15. Cavity R&D for ILC
- High Priority issues -

15.1 Development of the preparation with reproducible 35MV/m
15.2 Lorentz Detuning issue
    END Group design
    Lorentz Detuning Compensation by Piezo
15.3 Cavity Fabrication Cost reduction issues
    Large Grain Nb material
    Seamless cavity

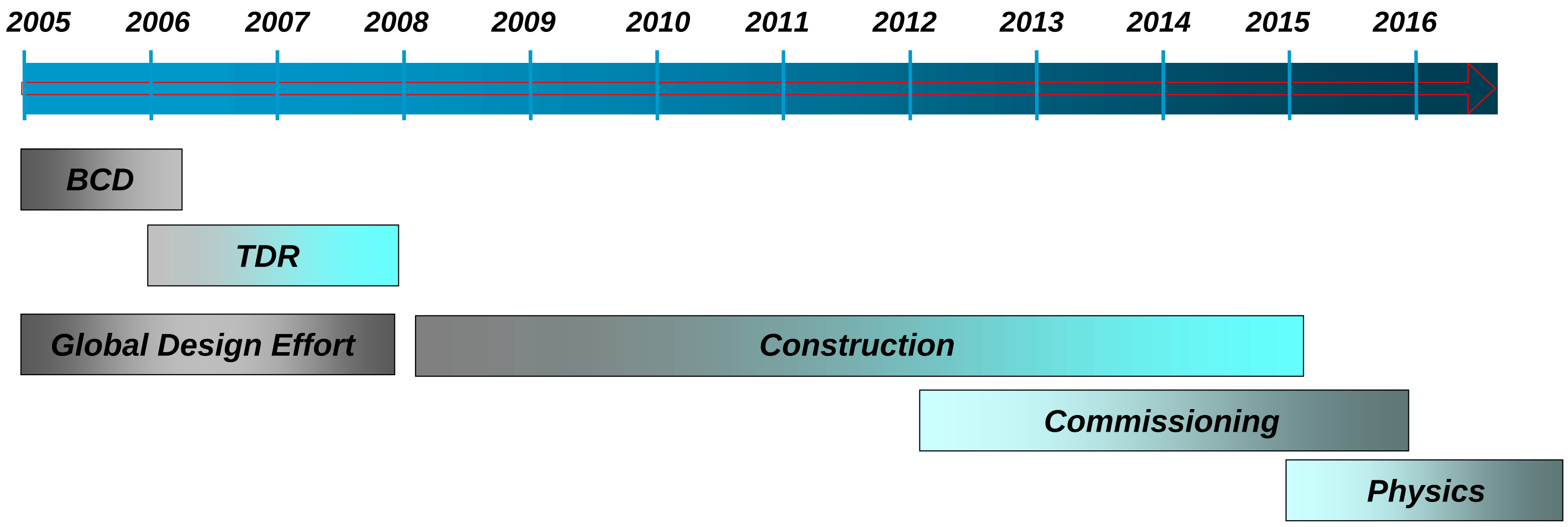
In 2003 ICFA created ***International Technology Recommendation Panel (ITRP)*** *which after one year studies and examination of two proposed approaches* ***(TESLA and NLC),*** *recommended in August 2004 to proceed* ***worldwide with the superconducting TESLA technology.***

In November 2004 the first International Linear Collider Workshop took place at KEK (Japan).

International Community re-opened discussions on following topics:

- *Parameter List.*
- *One or* ***Two Tunnels****.*
- *Laser Straight Tunnel or Following the* ***Earth Curvature.***
- *3 km,* ***6 km*** *or 17 km Damping Rings.*
- *What Kind of Positron Source. (Conventional or* ***Undulator Based****).*
- *How Many Interaction Points. (****Two 2 mrad and 20 mrad****).*
- *Optimum Gradient 30 MV/m or Higher. (****31.5 MV/m*** *and then* ***36 MV/m****).*
- *Optimum Cavity Shape and Superstructure Concept.(BCD* ***TESLA*** *and then…?).*

Proposed Schedule is very ambitious



but the Baseline Configuration Document will keep open all options, which need still R&D, but may lead to the cost reduction or/and improvement in the performance.

Second ILC meeting in Snowmass Colorado, defined more precisely BCD and what should be seen as an ACD (Alternative Configuration Document), at least for the cavities and couplers.

The recently (11.11.2005) proposed ILC layout.

	units	nom	low N	lrg Y	low P
N	10^{10}	2	1	2	2
n_b		2820	5640	2820	1330
$\varepsilon_{x,y}$	mm, nm	10, 40	10, 30	12, 80	10, 35
$\beta_{x,y}$	cm, mm	2, 0.4	1.2, 0.2	1, 0.4	1, 0.2
$\sigma_{x,y}$	nm	655, 5.7	495, 3.5	495, 8	452, 3.8
D_y		18.5	10	28.6	27
∂_{BS}	%	2.2	1.8	2.4	5.7
σ_z	mm	300	150	500	200
P_{beam}	MW	11	11	11	5.3

$L=2\times10^{34}\ cm^{-2}s^{-1}$

The proposed BCD and ACD for cavities with auxiliaries follow the Snowmass Workshop (August/September 2005) recommendation:

- ***Materials***
  - *BCD: Fine grain.*
  - *ACD: Large grain: serious R&D effort recommended.*

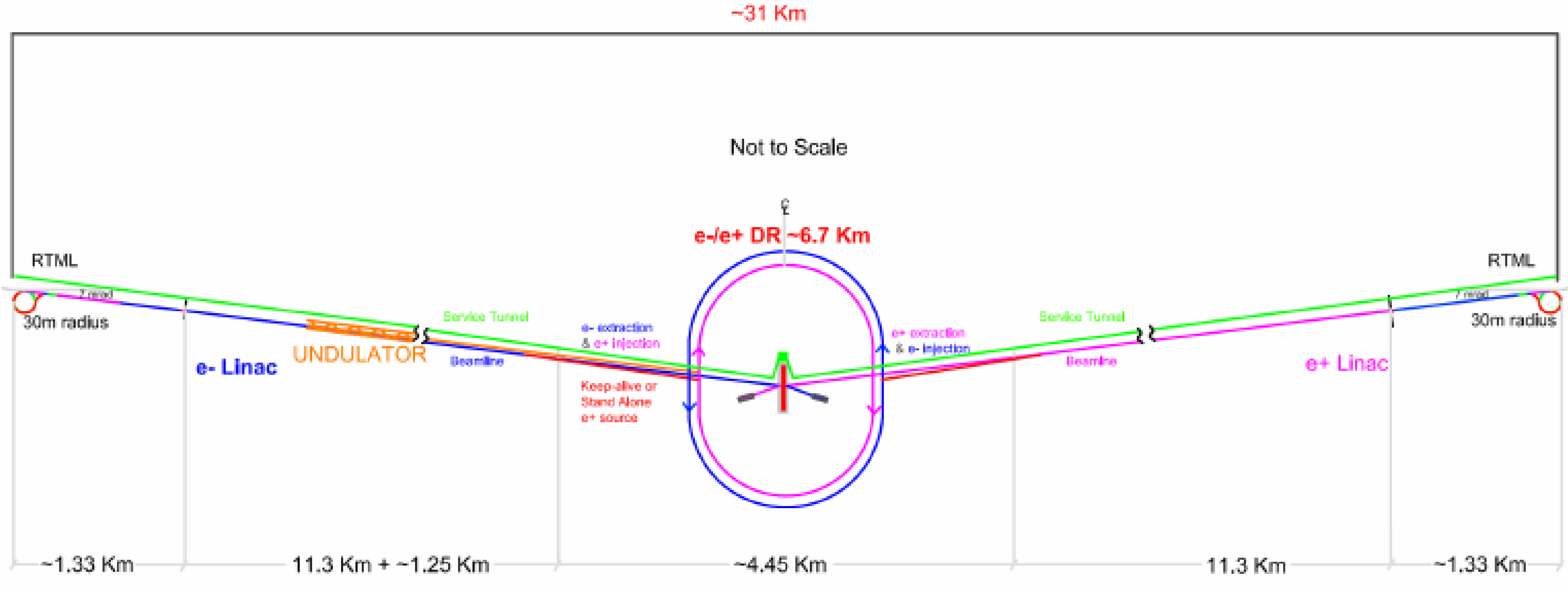
- ***Shape***
  - *BCD: TESLA shape: much experience.*
  - *ACD:*
    1. *Low-loss: serious R&D effort recommended.*
    2. *Re-entrant: multi-cell perceived to be difficult to prepare.*
    3. *Superstructure: would need superconducting seal as preparation for full unit is perceived difficult. R&D effort recommended to develop sc seal.*

- ***Fabrication***
  - *BCD: Electron-beam welding.*
  - *ACD: Hydroforming or Spinning: work on costing needed, tube fabrication needs R&D, serious R&D effort recommended.*

- ***Preparation***
  - *BCD: 800C furnace + EP + 120 C bake, still serious R&D effort recommended.*
  - *ACD: 1400 C + EP ́ + 120 C bake.*

Recent Design (RDR)

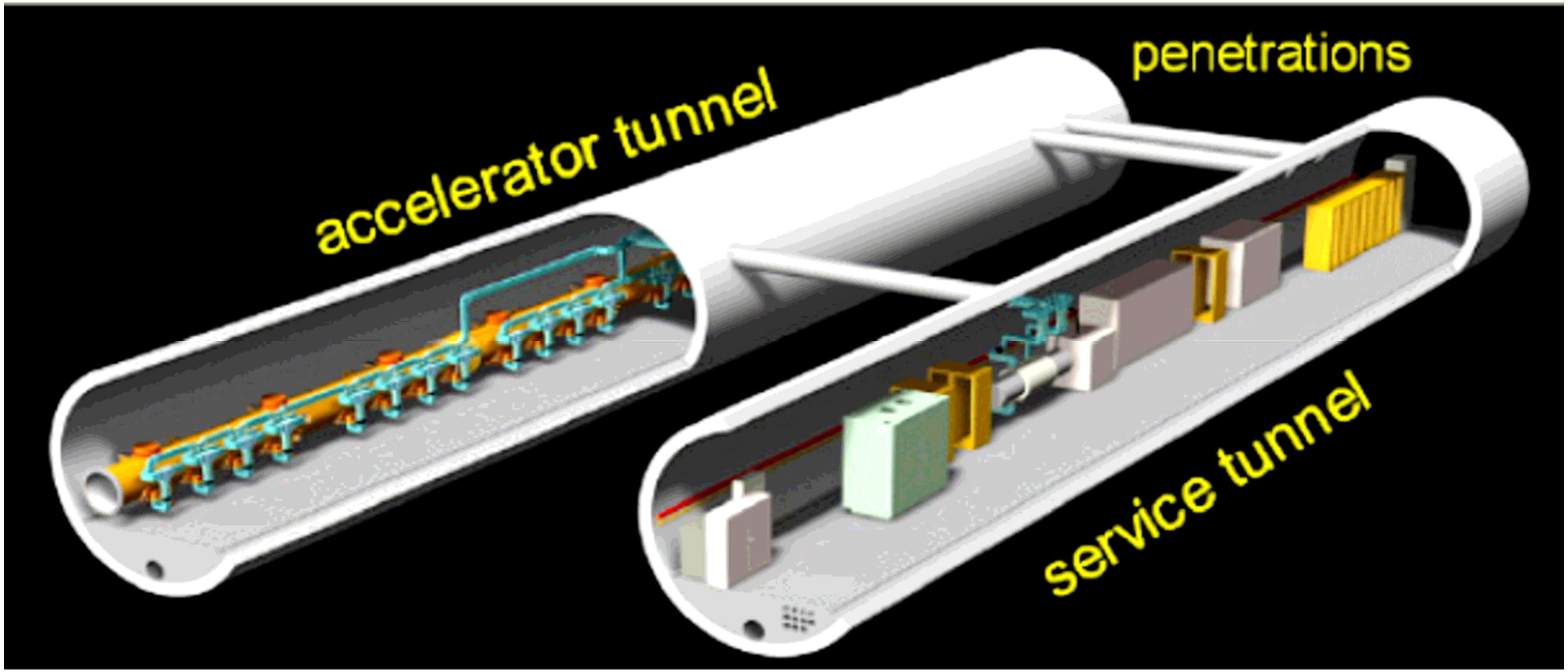
1st Stage: 500 GeV



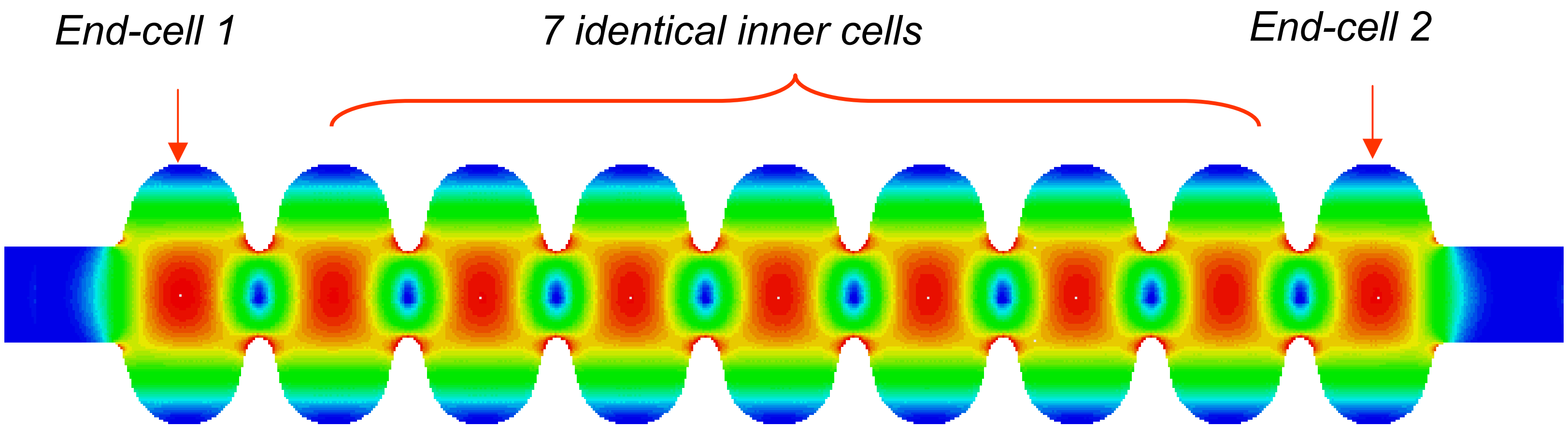
Schematic Layout of the 500 GeV Machine

ILC Main LINAC Tunnel

Two Tunnels



The cavity was designed in 1992 (A. Mosnier, D. Proch and J.S.).



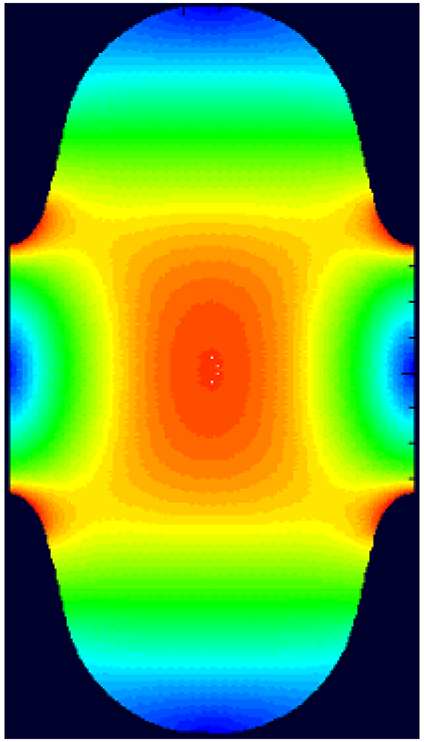
TTF 9-cells; Contour of E field

f_{π}	[MHz]	1300.00
$f_{\pi\text{-}1}$	[MHz]	1299.24
R/Q	[Ω]	1012
G	[Ω]	271
Active length	[mm]	1038

The inner cell geometry *was optimize with respect to:* ***low*** E_{peak}/E_{acc} *and coupling* k_{cc}.

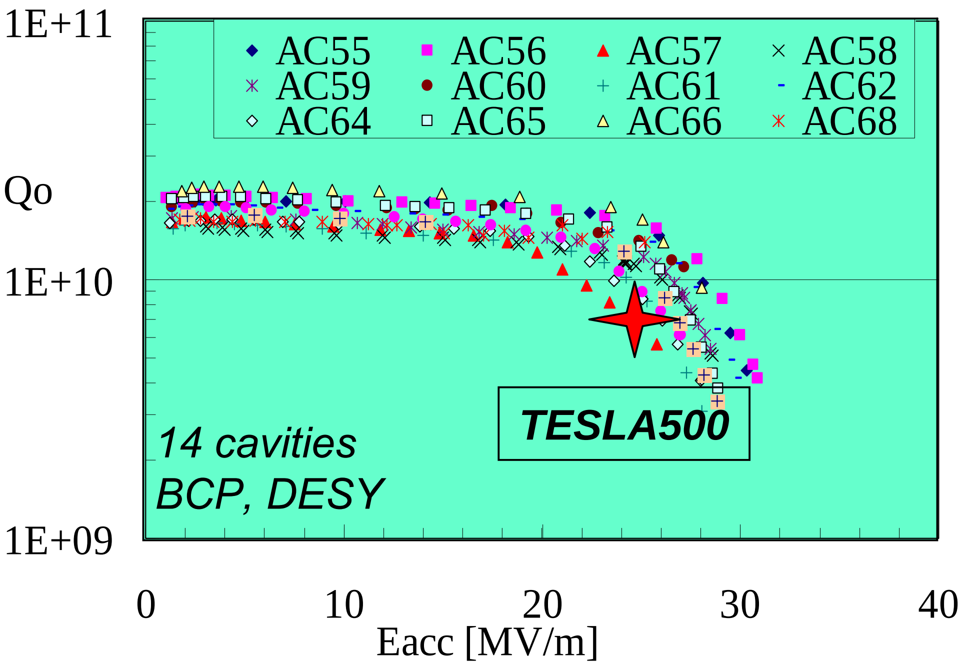
At that time (1992) the field emission phenomenon and field flatness were of concern, no one was thinking about reaching the magnetic limit.

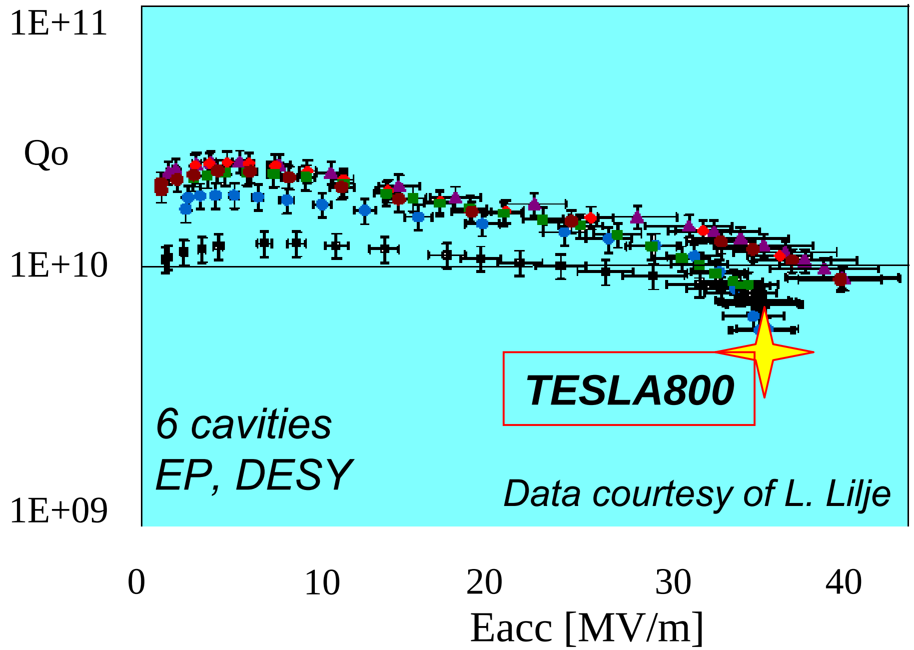
f_{π}	[MHz]	1300.0
r_{iris}	[mm]	35
k_{cc}	[%]	1.9
E_{peak}/E_{acc}	-	1.98
B_{peak}/E_{acc}	[mT/(MV/m)]	4.15
R/Q	[Ω]	113.8
G	[Ω]	271
R/Q*G	[Ω*Ω]	30840



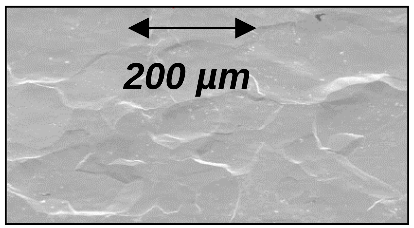
Inner cell; Contour of E field

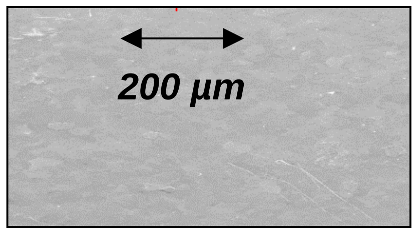
TTF Cavities performance for FM.





roughness ~10 µm



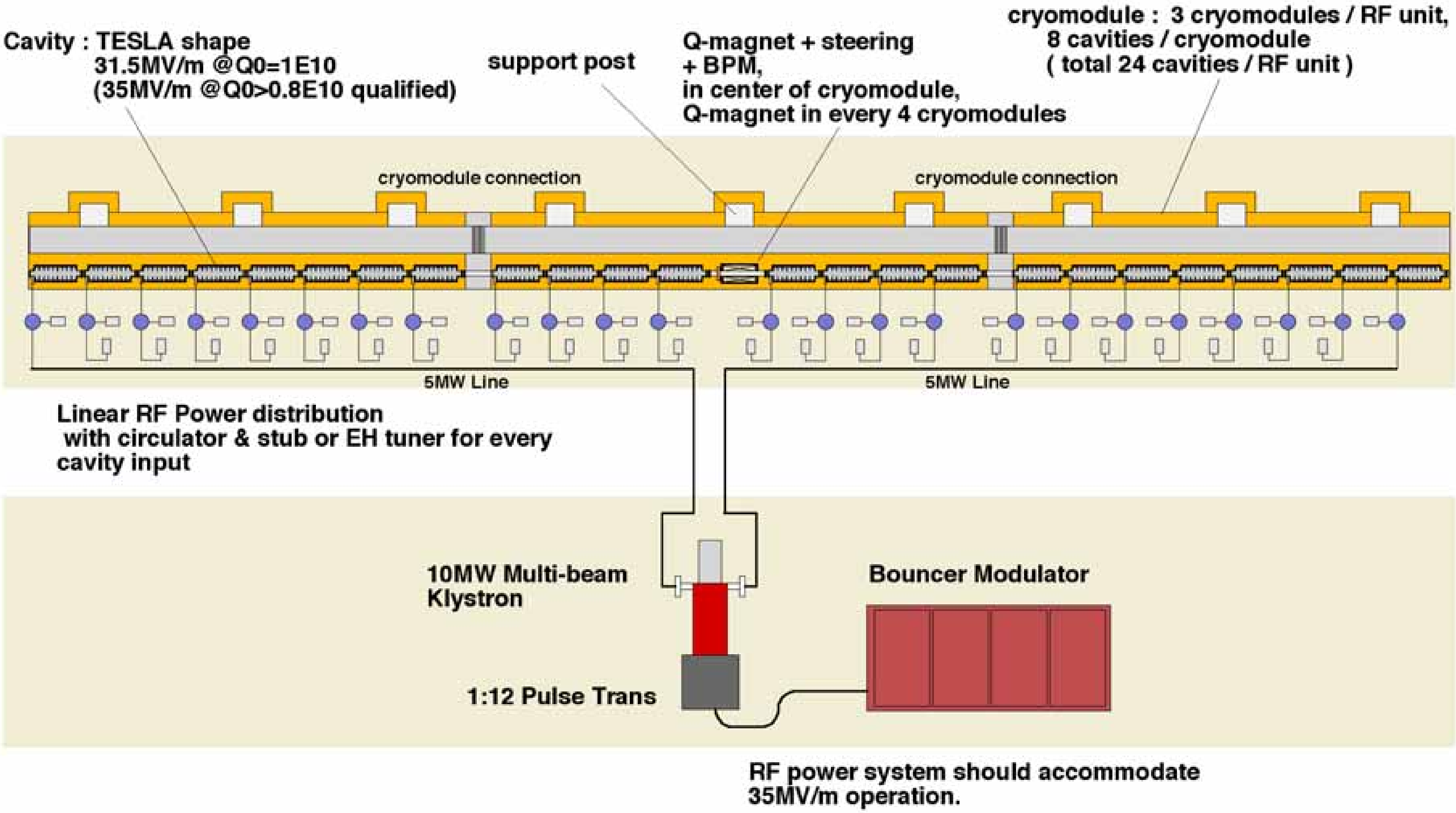


roughness ~1 µm

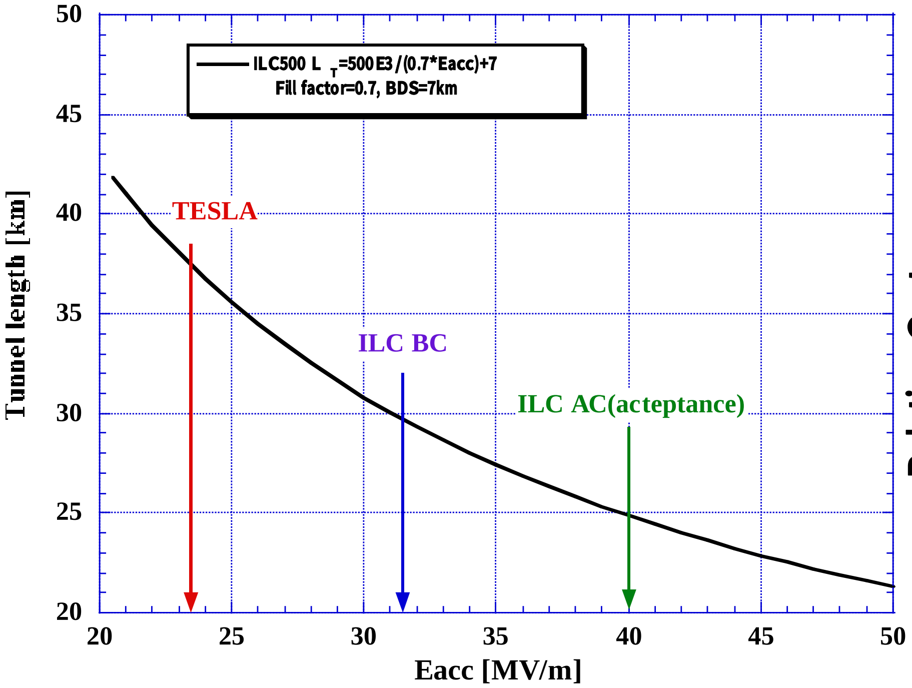
*The standard (BCP) procedure is with an acid mixture containing **1 part HF, 1 part HNO_3 and 2 parts H_3PO_4** in volume.*

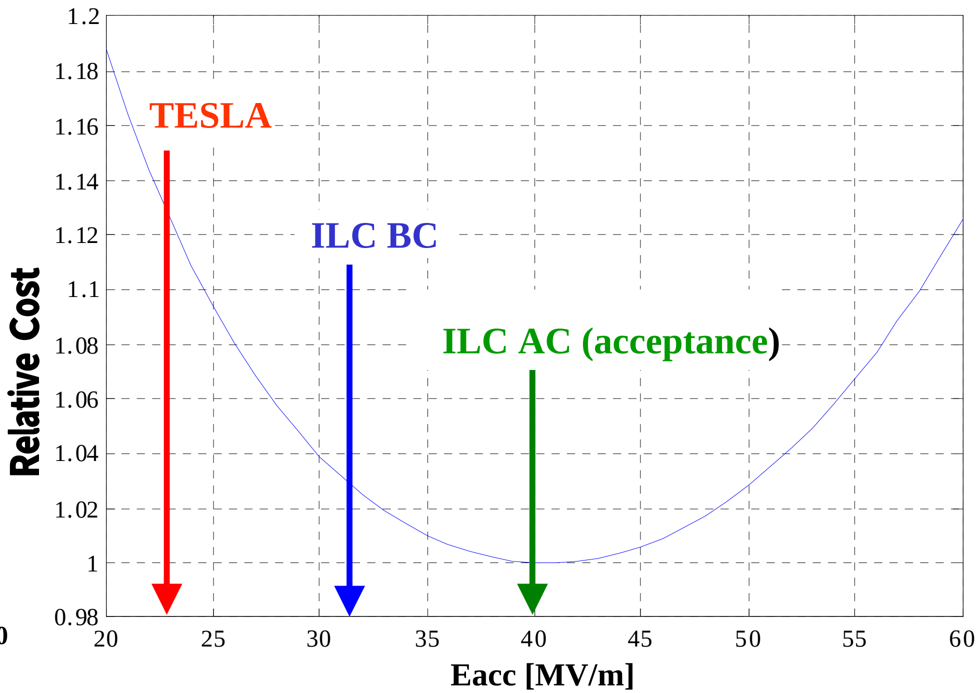
*The standard EP procedure is with electrolyte **HF** and **H_2SO_4** in volume ratio of **1:9.***

Construction of an ILC baseline RF unit in ILCTA



ILC500 Gradient dependence with tunnel length and cost



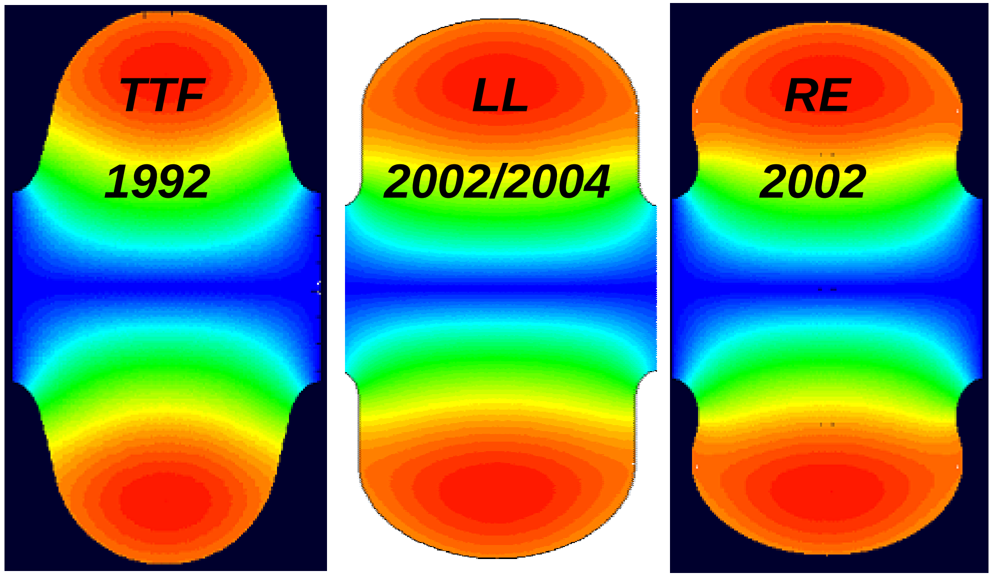


$$\text{Total cost} = \text{Tunnel}(1/\text{Eacc}) + \text{Cryomodul}(1/\text{Eacc}) + \text{RF}(\text{Eacc}) + \text{Cryoplant}(\text{Eacc}^2) + \text{Cryo-Operation}(\text{Eacc}^2) + \text{Beampower}(\text{const})$$

$$= [C_T + C_{CM}] \cdot \frac{1}{\text{Eacc}} + C_{RF} \cdot \text{Eacc} + [C_{Cryplant} + C_{Cryoop}] \cdot \text{Eacc}^2 + C_{Beampower}$$

Motivation cont.

We know how to reduce B_{peak} / E_{acc} (see Part I) : more volume in equator region and smaller iris.

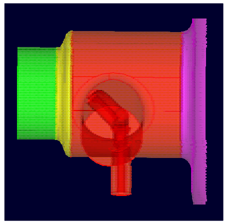


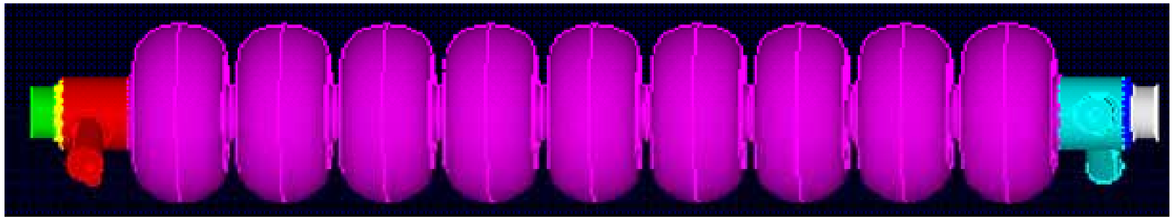
r_{iris}	[mm]	35	30	33
k_{cc}	[%]	1.9	1.52	1.8
E_{peak}/E_{acc}	-	1.98	2.36	2.21
B_{peak}/E_{acc}	[mT/(MV/m)]	4.15	3.61	3.76
R/Q	[Ω]	113.8	133.7	126.8
G	[Ω]	271	284	277
R/Q*G	[Ω*Ω]	30840	37970	35123

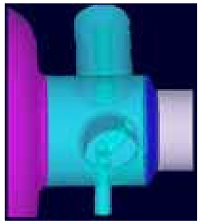
LL 9-cell cavity *(DESY, FERMI, KEK, SLAC, JLab)*

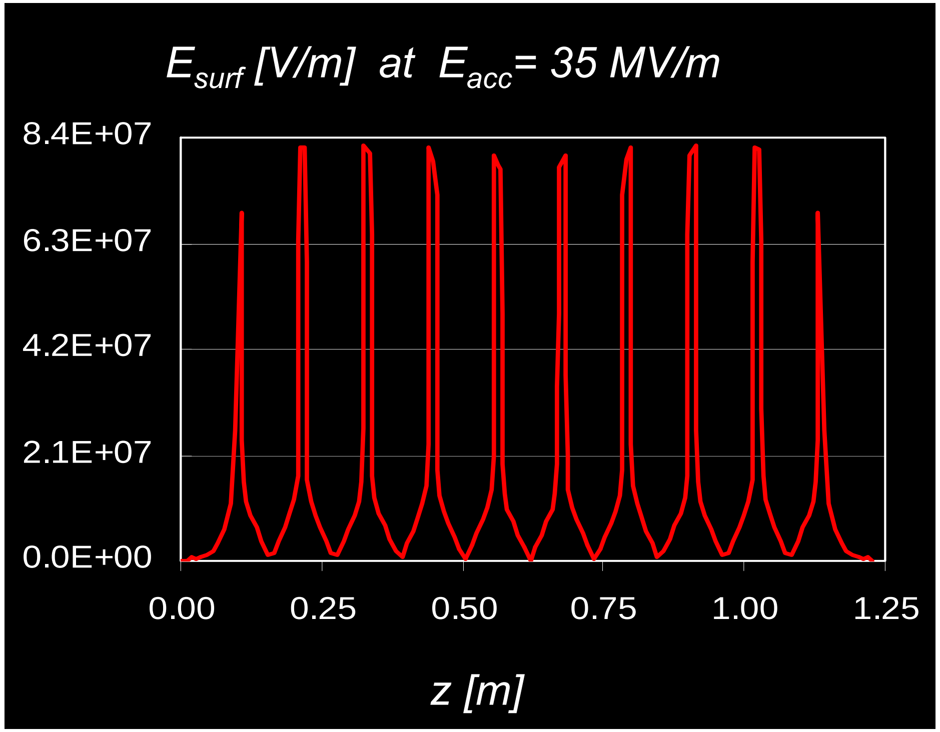
Courtesy K. Ko and ACD, SLAC

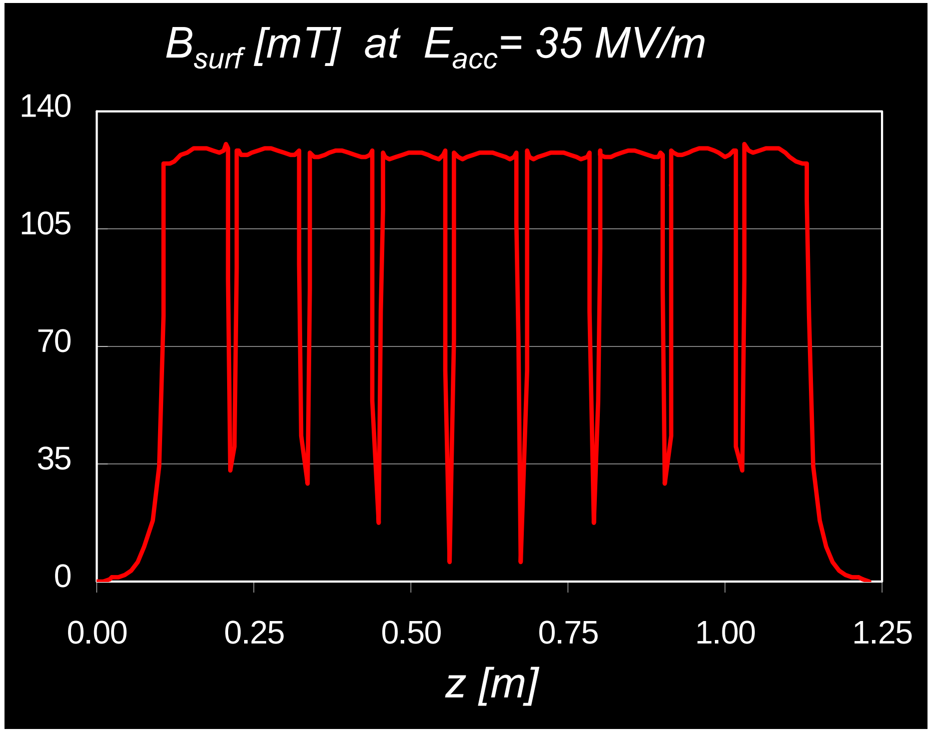
DESY (2D) , SLAC (3D)









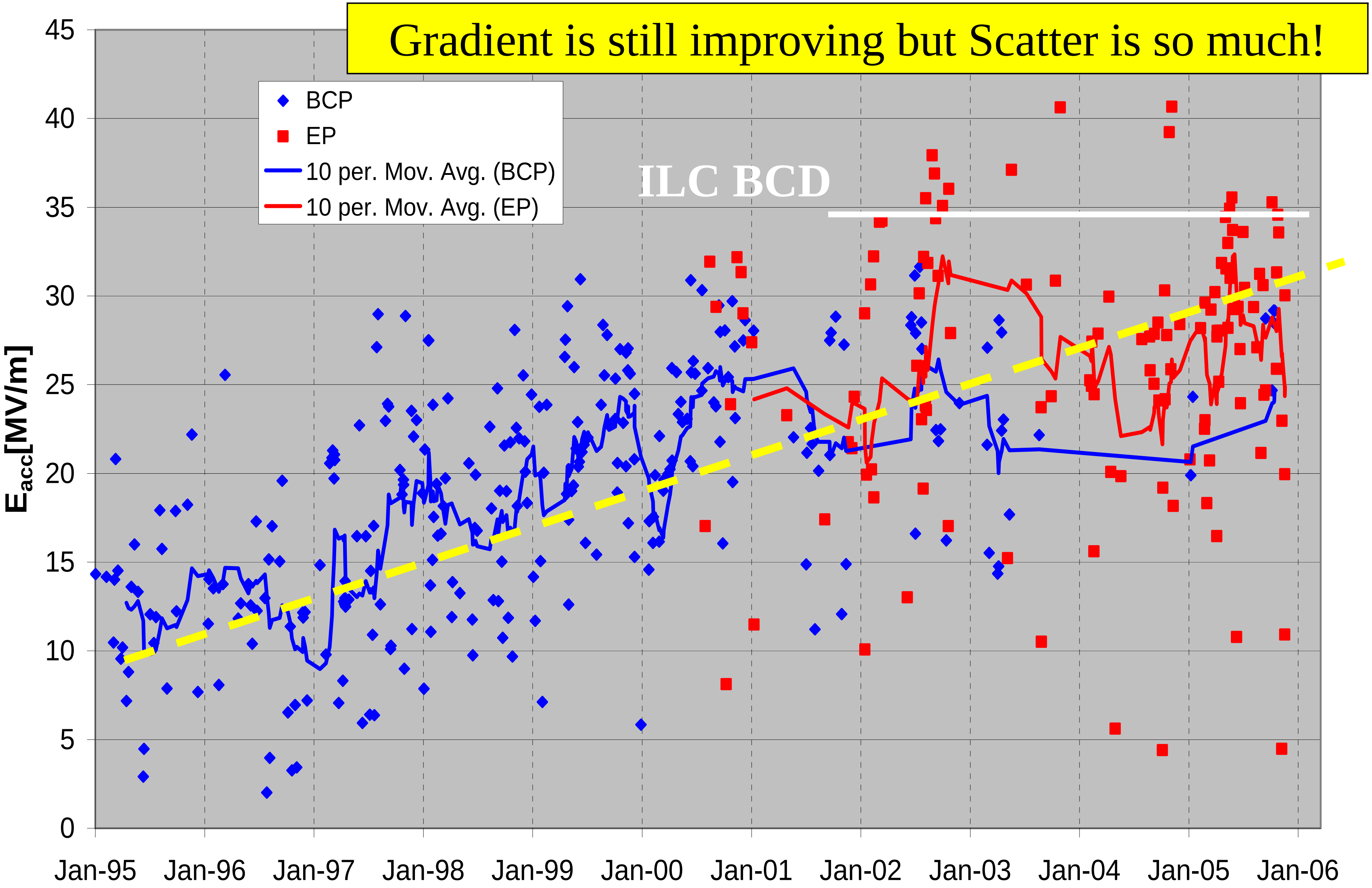


LL 9-cell cavity: FM parameters

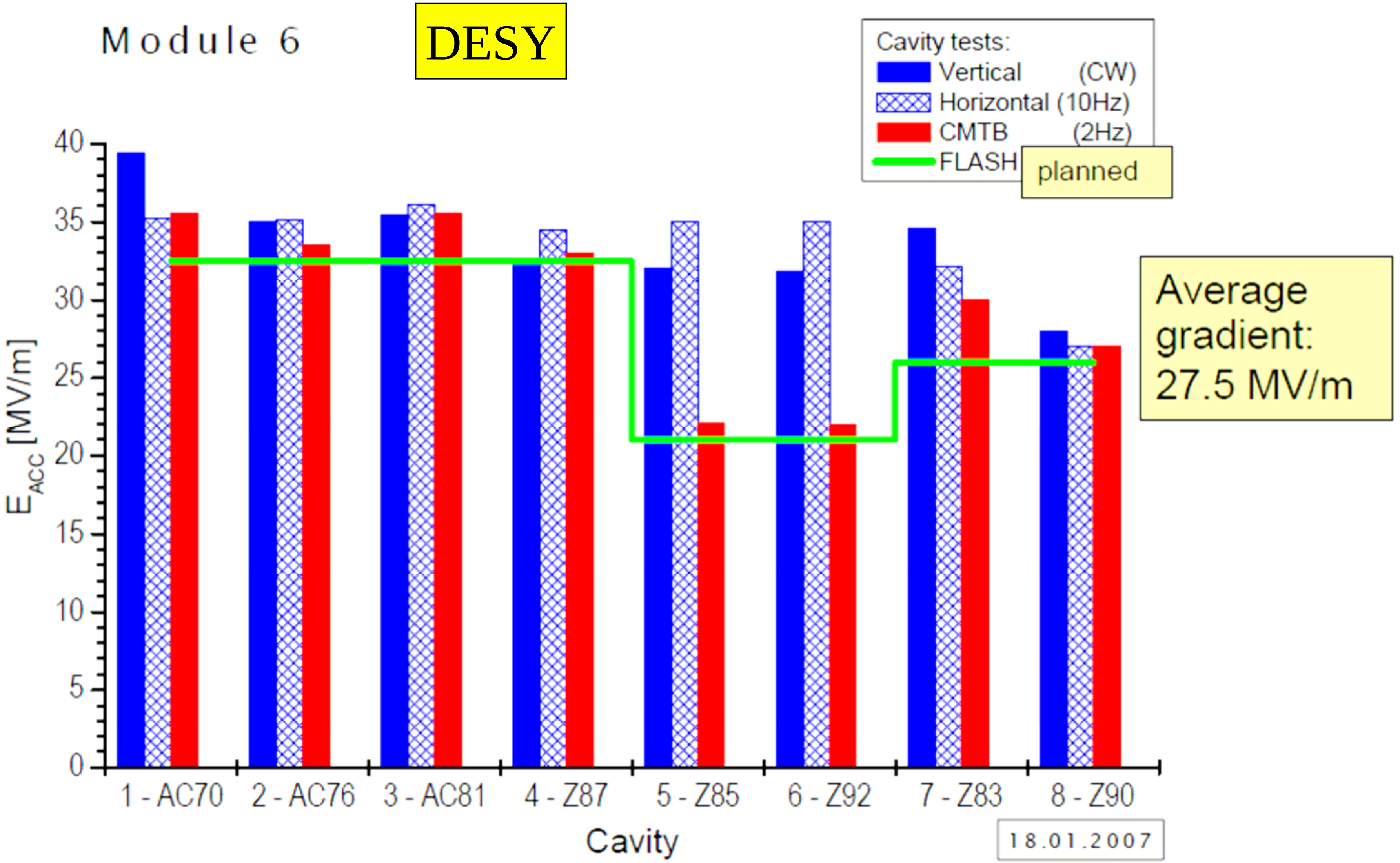
Parameter	*Unit*	*TESLA*	*LL-Shape End-cells I*
Øiris	*[mm]*	*70*	*60*
k_{cc}	*[%]*	*1.9*	*1.52*
E_{peak}/E_{acc}	-	*1.98*	*2.36*
B_{peak}/E_{acc}	$[mT\cdot(MV/m)^{-1}]$	*4.15*	*3.61*
*Lorentz factor**, k_L	$[Hz\cdot(MV/m)^{-2}]$	*-0.74*	*-0.81*
R/Q	*[Ω]*	*113.8*	*133.7*
G	*[Ω]*	*271*	*284*
R/Q·G	*[Ω·Ω]*	*30840*	*37970*
$k_{\perp}(\sigma_z=1mm)$	$[V/(pC\cdot cm^2)]$	*0.23*	*0.38*
$k_{\parallel}(\sigma_z=1mm)$	*[V/pC]*	*1.46*	*1.72*

**With optimally located stiffening ring: TESLA shape at r = 54mm, LL-shape at r=44mm when the wall thickness is 2.8 mm.*

Scatter at DESY E_{acc} vs. time



35MV/m High Gradient Cryomodule Demonstration

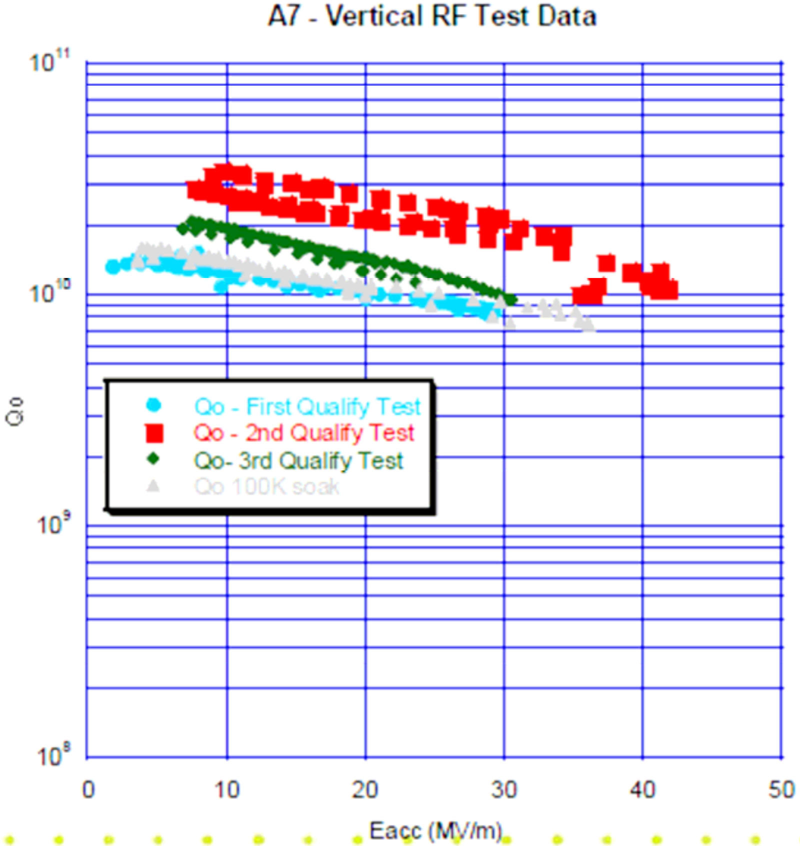


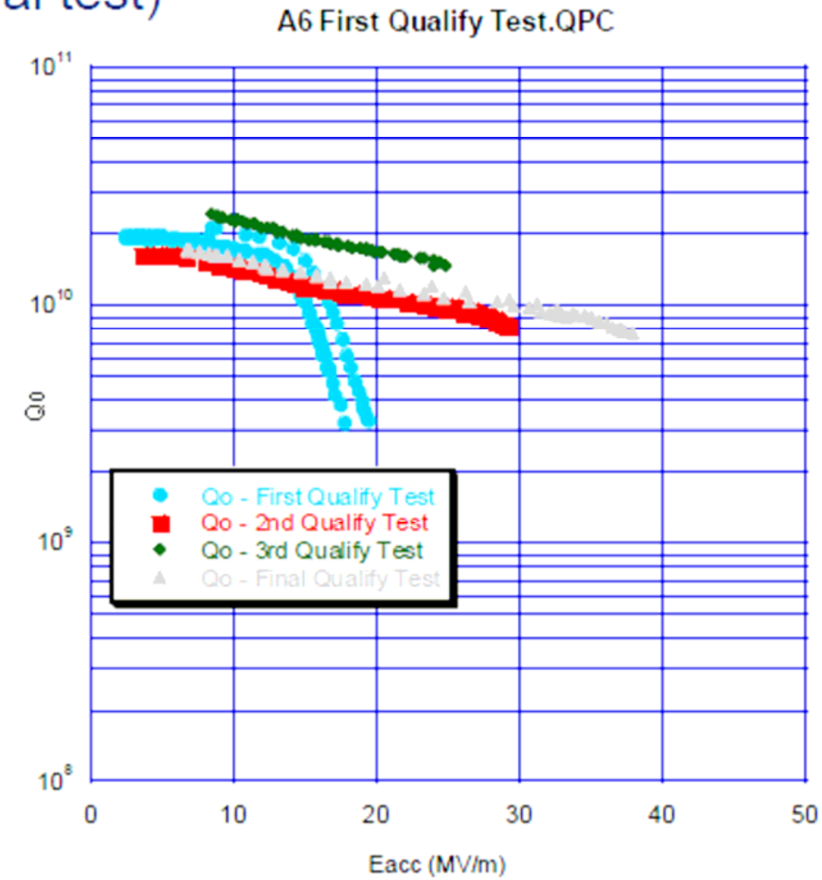
40MV/m Performance by Degreasing

- Second candidate rinse
  - Ultrasound degrease
- All curves but one limited by quench
- Field emission in one test (A6 final test)

ILC 9-cell cavity S0 tight loop test

By J.Mammosser



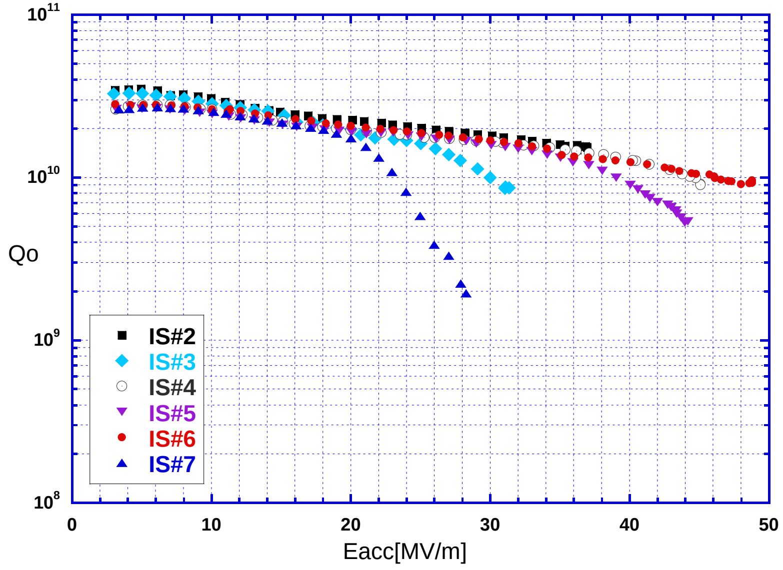


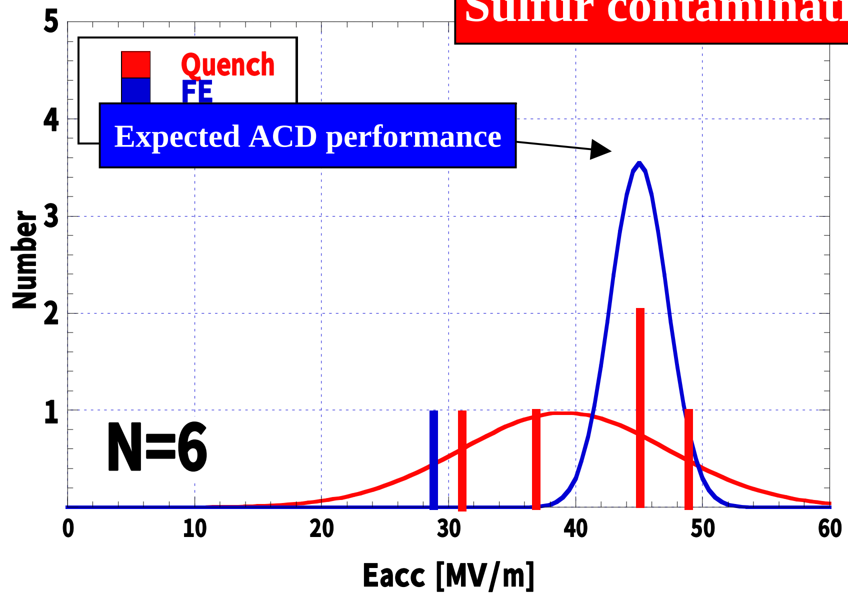
CBP(100μm)+CP(10μm)+Anneal(3hr@750^{O}C)+EP(80μm)+HPR+Baking

Single cell cavity study @ KEK

Large scatter!

Sulfur contamination?





Ave. Eacc=39.1±8.2MV/m

Scattering:20%, Acceptability@40MV/m(ACD):50%

		IS#2	IS#3	IS#4	IS#5	IS#6	IS#7
EP(80)	Eacc	36.90	31.40	45.10	44.20	48.80	28.30
	Qo	1.53e10	8.66e9	9.07e9	5.38e9	9.64e9	1.94e9

Development of the preparation with reproducible 35MV/m

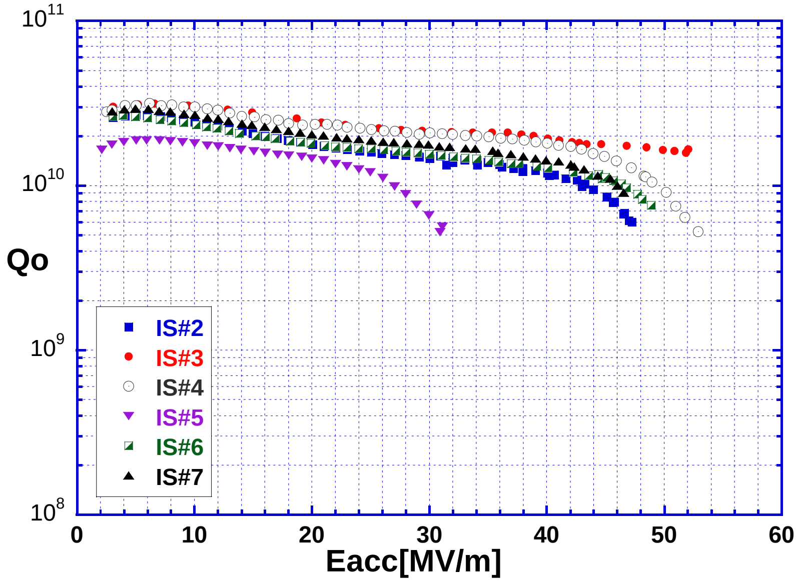
S0 Single Cell Study @ KEK on 21 Apr 2007

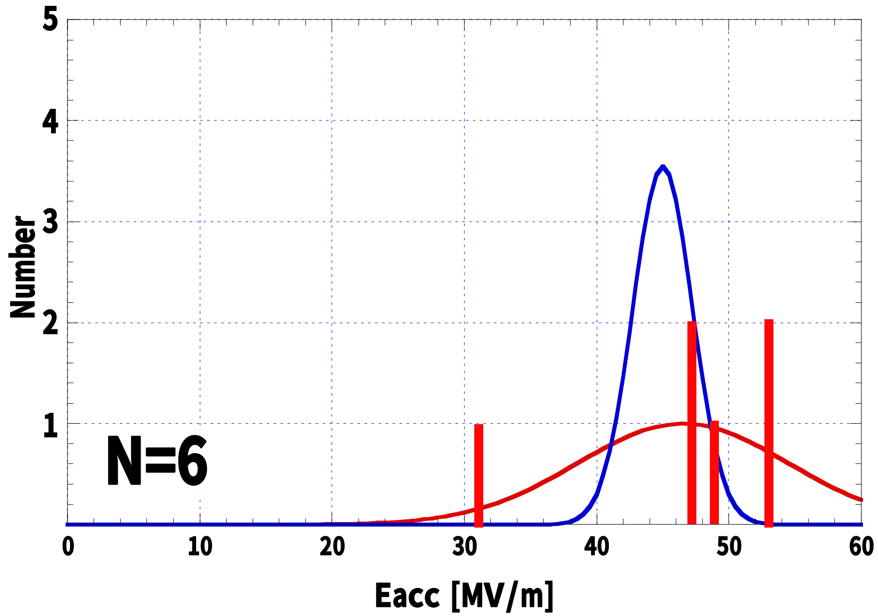
	Eacc,max [MV/m] / Qo @ Eacc,max									Emax average [MV/m]	Scatt. [%]	MP	Acceptability @ 40M V/m [%]
	IS#2	IS#3	IS#4	IS#5	IS#6	IS#7	IS#8	CLG#1	CLG#2				
CBP+CP+AN+EP(80) +HPR+ Bake	36.9	31.4	45.1	44.2	48.8	28.3				39.1 ± 8.2	21	Yes	50
	1.53E10	8.66E9	9.07E9	5.38E9	9.64E9	1.94E9							
CBP+CP+AN+ EP(80+3 fresh) +HPR+Bake		42.0	46.1	44.3	34.3	39.3			43.8	41.7 ± 4.4	11	Yes	67
		9.72E9	9.47E9	1.08E10	8.56E9	1.03E10			3.46E9				
CBP+CP+AN+ EP(40+3 fresh) +HPR+Bake	43.9						49.2*			46.6 ± 3.7	8	Yes	100
	9.47E9						4.33E9						
+EP(20)+HPR+Bake	47.2	52.2	52.9	31.1	48.9	46.5				46.4 ± 8.0	17	Yes	83
	5.98E9	1.51E10	5.23E9	5.21E9	7.56E9	9.03E9							
+EP(20+3 fresh)+HPR +HF+Bake	47.1	44.7	47.8		48.6	43.9		47.9		46.7 ± 1.9	4	Yes	100
	1.06E10	9.80E9	7.80E9		8.00E9	1.17E10		1.00E10					
+EP(20)+H_2O_2+HPR+ Bake	52.3			34.1	43.4	40.9				42.7 ± 6.0	18	Light	50
	1.09E10			1.37E10	1.39E10	3.01E9							
+EP(20)+Degreasing (US)+HPR+ Bake	50.1	52.2								51.2 ±1.5	2.9	Lights	100
	7.80E10	7.08E9											
Others Megasonic													

IS: Ichiro center cell shape, Tokyo Denkai polycrystalline Nb material

CLG: NingXia Large grain, Ichiro center cell shape

+EP(20μm)+HPR+Baking





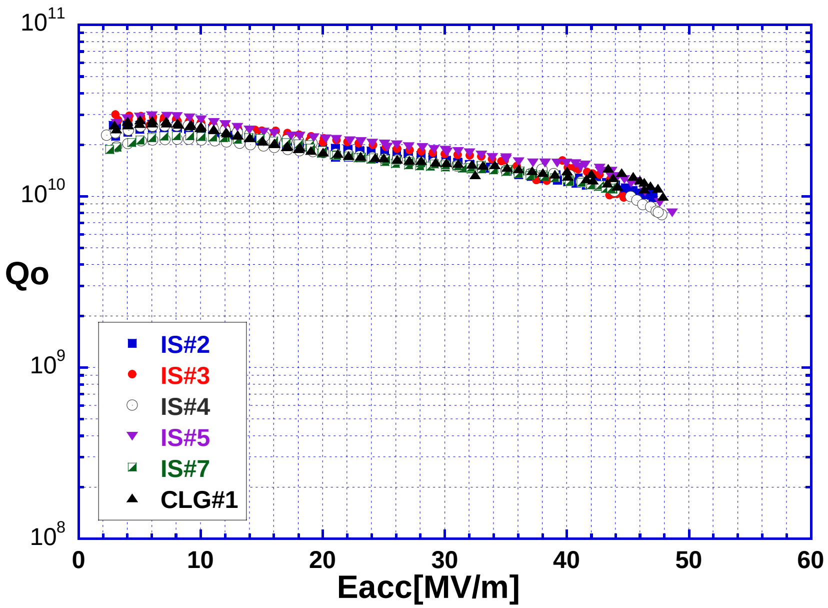
Light EP is effective to increase Eacc average, but large scatter appears again.

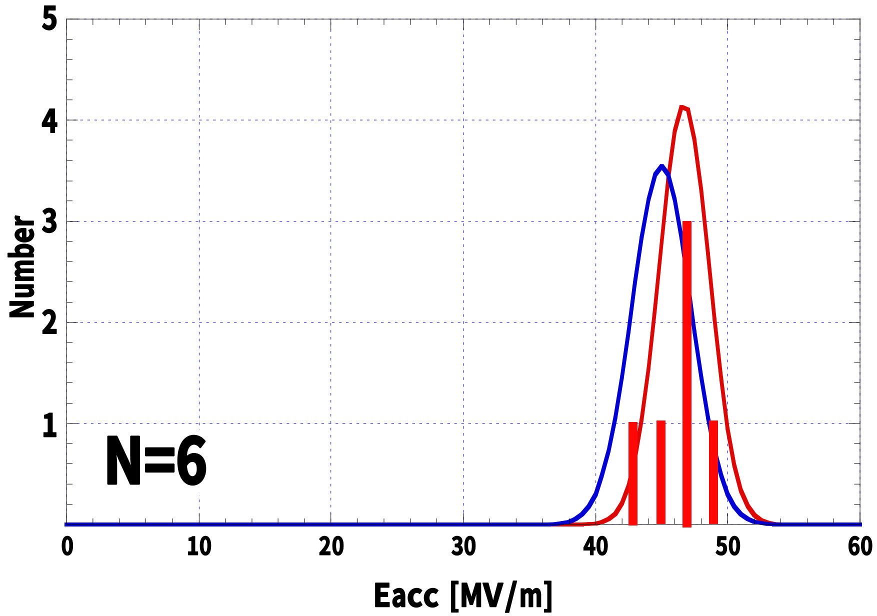
Ave. Eacc=46.5±8.0MV/m

Scattering:17%, Acceptability@40MV/m(ACD):83%

		IS#2	IS#3	IS#4	IS#5	IS#6	IS#7
+EP(20)	Eacc	47.24	52.44	52.91	31.10	48.92	46.53
	Qo	5.98e9	1.51e10	5.23e9	5.21e9	7.56e9	9.03e9

+EP(20μm)+EP(3μm, fresh, closed) +(HF*or No HF)+HPR+Baking





HF rinsing is no effective.

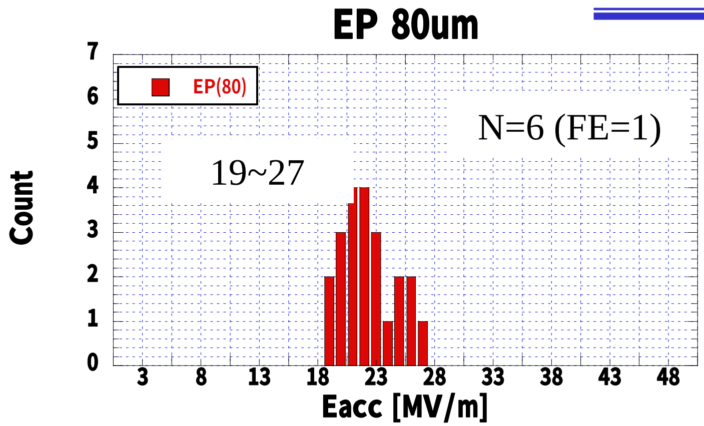
Light EP +EP(3) is effective for both high gradient and narrow scatter.

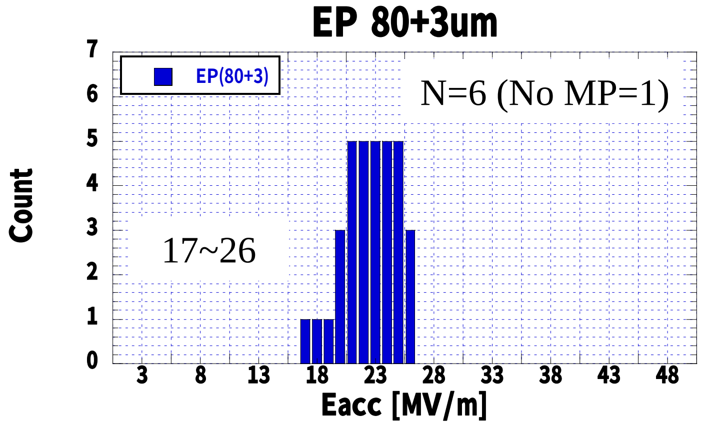
Ave. Eacc=46.7±1.9MV/m

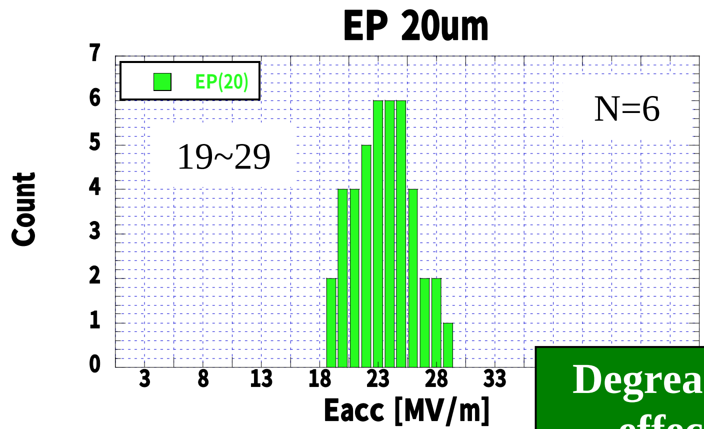
Scattering:4%, Acceptability@40MV/m(ACD):100%

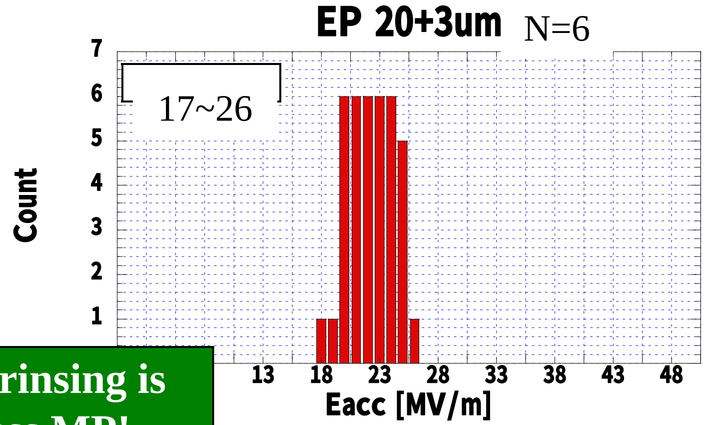
		IS#2	IS#3	IS#4	IS#6	IS#7	CLG#1
+EP(20+3) +HF*	Eacc	47.07	44.67*	47.82	48.60*	43.93*	47.90*
	Qo	1.06e10	0.98e10	0.78e10	0.80e10	1.17e10	1.0e10

Multipacting

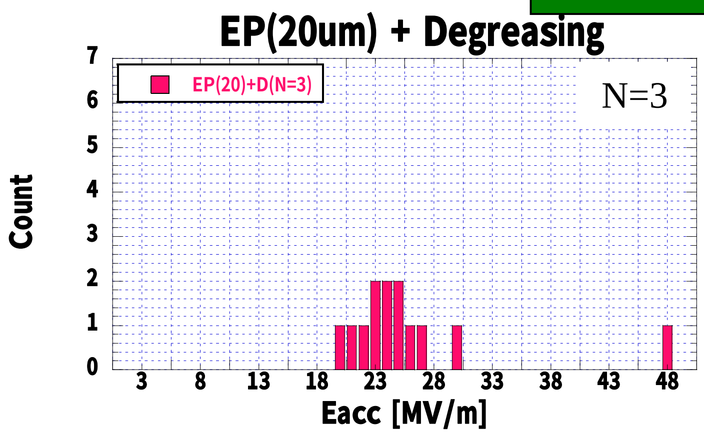


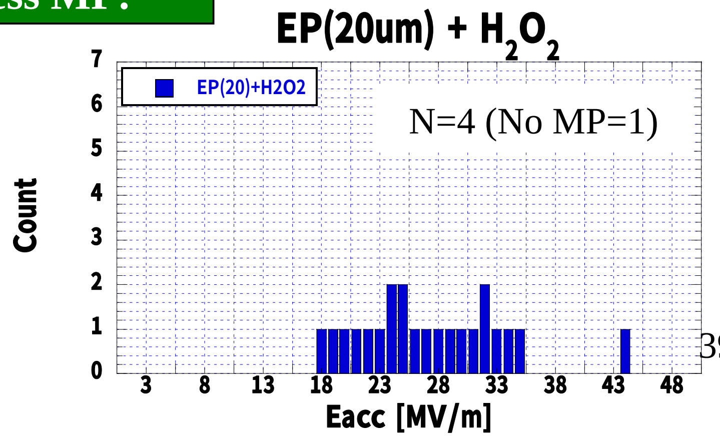




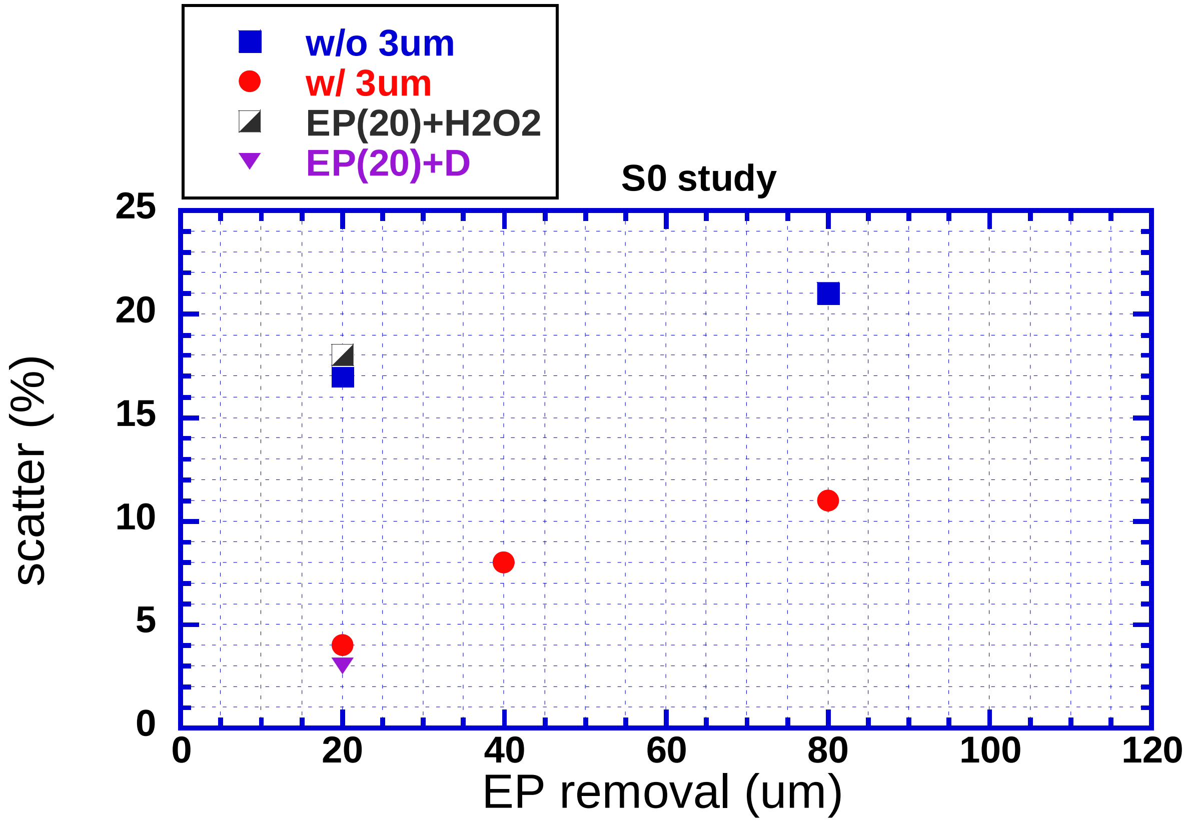


Degreasing or H_2O_2 rinsing is effective to suppress MP!





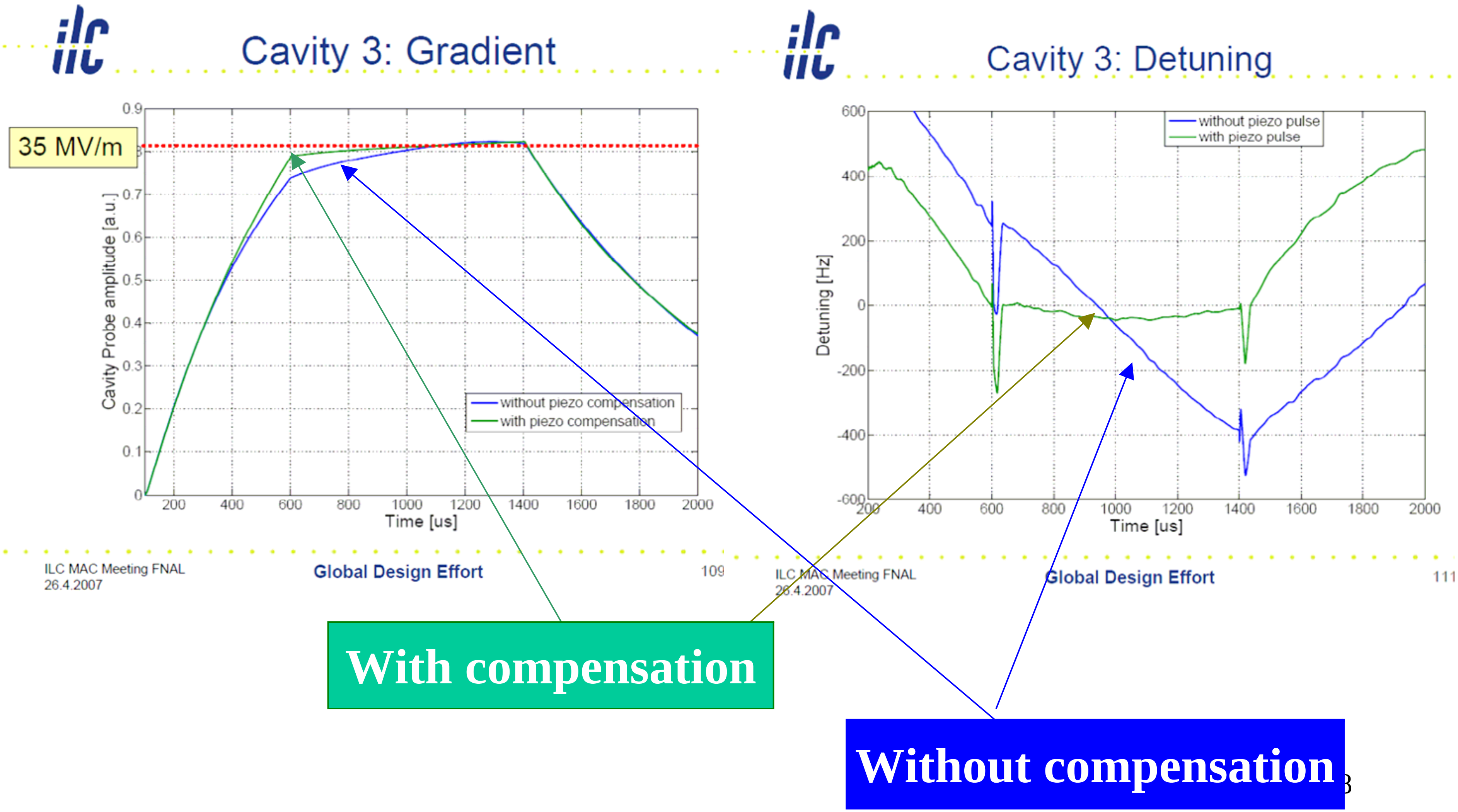
Eacc max scattering



	EP(20)	EP(20+3)	EP(80)	EP(80+3)	EP(20)+H_2O_2	EP(20)+D
Eacc ave	46.5±8.0	46.7 ±1.9	39.1±8.2	41.7±4.4	42.6±7.6	51.2±1.4
Scatter(%)	17	4	21	11	18	3
N	6	6	6	6	4	2

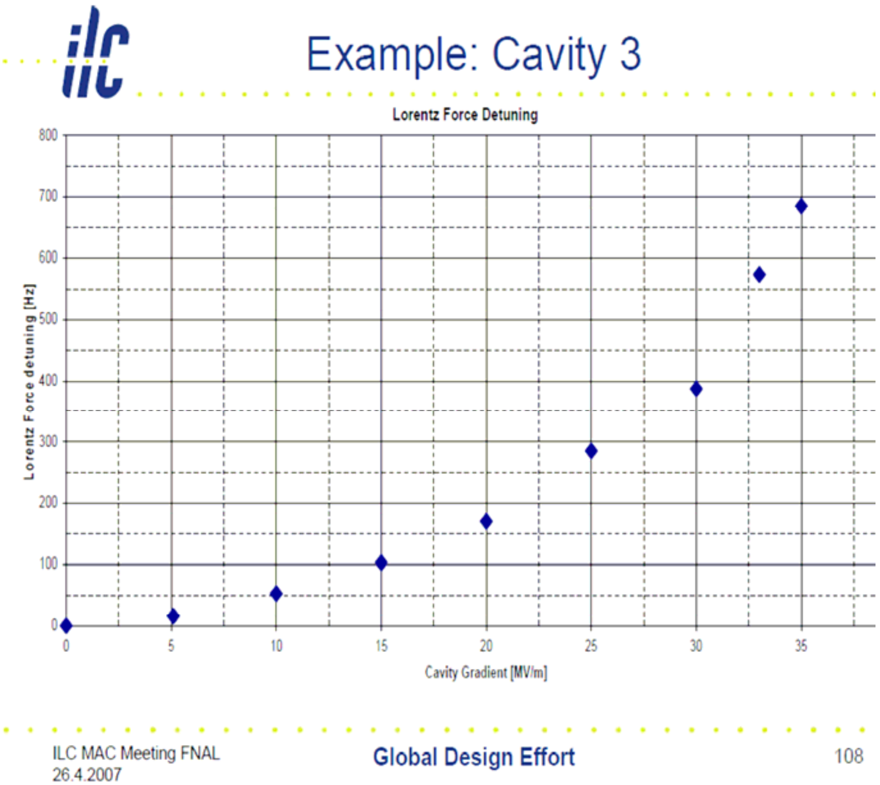
Lorentz Detuning Compensation by Piezo

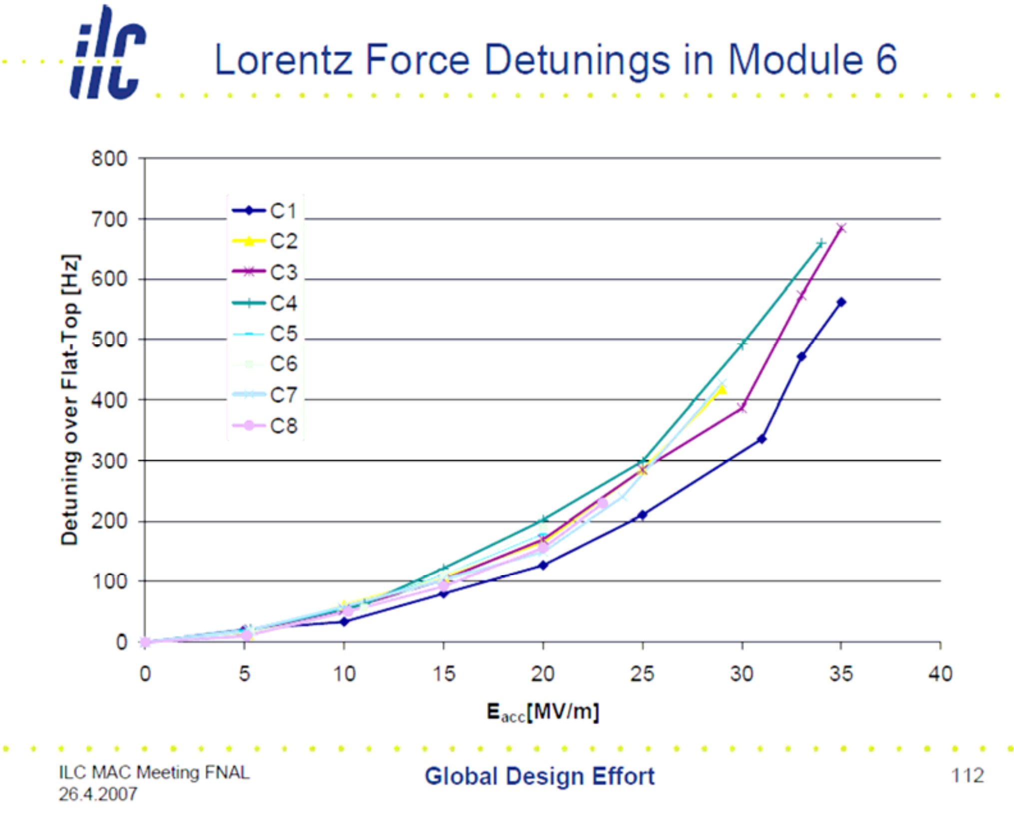
Demonstration of Lorentz detuning compensation @ 35MV/m operation



Lorentz Detuning @ 35MV/m (TESLA shape)

$$\Delta f = \kappa_L \cdot E_{acc}{}^2, \quad \kappa_L = 1Hz/(MV/m)^2$$





Cavity Fabrication Cost Reduction Issues

Large Grain/Single Crystal Niobium

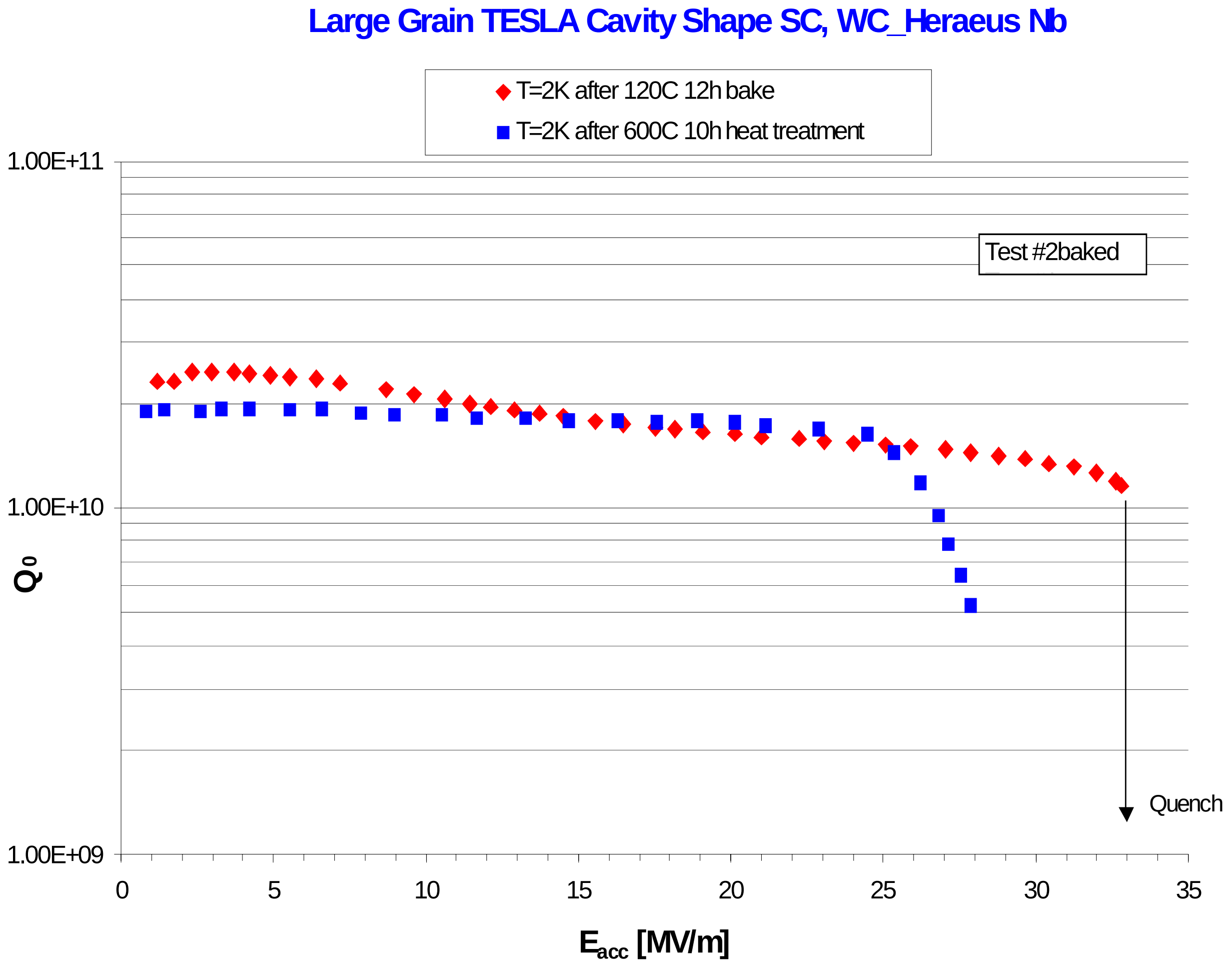
By P.Kneisel

Potential Advantages

- Reduced costs
- Comparable performance
- Very smooth surfaces with BCP, no EP necessary
- Possibly elimination of "in situ" baking because of "Q-drop" onset at higher gradients
- Possibly very low residual resistances (high Q's), favoring lower operation temperature (B. Petersen), less "cryo power" and therefore lower operating costs
- Higher thermal stability because of "phonon-peak" in thermal conductivity
- Good or better mechanical performance than fine grain material (e.g. predictable spring back..)
- Less material QA (eddy current/squid scanning)

Material R&D for ILC

Large grain niobium cavity R&D in Jlab



Large grain Nb sheet production can bring a cost down.
BCP could produce 35MV/m gradient and it brings further cost down.

Large Grain/Single Crystal Niobium at JLAB

By P.Kneisel and G.Rao

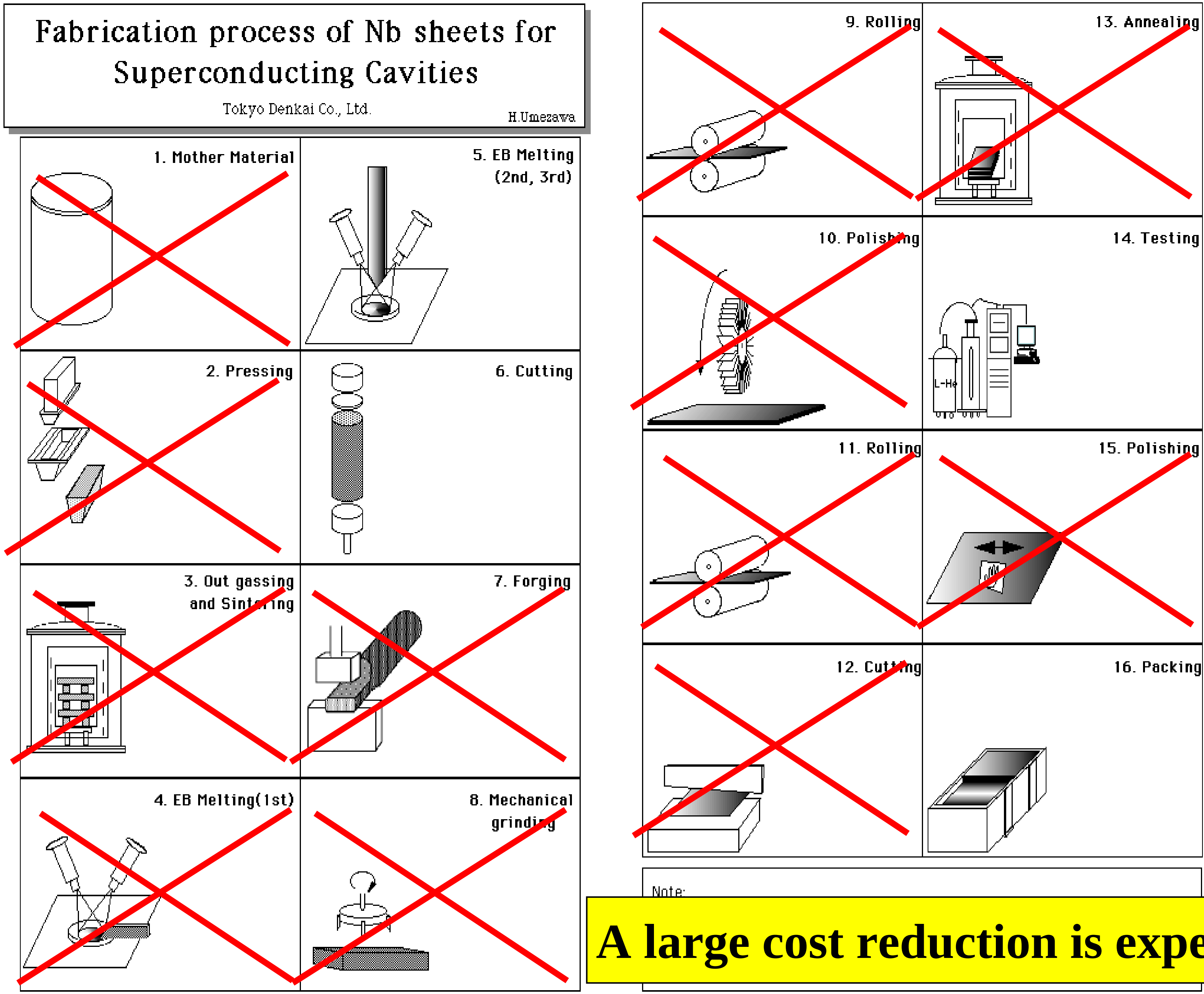
Discs from Ingot

Cavity

$E_{peak}/E_{acc} = 1.674$

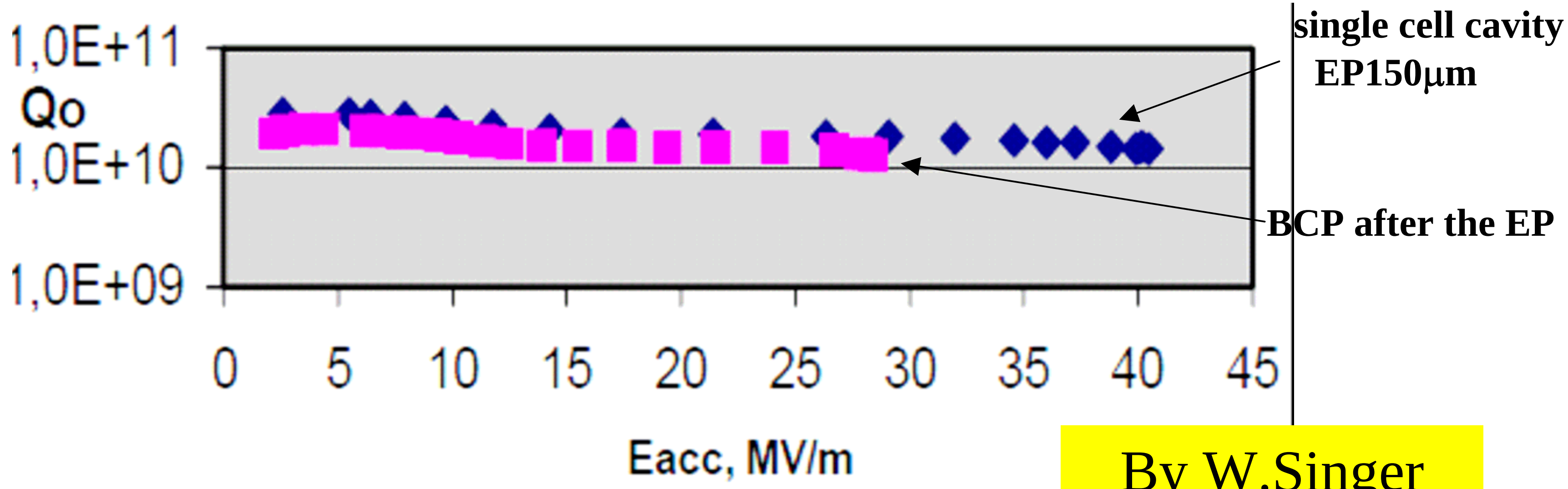
$H_{peak}/E_{acc} = 4.286$ mT/MV/m

Single Crystal / Large Grain Nb Production



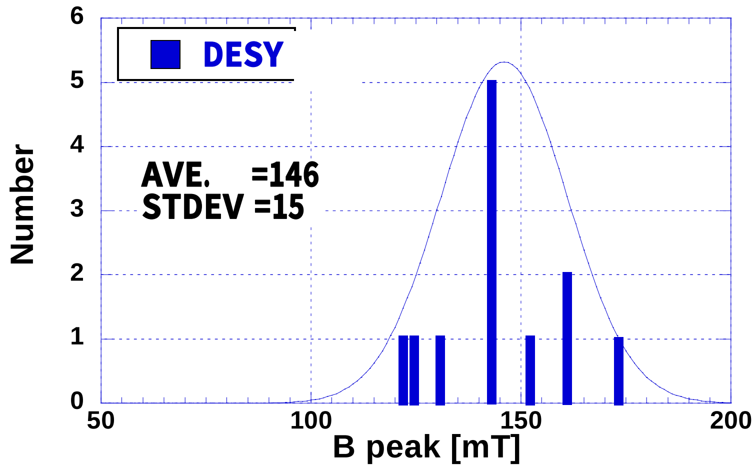
A large cost reduction is expected !

Large grain Nb cavity is close to the ILC BCD performance but The scatter still ~10%

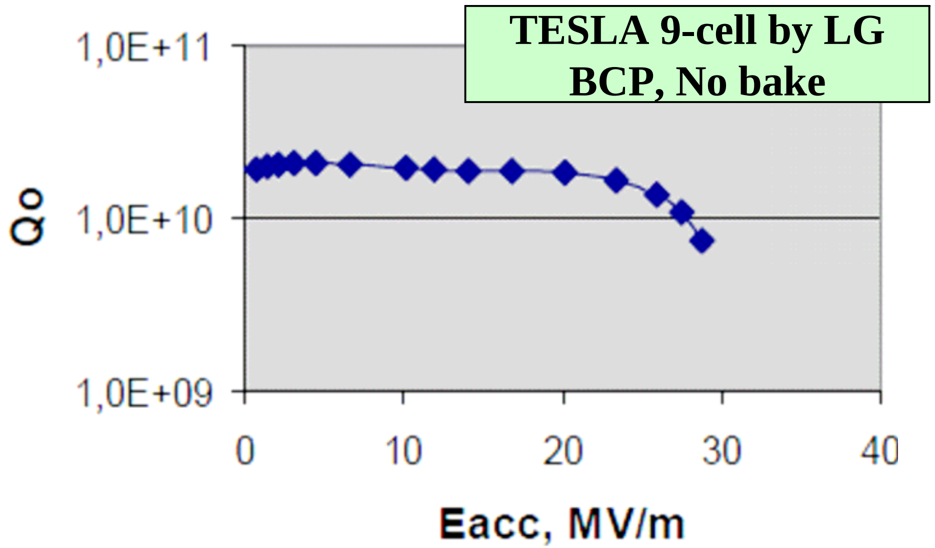


By W.Singer

Statistics of LG with single cell cavity @ DESY



Eacc ave=34.3±3.5MV/m(10.3%)



Single Crystal Cavity