ILC Coupler requirements and TTF3 performance

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ILC Coupler Requirements

- **Discuss only three basic requirements:**
  - Power handling
  - Pulse length
  - Q_{ext} range

- **Based on operation modes**
  - Spread in accelerating gradient of ±20% around 31.5 MV/m (average)
    - 25 MV/m ≤ G_a ≤ 38 MV/m
  - Beam currents of 5.8 mA and 8.8 mA (lumi upgrade)
    - often referred to as 6 mA and 9 mA

- **Theoretical limits!**
  - suitable margins need to be added (see slide 9)

TDR specifications

TDR v3-II
Table 3.7
(page 35)

Parameter	Specifications
Frequency	1.3 GHz
Operation pulse width	1.65 ms
Operation Repetition rate	5 Hz / 10 Hz
Maximum beam current	8.8 mA
Accelerating gradient of cavity	31.5 MV/m $\pm$ 20%
Required RF power in operation	$\sim$ 400 kW
Range of external Q value	(1.0 $\sim$ 10.0) $\times 10^6$ (tunable)
RF process in cryomodule	$>$ 1200 kW for $\leq$ 400 μs pulse width $>$ 500 kW for $>$ 400 μs pulse width
RF process with reflection mode in test stand.	$>$ 600 kW for 1.6 ms pulse width
RF process time	$<$ 50 hours in warm state $<$ 20 hours in cold state
Approximate heat loads	$<$ 0.01 mW (2K static) 0.07 W (5K static) 0.6 W (40K static) $<$ 0.02 W (2K dynamic) 0.12 W (5K dynamic) 1.6 W (40K dynamic)
Number of windows	2
Bias voltage capability	Required

Simple approach: Beam Power

	I_b = 6 mA	I_b = 9 mA
G_a = 25 MV/m	175 kW	236 kW
G_a = 31.5 MV/m	196 kW	294 kW
G_a = 38 MV/m	237 kW	355 kW

Minimum power that needs to be handled.

Specification set by the “worst case” (355 kW)

True requirement is higher than this, and depends on choice of fill time (t_{fill}) and Q_{ext}.

Impact of ±20% gradient spread

- **Maximising voltage from an RF unit requires so-called P_k and Q_L ($\sim Q_{ext}$) control.**

- **As a result, most cavities will not be "matched" and power is reflected**
  - this has to be added to the beam power for the coupler
  - Equivalent power (transmission mode power → V_{SW})

$$P_{t,eff} = P_{for} + P_{ref} + 2\sqrt{P_{for}P_{ref}}$$

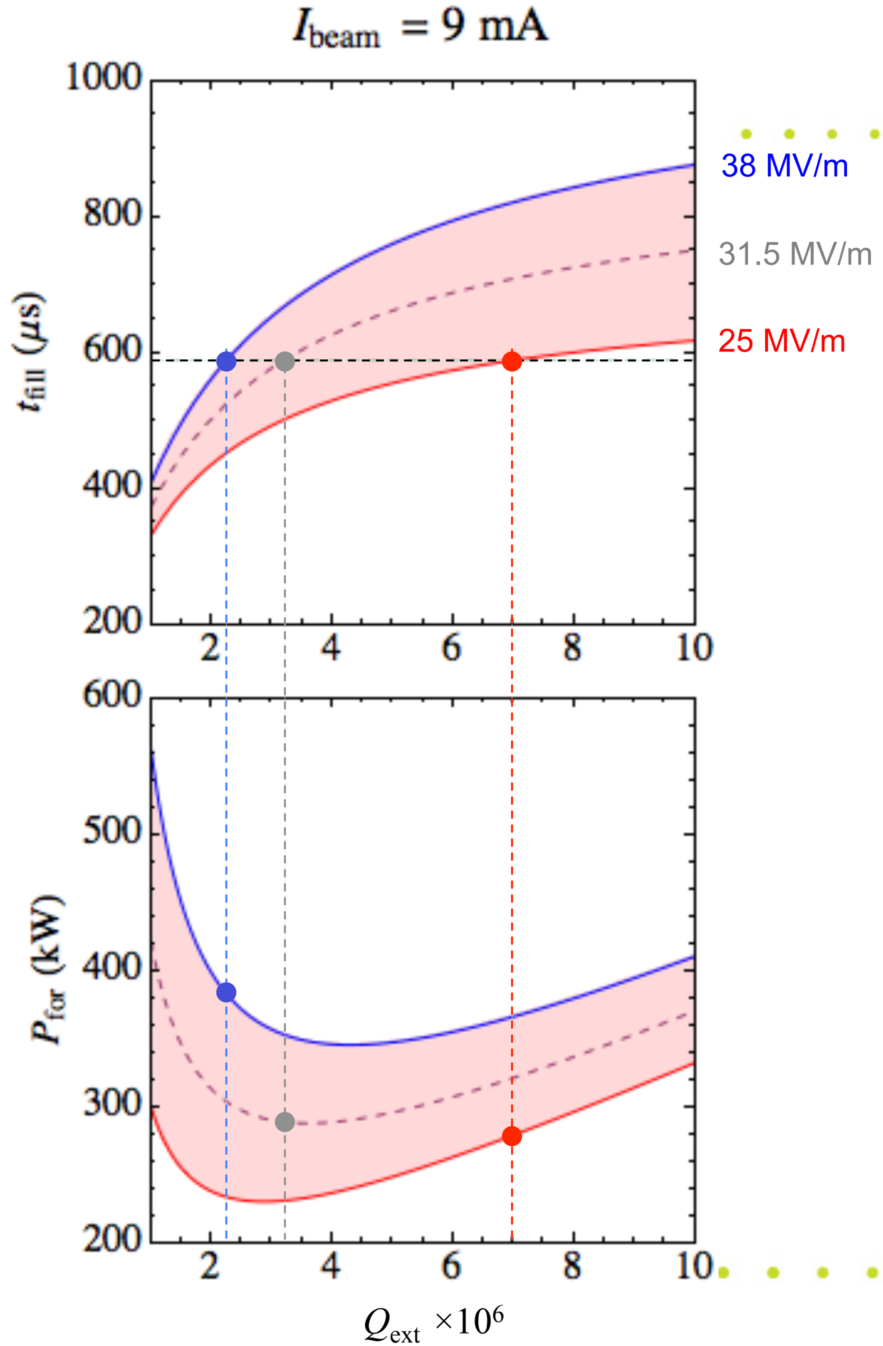
- **This overhead is linked to the choice of Q_{ext} range, t_{fill} and overall klystron power overhead.**

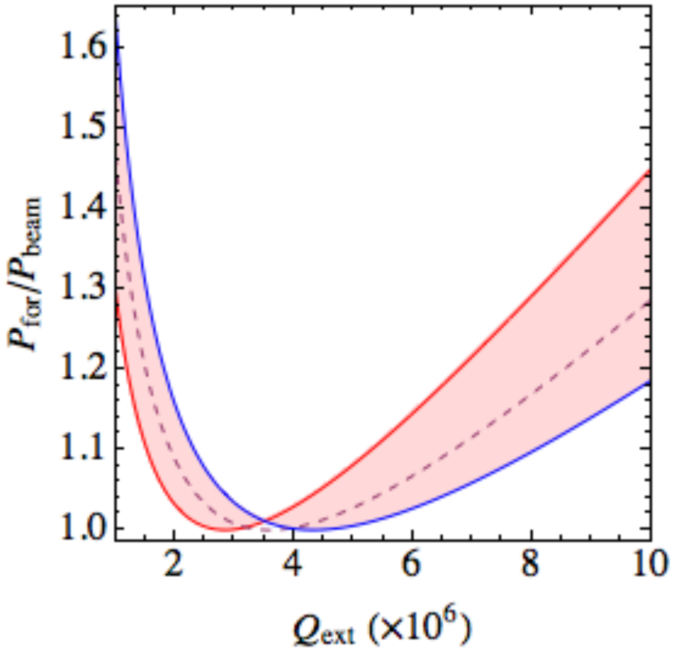
P_K Q_L solutions

Worst case 9 mA

Constrained $Q_{ext} \leq 7\times10^6$

t_{fill} = 585 μs (set by 25 MV/m cavity)





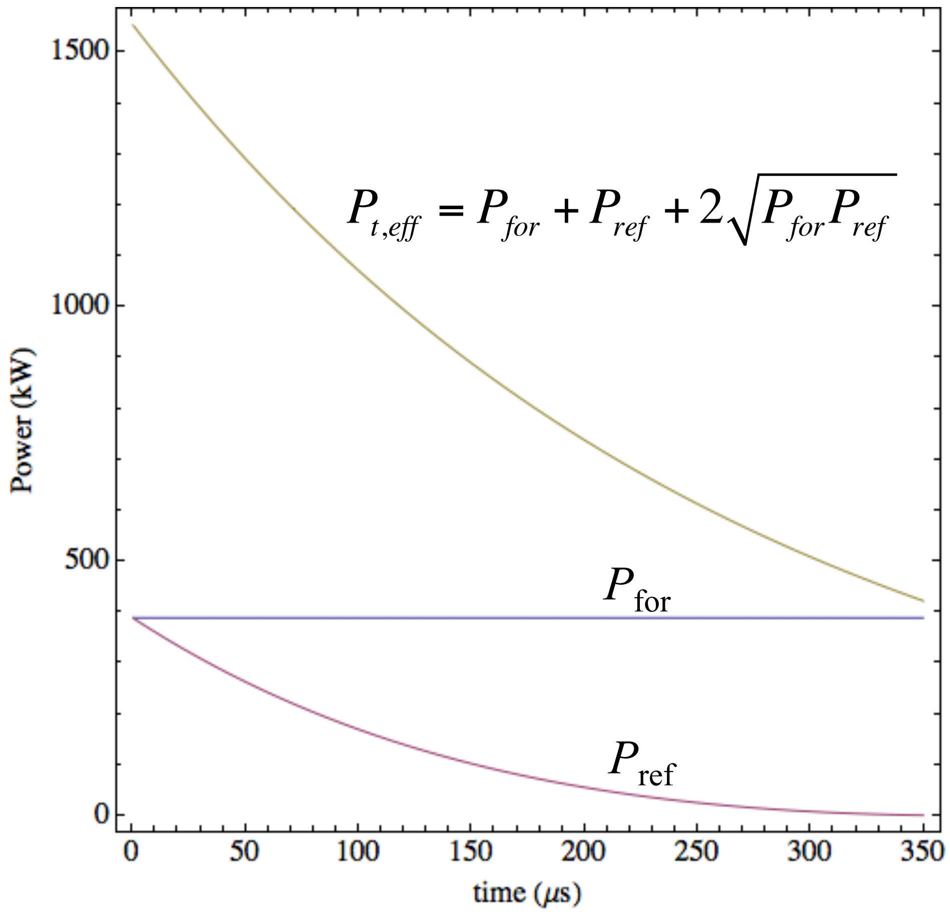
Summary

I_{beam} =	5.8	matched @ 31.5 MV/m						$Q_{ext} \le 7\times10^6$					
Gradient MV/m	P_{beam} kW	Q_{ext} $\times10^6$	t_{fill} µs	t_{pulse} ms	P_{for} kW	P_{ref} kW	$P_{t,eff}$ kW	Q_{ext} $\times10^6$	t_{fill} µs	t_{pulse} ms	P_{for} kW	P_{ref} kW	$P_{t,eff}$ kW
25.0	151	14.2			211	60	384	7.0			159	9	244
31.5	190	5.4	923	1.65	190	0	190	3.756	824	1.55	196	7	275
38.0	229	3.7			248	20	407	2.767			274	45	543

I_{beam} =	8.8	matched @ 31.5 MV/m						$Q_{ext} \le 7\times10^6$					
Gradient MV/m	P_{beam} kW	Q_{ext} $\times10^6$	t_{fill} µs	t_{pulse} ms	P_{for} kW	P_{ref} kW	$P_{t,eff}$ kW	Q_{ext} $\times10^6$	t_{fill} µs	t_{pulse} ms	P_{for} kW	P_{ref} kW	$P_{t,eff}$ kW
25.0	228	9.4			320	91	753	7.0			278	49	562
31.5	288	3.6	609	1.57	288	0	288	3.1	585	1.55	289	1	330
38.0	347	2.4			377	30	617	2.2			389	42	686

Maximum pulse repetition rate: 10 Hz
(covers L upgrade scenarios)

Fill Time (P_{ref})



G_a = 38 MV/m
I_{beam} = 9 mA
t_{fill} = 585 μs

Coupler must also withstand reflected power during fill time.

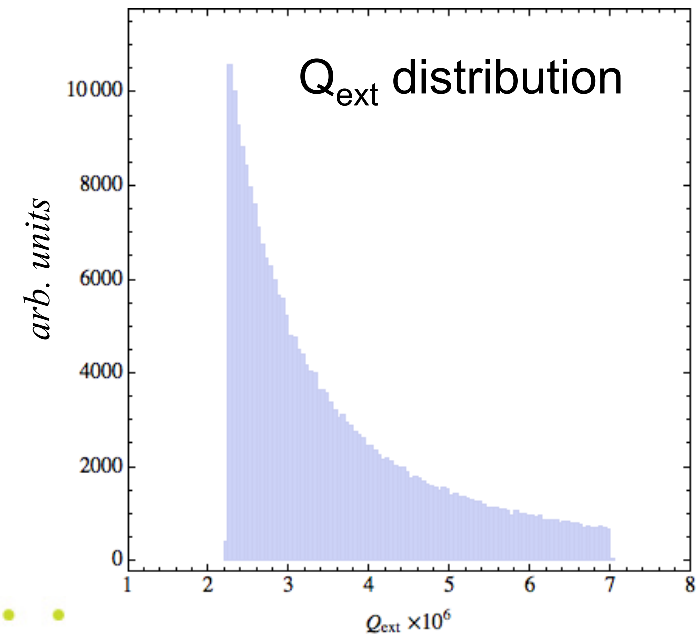
Monte Carlo

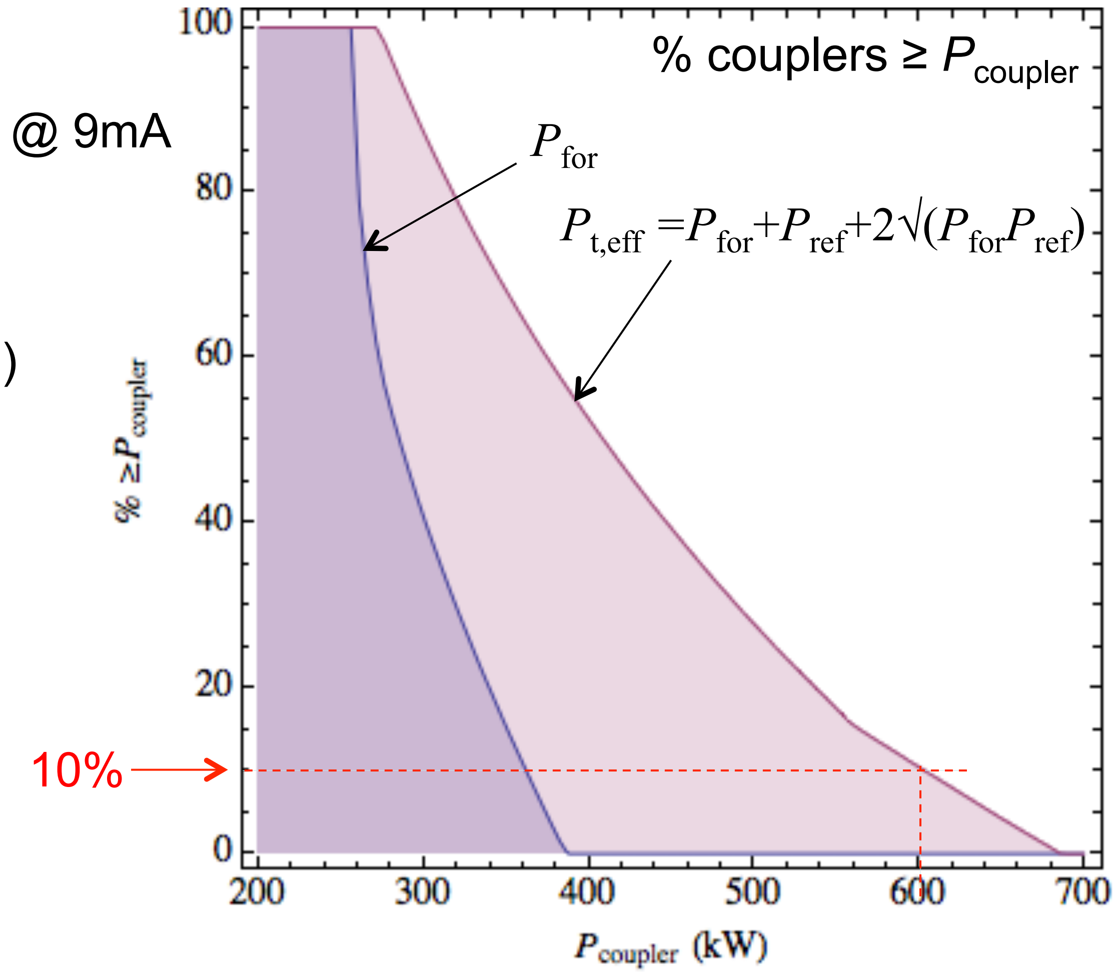
MC simulation of random cavities

Flat distribution $25 \leq G_a \leq 38$ MV/m @ 9mA

26 cavity per RF unit

Assumed $Q_{ext} \leq 7\times10^6$ (t_{fill} = 585 μs)





Additional considerations

- **Operational margins** **+ ?**
- **Conditioning** **+ ?**
  - Generally conditioned to higher power than operations
  - Should be included in the specification
- **Q_{ext} range**
  - Actual required operational ranges specified
  - Mechanical solution also requires margin
    - Note FLASH operational coupler ranges vary considerably due to assembly tolerances

Tests at 35 MV/m

- **Long run test of EP cavities in the horizontal cryostat**
  - This test includes all auxiliaries like power coupler, HOM coupler, tuner…
  - Gradient: 35 MV/m
  - Max forward power: 600 kW
  - RF on time 2400 hs, at 600 kW 1100 hs
  - No breakdowns in the coupler

- **High gradient test with beam (in module ACC1)**
  - Gradient: 35 MV/m
  - Gradient calibration with beam