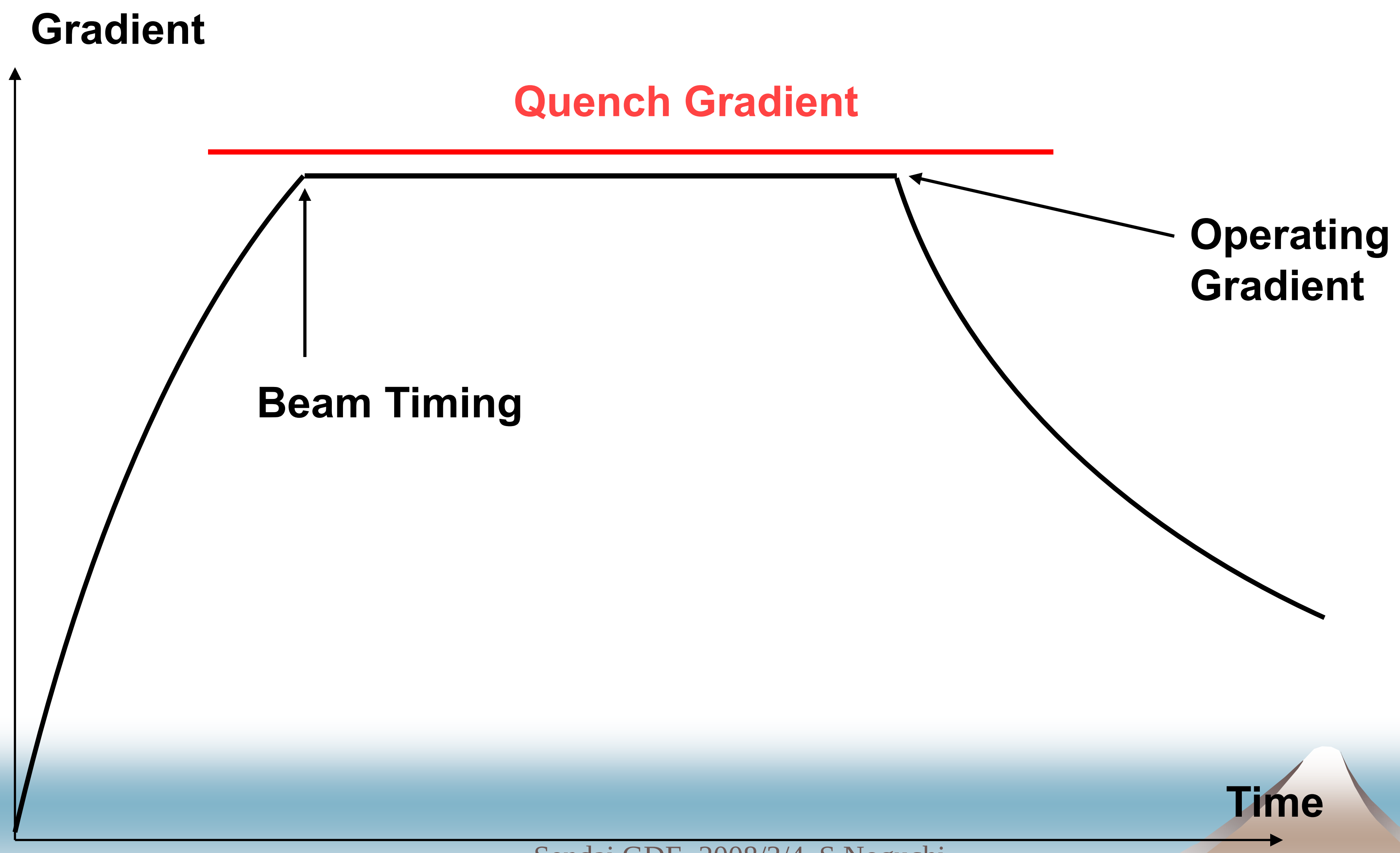
for the Simple
Highest Gradient Operation

- Grouping Concept
  for Scattered Cavity Gradient.
- Fixed Coupling.
- Required Coupler Power Capacity.

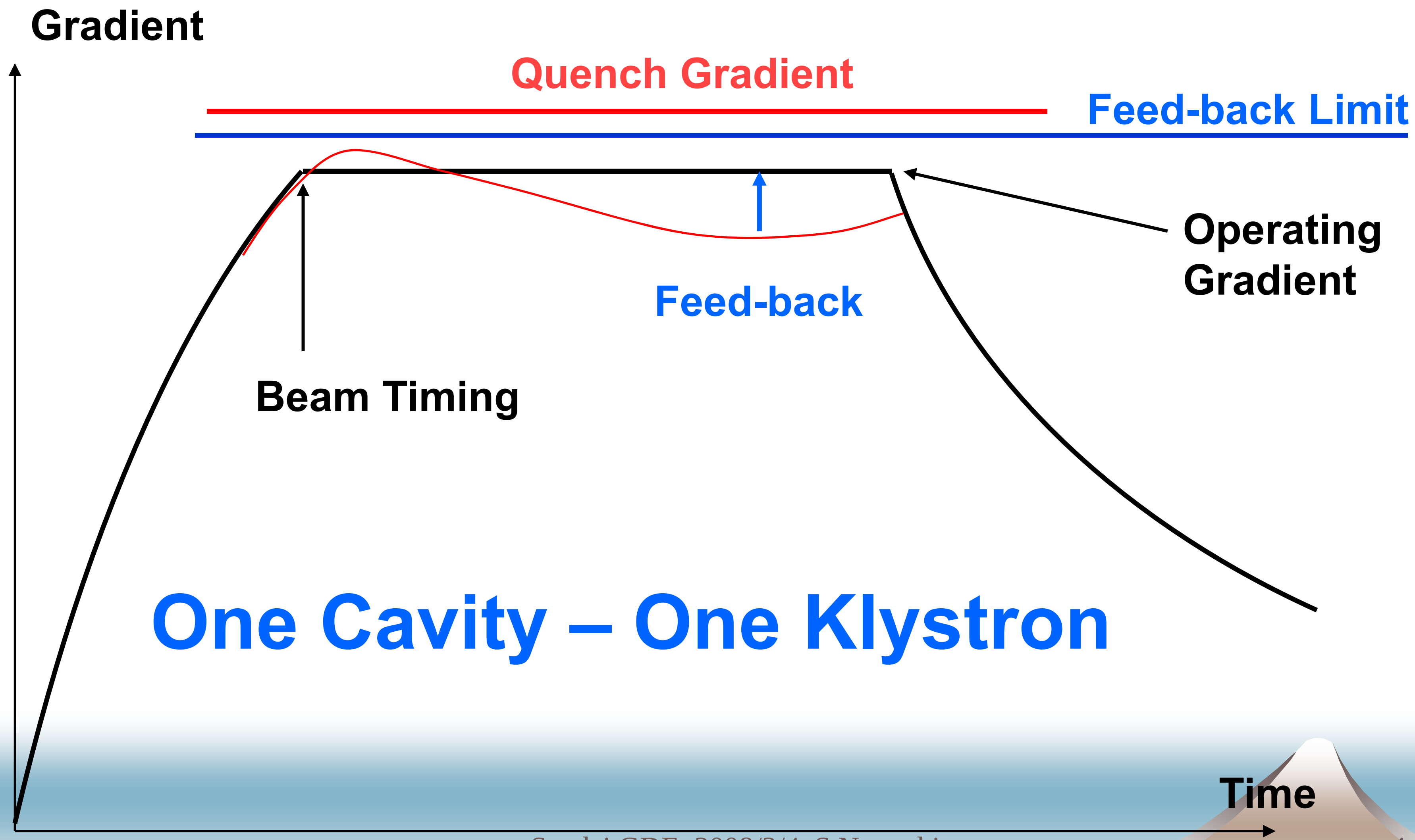
Operating Condition in ILC - ML

- 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.

Highest Gradient Operation



Highest Gradient Operation

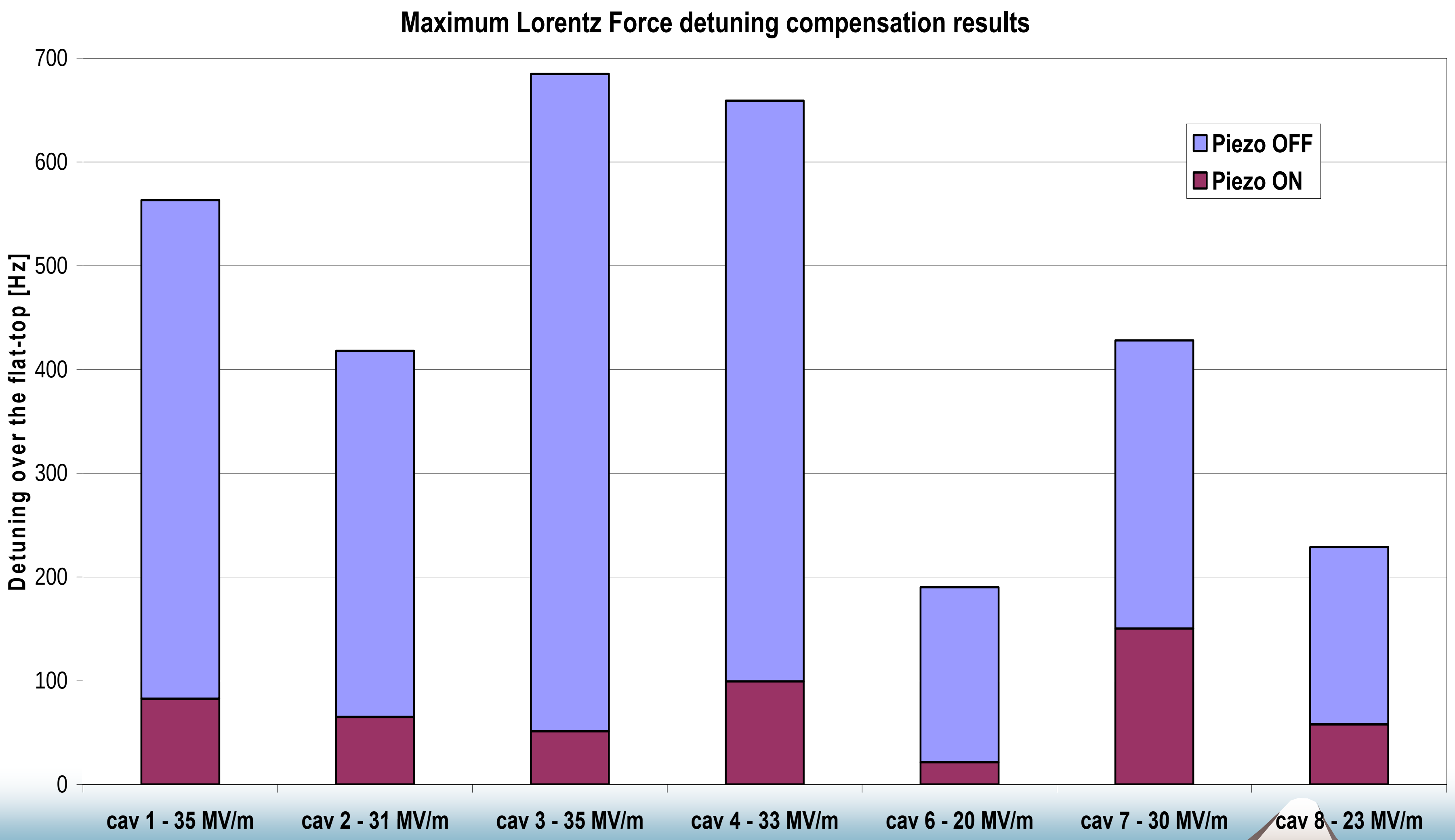


One Cavity – One Klystron

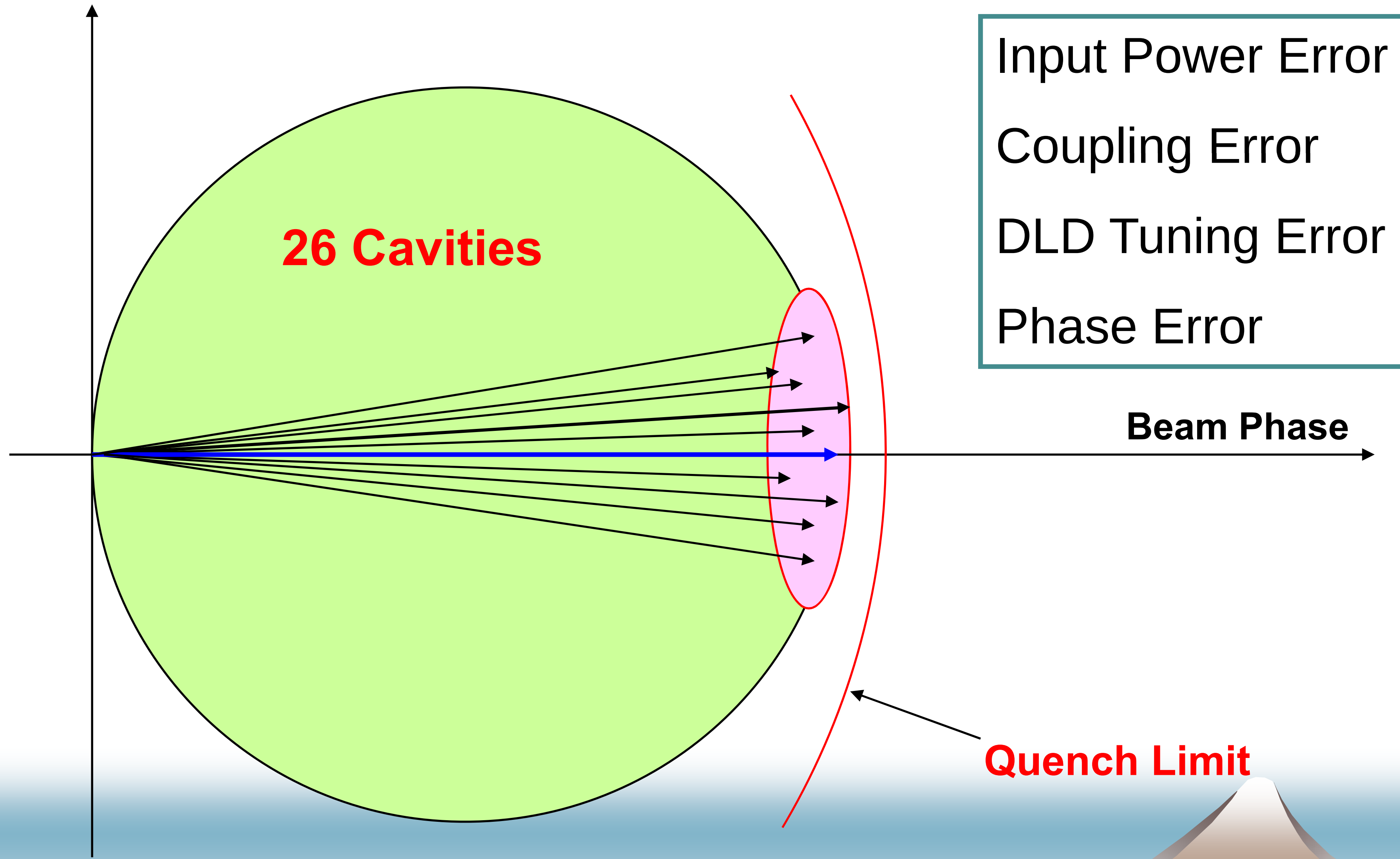
Error Souses of Operating Gradient

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

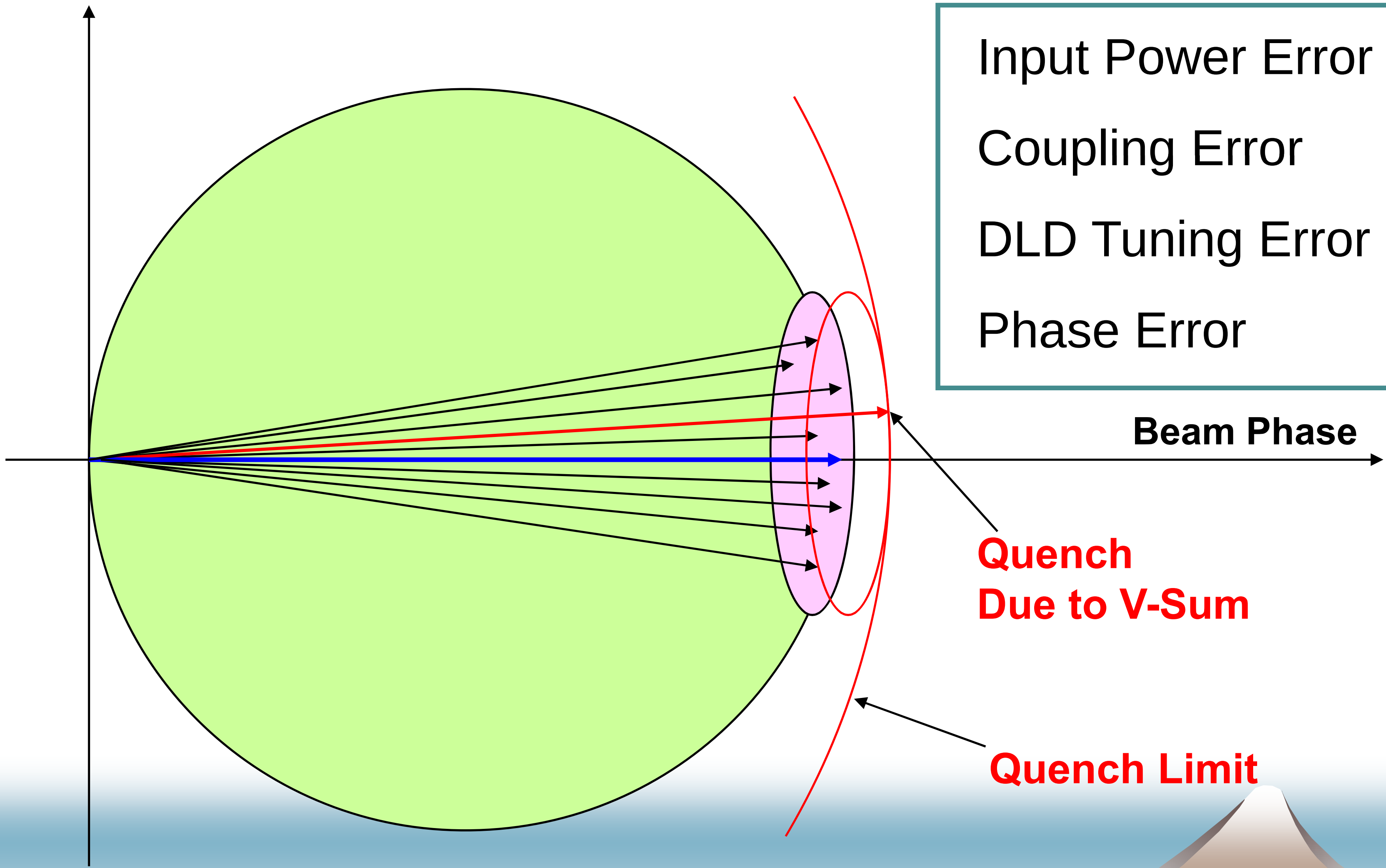
DLD Compensation Error



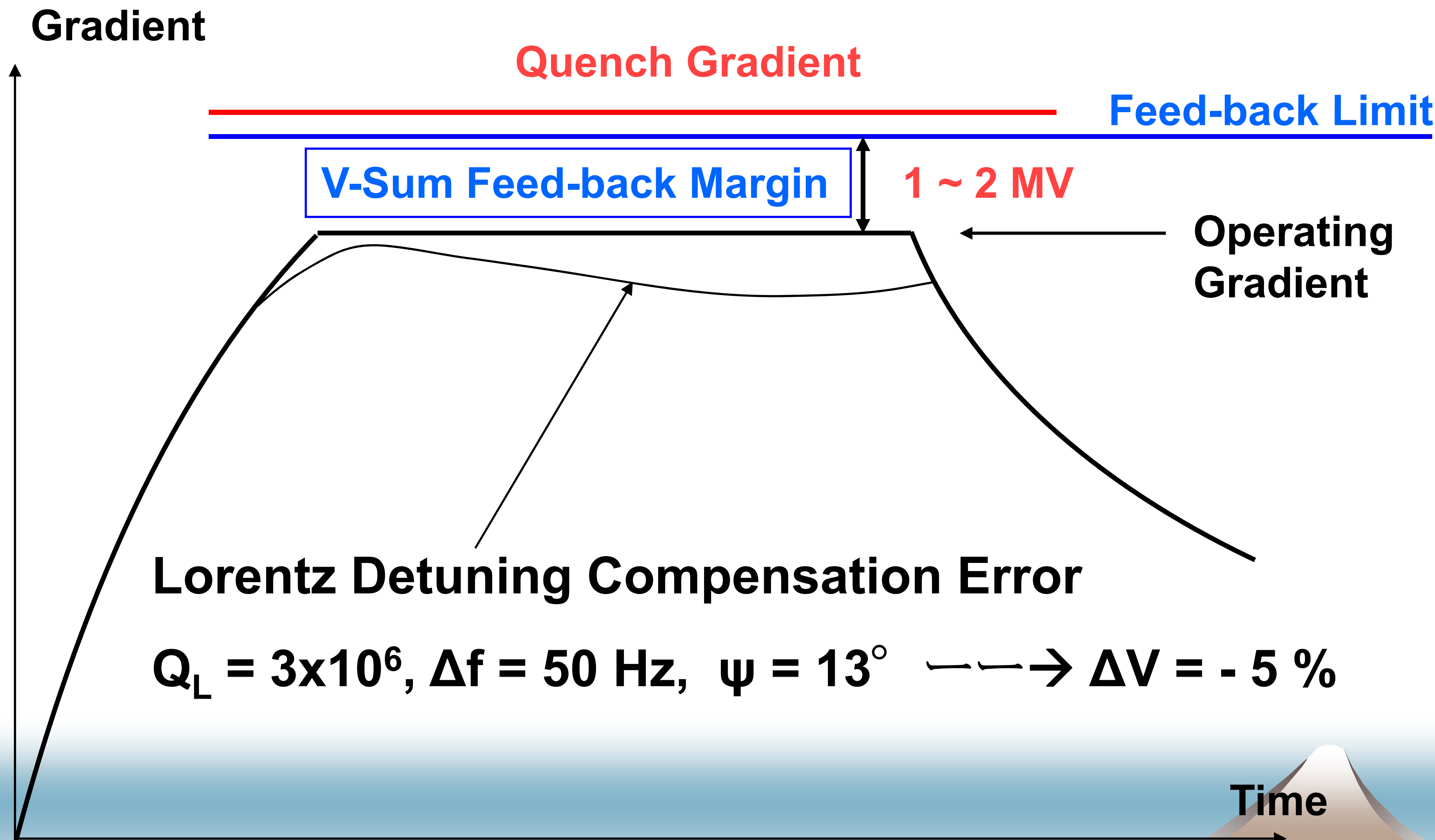
Vector Sum Control



Vector Sum Control



Highest Gradient Operation



$Q_L = 3\times10^6$, $\Delta f = 50$ Hz, $\psi = 13^\circ$ $\longrightarrow$ $\Delta V = -5\,\%$

Parameter Setting for Flat-Top

Accelerating Voltage V_0 , Beam Current I_b

↓

Optimum $\beta = \beta_b + 1$, $\beta_b = P_{Beam} / P_0$

↓

CW

Pg

Pulse for Flat-Top

↓

Beam Timing	$T_e = T_F \ln \dfrac{1 + \beta + \beta_b}{\beta_b}$

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.

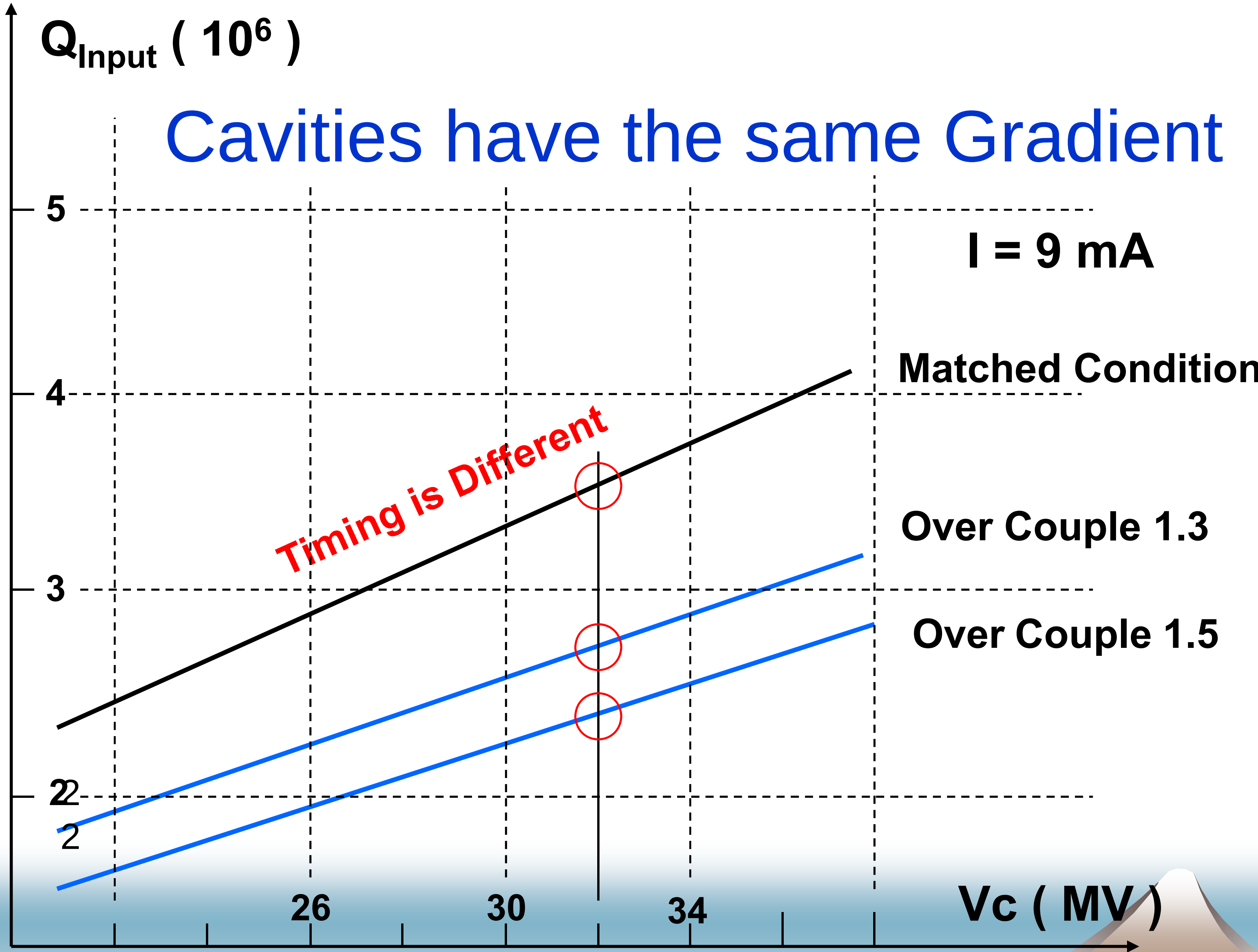
Cavity Voltage

During Build-up

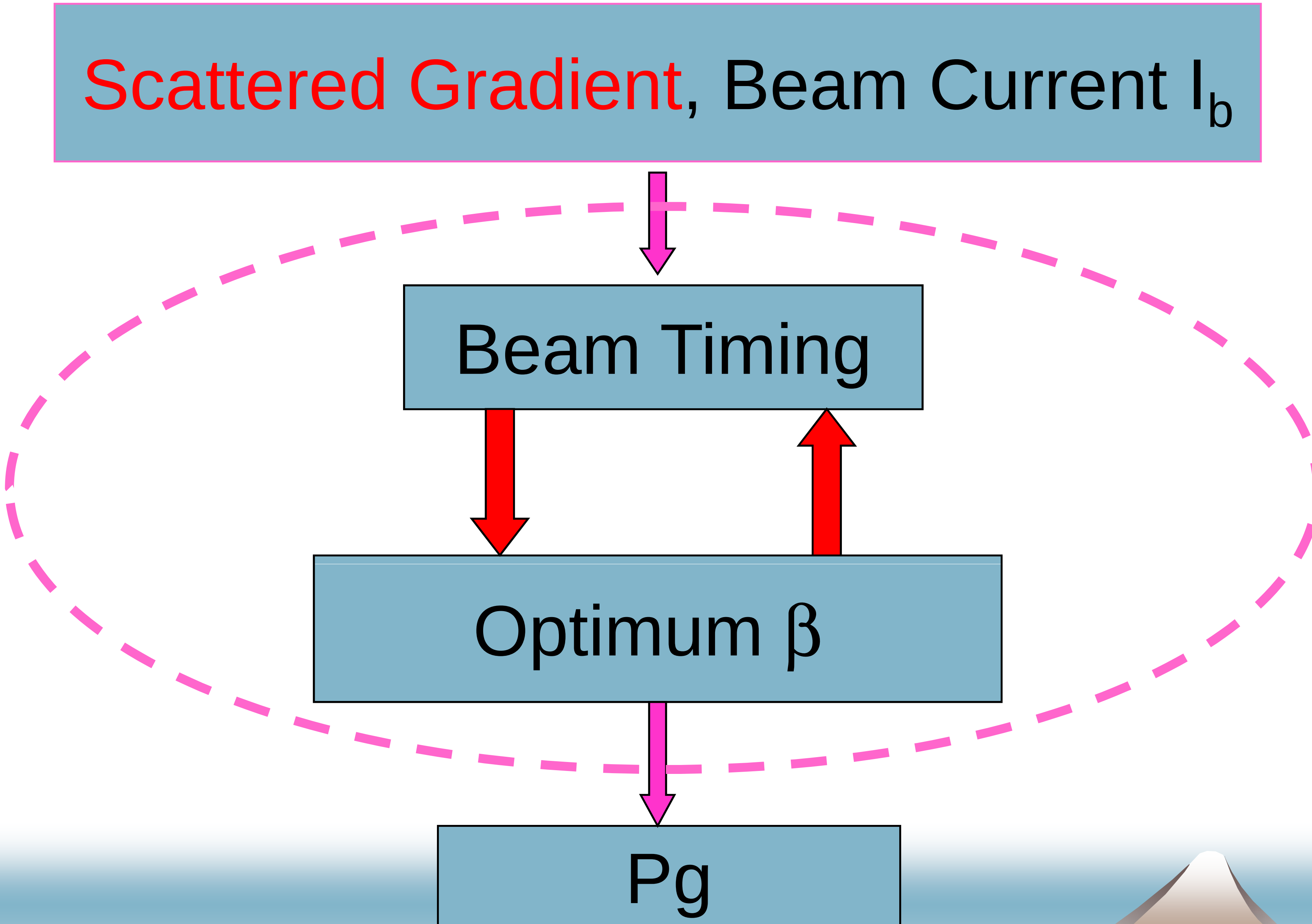
$$\vec{V} = V_d \left[1 - \exp\left(-\frac{t}{T_F} \right) \exp\left(j \frac{\tan\psi}{T_F} t \right) \right] \cos\psi \exp\{ j(\theta + \psi) \}$$

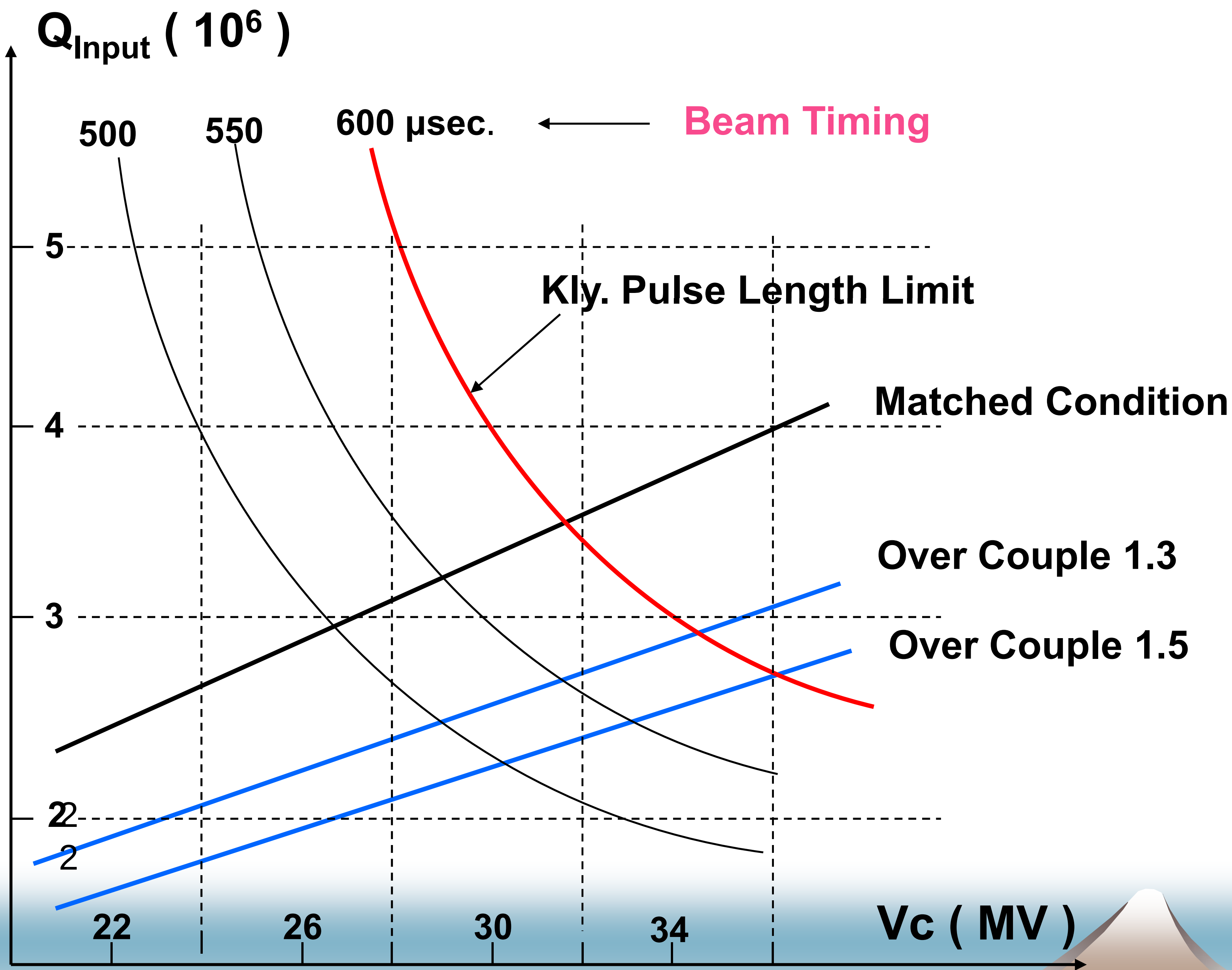
$$V_d = V_g = 2\sqrt{P_g \left(\frac{R}{Q} \right) Q_0 \frac{\beta}{(1+\beta)^2}}$$

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

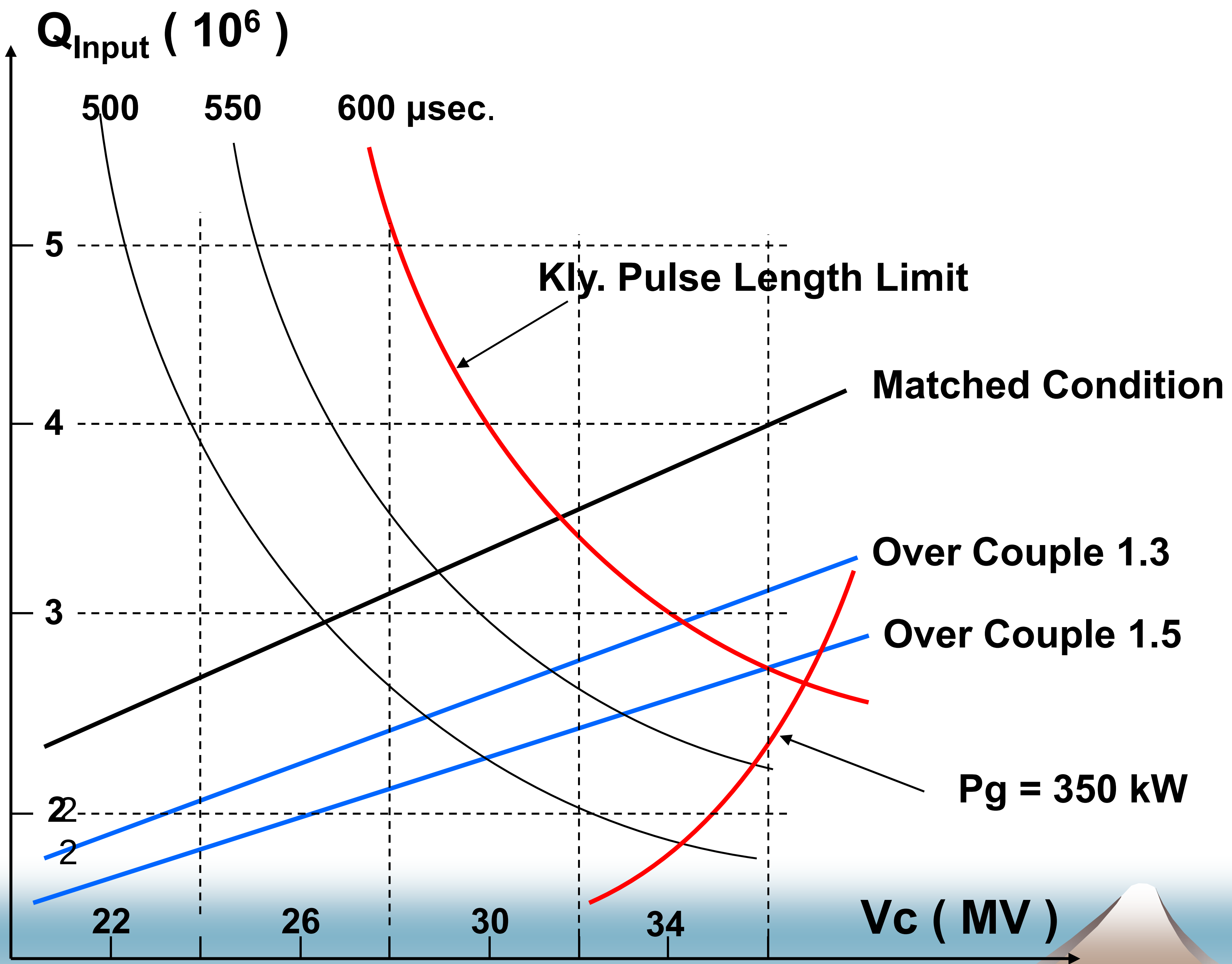


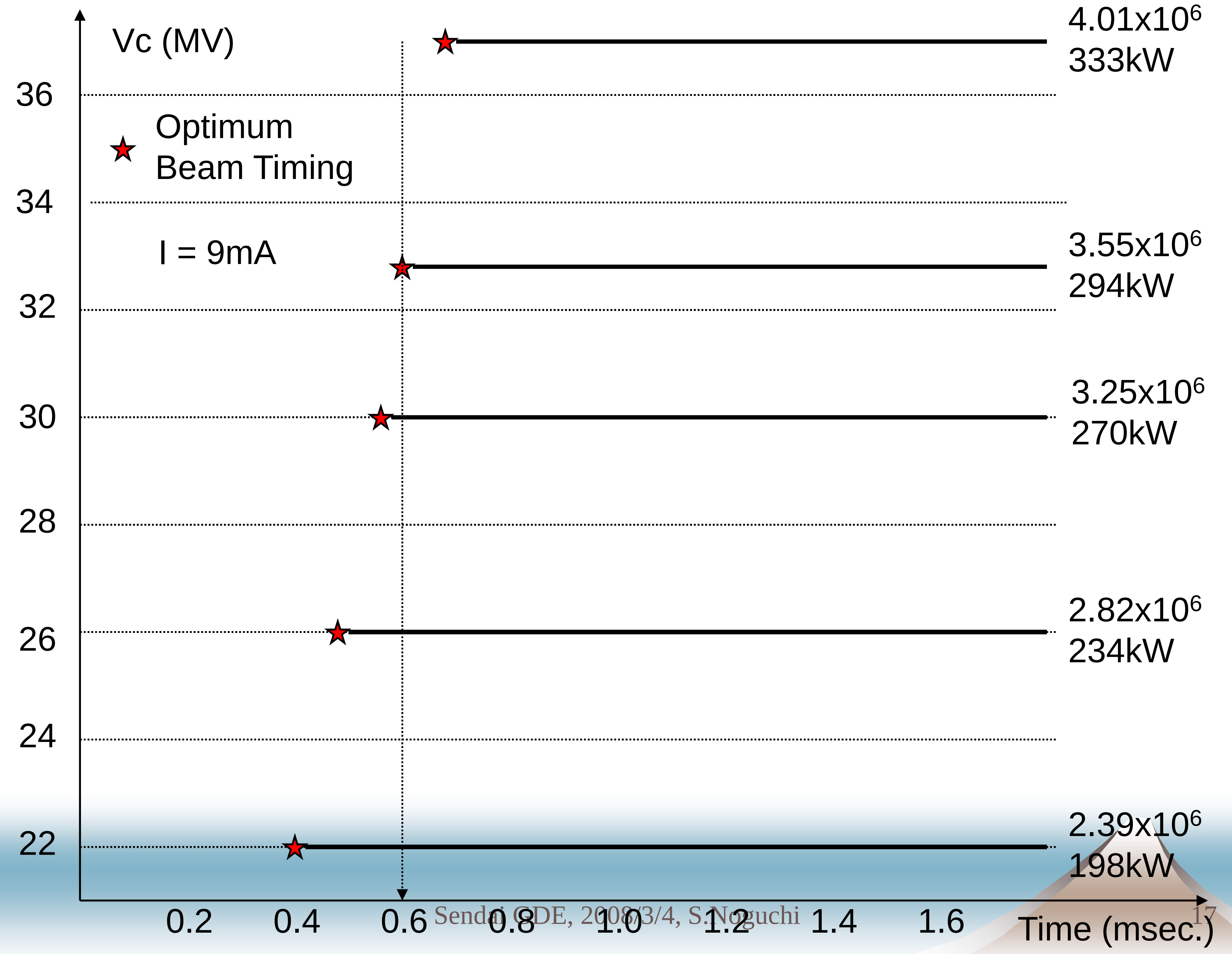
Q_{Input} (10^6)
Cavities have the same Gradient
5
I = 9 mA
Matched Condition
4
Timing is Different
Over Couple 1.3
3
Over Couple 1.5
2
2
2
26
30
34
Vc (MV)

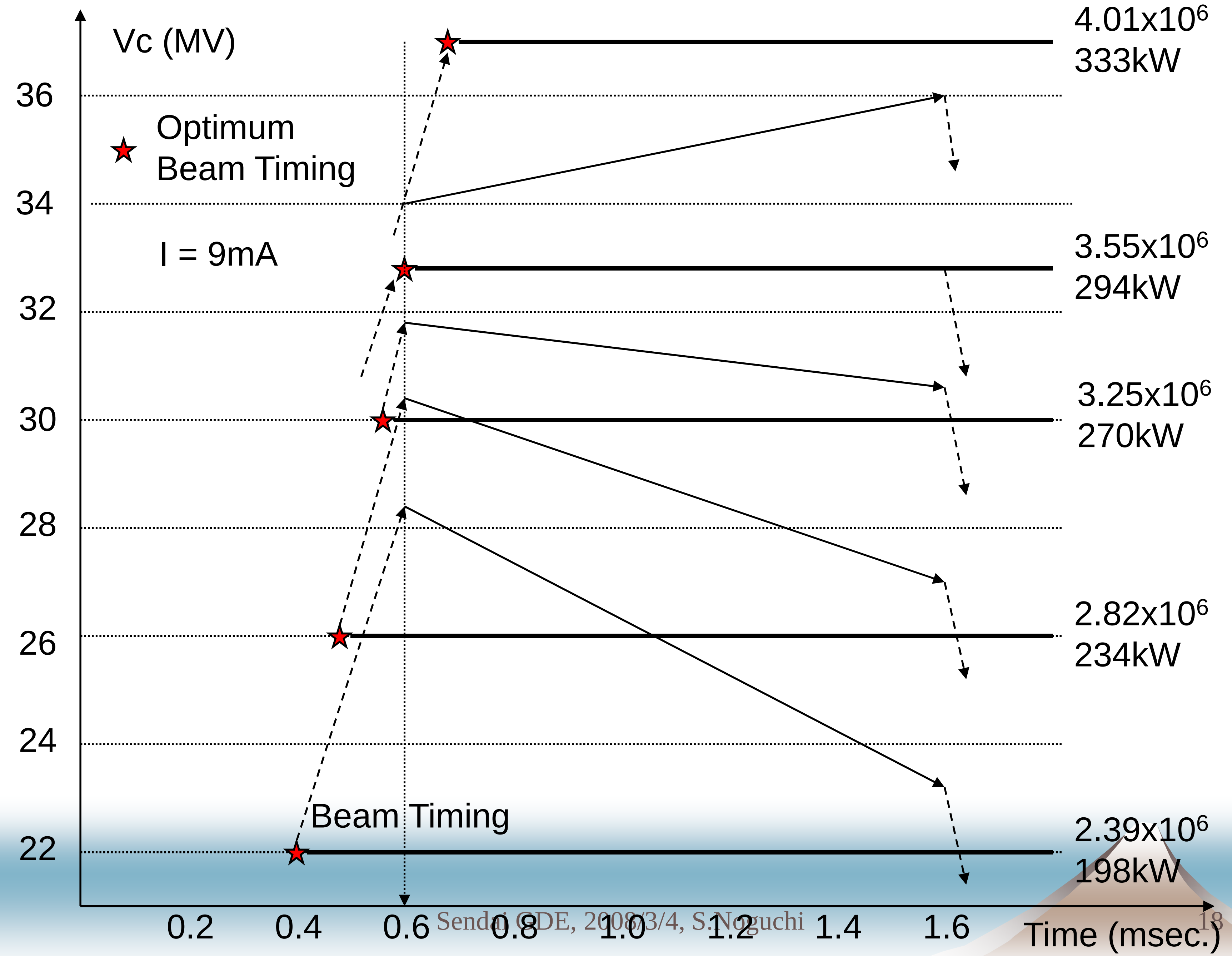

Scattered Gradient, Beam Current I_b
Beam Timing
Optimum β
Pg

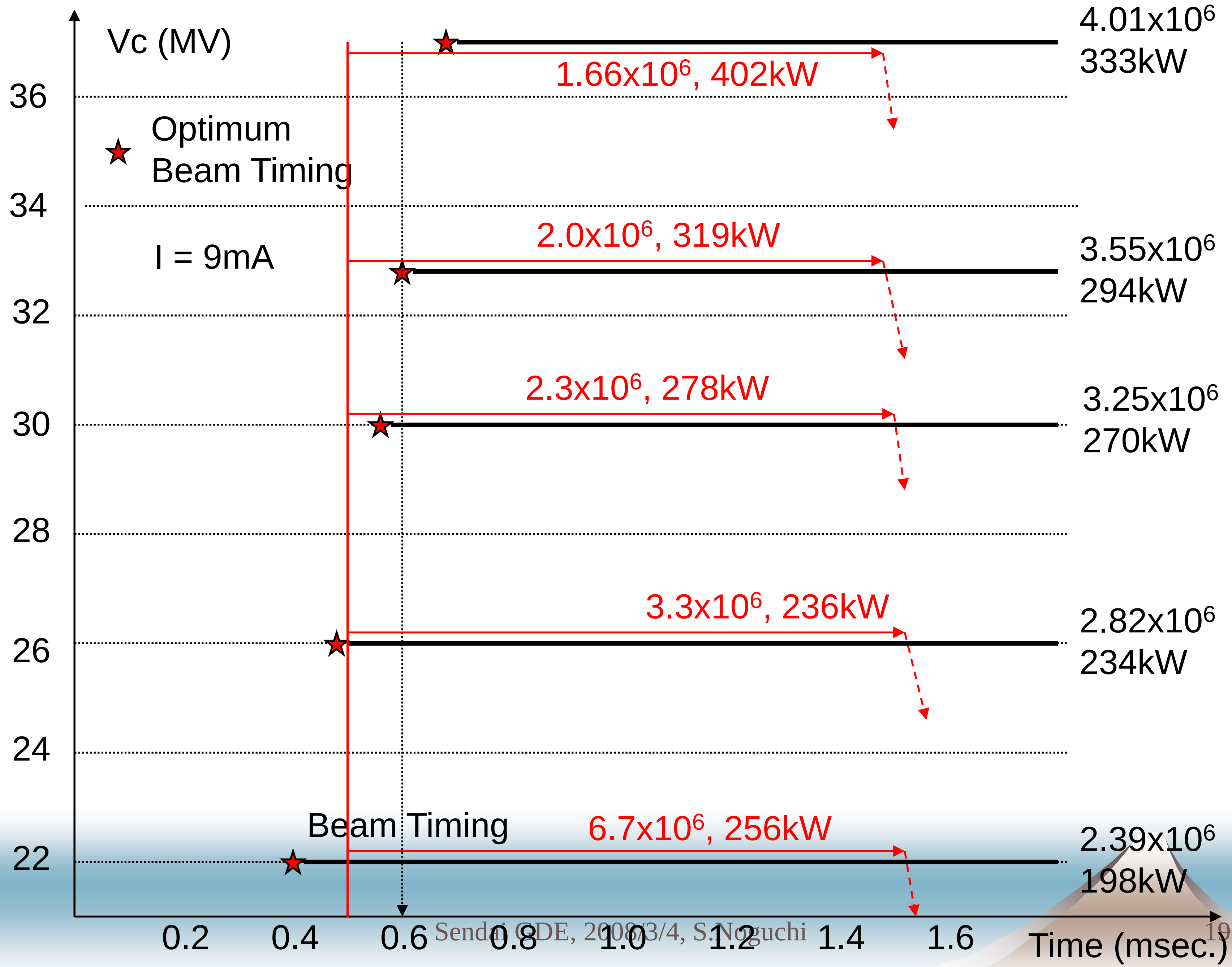


Q_{Input} (10^6)
500
550
600 µsec.
Beam Timing
Kly. Pulse Length Limit
Matched Condition
Over Couple 1.3
Over Couple 1.5
5
4
3
2
22
26
30
34
Vc (MV)


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
22
26
30
34
Vc (MV)


Vc (MV)
Optimum
Beam Timing
I = 9mA
36
34
32
30
28
26
24
22
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.)

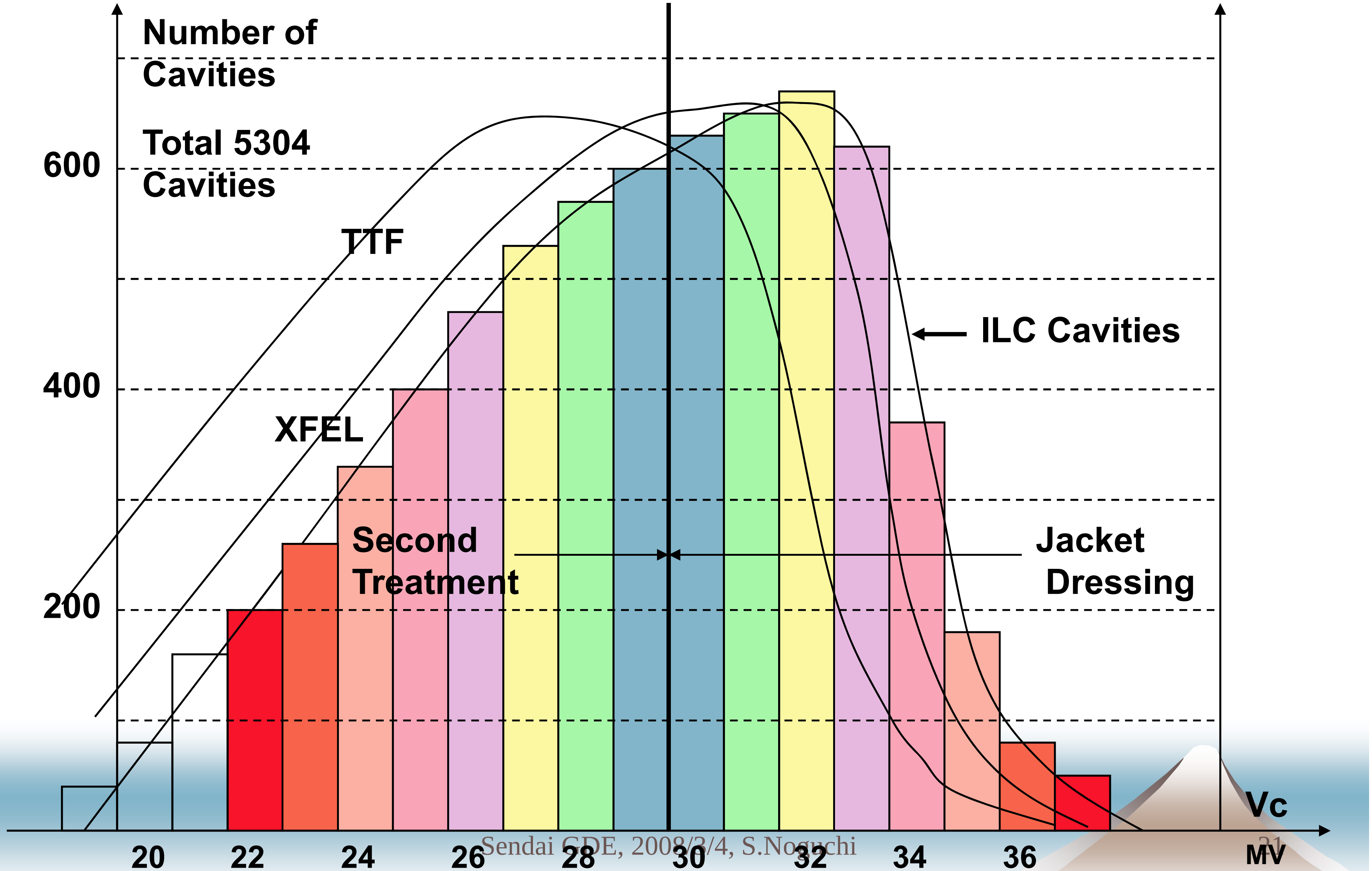

Vc (MV)
36
34
32
30
28
26
24
22
Optimum Beam Timing
I = 9mA
Beam Timing
4.01x10^6
333kW
3.55x10^6
294kW
3.25x10^6
270kW
2.82x10^6
234kW
2.39x10^6
198kW
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Time (msec.)


Vc (MV)
Optimum
Beam Timing
I = 9mA
36
34
32
30
28
26
24
22
4.01x10^6
333kW
1.66x10^6, 402kW
2.0x10^6, 319kW
3.55x10^6
294kW
2.3x10^6, 278kW
3.25x10^6
270kW
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.)

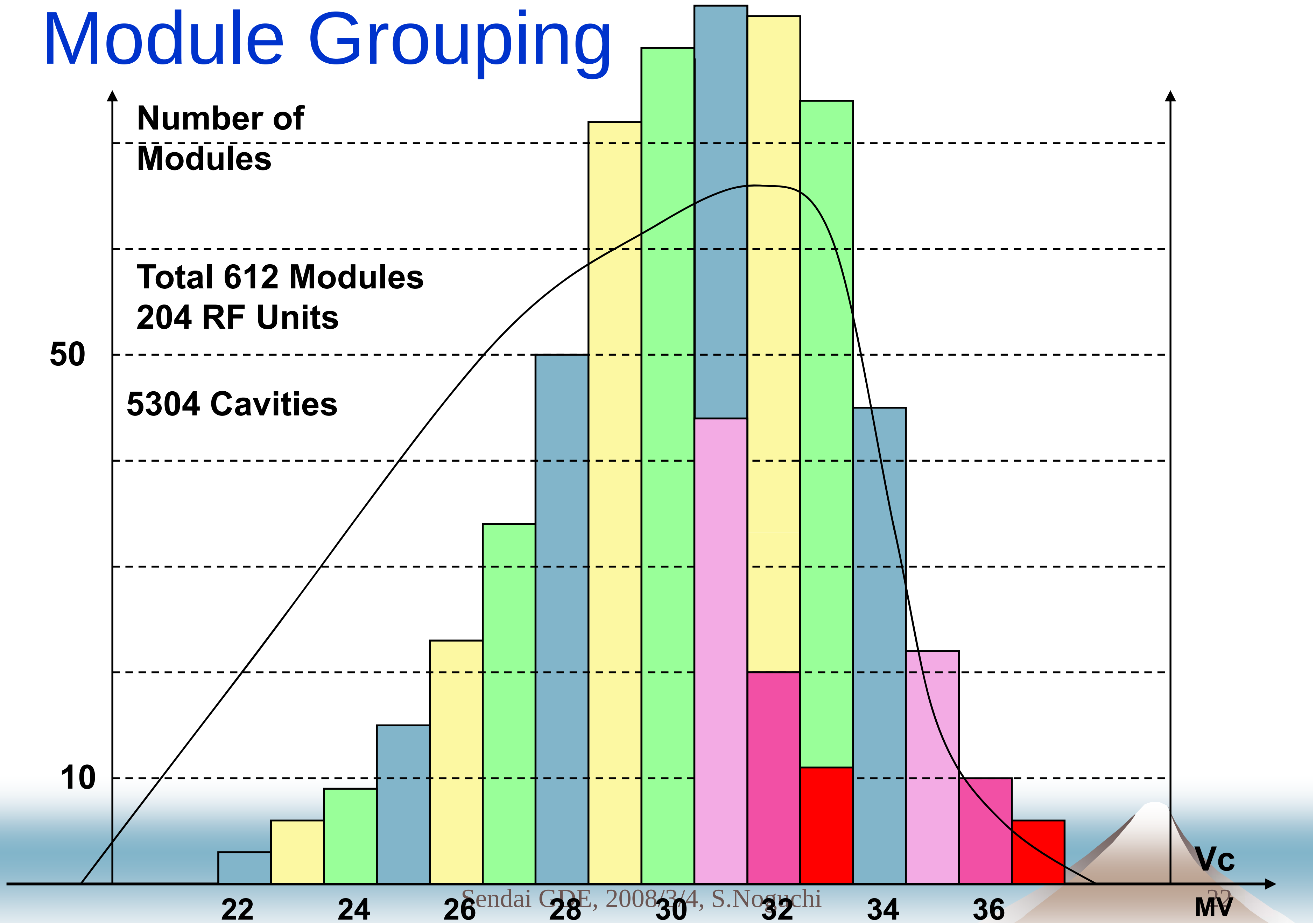
Cavity Grouping Concept

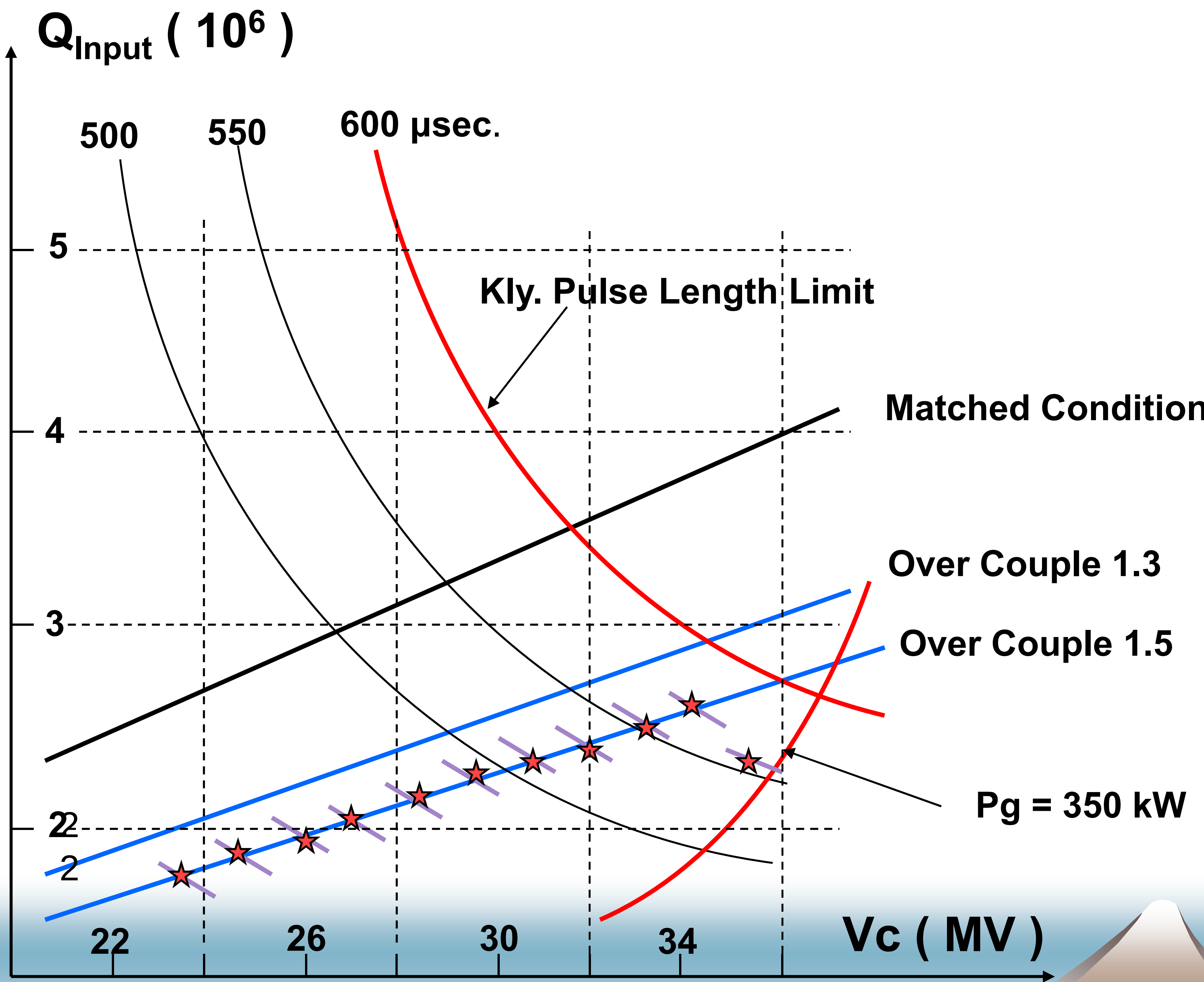
- Install the Cavities having the same Maximum Gradient into the same Cryostat.
- Drive the same Gradient Cryomodules by one Klystron.
- Combine a high Gradient module with two other low Gradient Modules.

Cavity Grouping



Module Grouping




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

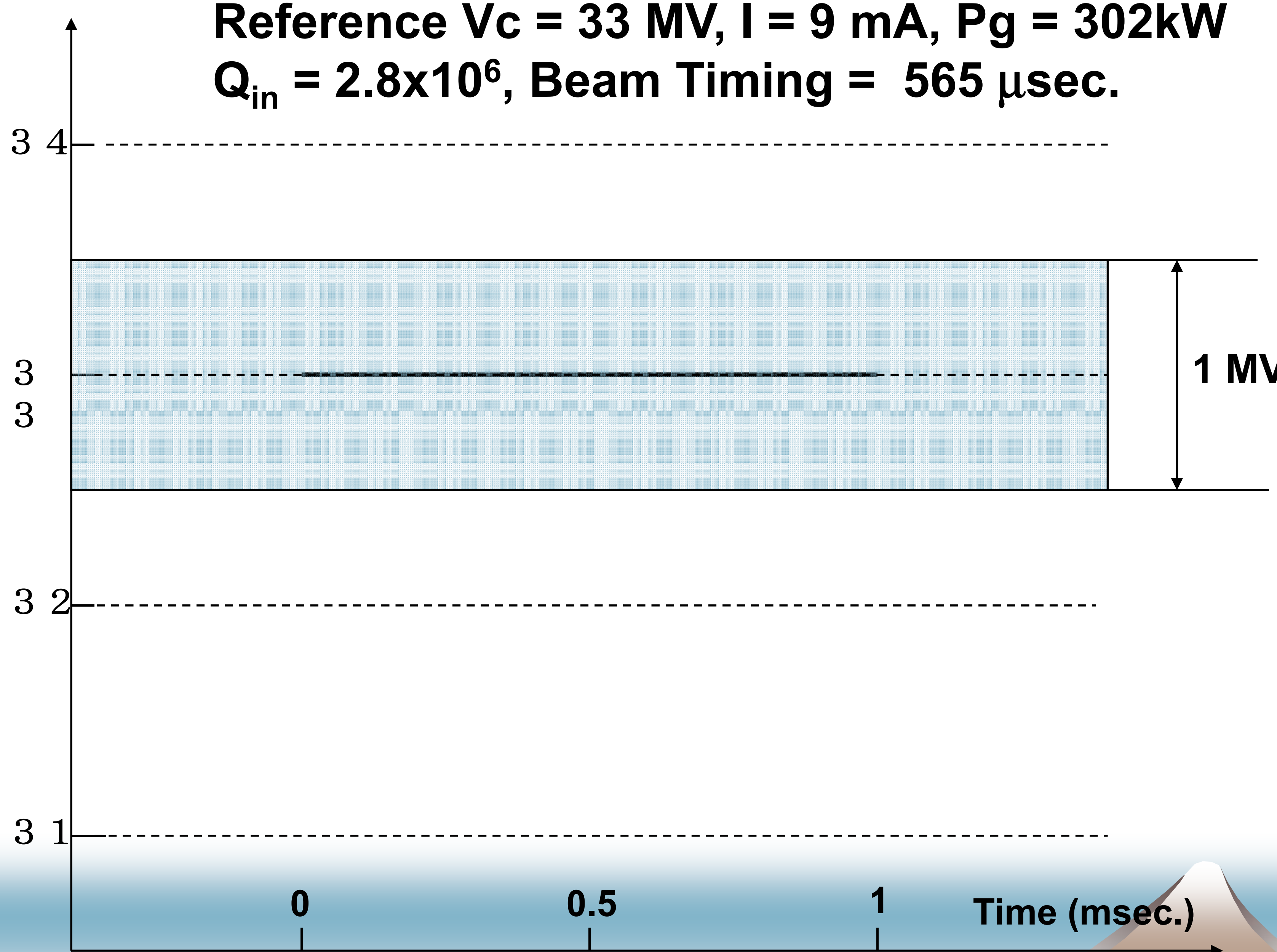
Gradient Reduction & Tuning in Grouped Cavities

- No Tuning
- Power Tuning
- Coupling Tuning
- Power & Coupling Tuning
- DLD Compensation Error is not Included.

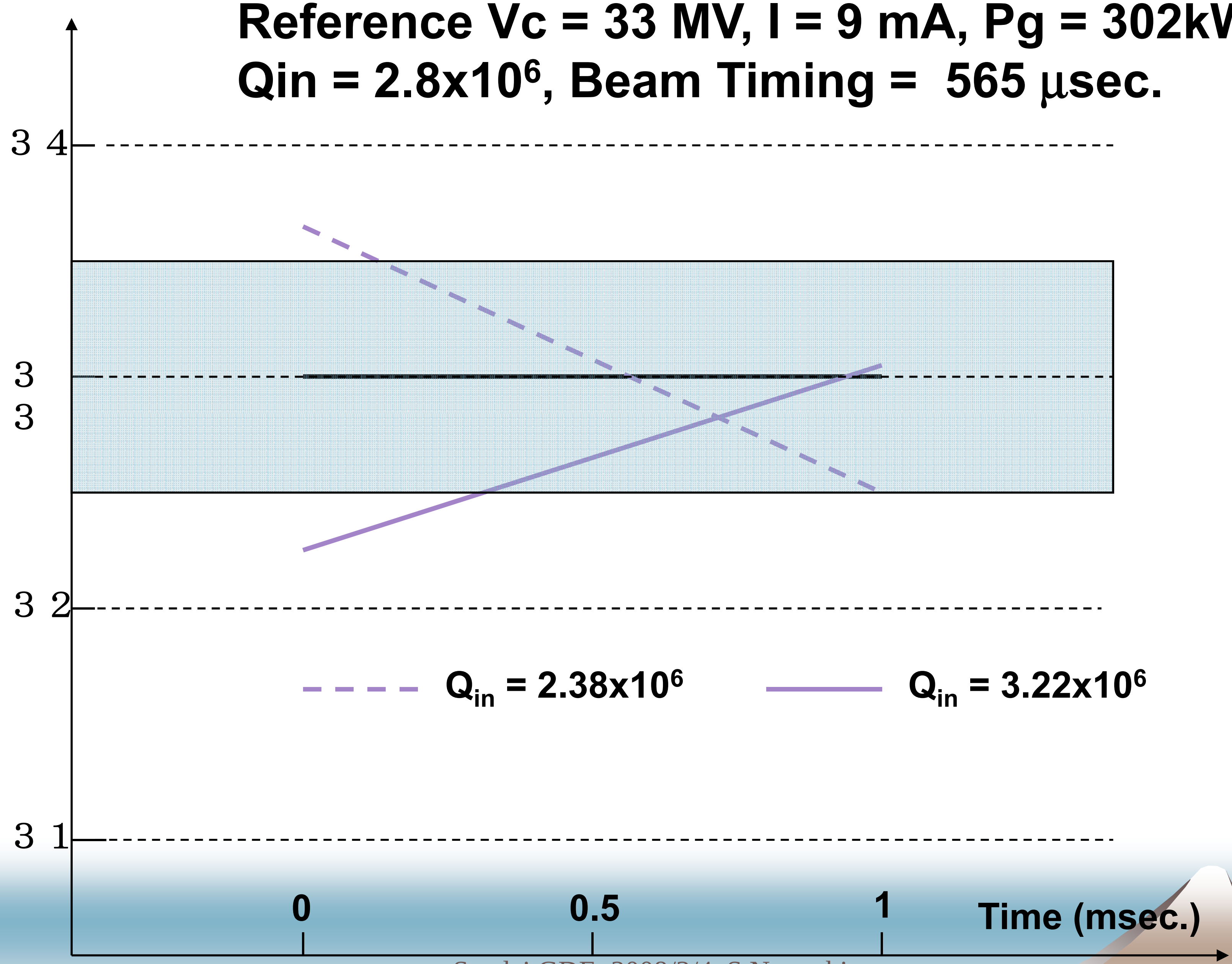
Error Souses of Operating Gradient

Error Souse	Error	Effect on Energy Gain	
Input Coupling Geometric + Field Flatness	15%	+1.9, -2.3%	Fixed
Input Power	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

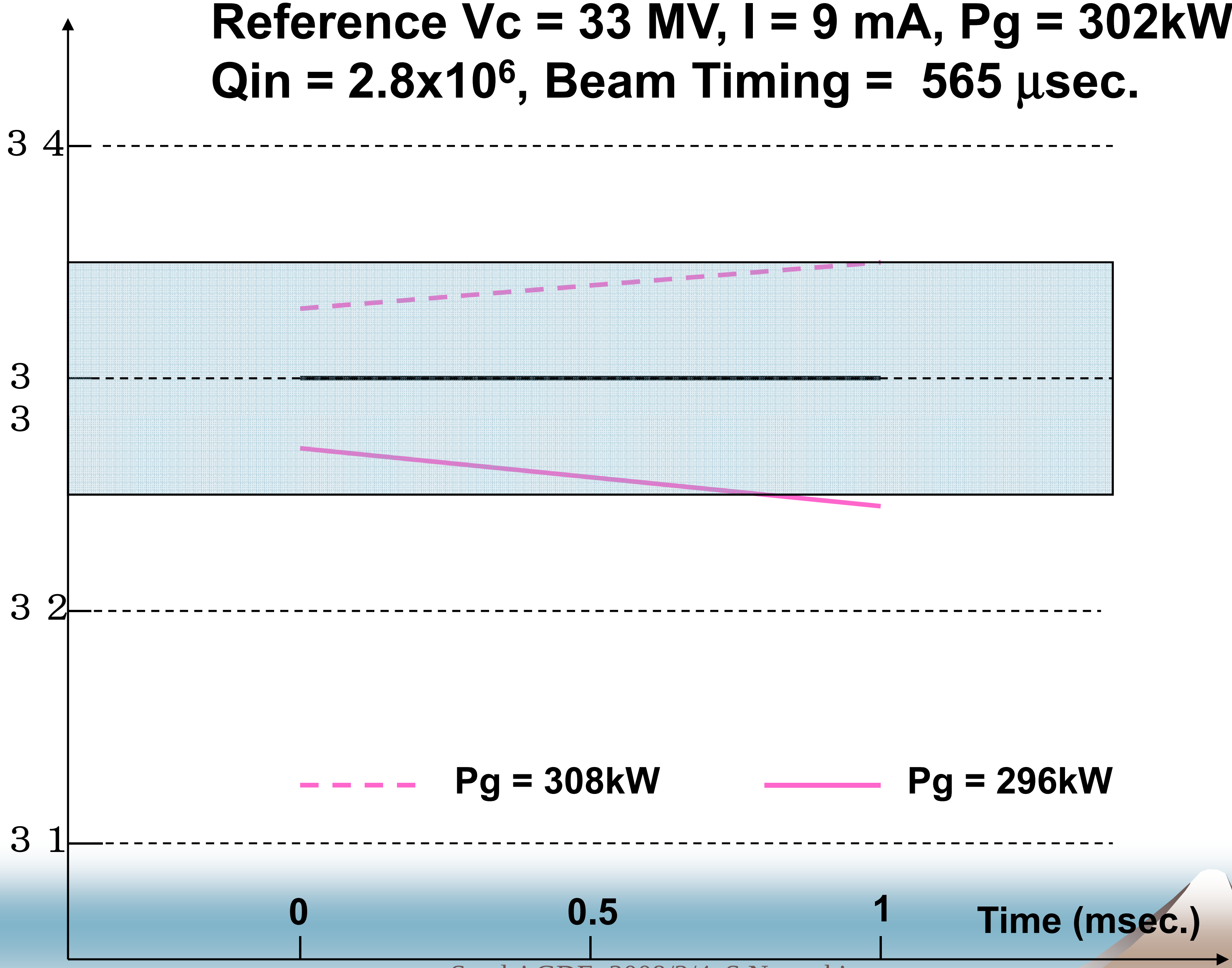
Reference Vc = 33 MV, I = 9 mA, Pg = 302kW
Q_{in} = 2.8x10^6, Beam Timing = 565 μsec.



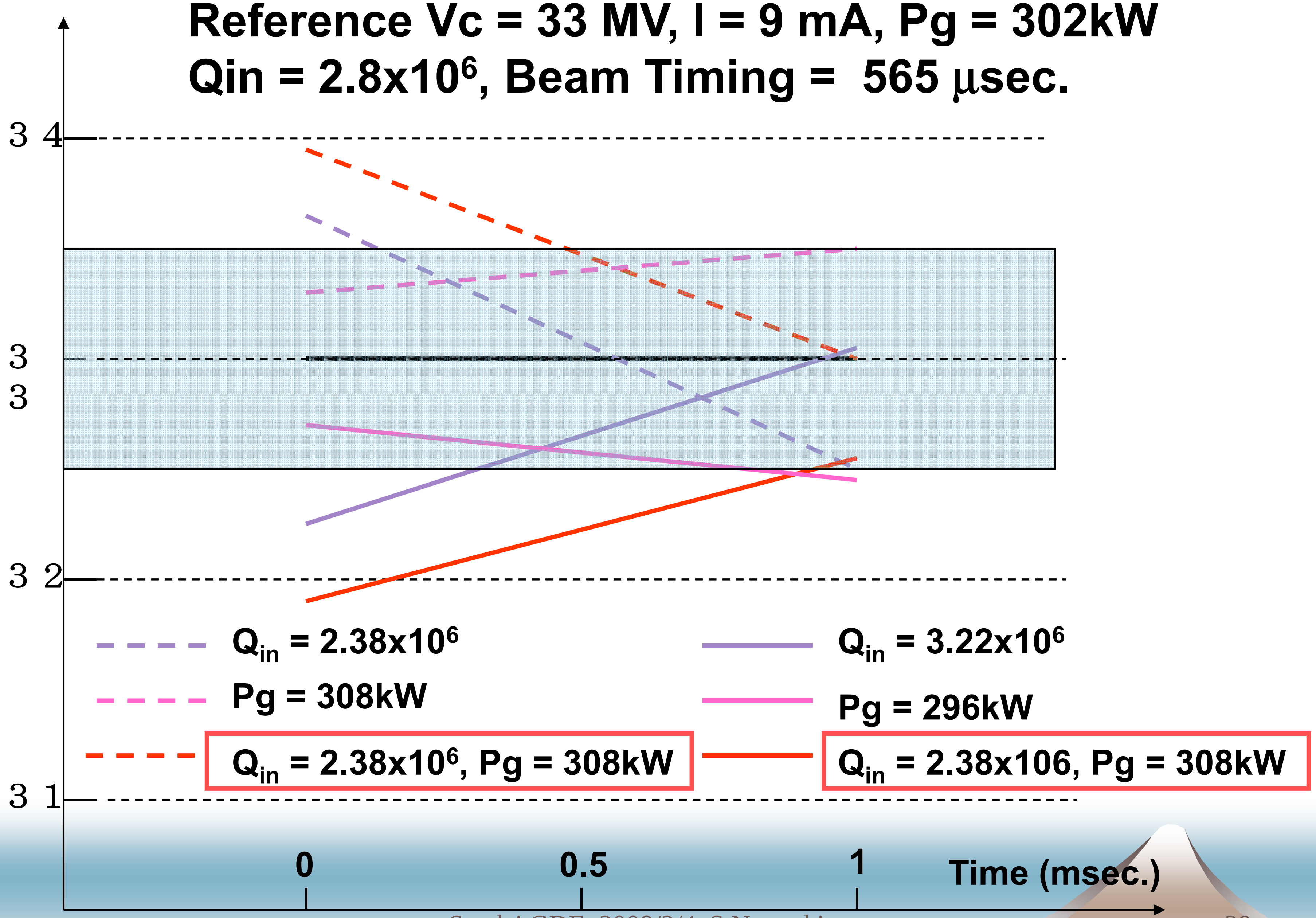
Reference Vc = 33 MV, I = 9 mA, Pg = 302kW
Qin = 2.8×10^6, Beam Timing = 565 μsec.



Reference Vc = 33 MV, I = 9 mA, Pg = 302kW
Qin = 2.8x10⁶, Beam Timing = 565 μsec.



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



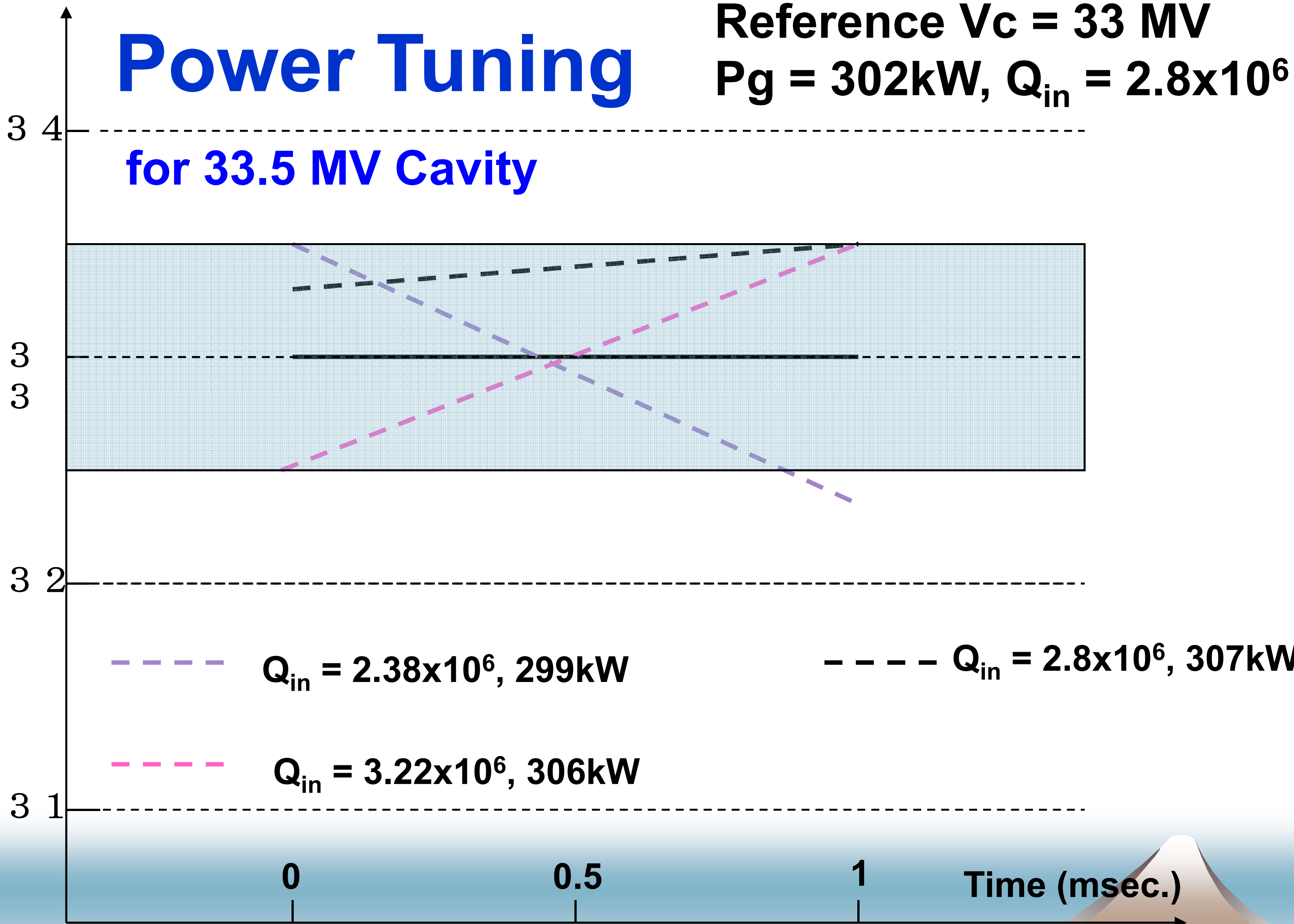
No Tuning

- Average Gradient is 1.5 MV Lower.
- 4.5 % costs 180 MILC

Power Tuning

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

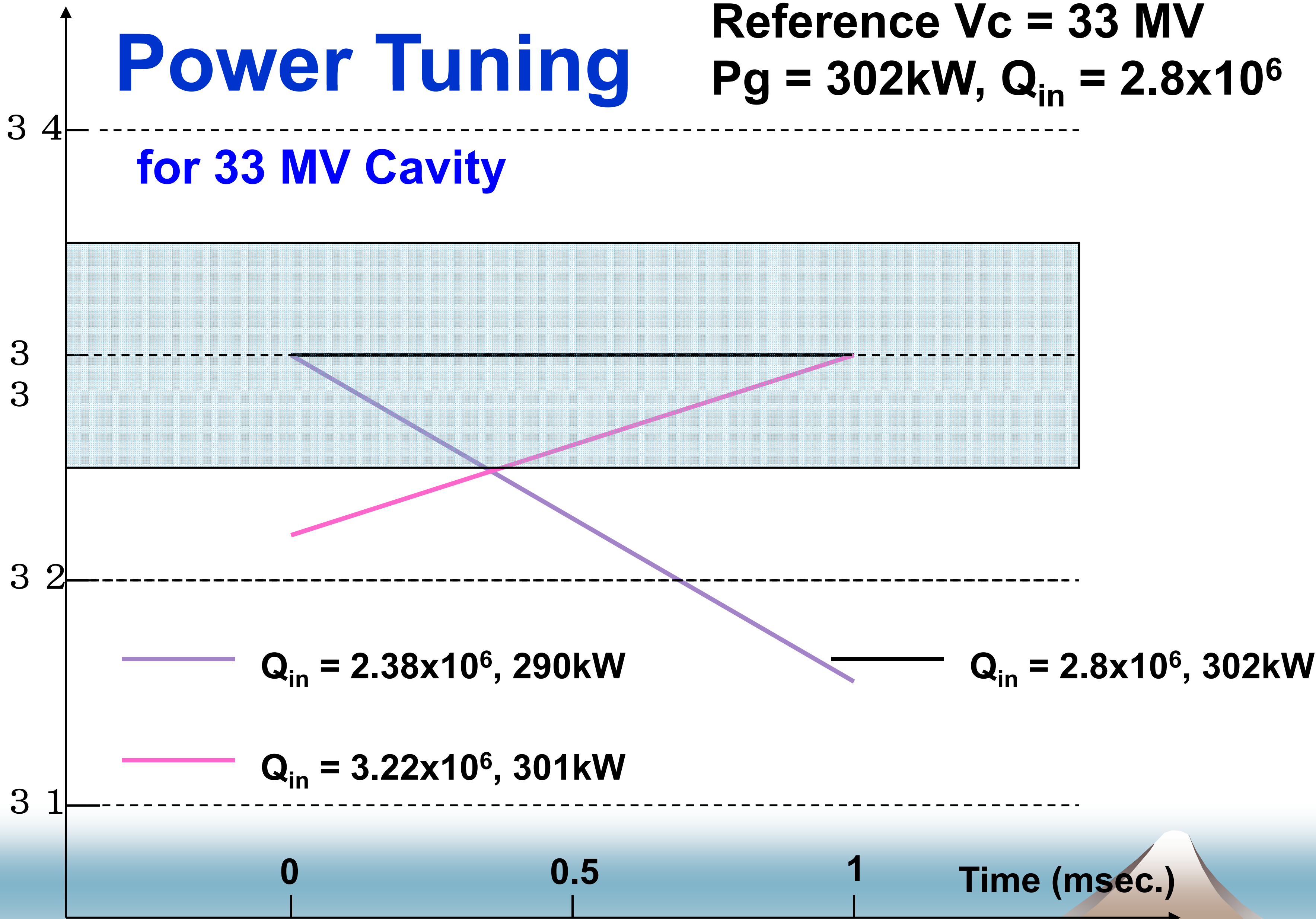
for 33.5 MV Cavity



Power Tuning

for 33 MV Cavity

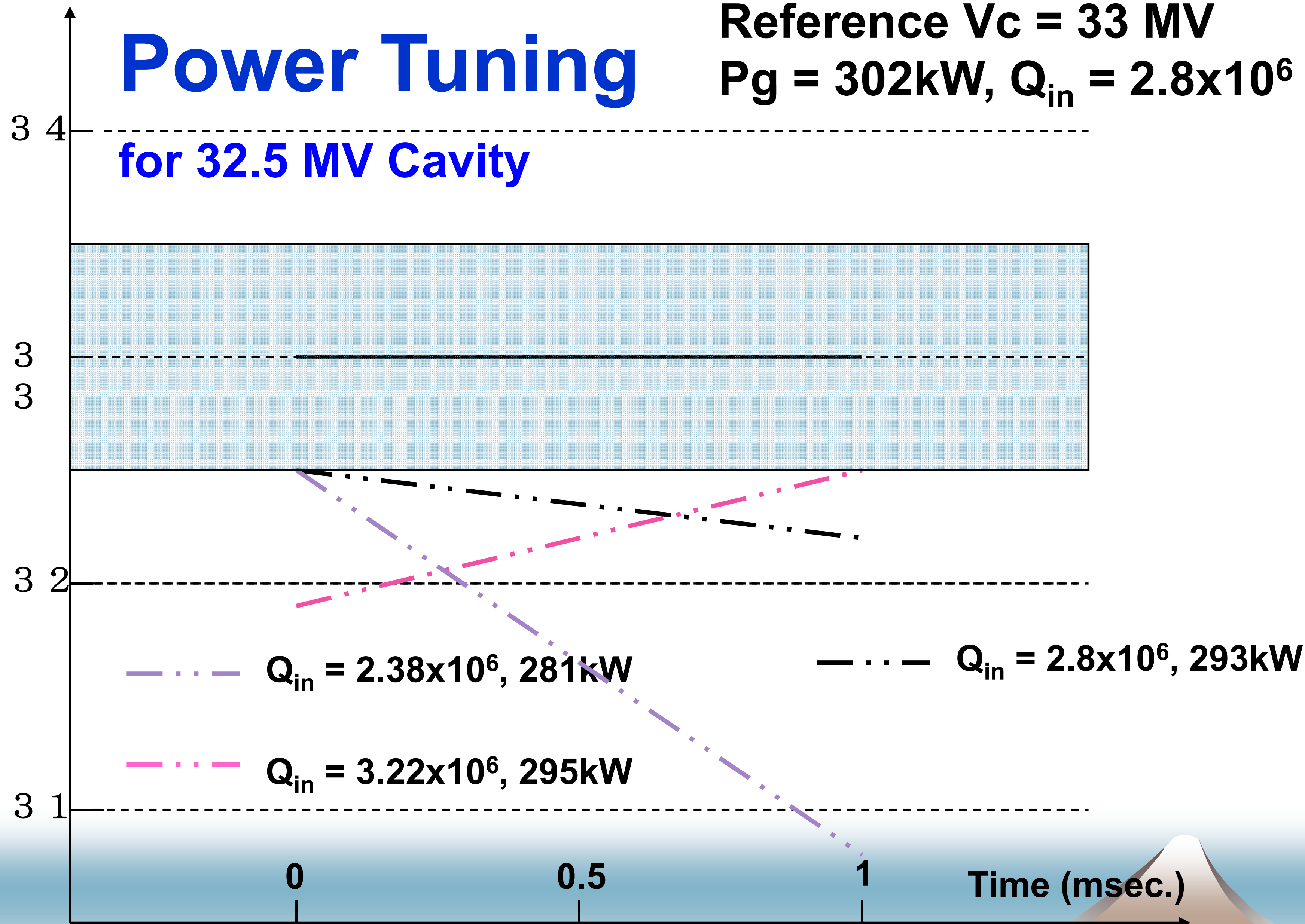
Reference Vc = 33 MV
Pg = 302kW, Q_{in} = 2.8x10^6



Power Tuning

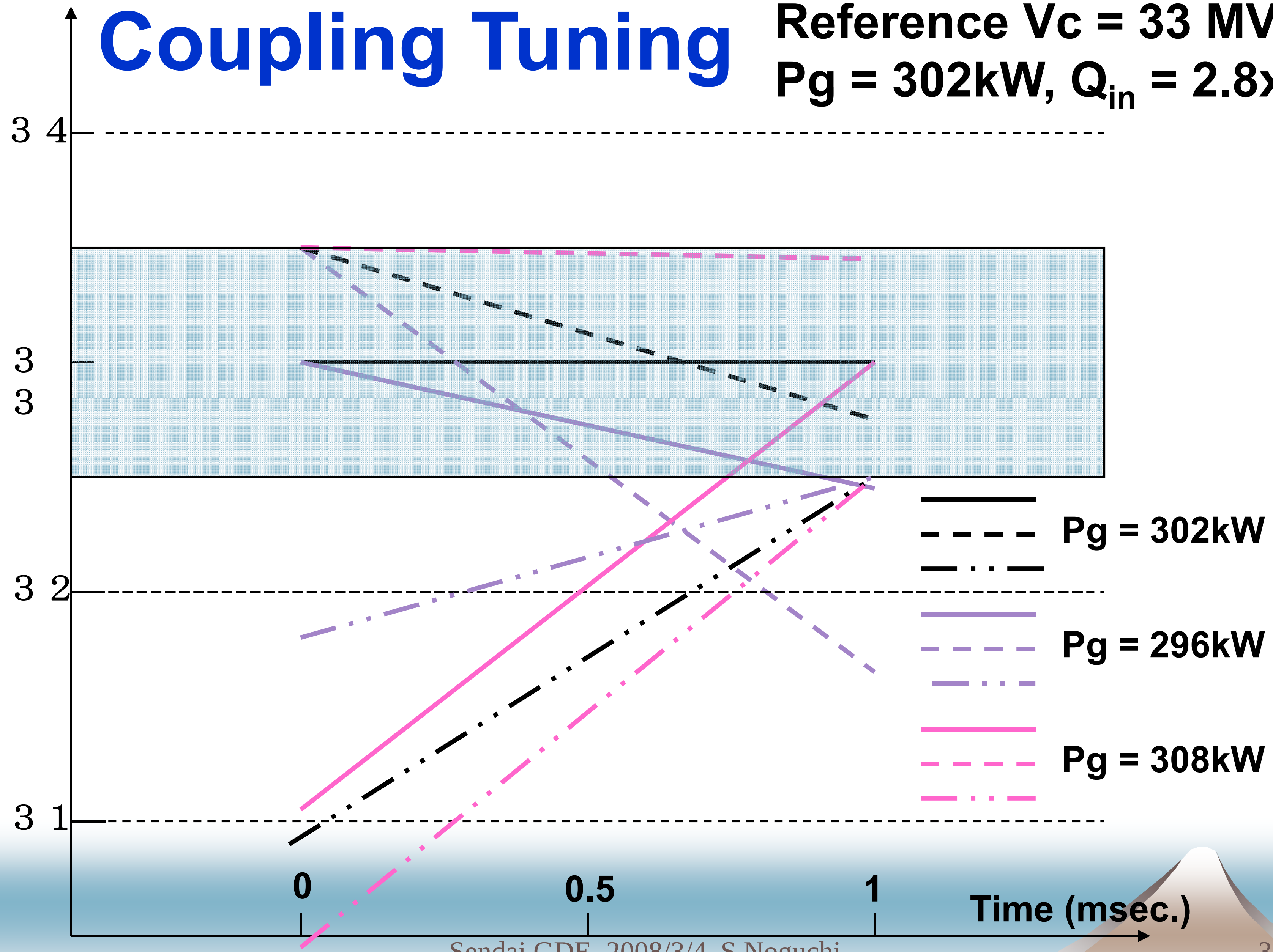
for 32.5 MV Cavity

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



Coupling Tuning

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

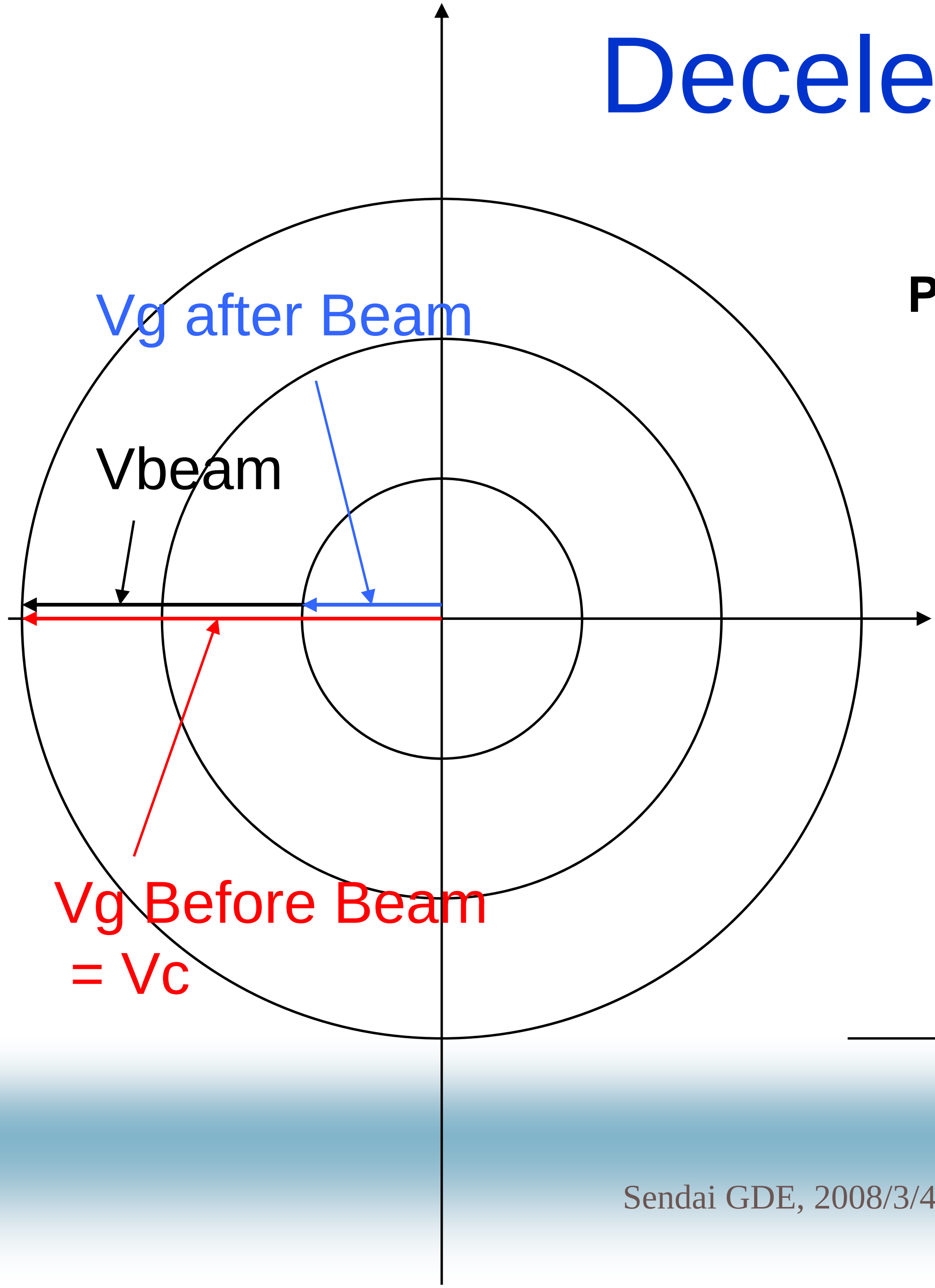


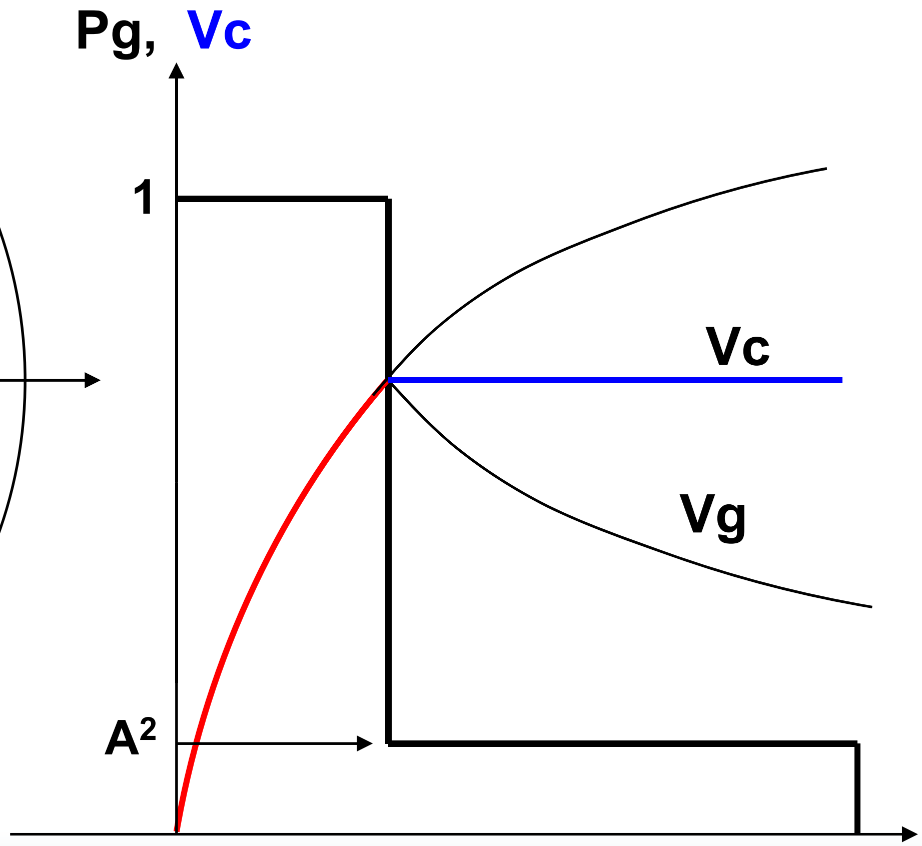
Cost Comparison

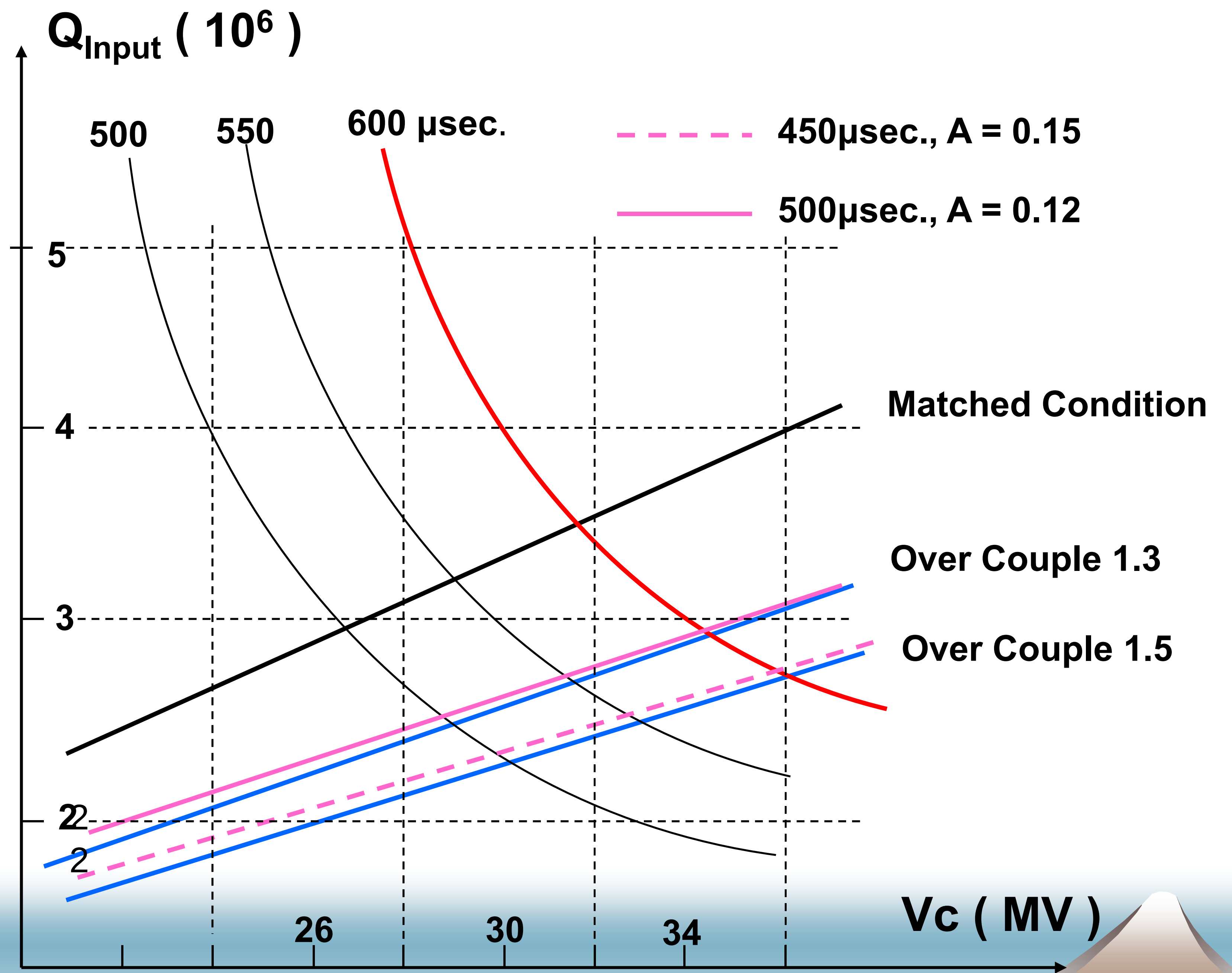
ML costs 4000 MILC **1.0 MV bin Size**

	Energy Reduction	Extra Cost	Devise Cost	Total Cost-Up
No Tuning	- 4.5 %	180	0	180
Full Tuning	0	0	40 + 50	90
Coupling	- 1.8 %	72	40	112
Power	- 0.9 %	36	50	86

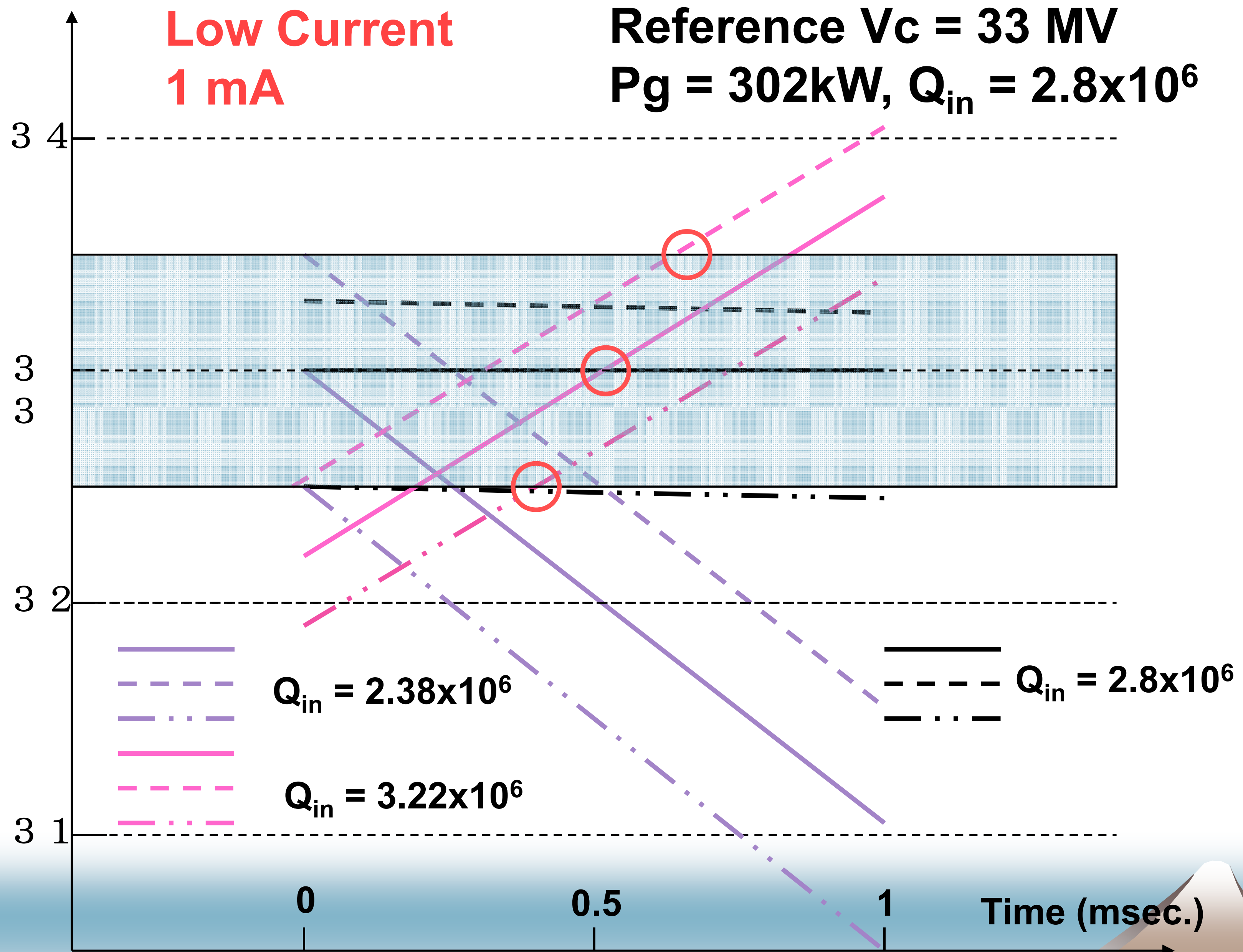
Deceleration







Q_Input (10^6)
500
550
600 µsec.
450µsec., A = 0.15
500µsec., A = 0.12
5
4
3
2
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, Q_{in} = 2.8x10[6]
3 4
3
3
3 2
3 1
Q_{in} = 2.38x10[6]
Q_{in} = 3.22x10[6]
Q_{in} = 2.8x10[6]
0
0.5
1
Time (msec.)

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.

Summary

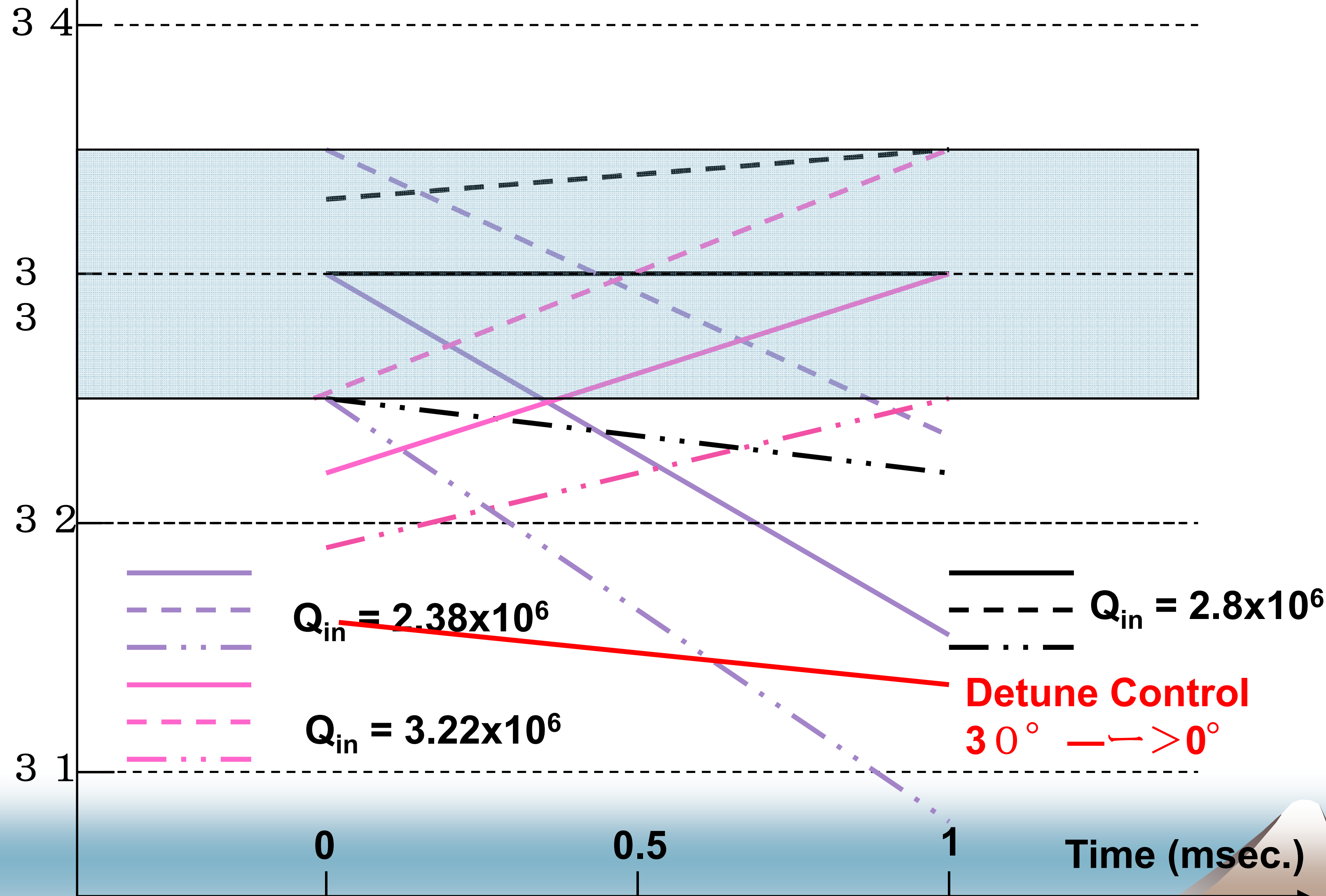
- Cavity Grouping Scheme is Proposed.
  Power Effective, Small Tuning Range
  & Less DLD Effect.
- If we use this scheme, and assume the following number, the coupling tune-ability may be not cost effective.
  Coupling Error : ±15 %
  Power Distribution Error : ± 2 %
- Input Coupler must have a capacity of 400 kW.
- Precise Evaluation of cost performance is necessary.

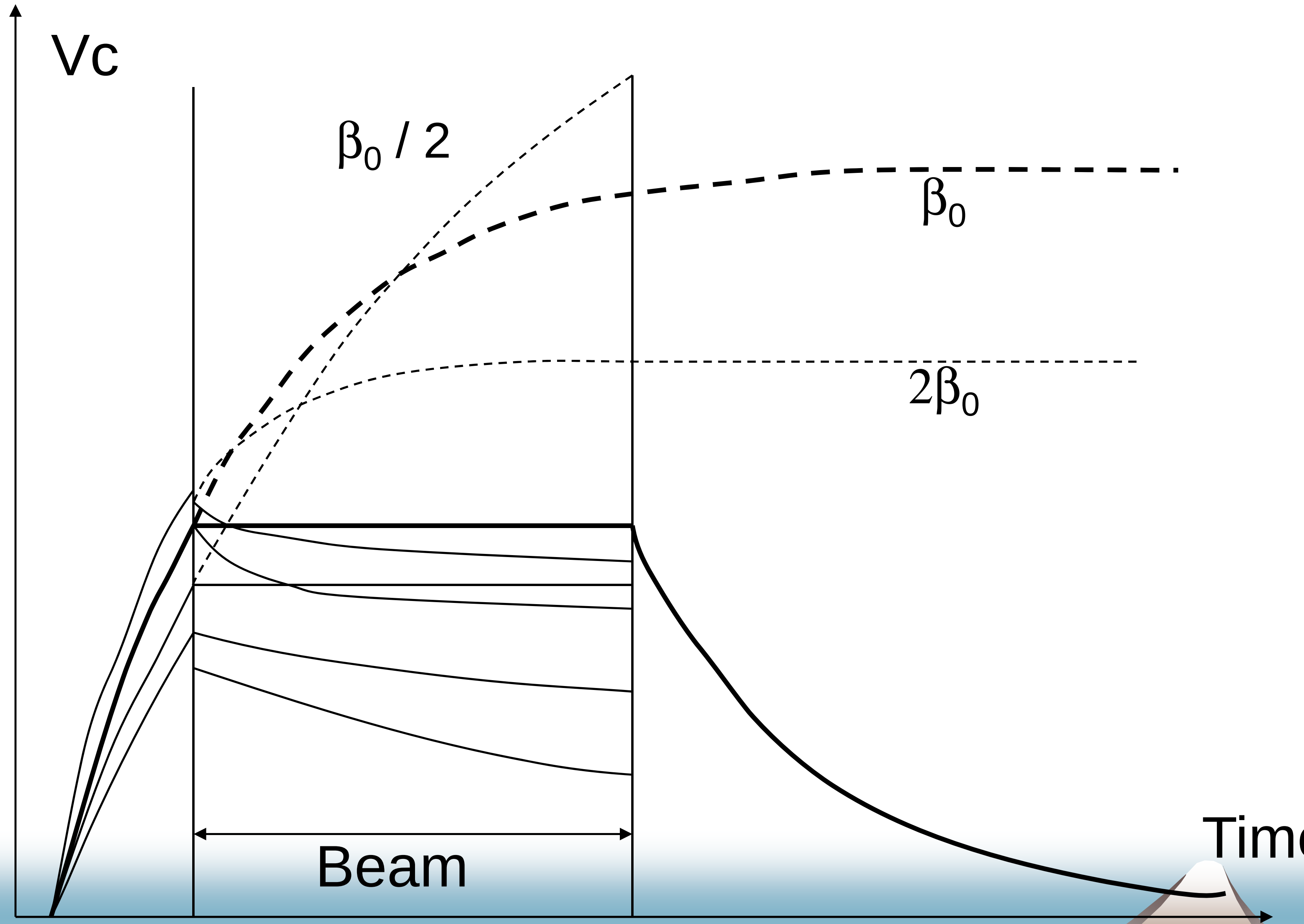
Construction Schedule

	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									

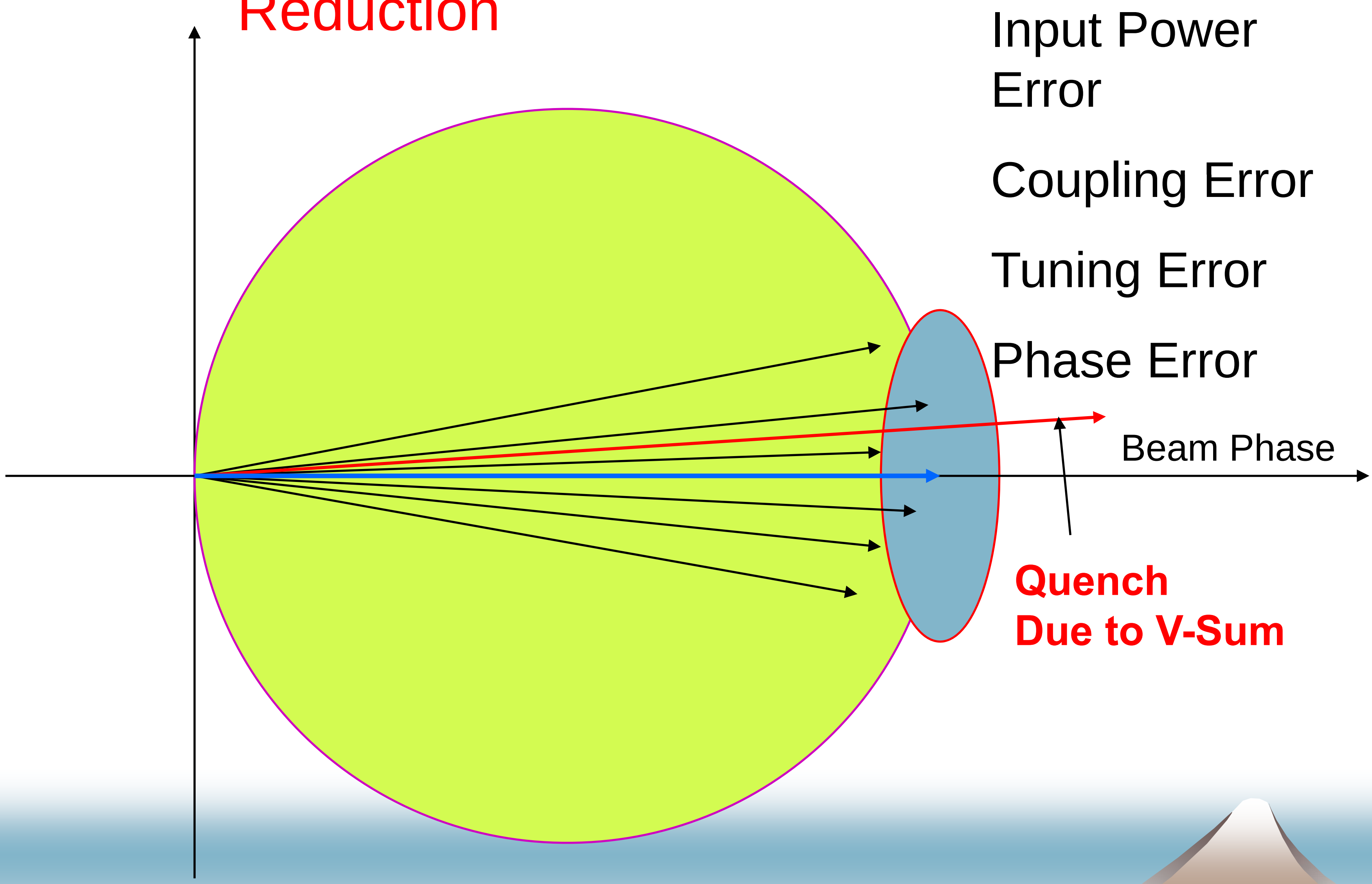
Power Tuning

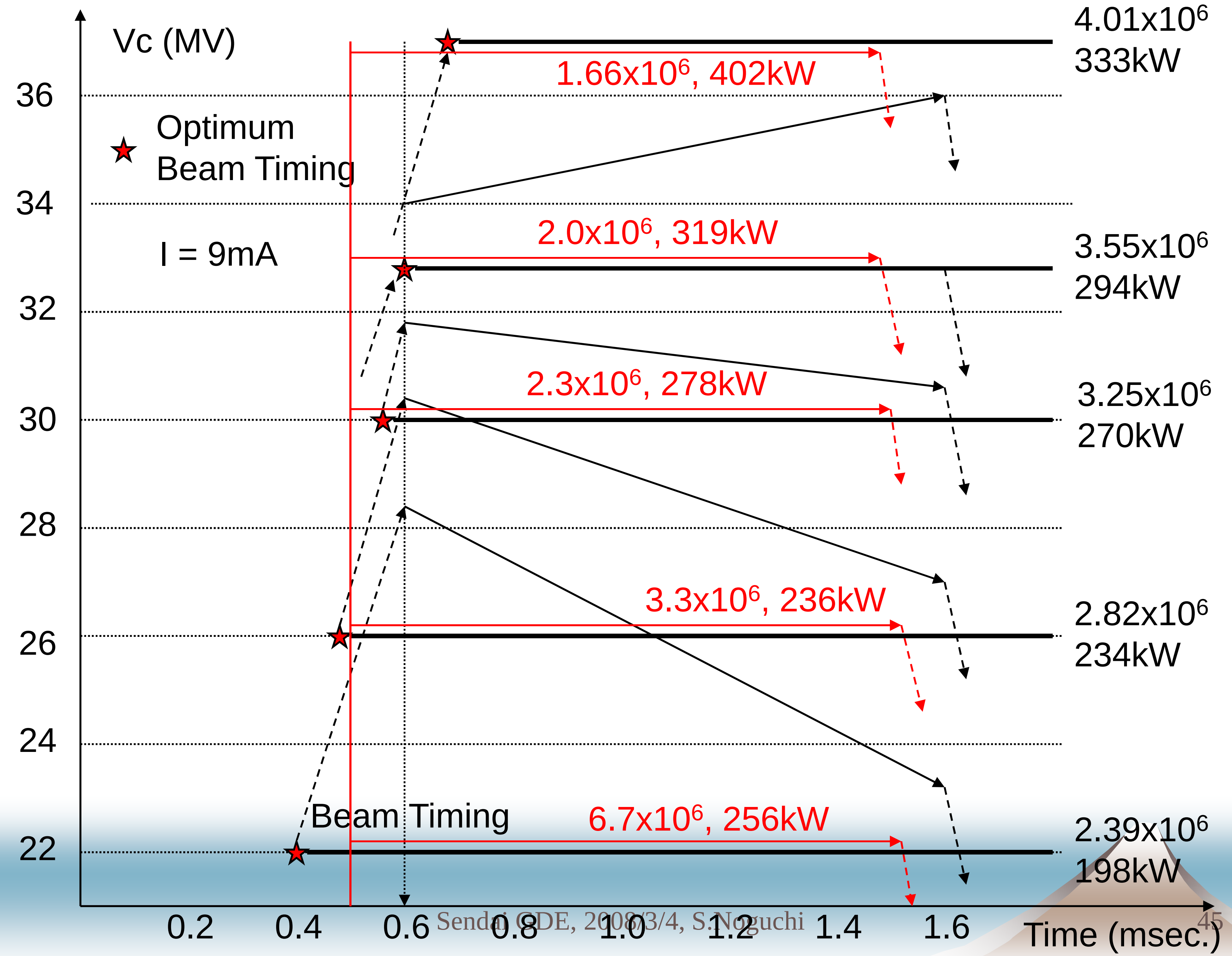
Reference Vc = 33 MV
Pg = 302kW, Q_{in} = 2.8x10^6




Vc
β0 / 2
β0
2β0
Beam
Time

Cavity Voltage Error & Gain Reduction




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.)