R&D Programs Towards Cost Reduction of the ILC ILC Main Accelerator

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- Introduction
- Cryogenic Load, RF-distribution system and Real Estate Gradient
- Estimation of Potential Cost Reduction
- Conclusions

- **Big Grain (Single Crystal) Niobium**

I. Lower production costs (no rolling, thinner damaged layer).

II. BCP gives very smooth surface, no more expensive EP needed.

III. High intrinsic Q, lower operation costs, less expensive cryoplant.

IV. No sheets scanning needed

Cons: No cons known at the moment.However, the single cell results need to be confirmed with multi-cell cavities, also slicing of sheets from ingots need to be explored.

High Impedance Structures (LL, RE)

I. Lower operation costs due to lower cryo load (20%) and less stored energy.

II. Possible operation at higher E_{acc} due to lower B_{peak}/E_{acc}.

Cons: Tighter cavity alignment in the linac to compensate for higher $k_{\perp}$.

More difficult cleaning.

Higher E_{peak}/E_{acc}.

HOM damping needs careful design of end cells.

Weakly coupled structures (SST)

I. Significantly lower cost of the RF-system (40-50% less components).
II. 40-50% less Input Couplers, therefore cleaning/assembly/processing time and cost reduced
III. Tunnel shorter by 5-6%, because of shorter inter-cavity connection
IV. Less openings in cryostat (40-50%), simplified assembly and design.
V. Less time for assembly of cryostats in the linac.
VI. Less LLRF units.
VII. Remedy to synchronic excitation of dangerous HOMs.

Cons: No much experience with beam (Proof of Principle at TTF is the only test).

More difficult production and cleaning, unless we will have sc-joint.

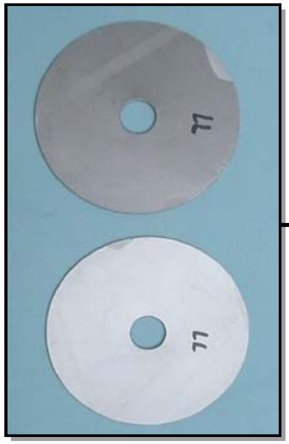
1.8-2 x higher power capability of Input Couplers (fortunately it is ~ $Ø^4$).

Cold tuner on He vessel (like the blade tuner), more experience needed.

Cryogenic Load

$$CL = \frac{\overbrace{R_{BCS} + R_{residual}}^{\text{Temperature and Surface quality}}}{(R/Q)\cdot G} \cdot V^2$$

$R_{residual}$ can be very small (~ nΩ) for big grain Nb



Very smooth surface (roughness 30 nm)

Much less grain boundaries

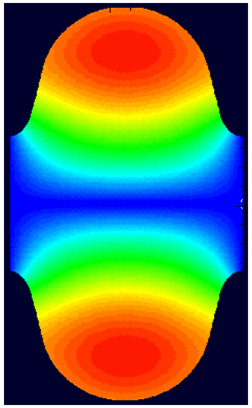
Less inclusions

Cryogenic Load (cont'd)

$$\mathbf{CL} = \underbrace{\frac{\mathbf{R_{BCS} + R_{residual}}}{\mathbf{(R/Q)\cdot G}}}_{\text{Cell geometry}} \cdot \mathbf{V^2}$$

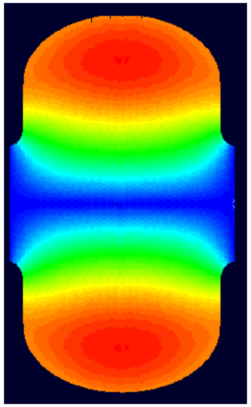
Example:

TTF inner cell



$(R/Q)\cdot G =$ **30840**

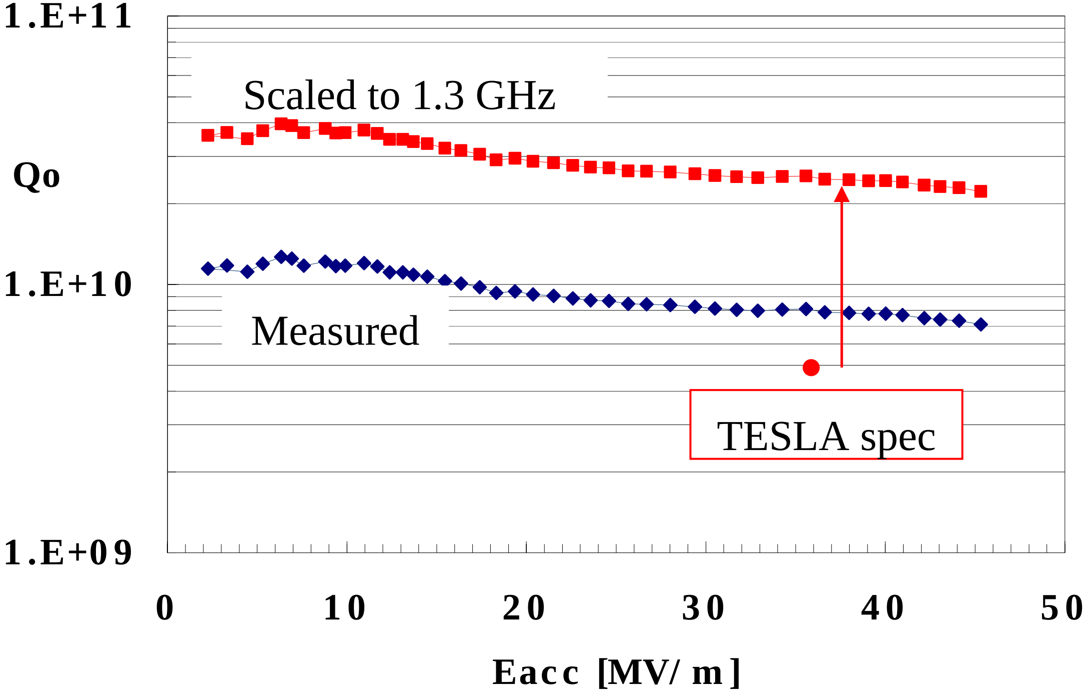
LL ILC inner cell



$(R/Q)\cdot G =$ **37970**

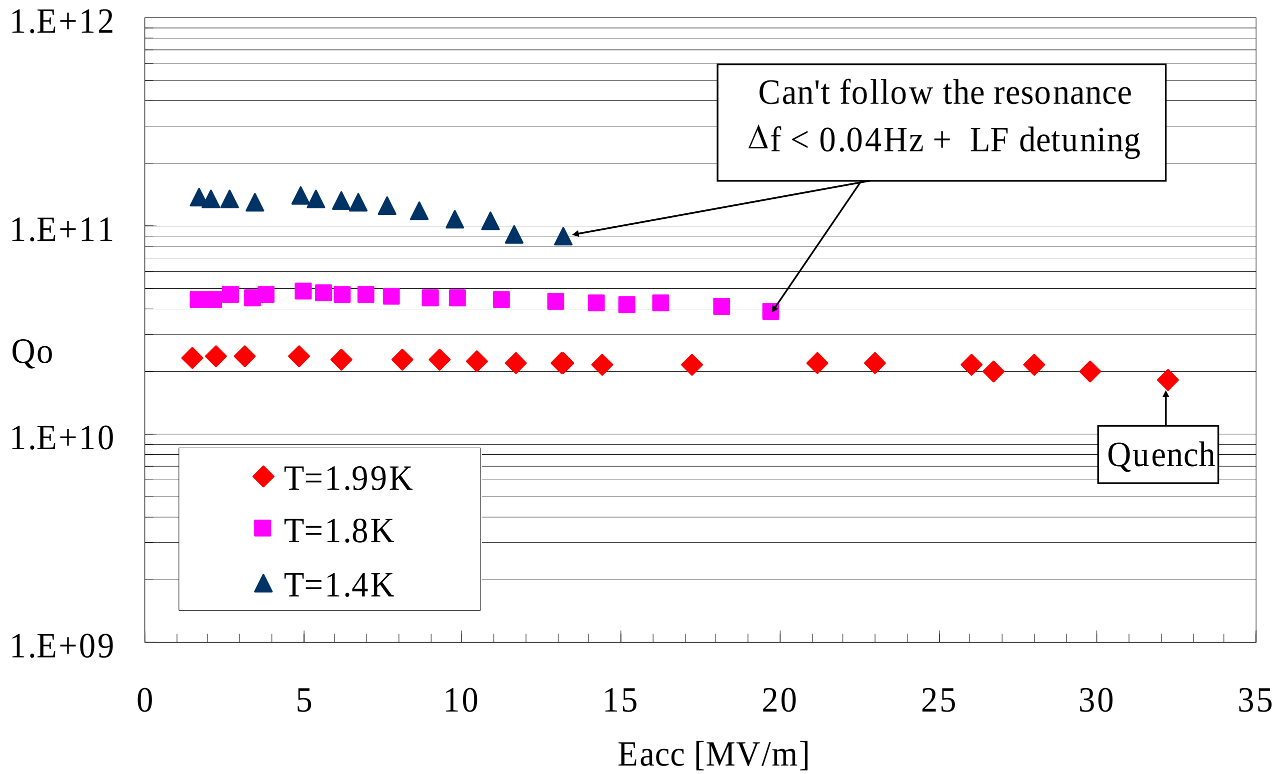
Cryogenic Load, RF-distribution system and Real Estate Gradient

LL 2.3 GHz



The improvement in intrinsic Q is mainly due to the big grain Nb !!!

ILC LL 1.3GHz

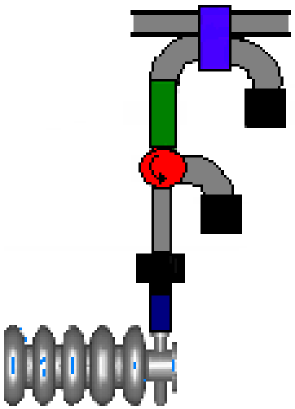


1500 ppm Ta in Niobium

Cryogenic Load (cont'd)

Suppl.	Ingot	RRR/Ta [ppm]	Type/ Nc	F [GHz]	Q [10^{10}] (2K, E_{max})	E_{acc} [MV/m]	Fabrication
CBMM	A	280/800	HG / 1	1.5	**1.25**	**34**	*W-EDM*
CBMM	B	280/800	HG /1	1.5	**0.93**	**32**	*W-EDM*
CBMM	C	280/1500	ILC_LL / 1	1.3	**1.4**	**34**	*S-cut / W-EDM*
CBMM	B	280/800	OC / 1	1.5	**0.5**	**25**	*S-cut (80 µm)*
CBMM	B	280/800	HG / 1	1.5	**0.48**	**27.5**	*S-cut, removal test ~ 75 micron removal*
CBMM	A (single)	280/800	HG / 1	2.2	**0.5**	**38** *(185/165 mT)*	*W-EDM*
CBMM	A (single)	280 / 800	ILC_LL/1	2.3	**0.7**	**45**	*W-EDM*
CBMM	A	280/800	HG /7	1.5	**1**	**25.8** *(quench,no baking)*	*W-EDM*
CBMM	C	280/1500	ILC_LL /7	1.3			*S-cut / W-EDM In fabrication*
Ninxia		330-360/150	OC / 1	1.5	**0.21**	**33** *(Q-drop still after bake)*	*S-Cut, machined*
Wah Chang	C1/C2	> 300 / < 500	HG/1	2.2		*Not yet tested*	*W-EDM*
Wah Chang	B1/B2	> 300 / < 500	HG/1	2.2		*Not yet tested*	*W-EDM*

- **RF-distribution system and Real Estate Gradient**



FPC,

Waveguides

Directional Coupler,

Loads,

Bends,

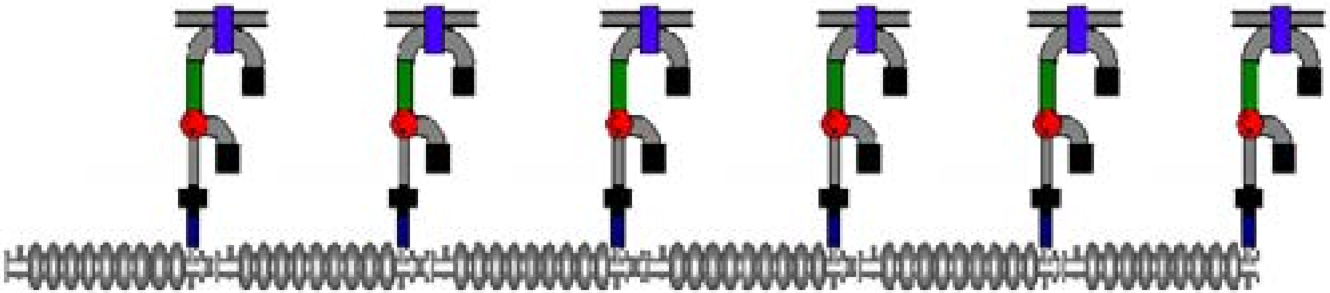
Circulator,

3-stub Transformer

x**20592**

RF-distribution system and Real Estate Gradient (cont’d)

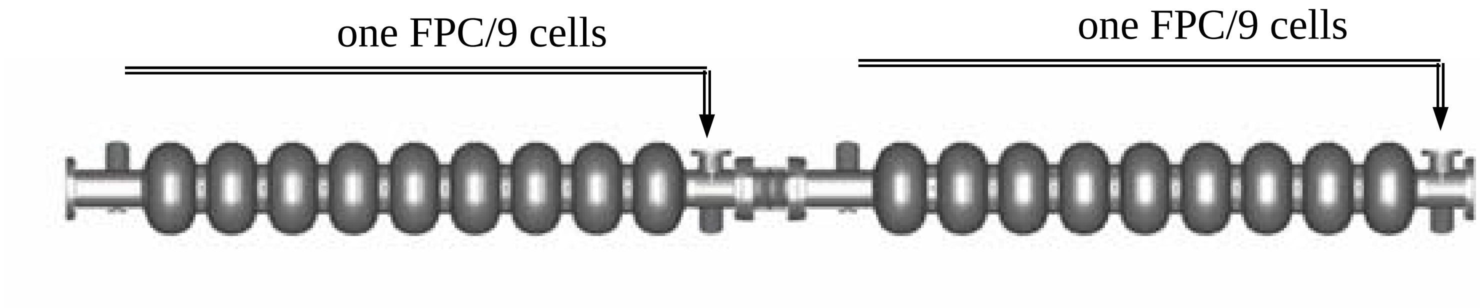
Standard layout:



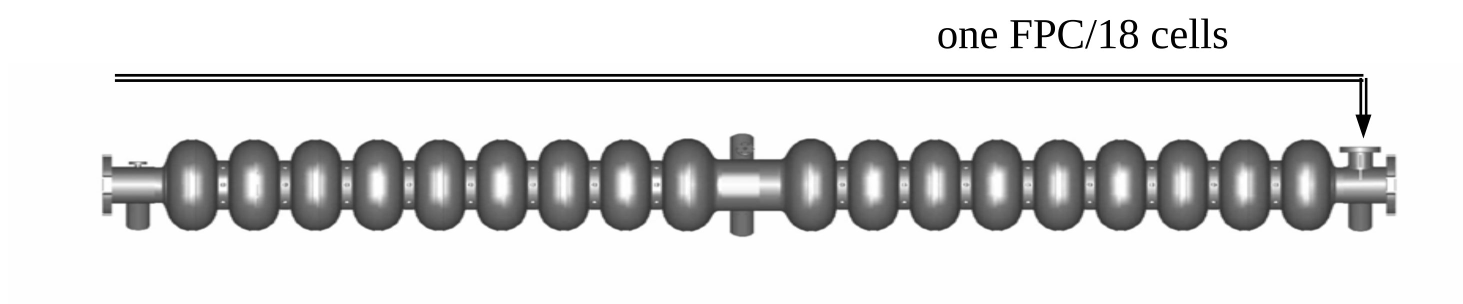
SST layout **saves thousands** of these components

RF-distribution system and Real Estate Gradient (cont'd)

Standard layout: 9-cell structures separated by **286 mm** long tube



SST layout: two 9-cell structures coupled by **λ/2= 115 mm** long tube



Space saved per one pair is: 286 mm - 115 mm = **171 mm**

- **Big Grain (Single Crystal) Niobium**

Table I. Potential savings

	Single 9-cell	Estimated Savings/9cell	Estimated Savings for ILC/Tesla
Material cost	**$ 14000**	**$ 5000**	**$ $100\cdot10^6$**
QA		**$ 1000**	**$ $20\cdot10^6$**
Processing		**$ 4000**	**$ $80\cdot10^6$**
Total			**$ $200\cdot10^6$**

- **Weakly coupled structures (SST)**

Table II compares two layouts for the scenario, when the 500 GeV stage <u>Eacc is fixed</u> and the tunnel is shorter by:

10296x (.286m -0.115m) = 1.76 km <u>(6% of the tunnel)</u>

Table II. Number of cavities, FPC, HOM couplers, tuners and LHe vessels.

Layout	FPCs	HOM Couplers	Cold Tuners, He Vessels
9-cells	20592	41184	20592
SST 2x9	10296	41184	20592
Saved parts	10296	0	0

Weakly coupled structures (SST), cont'd

Element	Number of saved parts	Drawback /Comments/Status of at present used elements
Fundamental Power Coupler	10296	The power capability of input couplers must be doubled. The design should be based on the coax line Ø>60 mm. The bigger diameter is favorable for the multipacting suppression. The coupler price is dominated by the labor not by the cost of parts, so coupler with bigger Ø will be marginally more expensive.
3-stub waveguide transformer	10296	The power capability has been tested up to 2 MW.
Circulator	10296	The power capability must be doubled what probably costs twice as much; almost no saving here.
Directional couplers	10296	The power capability has been tested up to 5 MW.
Loads	10296	The power capability has been tested up to 400 kW.
Waveguides: straight sections, bellows, H-bands	10296	The power capability is not a problem
LLRF amplitude/phase control units	-	No technical problem
Electronic units for 3-stub transformer	-	No technical problem saving ~20%
Electronic units for tuners	-	No technical problem

Weakly coupled structures (SST), cont'd

We cannot say how big will be the cost saving for ILC. For the TESLA-like machine with 20592 of 9-cell structures it can be estimated by formula:

saving = 10296*(FPCcost + $7000) + LLRF_cost_saving + Tunnel_cost_saving

- The dominant is FPC cost and we cannot speculate here because the price at present is very far from what we can afford for the real machine

- Coupler Cleaning/Assembly/Processing: ~$3000 x 10296 = $\$31\cdot10^{6}$

- $7000 is the RF-distribution system cost per/FPC.

- Simplified cryomodule design (less openings) should also reduce the cost

- Present coupler costs are ~ $ 30000
- Goal is $ 10000
- Actual costs maybe in between~ $ 20000
- Coupler Processing: estimated cost/coupler: $ 3000

Table III. Potential savings

FPC price	**$ 30000**	**$20000**	**$ 10000**
Savings	**$ 398·10^6**	**$ 292·10^6**	**$ 189·10^6**

Conclusions

- **We believe that potentially significant cost savings can be realized with the use of large grain/single crystal high purity niobium due to reduced material cost and a "streamlining " of the procedures**

- **We also believe that an accelerator configuration based on weakly coupled structures can have a significant effect on construction and operation costs due to reducing the number of components for the RF system by roughly a factor of 2**

- **Both the material and the superstructure concept have had their "proof of principle" tests, but further exploration is necessary.**

- **In view of a potential combined cost savings of up to half a billion dollars for the ILC, we believe that it would be a justifiable and clever decision to invest as little as 0.1 % of the potential cost savings in the developments pointed out in the previous presentation.**