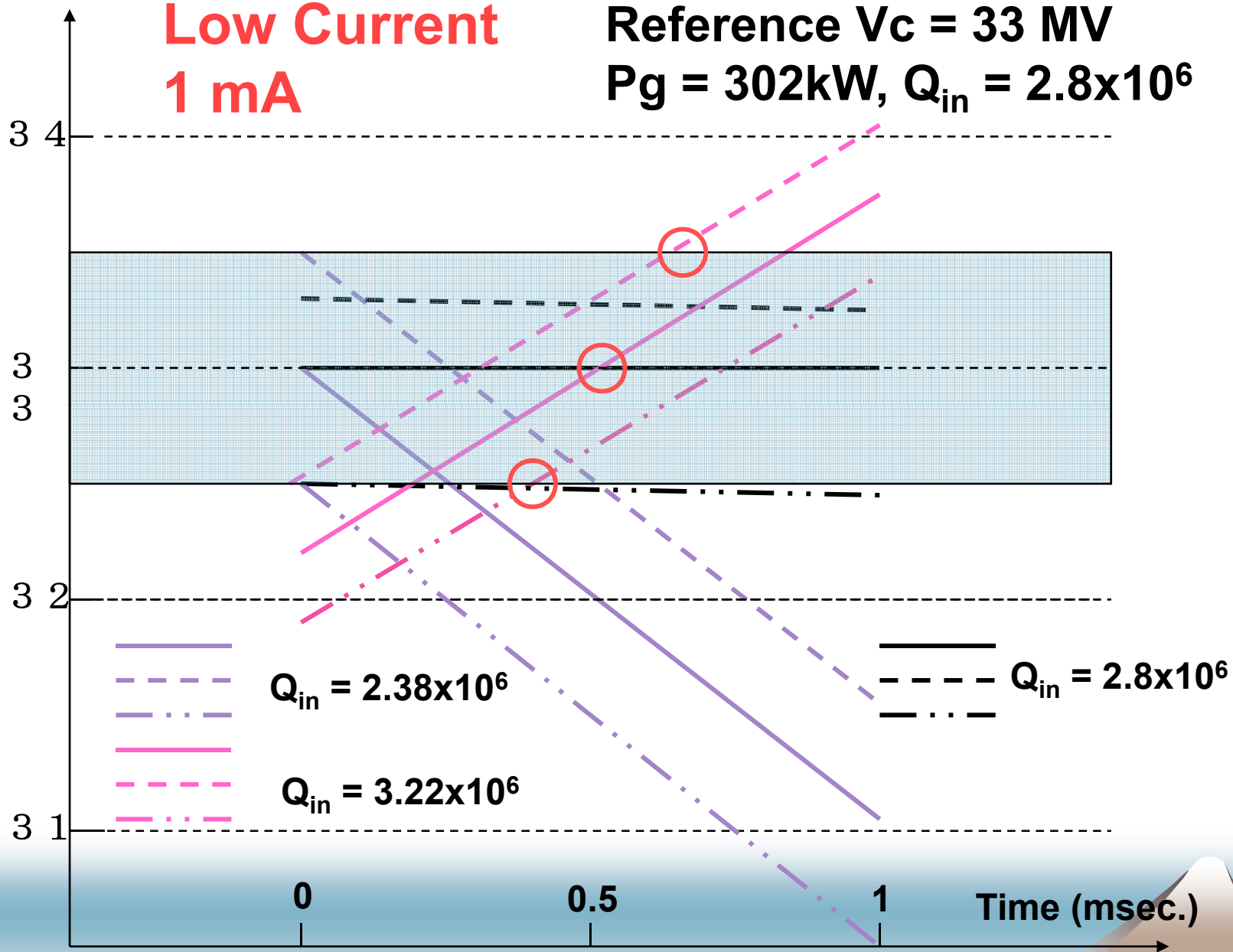


Deceleration






Q_{Input} (10^6)
500
550
600 μsec.
450μsec., A = 0.15
500μsec., A = 0.12
5
4
3
2
Matched Condition
Over Couple 1.3
Over Couple 1.5
26
30
34
Vc (MV)


Low Current
1 mA
Reference Vc = 33 MV
Pg = 302kW, Qin = 2.8x10^6
3 4
3 3
3 2
3 1
Qin = 2.38x10^6
Qin = 3.22x10^6
Qin = 2.8x10^6
0
0.5
1
Time (msec.)

Simple 1mA Beam Tuning

If we do not Re-tune the power Ratio, Pulse Head Gradient have to be Reduced in some Low Gradient Cavities.

Then the Gain Reduction becomes 1.8 % in 9 mA Operation.

Summary

- Cavity Grouping Scheme is Proposed.
  Power Effective, Small Tuning Range
  & Less DLD Effect.
- If we use this scheme, and assume the following number, the coupling tune-ability may be not cost effective.
  Coupling Error : 15 % RMS
  Gradient Distribution : 1.5MV RMS
- Input Coupler must have a capacity of 400 kW.
- Precise Evaluation of cost performance is necessary.

Power Tuning : 9mA Head, 2MV

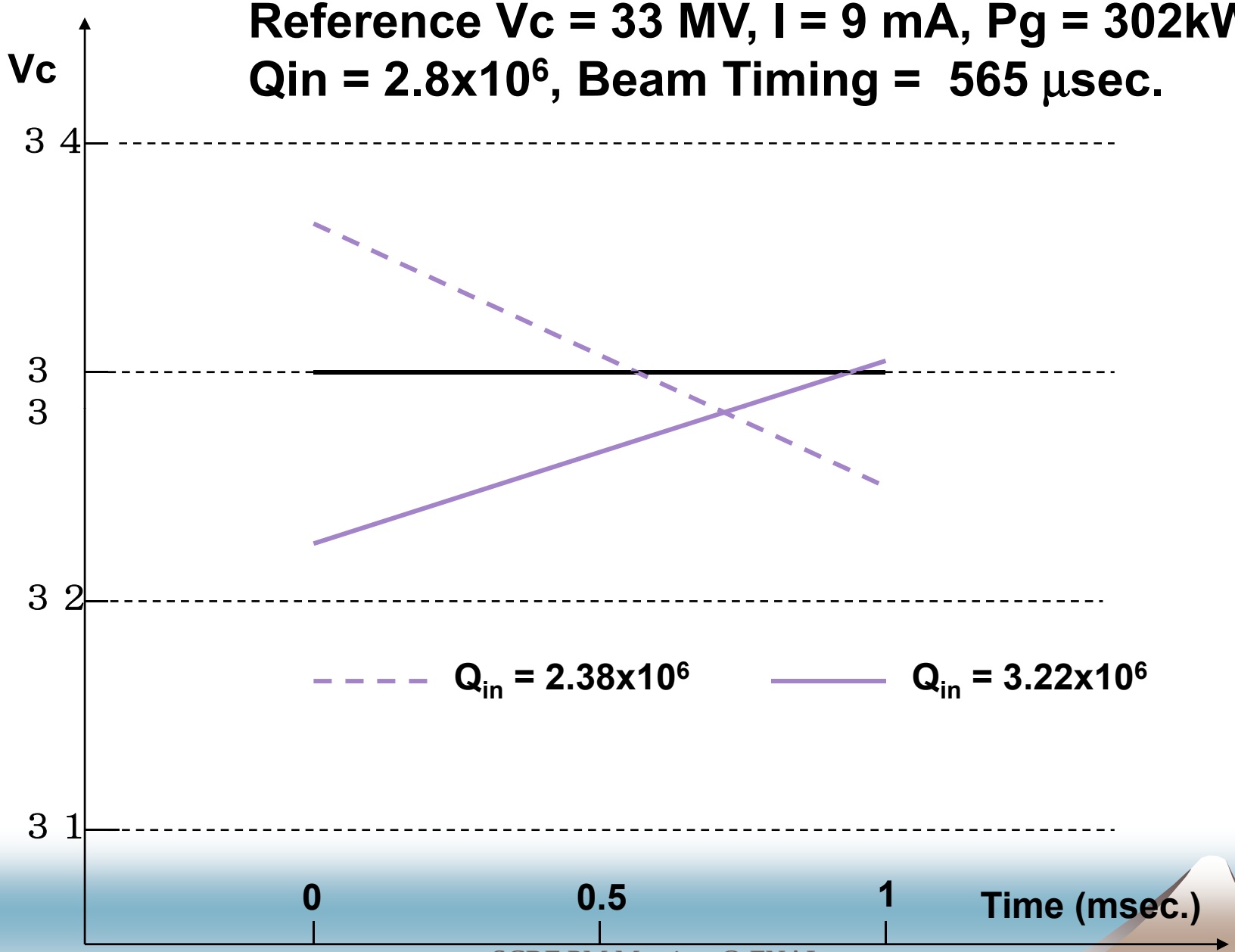
	V																	
Q	28.5	29	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5	37
1.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004	0.02	0.023
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0.023	0.076	0.093	0.084	0.067
2.6	0	0	0	0	0	0	0	0	0	0	0	0.043	0.148	0.218	0.232	0.212	0.173	0.127
2.8	0	0	0	0	0	0	0	0	0	0	0.157	0.31	0.402	0.433	0.409	0.349	0.269	0.193
2.9	0	0	0	0	0	0	0	0	0.078	0.28	0.475	0.574	0.649	0.643	0.572	0.471	0.355	0.248
3.0	0	0	0	0	0	0	0	0.134	0.313	0.523	0.691	0.789	0.825	0.773	0.67	0.534	0.397	0.274
3.2	0	0	0	0	0	0	0.099	0.274	0.452	0.646	0.784	0.866	0.87	0.788	0.674	0.533	0.392	0.268
3.3	0	0	0	0	0	0.073	0.187	0.336	0.505	0.648	0.757	0.807	0.787	0.717	0.599	0.468	0.339	0.23
3.5	0	0	0	0	0.035	0.106	0.202	0.319	0.446	0.549	0.632	0.658	0.634	0.566	0.472	0.364	0.262	0.177
3.6	0	0	0	0.013	0.047	0.1	0.169	0.253	0.33	0.40	0.45	0.46	0.44	0.39	0.32	0.25	0.18	0.122

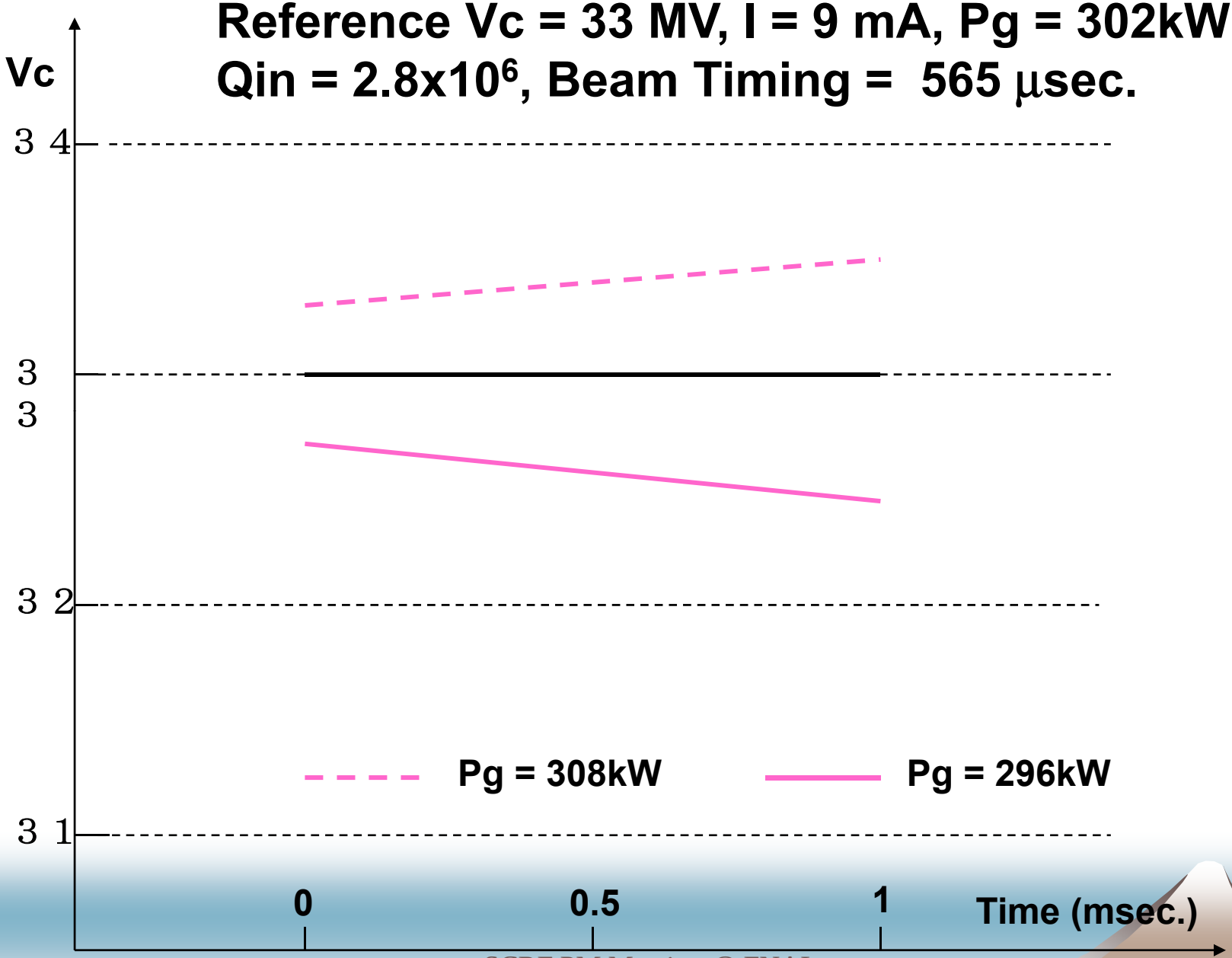
Power Tuning : 9mA Tail, 2MV

			V														
Q	28.5	29	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5	37
1.96	0.03	0.05	0.08	0.11	0.15	0.19	0.22	0.25	0.26	0.25	0.23	0.19	0.15	0.11	0.08	0.05	0.03	0.02
2.1	0.06	0.09	0.14	0.2	0.26	0.32	0.38	0.41	0.42	0.4	0.35	0.29	0.22	0.16	0.1	0.06	0.03	0.01
2.24	0.09	0.15	0.22	0.31	0.4	0.49	0.56	0.6	0.59	0.55	0.47	0.37	0.27	0.17	0.1	0.05	0.02	0
2.38	0.13	0.21	0.31	0.42	0.55	0.66	0.73	0.76	0.74	0.65	0.52	0.37	0.23	0.12	0.04	0	0	0
2.52	0.17	0.27	0.39	0.53	0.66	0.77	0.83	0.84	0.76	0.62	0.41	0.21	0.07	0	0	0	0	0
2.66	0.2	0.3	0.43	0.58	0.71	0.8	0.81	0.74	0.61	0.37	0.15	0	0	0	0	0	0	0
2.8	0.2	0.31	0.43	0.55	0.65	0.67	0.65	0.5	0.27	0	0	0	0	0	0	0	0	0
2.94	0.19	0.28	0.38	0.46	0.52	0.5	0.37	0.14	0	0	0	0	0	0	0	0	0	0
3.08	0.16	0.22	0.29	0.33	0.32	0.25	0.07	0	0	0	0	0	0	0	0	0	0	0
3.22	0.11	0.16	0.19	0.19	0.14	0.01	0	0	0	0	0	0	0	0	0	0	0	0
3.36	0.07	0.09	0.1	0.07	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0.04	0.05	0.04	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.64	0.02	0.02	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.78	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Coupling Tuning : 9mA Tail

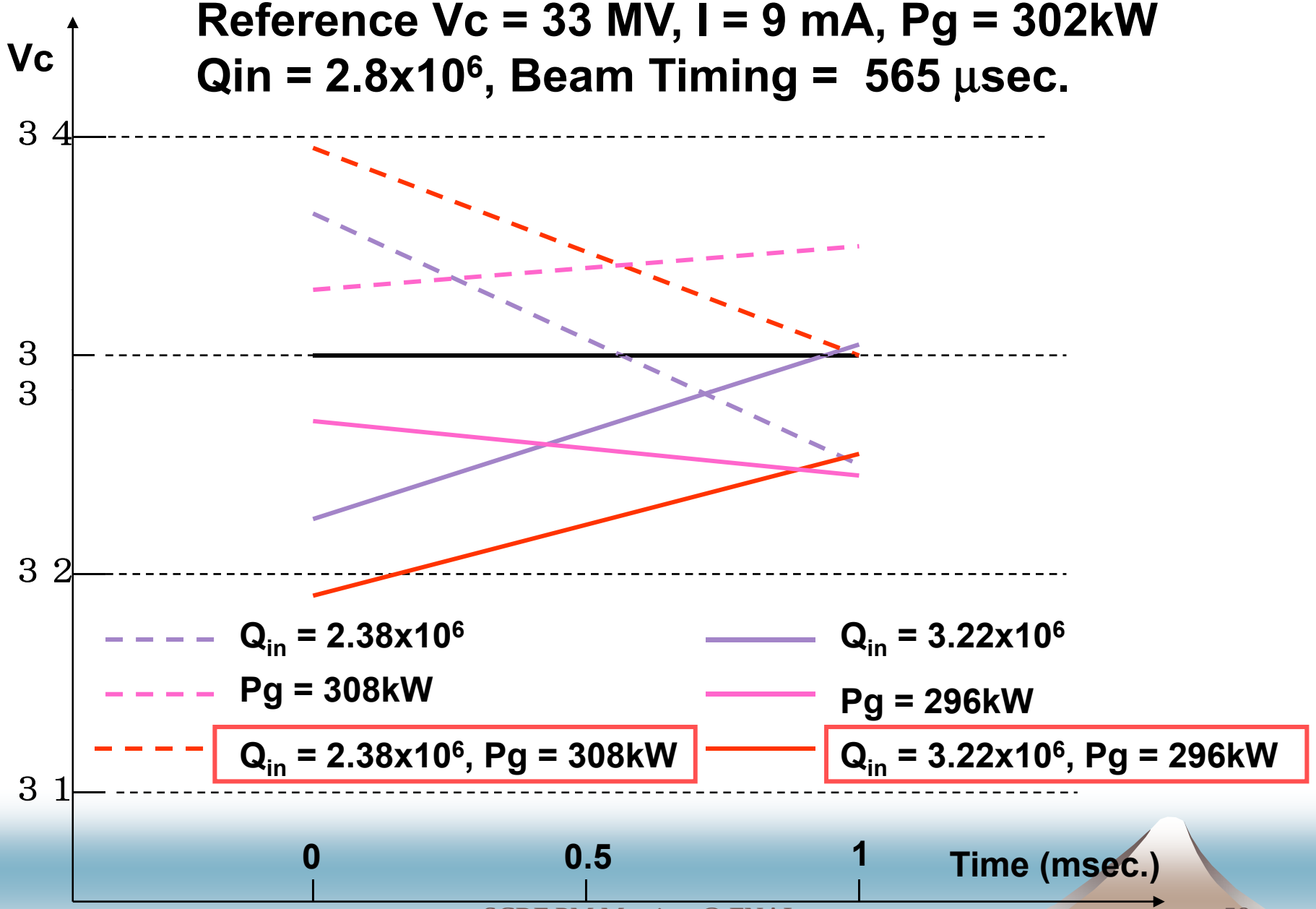
	V													
Power	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5
287.42	0	0	0	0	0	0.07	0.4	0.86	1.47	2.15	2.65	3.15	3.65	4.15	4.65
289.22	0	0	0	0	0	0	0.26	0.69	1.27	2.12	2.62	3.12	3.62	4.12	4.62
291.02	0	0	0	0	0	0	0.12	0.53	1.07	1.85	2.35	2.85	3.35	3.85	4.35
292.82	0	0	0	0	0	0	0	0.37	0.88	1.6	2.17	2.67	3.17	3.67	4.17
294.62	0	0	0	0	0	0	0	0.22	0.7	1.38	2.01	2.51	3.01	3.51	4.01
296.42	0	0	0	0	0	0	0	0.07	0.53	1.16	1.86	2.36	2.86	3.36	3.86
298.22	0	0	0	0	0	0	0	0	0.36	0.96	1.7	2.2	2.7	3.2	3.7
300.02	0	0	0	0	0	0	0	0	0.2	0.76	1.53	2.03	2.53	3.03	3.53
301.82	0	0	0	0	0	0	0	0	0.05	0.57	1.3	1.89	2.39	2.89	3.39
303.62	0	0	0	0	0	0	0	0	0	0.39	1.08	1.73	2.23	2.73	3.23
305.42	0	0	0	0	0	0	0	0	0	0.22	0.86	1.58	2.08	2.58	3.08
307.22	0	0	0	0	0	0	0	0	0	0.05	0.66	1.42	1.92	2.42	2.92
309.02	0	0	0	0	0	0	0	0	0	0	0.46	1.27	1.77	2.27	2.77
310.82	0	0	0	0	0	0	0	0	0	0	0.26	1.02	1.77	2.27	2.77
312.62	0	0	0	0	0	0	0	0	0	0	0.1	0.79	1.46	1.96	2.46


Reference Vc = 33 MV, I = 9 mA, Pg = 302kW
Qin = 2.8x10^6, Beam Timing = 565 μsec.
Vc
3 4
3
3 3
3 2
3 1
Qin = 2.38x10^6
Qin = 3.22x10^6
0
0.5
1
Time (msec.)


Reference Vc = 33 MV, I = 9 mA, Pg = 302kW
Qin = 2.8x10^6, Beam Timing = 565 μsec.
Vc
3 4
3
3 3
3 2
3 1
Pg = 308kW
Pg = 296kW
0
0.5
1
Time (msec.)

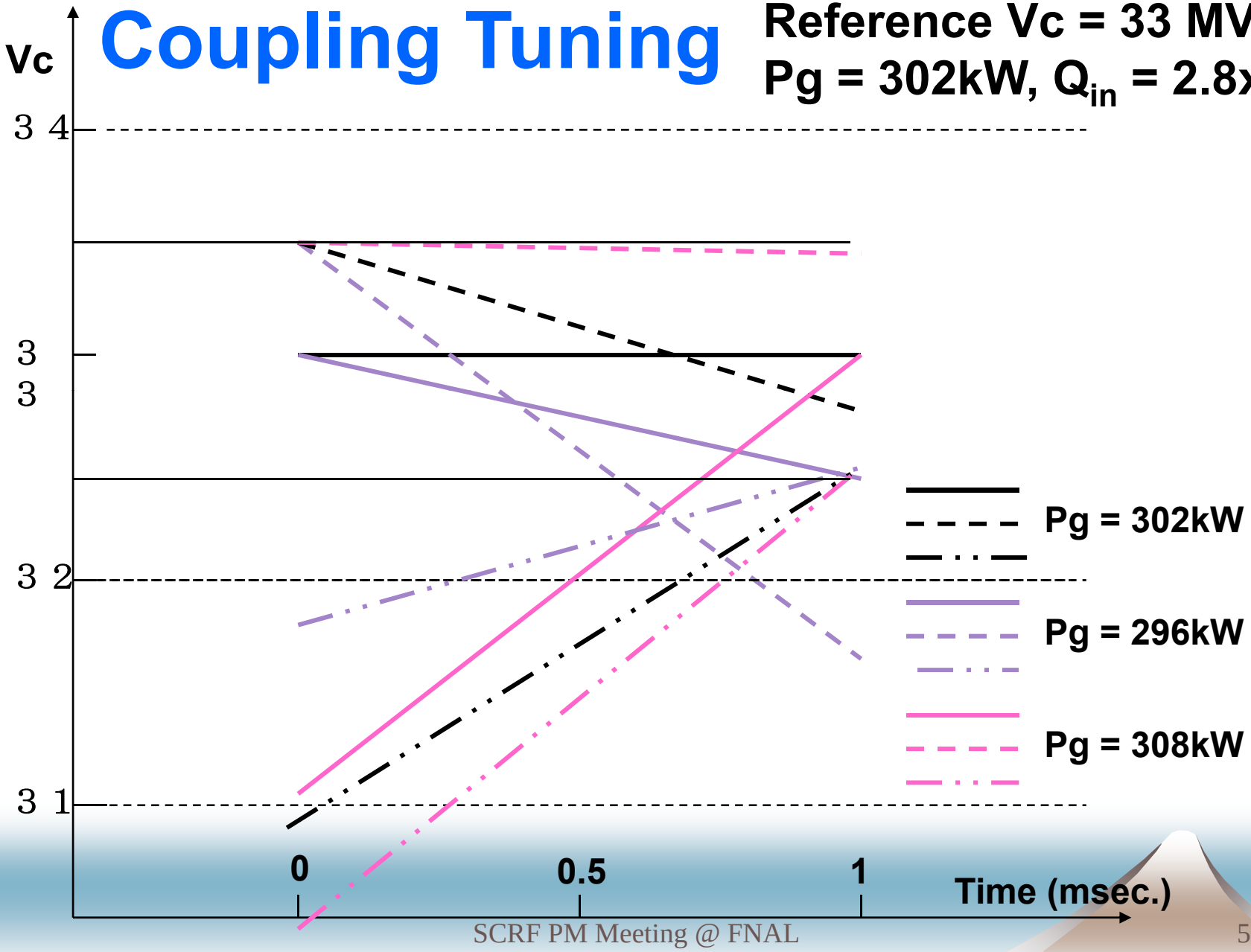
Coupling Tuning : 9mA Head

	V														
Power	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5
287.4	0.45	0.5	0.5	0.44	0.28	0	0	0	0	0.24	0.74	1.24	1.74	2.24	2.74
289.2	0.52	0.57	0.59	0.55	0.41	0.12	0	0	0	0	0.5	1	1.5	2	2.5
291	0.58	0.64	0.66	0.64	0.56	0.32	0	0	0	0	0.5	1	1.5	2	2.5
292.8	0.63	0.7	0.75	0.74	0.67	0.51	0.03	0	0	0	0.42	0.92	1.42	1.92	2.42
294.6	0.69	0.76	0.82	0.83	0.79	0.67	0.34	0	0	0	0.32	0.82	1.32	1.82	2.32
296.4	0.74	0.83	0.89	0.91	0.89	0.79	0.56	0	0	0	0.21	0.71	1.21	1.71	2.21
298.2	0.78	0.89	0.95	0.99	0.98	0.92	0.74	0.26	0	0	0.11	0.61	1.11	1.61	2.11
300	0.83	0.93	1.01	1.06	1.09	1.02	0.93	0.59	0	0	0.01	0.51	1.01	1.51	2.01
301.8	0.88	0.99	1.08	1.12	1.14	1.12	1.03	0.29	0	0	0	0.4	0.9	1.4	1.9
303.6	0.92	1.04	1.13	1.19	1.24	1.23	1.16	0.97	0.47	0	0	0.3	0.8	1.3	1.8
305.4	0.97	1.09	1.18	1.26	1.31	1.31	1.26	1.13	0.79	0	0	0.2	0.7	1.2	1.7
307.2	1.01	1.14	1.23	1.32	1.37	1.39	1.36	1.26	1.01	0	0	0.09	0.59	1.09	1.59
309	1.06	1.17	1.28	1.37	1.44	1.47	1.46	1.39	1.18	0.68	0	0	0.49	0.99	1.49
310.8	1.1	1.22	1.34	1.44	1.52	1.55	1.56	1.51	1.35	0.98	0	0	0.26	0.76	1.26
312.6	1.13	1.26	1.39	1.49	1.57	1.61	1.62	1.59	1.49	1.22	0	0	0.29	0.79	1.29


Reference Vc = 33 MV, I = 9 mA, Pg = 302kW
Qin = 2.8x10^6, Beam Timing = 565 μsec.
Vc
3 4
3
3 3
3 2
3 1
0
0.5
1
Time (msec.)
Qin = 2.38x10^6
Pg = 308kW
Qin = 2.38x10^6, Pg = 308kW
Qin = 3.22x10^6
Pg = 296kW
Qin = 3.22x10^6, Pg = 296kW

Coupling Tuning

Reference Vc = 33 MV
Pg = 302kW, Q_{in} = 2.8x10^6



Coupler Acceptance Test Parameters

- Maximum Operating Power

  350 kW x 1.15 = 400 kW

- Test Parameter (Example)

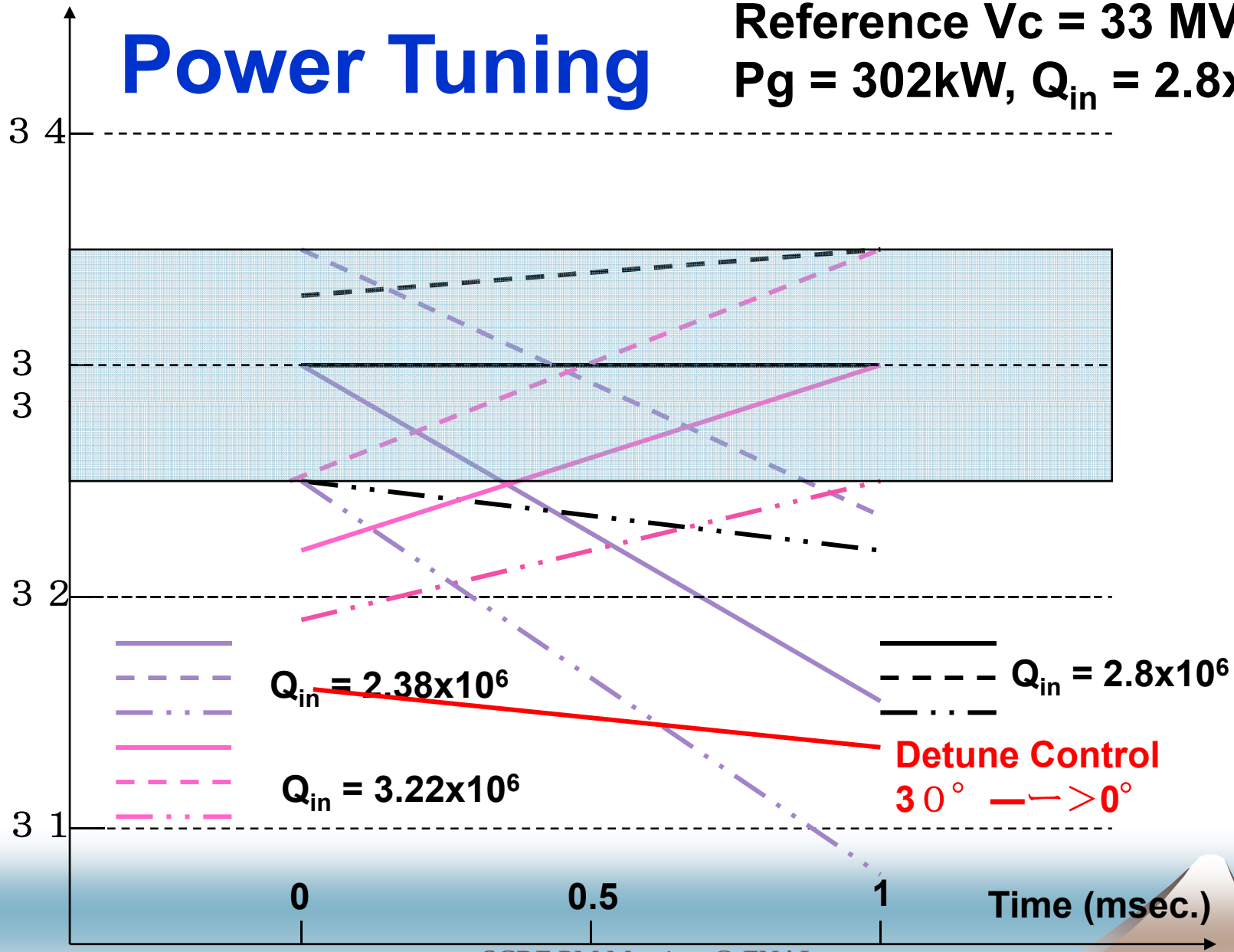
  1.0 MW, 1.6msec.

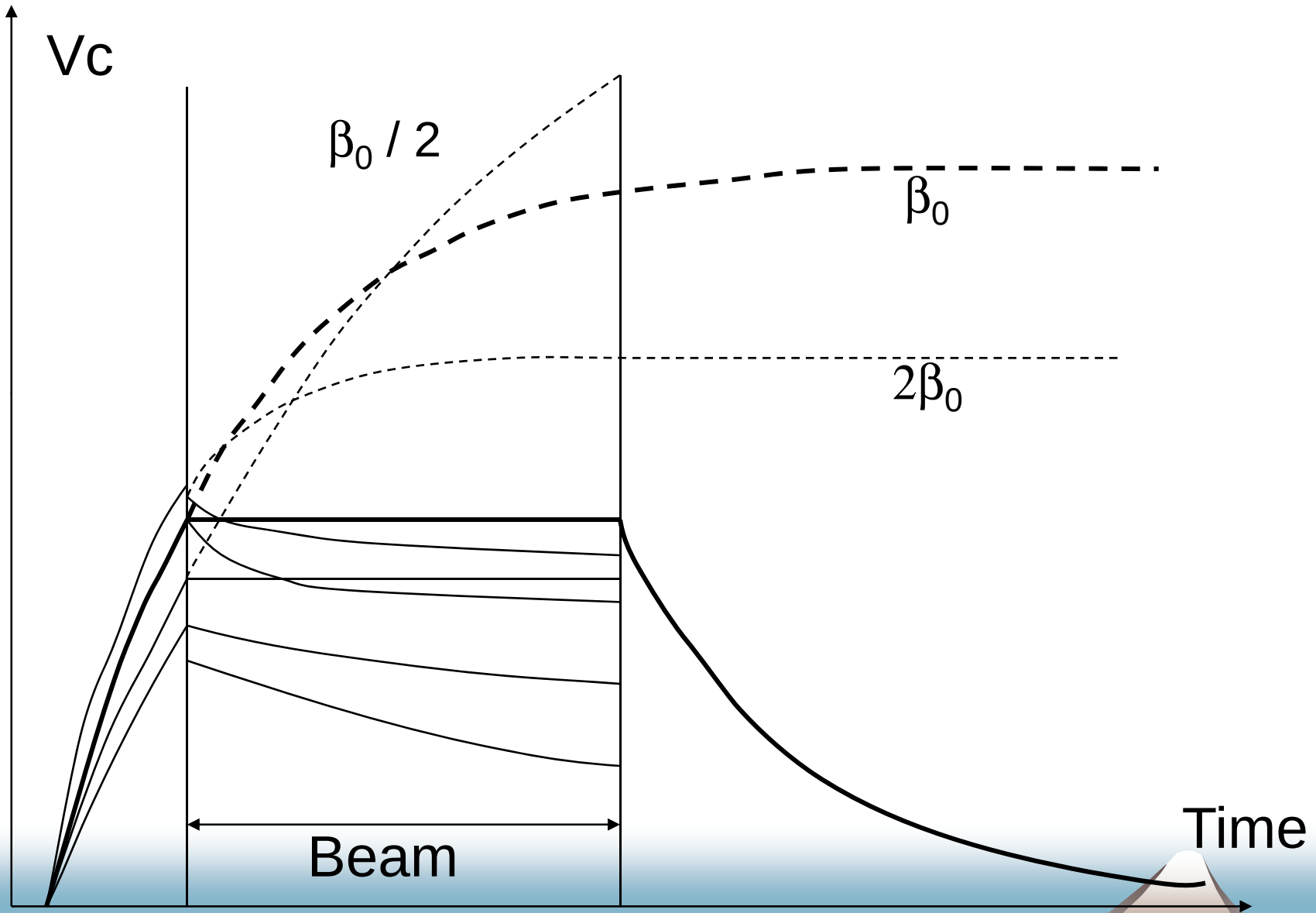
  1.7 MW, 0.3msec.

Construction Schedule

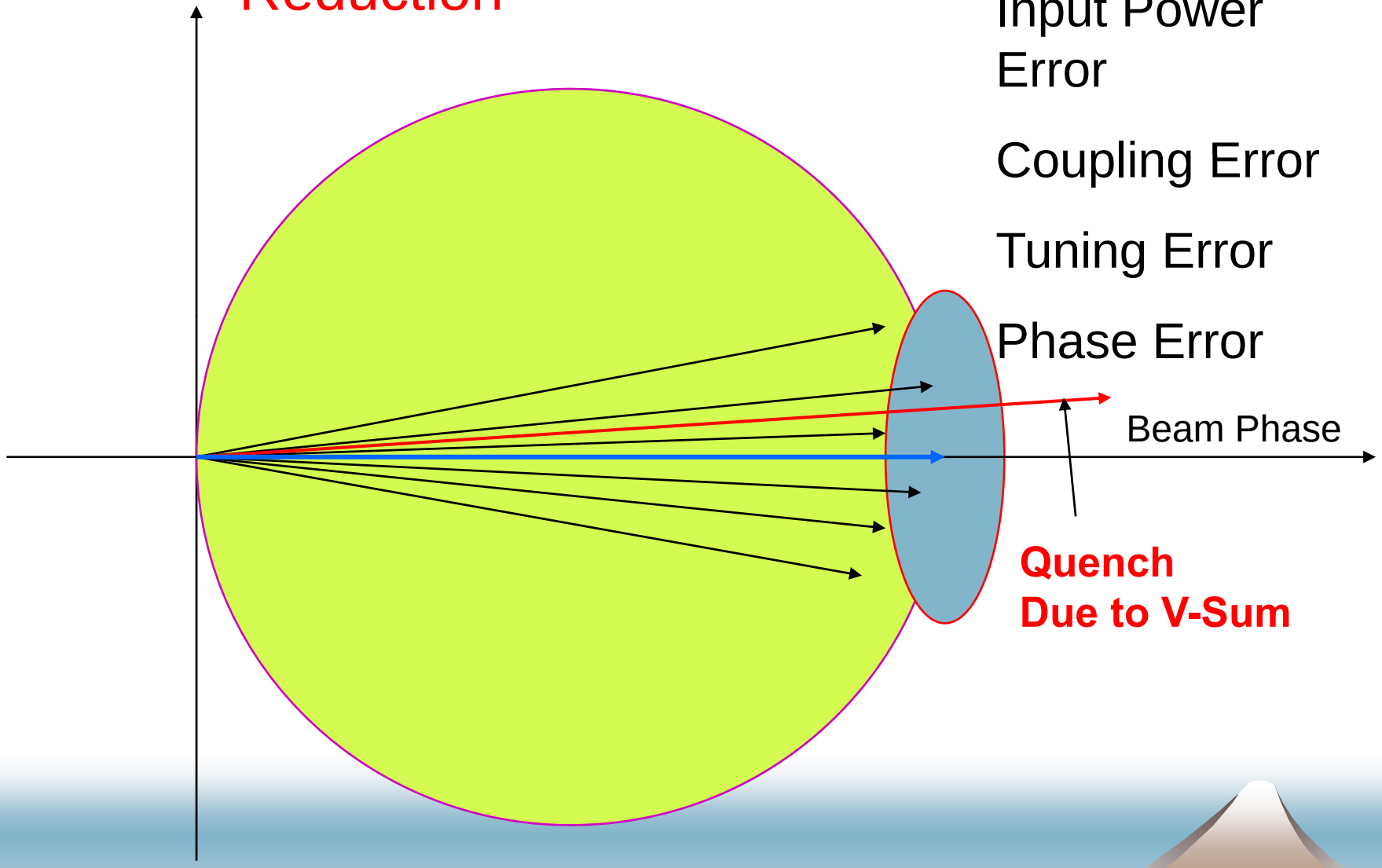
	0	1	2	3	4	5	6	7	8
Tunnel Construction									
Cavity Package		600	1000	1200	1200	1200			
Input Coupler		600	1000	1200	1200	1200			
Cryo-module Assembly			80	150	150	150	70		
Installation with Grouping						300	300		
System Commissioning									
Beam Commissioning									

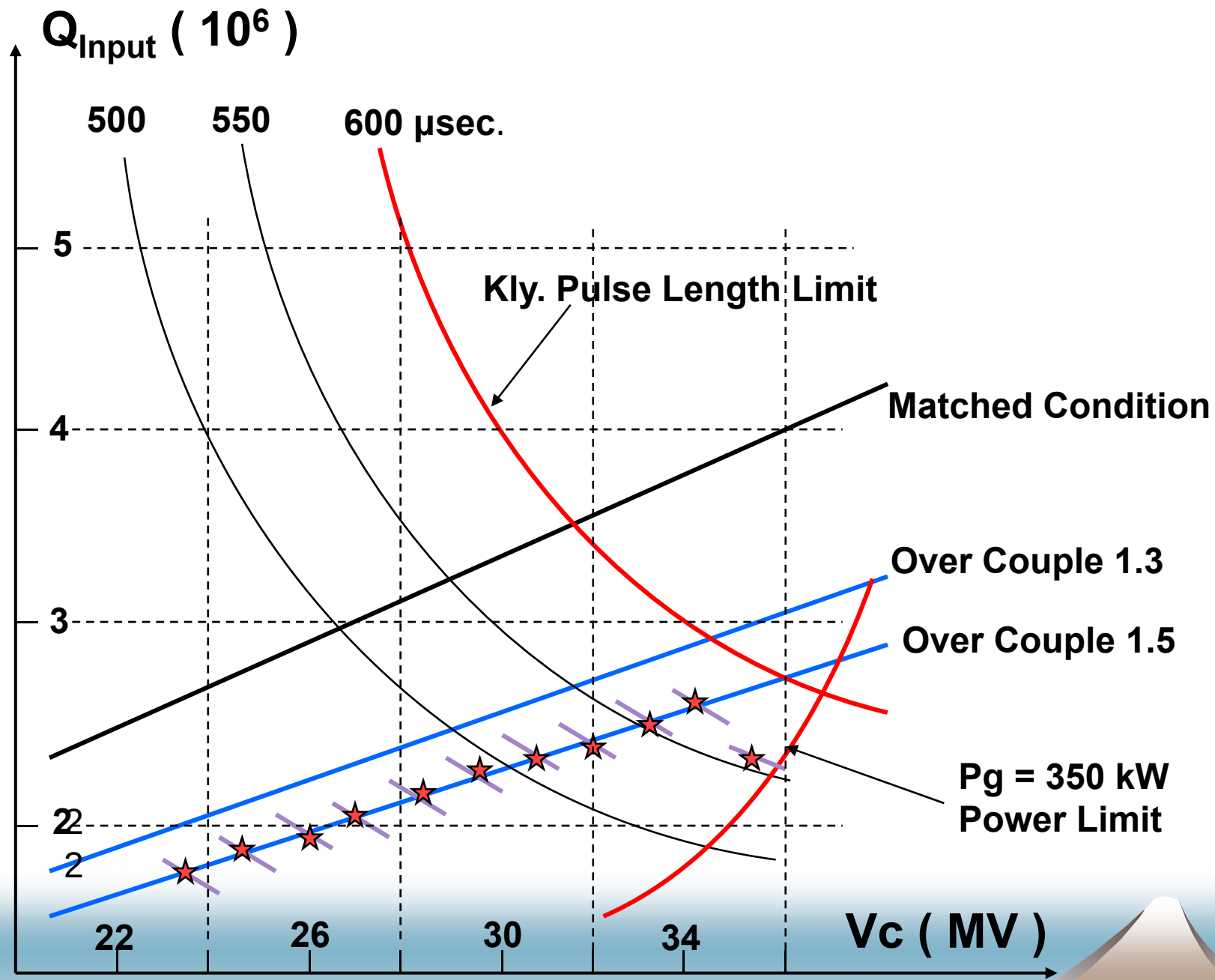
Power Tuning

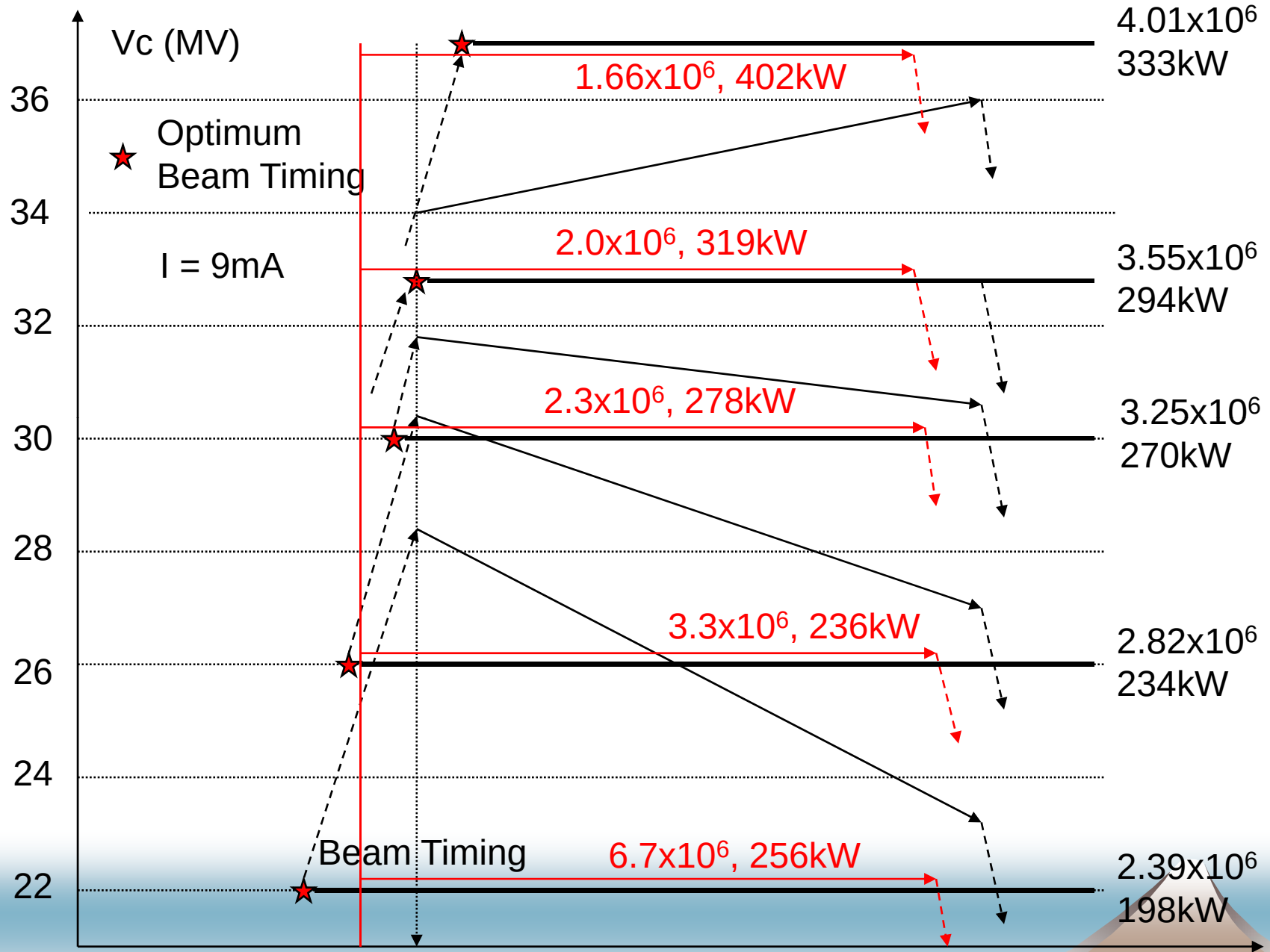



Vc
β0 / 2
β0
2β0
Beam
Time

Cavity Voltage Error & Gain Reduction




Q_{Input} (10^6)
500
550
600 μsec.
5
4
3
2
2
Kly. Pulse Length Limit
Matched Condition
Over Couple 1.3
Over Couple 1.5
Pg = 350 kW
Power Limit
22
26
30
34
Vc (MV)


Vc (MV)
36
34
32
30
28
26
24
22
Optimum
Beam Timing
I = 9mA
Beam Timing
1.66x10^6, 402kW
2.0x10^6, 319kW
2.3x10^6, 278kW
3.3x10^6, 236kW
6.7x10^6, 256kW
4.01x10^6
333kW
3.55x10^6
294kW
3.25x10^6
270kW
2.82x10^6
234kW
2.39x10^6
198kW
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Time (msec.)

5 mA Head (0.6msec.,73% Power)

	V														
Q	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5
1.96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01
2.8	0	0	0	0	0	0	0	0	0	0	0	0.11	0.23	0.35	0.46
2.94	0	0	0	0	0	0	0	0	0.13	0.26	0.38	0.51	0.64	0.77	0.9
3.08	0	0	0	0	0	0.09	0.22	0.36	0.49	0.62	0.76	0.89	1.03	1.16	1.29
3.22	0	0	0	0.13	0.27	0.41	0.55	0.69	0.82	0.96	1.11	1.24	1.39	1.53	1.67

5 mA Tail (0.6msec.,73% Power)

	V														
Q	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	35.5	36	36.5
1.96	4.34	4.26	4.19	4.1	4.04	3.97	3.89	3.81	3.74	3.67	3.59	3.51	3.44	3.36	3.29
2.1	3.87	3.77	3.68	3.59	3.5	3.42	3.32	3.23	3.14	3.05	2.96	2.86	2.78	2.69	2.59
2.24	3.4	3.28	3.18	3.08	2.98	2.87	2.75	2.66	2.55	2.44	2.34	2.24	2.13	2.03	1.92
2.38	2.93	2.81	2.69	2.57	2.46	2.33	2.22	2.09	1.97	1.86	1.74	1.62	1.5	1.38	1.26
2.52	2.48	2.34	2.21	2.08	1.94	1.81	1.68	1.55	1.41	1.28	1.15	1.01	0.88	0.75	0.61
2.66	2.04	1.89	1.74	1.6	1.45	1.31	1.16	1.01	0.87	0.72	0.57	0.42	0.28	0.13	0
2.8	1.61	1.45	1.29	1.13	0.97	0.81	0.65	0.5	0.33	0.18	0.02	0	0	0	0
2.94	1.2	1.02	0.85	0.68	0.51	0.34	0.17	0	0	0	0	0	0	0	0
3.08	0.79	0.61	0.43	0.24	0.06	0	0	0	0	0	0	0	0	0	0
3.22	0.39	0.21	0.02	0	0	0	0	0	0	0	0	0	0	0	0

Realistic Gradient Distribution