ILC Total Project Cost Scaling with Gradient and Cost Cutting Proposals

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Cryomodule and Cryogenic Costs

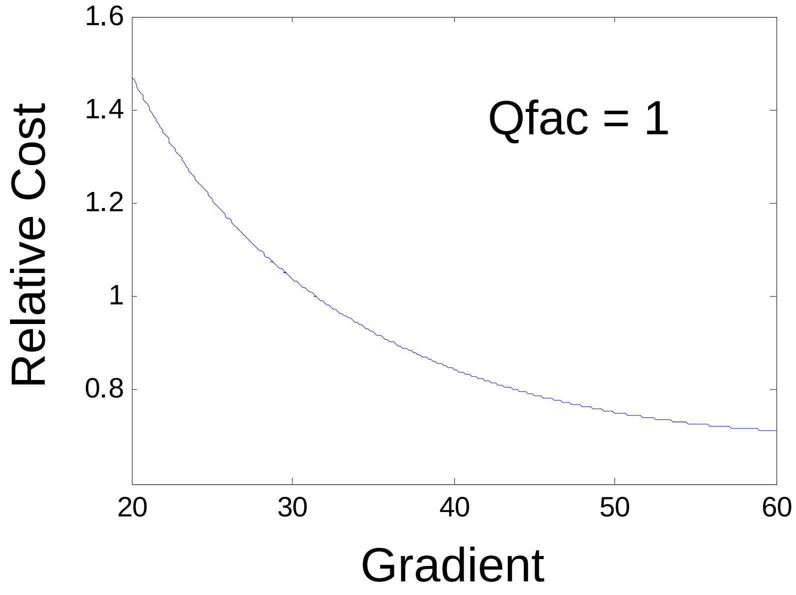
Pulse Length: Tfac = (Tb + Tfo*g/go)./(Tb + Tfo);

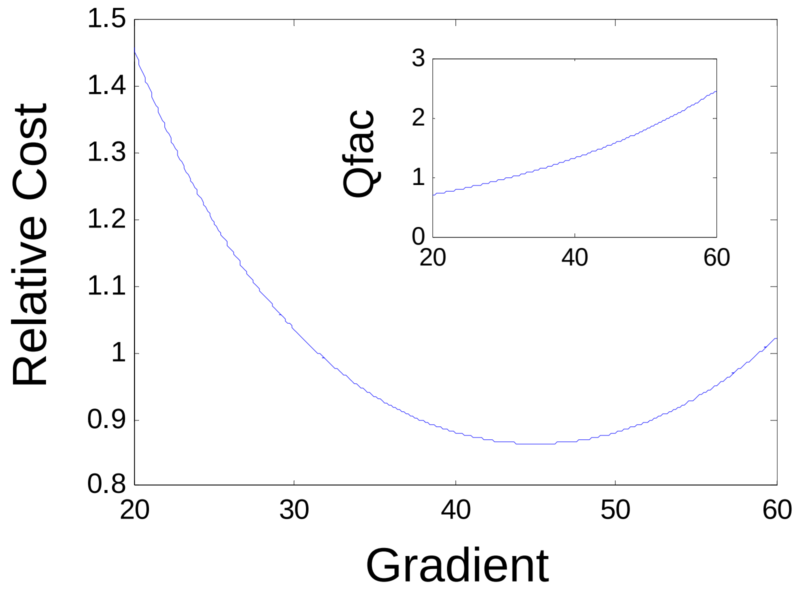
Coupler Cryo Loading Pfac = (g/go).*(Tb + 2*Tfo*g/go)./(Tb + 2*Tfo);

Cavity Cryo Loading: Gfac = (g.^2/go^2).*Qfac.*(Tb + 1.1*Tfo*g/go)./(Tb + 1.1*Tfo);

Cryomodule + Cryogenic Costs = (C_mod + C_inst + C_vac

+ (C_plant + C_dist + C_shaft)*(0.51 + 0.9*Pfac + 0.40*Gfac)) .* (go./g);



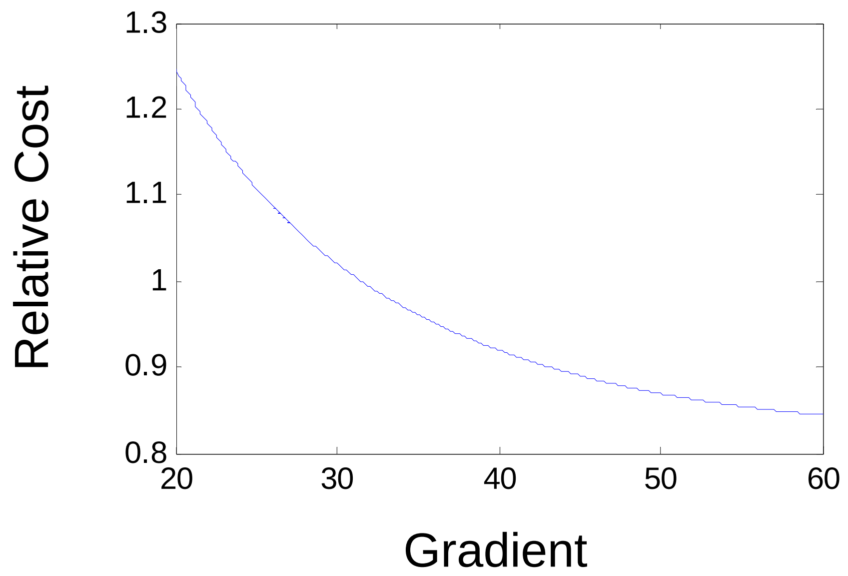


RF System Cost

Pulse Length: Tfac = (Tb + Tfo*g/go)./(Tb + Tfo);

Number of klystrons and modulators independent of gradient – cavities fed per klystron scale as go/g.

RF System Cost = C_mod * (0.45 + 0.55*Tfac) + C_kly * (0.74 + 0.26*Tfac) + (C_dist + C_llrf + C_global) *(go./g) + C_inst * (0.3 + 0.7*(go./g));

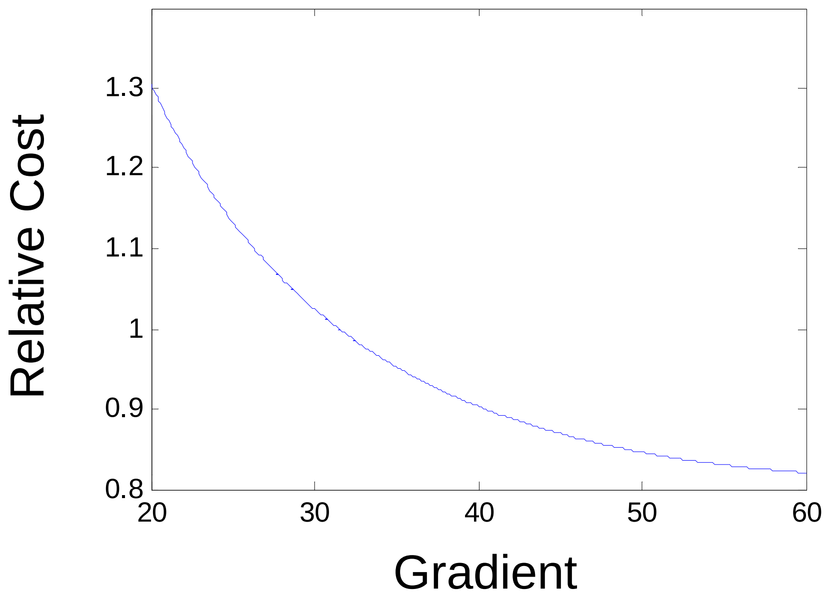


Civil Cost

Pulse Length: Tfac = (Tb + Tfo*g/go)./(Tb + Tfo);

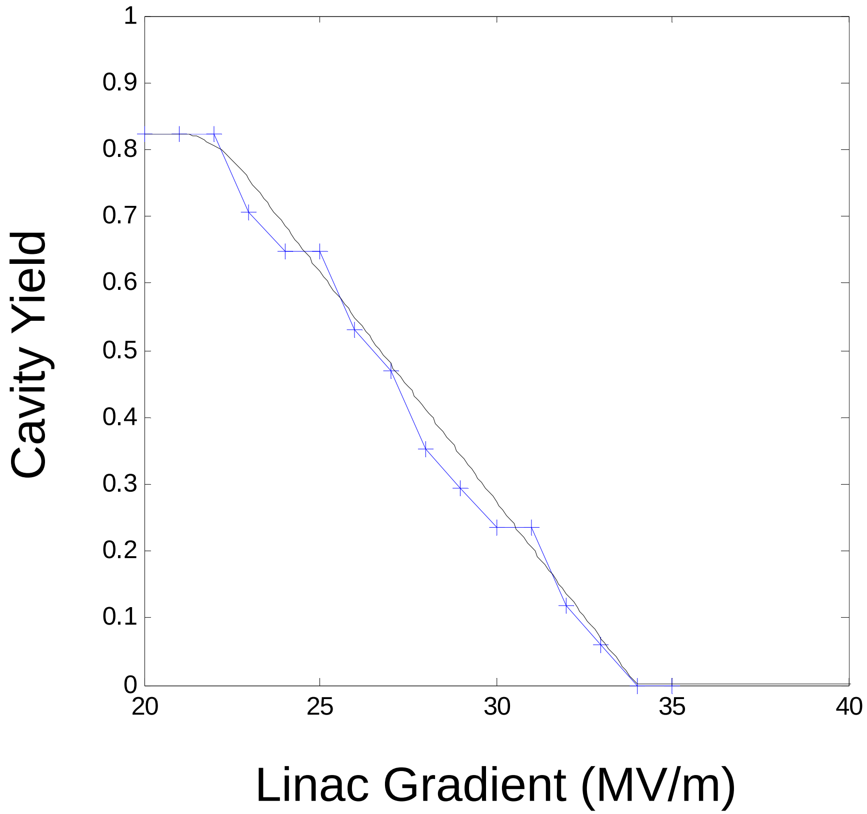
Assume electrical and cooling cost scale as load

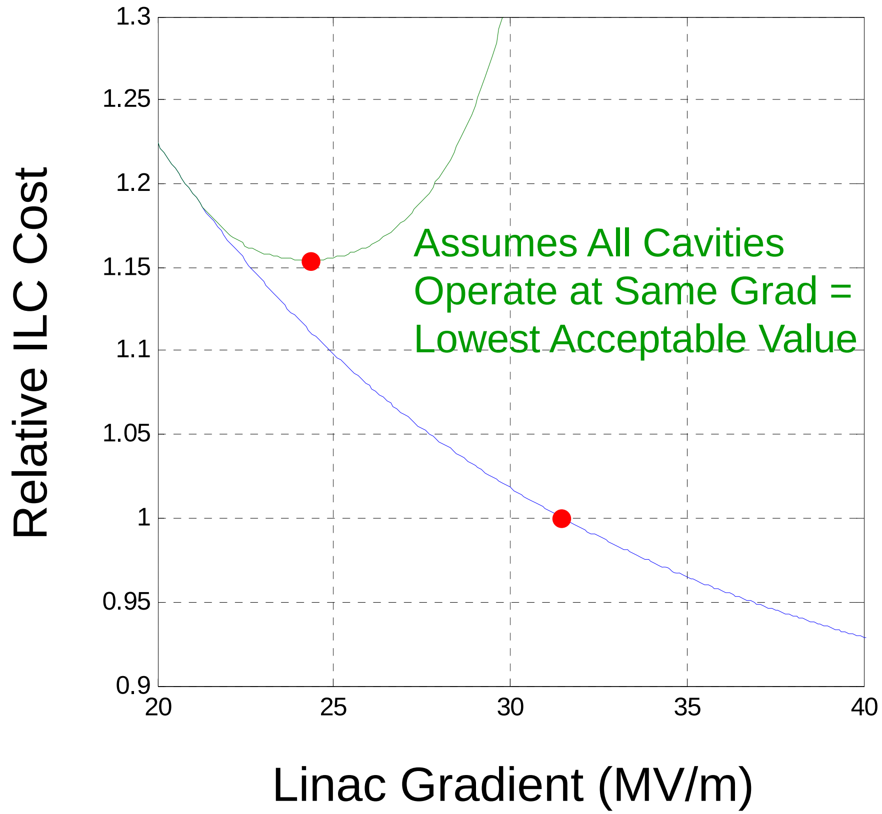
Civil Cost = C_tunnel *(go./g) + C_elect*Tfac + C_cooling*(0.22 + 0.78*Tfac);



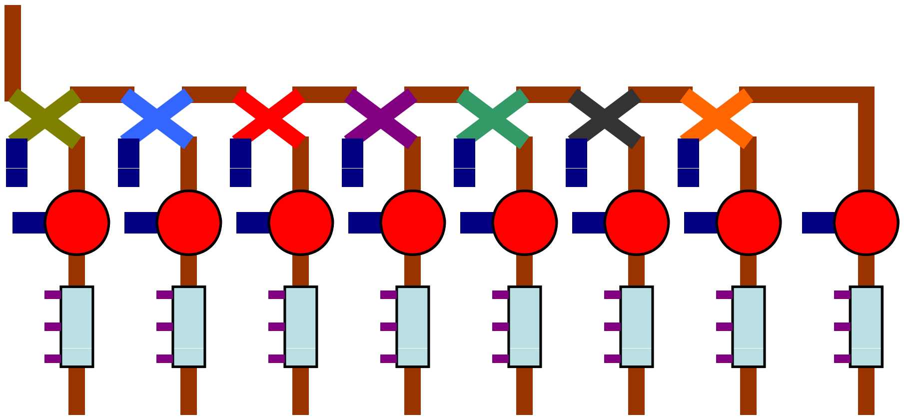
Americas ILC Cost Versus Linac Gradient

for gradient-independent cavity costs (blue curve, right plot), and
gradient-dependent cavity costs (green curve, right plot)
based on the yield from 17 Zanon EP cavities (left plot)





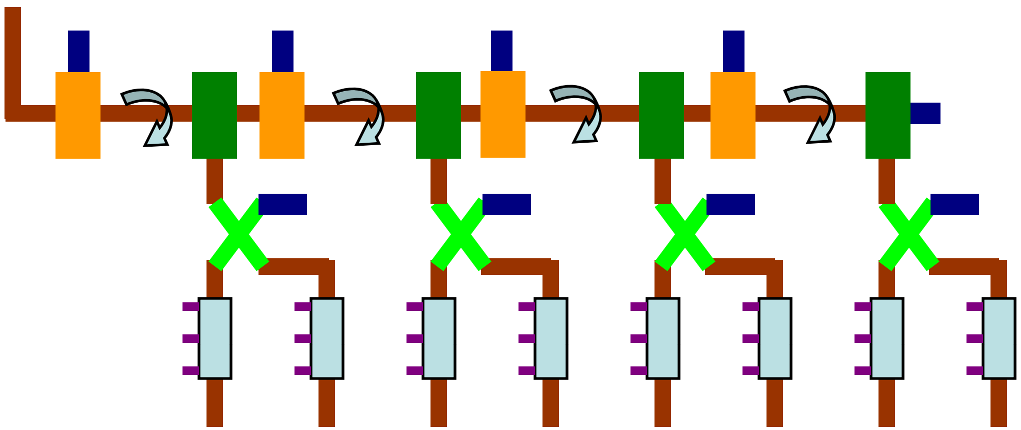
Baseline RF Distribution System



Fixed Tap-offs

Isolators

Alternative RF Distribution System



Variable Tap-offs (VTOs)

3 dB Hybrids

Gradient Optimization with VTOs and Circulators

Consider uniform distribution of gradient limits $(G_{lim})_i$ from 22 to 34 MV/m in a 26 cavity rf unit - adjust cavity Q's and/not cavity power (P) to maximize overall gradient while keeping gradient uniform (< 1e-3 rms) during bunch train

Optimized $1-\langle G\rangle/\langle G_{lim}\rangle$; results for 100 seeds

Case	Not Sorted [%]	Sorted [%]
Individual P's and Q's (VTO and Circ)	0.0	0.0
1 *P*, individual *Q*'s (Circ but no VTO)	2.7 ± 0.4	2.7 ± 0.4
P's in pairs, *Q*'s in pairs (VTO but no Circ)	7.2 ± 1.4	0.8 ± 0.2
1 *P*, *Q*'s in pairs (no VTO, no Circ)	8.8 ± 1.3	3.3 ± 0.5
G_i set to lowest G_{lim} (no VTO, no Circ)	19.8 ± 2.0	19.8 ± 2.0

Cost Implications of Current Yield

- Assume cavities produced with flat distribution of sustainable gradients (G) from 22 MV/m to 34 MV/m with <G> = 28 MV/m
- With Qeo optimized for Go = <G>, achieve flat cavity field at G with
  - $Qe = Qeo * \ln(2) / \ln(1 + G/Go * Qeo/Qe)$
  - $\text{Input Power} = Po * (1/4) * (1 + G/Go * Qeo/Qe)^2 * (Qe/Qeo)$
- Requires 6.8% more power on average per rf unit
- Maintain rf unit layout but increase linac length by 31.5/28 -1 = 12.5%
- At 31 MV/m, which is a +3-sigma variation in the mean gradient of a half rf unit, have same 16% tuning overhead as present design at 33 MV/m.
- Considering all changes, ILC cost increases by about 7%

Main Linac Cost Cutting Proposals

- Lower power-limited gradient to 33 MV/m from 35 MV/m - incorporated in design
  - One 10 MW klystron feeds 26 cavities (9-8-9 configuration) instead of 24 (three 8-cavity cryomodules)
  - Number of rf units reduced by 1/13, as is the peak AC power and cooling to first order.
  - Lowered linac beam current form 9.5 mA to 9.0 mA in second round request to allow more LLRF tuning overhead.

Cost Cutting Proposals (cont)

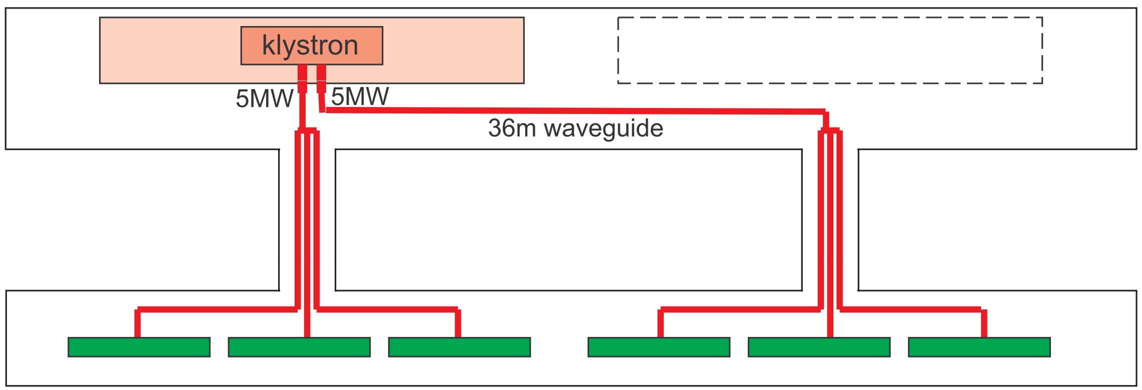
- Eliminate 3.5% overhead of rf units - incorporated in design (although included 400 m additional empty tunnel length for future upgrade)
  - If the sustainable cavity gradient on average equals the design gradient of 31.5 MV/m, have no overhead at 500 GeV cms so energy lower if any rf units fail
  - If the sustainable cavity gradient on average equals or exceeds the 33 MV/m power-limited gradient, have 4.8% rf unit overhead at 500 GeV cms
  - Retain the ~ 400 m of tunnel length (as drift space) to be used if more overhead is desired in the future

Cost Cutting Proposals (cont)

- Eliminate cryomodule static loss uncertainty factor - incorporated in design, but as a 1.5 factor for both static and dynamic ?
  - Cryoplant heat load = Fo*(Fu*static + dynamic)
  - Fo = 1.4 is an overcapacity factor to account for degradation of plant performance, variation in cooling water temperature, and operational overhead.
  - Fu = 1.5 was included as a uncertainty factor in the cryomodule static heat load, which increases the cryo-capacity by 13%. Instead, include this as a risk factor in the cryogenic system cost.

Cost Cutting Proposals (cont)

- Halve Beam Current – Rejected for now
  - One 10 MW klystron would drive 6 cryomodules
  - Install only every other RF unit in the service tunnel – leave room for future upgrade.
  - RF pulse would increase from 1.565 ms to 2.130 ms
  - Still would allow full current operation at half energy



Cost Cutting Proposals (cont)

- Eliminate Service Tunnel and put RF System in Beam Tunnel as in XFEL – Rejected
  - Offsetting costs from
    - Decreased availability – need to increase rf unit overhead by 3% so klystron/modulator MTBFs reasonable.
    - Shielding required to limit electronics expose to cavity dark current induced radiation
    - Installation constraints – would likely slow process
    - Limited access during operation
  - From cost analysis, found that if dual-tunnels reduced from 5.0 m to 4.5 m, there would not be much savings compared with a single, larger diameter tunnel

Cost Cutting Proposals (cont)

- Decrease beam pipe diameter in Quad, BPM and Correctors from ~ 80mm to 35 mm - Postponed
  - Quad package smaller hence cheaper. Also
    - Quad magnetic center more stable with field change
    - BPM resolution better
    - Prevents beam from hitting cavity irises
  - Quad package shorter by up to 0.6 m (each Linac up to 160 m shorter)
  - Short-range transverse wakes ~ 10% larger, and up to 10% more HOM power loss in cryo-system (1% increase in cryo capacity)

Cost Cutting Proposals (cont)

- Adopt ACD RF System - Postponed
  - For pulse charger, use central 10kV SCR converter and satellite ~2 kV switching supplies at each station
  - Use Marx Modulator instead Pulse Transformer / Bouncer design
  - Use Sheet Beam Klystron (SBK) instead of MBK. Also saves 3 MW of solenoid power and associated cooling.
  - Feed cavities in pairs to eliminate circulators. Use manual phase shifters instead of 3-stub tuners, and use adjustable tap-offs to maximize average gradient
  - Total rf system savings ~ 50%

Cost Cutting Proposals (cont)

- Streamline LLRF System - Postponed
  - Place 100:1 down-mixers in tunnel to drop cable costs by 10.
  - Multiplex forward and reflected power RF signals in tunnel to save cable plant
  - Use single larger penetration with steel conduit for DC power and copper conduit for signals, shared with two water-cooled waveguides
  - Multiplex motor drives for the cavity tuner motors and coupler Qext control
  - Eliminate core processor redundancy in ATCA crates