Cavity Shape and Configuration

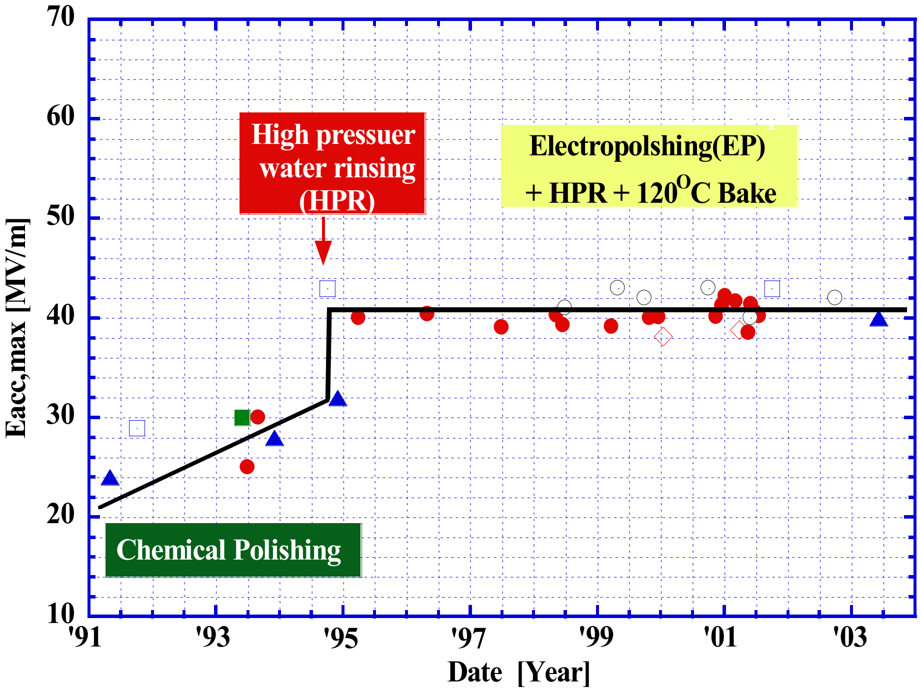
- SCRF Technology for The 1 TeV Upgrade -

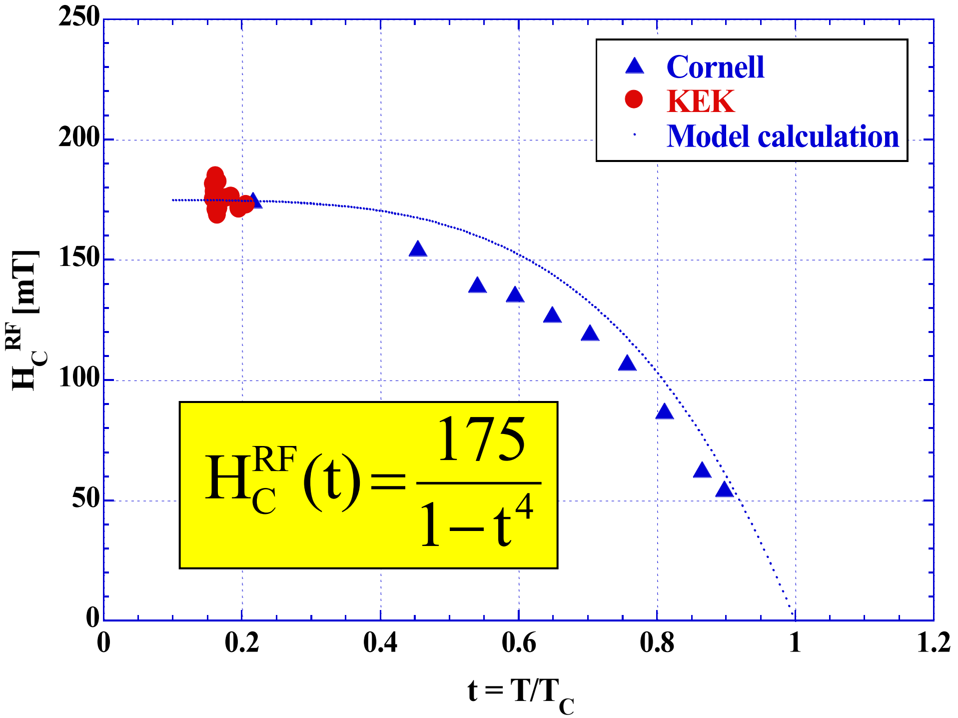
Kenji Saito, KEK

Statement:
Combine the LL high gradient cavity shape and the Superstructure,

then we could operate cavities at an effective gradient of 40-45MV/m .

RF Magnetic Critical Field





$$H_C^{RF}(t) = \frac{175}{1-t^4}$$

$$H_C^{RF}\,[\mathrm{mT}] = \left(\frac{H_P}{E_{acc}}\right) \times E_{acc,max}\,[\mathrm{MV/m}], \quad \frac{H_P}{E_{acc}} = 4.23\,[\mathrm{mT/(MV/m)}]\;@\;\mathrm{TESLA\,shape}$$

Current technology has reached the fundamental limit !

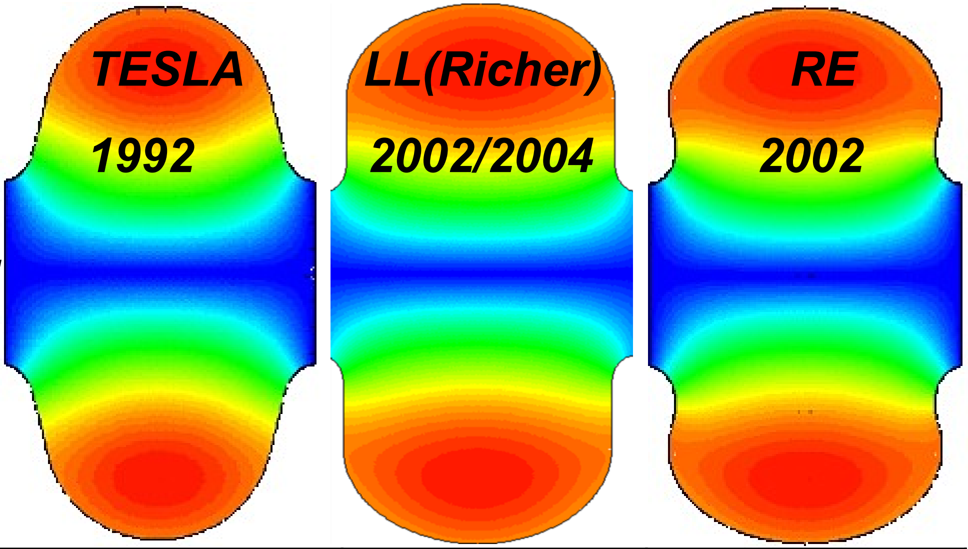
RF magnetic critical field is around 180mT.

New Cavity Shape optimized for Hp/Eacc

TESLA shape was well optimized on Ep/Eacc(~2.0) in 1990's against field emission.

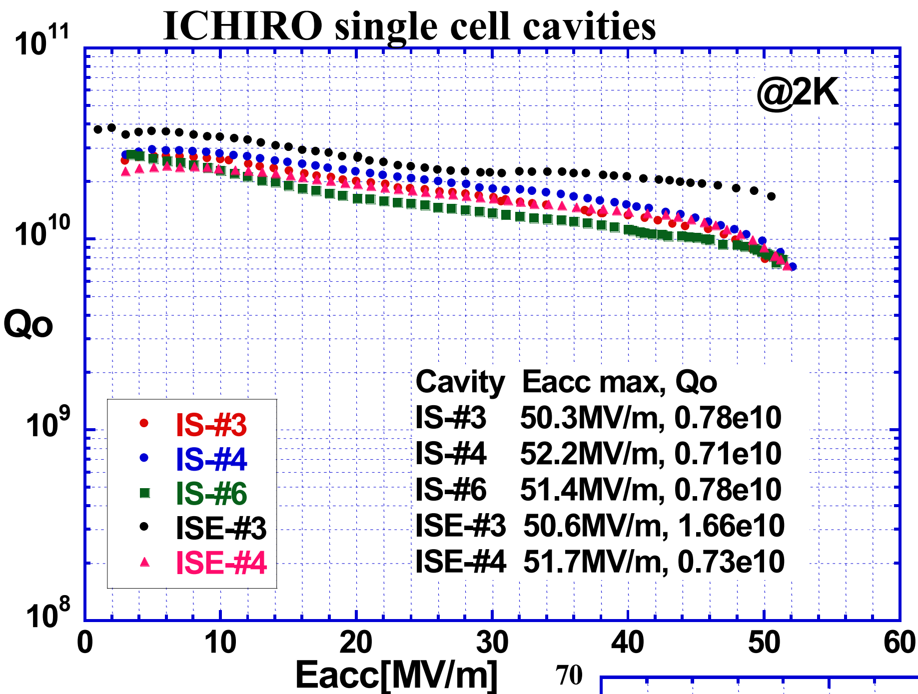
We know how to reduce H_P / Each :
more volume in equator region and smaller iris.

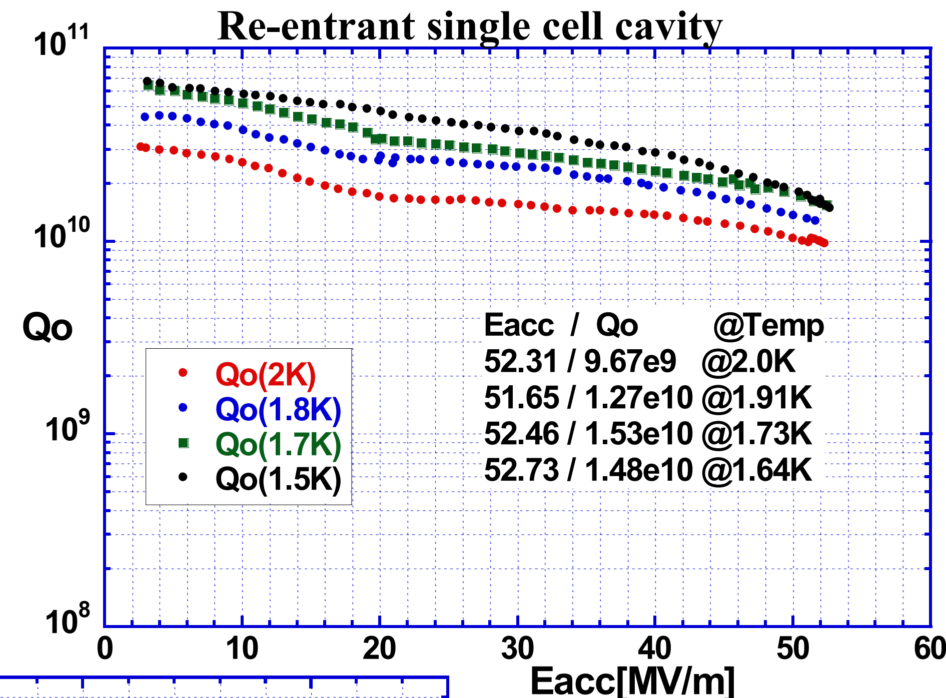
Courtesy Jack Sekutowicz, DESY

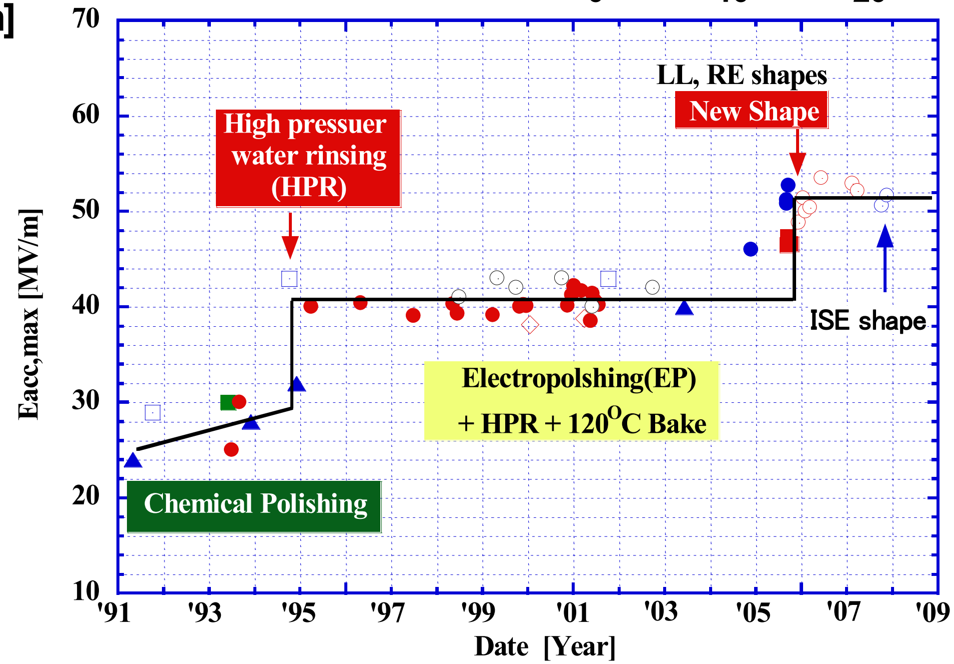


		TESLA	LL(Ichiro)	RE
R_{iris}	[mm]	35	30	33
κ_{CC}	[%]	1.9	1.52	1.8
E_P/E_{acc}	-	1.98	2.36	2.21
H_P/E_{acc}	[mT/(MV/m)]	4.25	3.61	3.76
R/Q	[Ω]	113.8	133.7	126.8
Γ	[Ω]	271	284	277
Expected $E_{acc,max}$ @ H_P=180mT	[MV/m]	42.4	49.9	47.9

Successful Principle-Proof of High Gradient Cavity Shapes at KEK







LL 9-Cell Cavity Design/ RF Parameters

LL 9-cell cavity: FM parameters

Courtesy Jacek Sekutowicz, DESY

Parameters	*Unit*	*TESLA - Shape*	*LL-Shape*
Øiris	*[mm]*	*70*	*60*
κ_{cc}	*[%]*	*1.9*	*1.52*
E_p/E_{acc}	*-*	*1.98*	*2.36*
H_p/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.*

	H-Gradient	**RF Efficiency**	**Field emission**	**Cell to Cell coupling**	**Lorentz factor**	**HOM issue**
Pros	20% high	20% high		no excites other passband		
Cons			20% high	20% small	10% week	65% increase

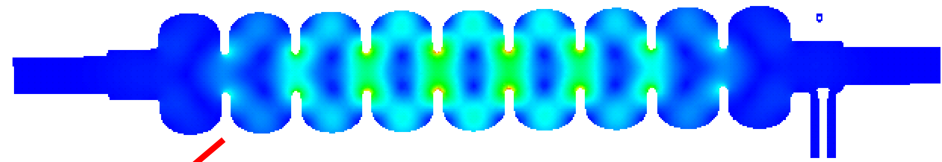
HOM Issues in LL 9-Cell Cavity

Courtesy Jacek Sekutowicz, DESY

3rd passband makes always some problems.

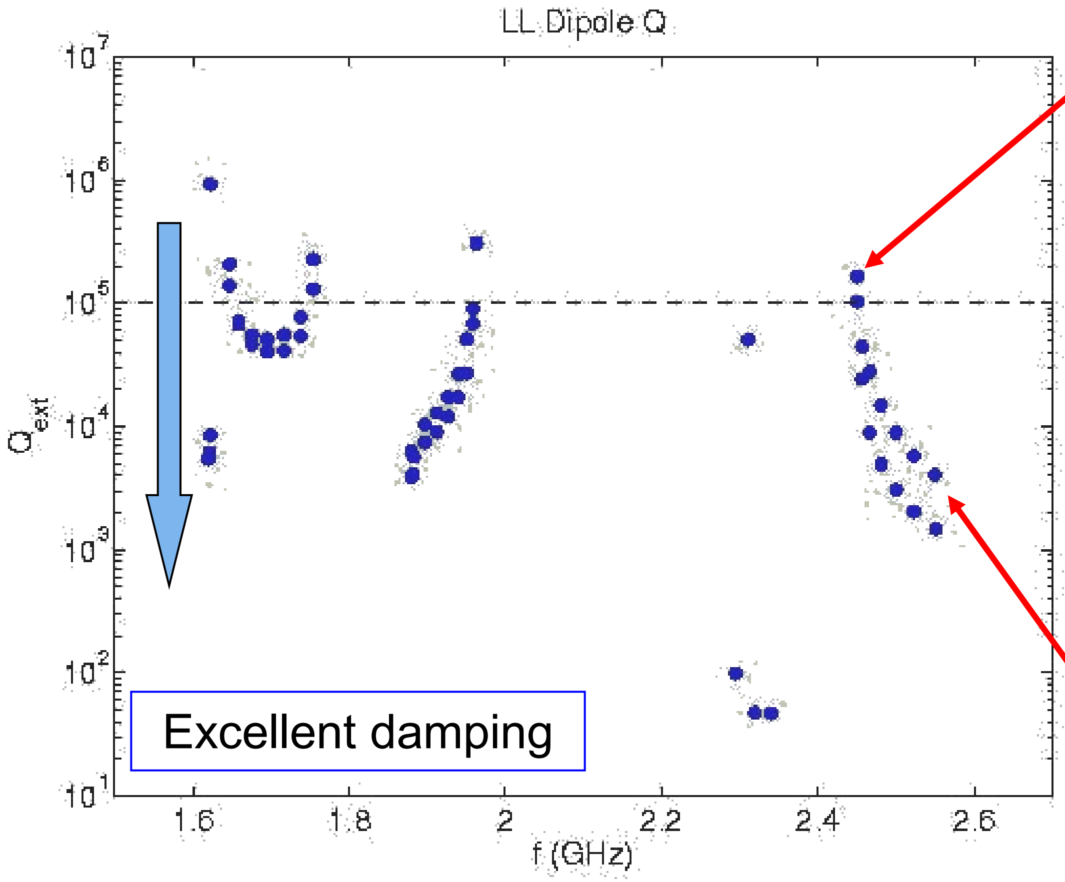
Needs to optimize the End-cell !

F=2.451071E+09



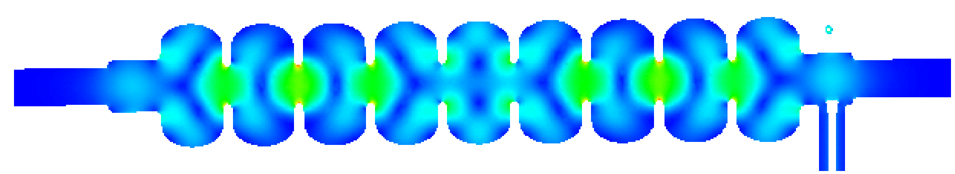
$(R/Q)\cdot Q_{ext}$ = 3.5 MΩ/cm²

Insufficient damping



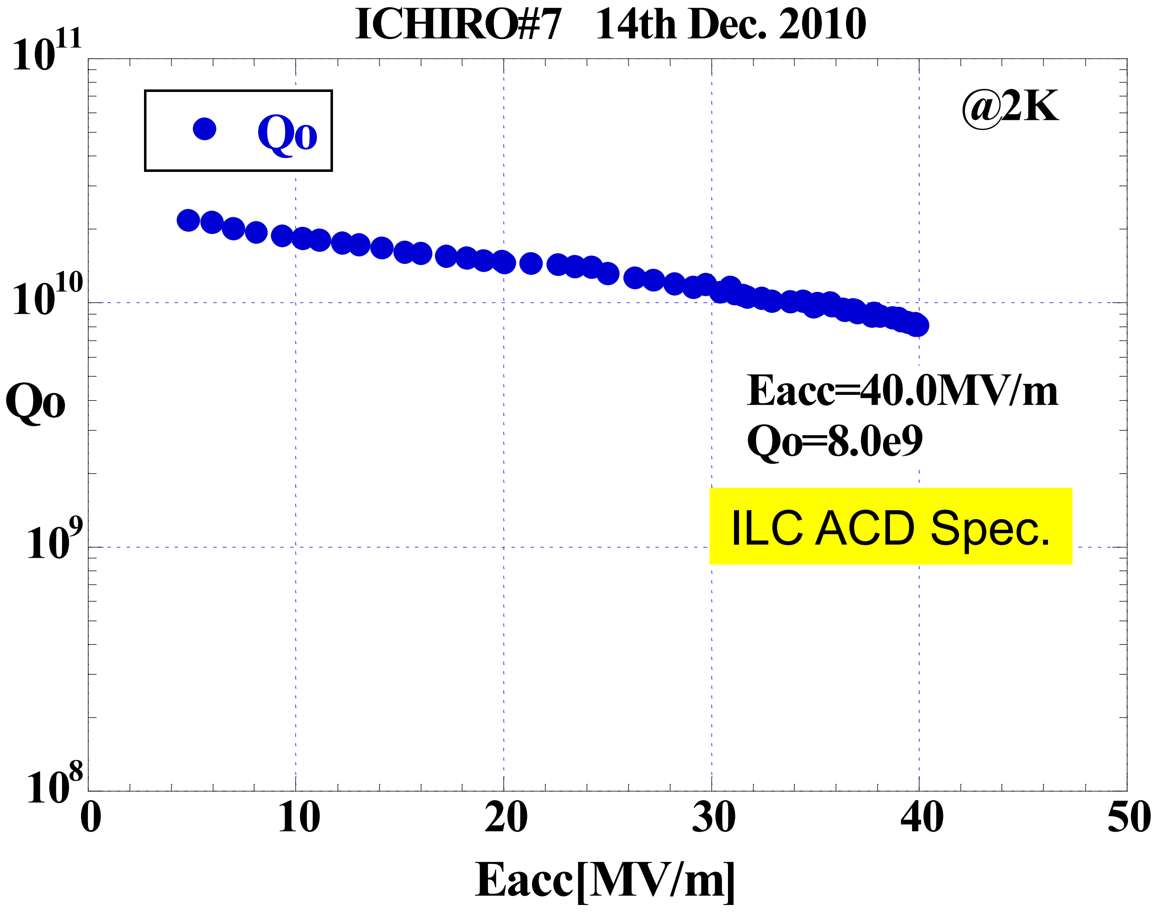
Excellent damping

F=2.551659E+09

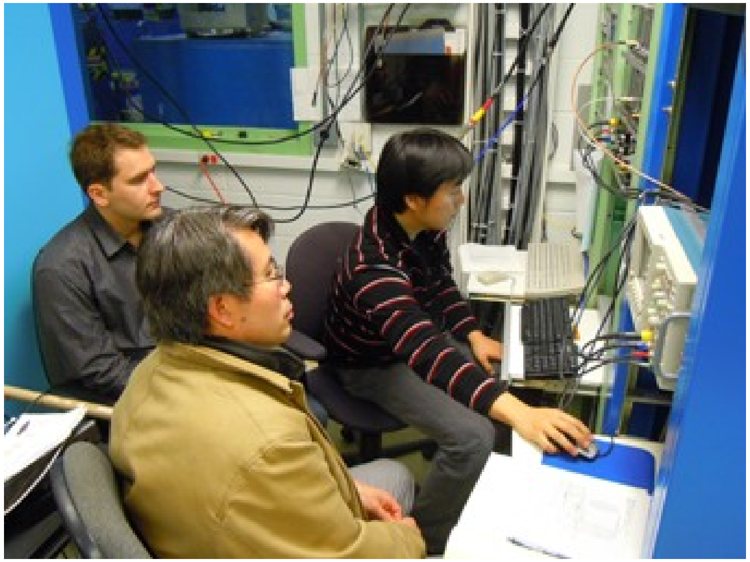


Successful Demonstration of ILC ACD Spec. by Ichiro Full 9-cell Cavity

CBP(80μm)+ CP(10μm)+AN(750^{O}C, 3hr)+EP(80μm)+HPR Bake+VT @ KEK, then sent Jlab.

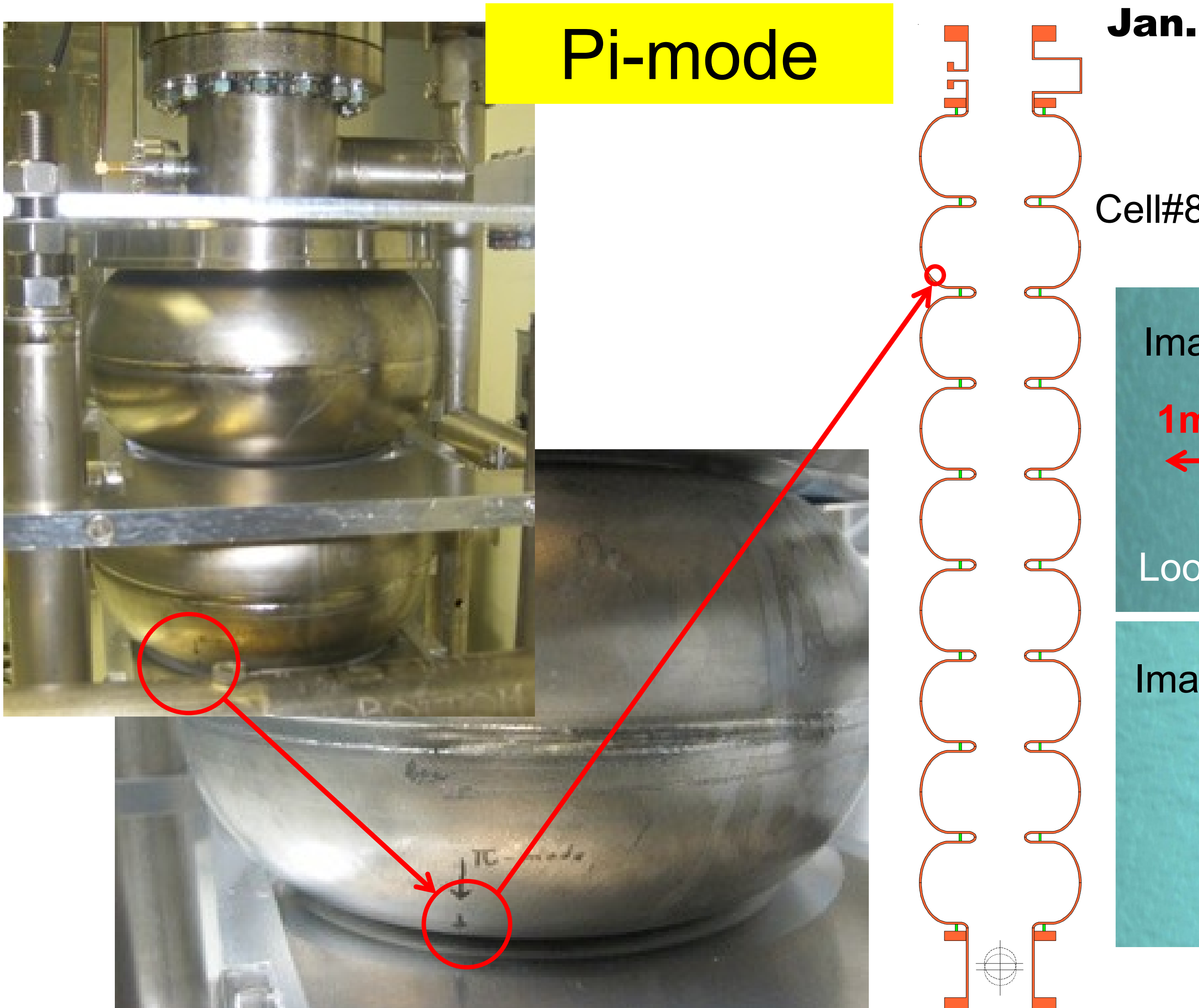


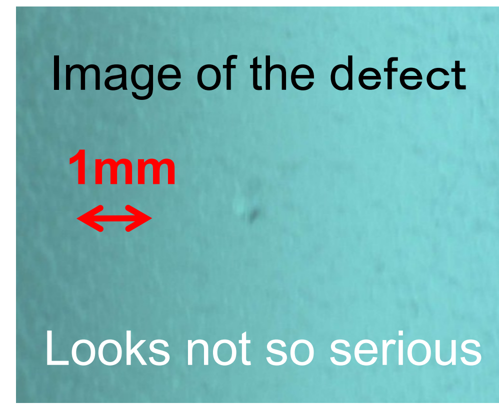
KEK/JLAB collaboration

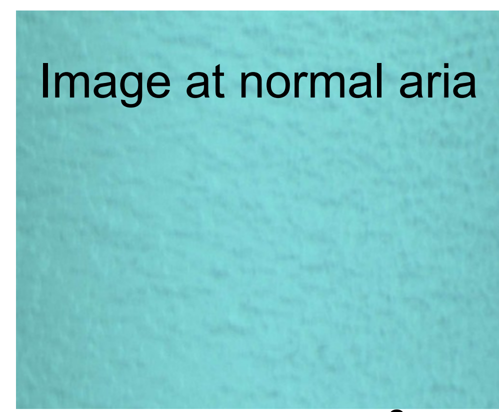


Optical Inspection of the Quench Location from 2nd Sound Signals

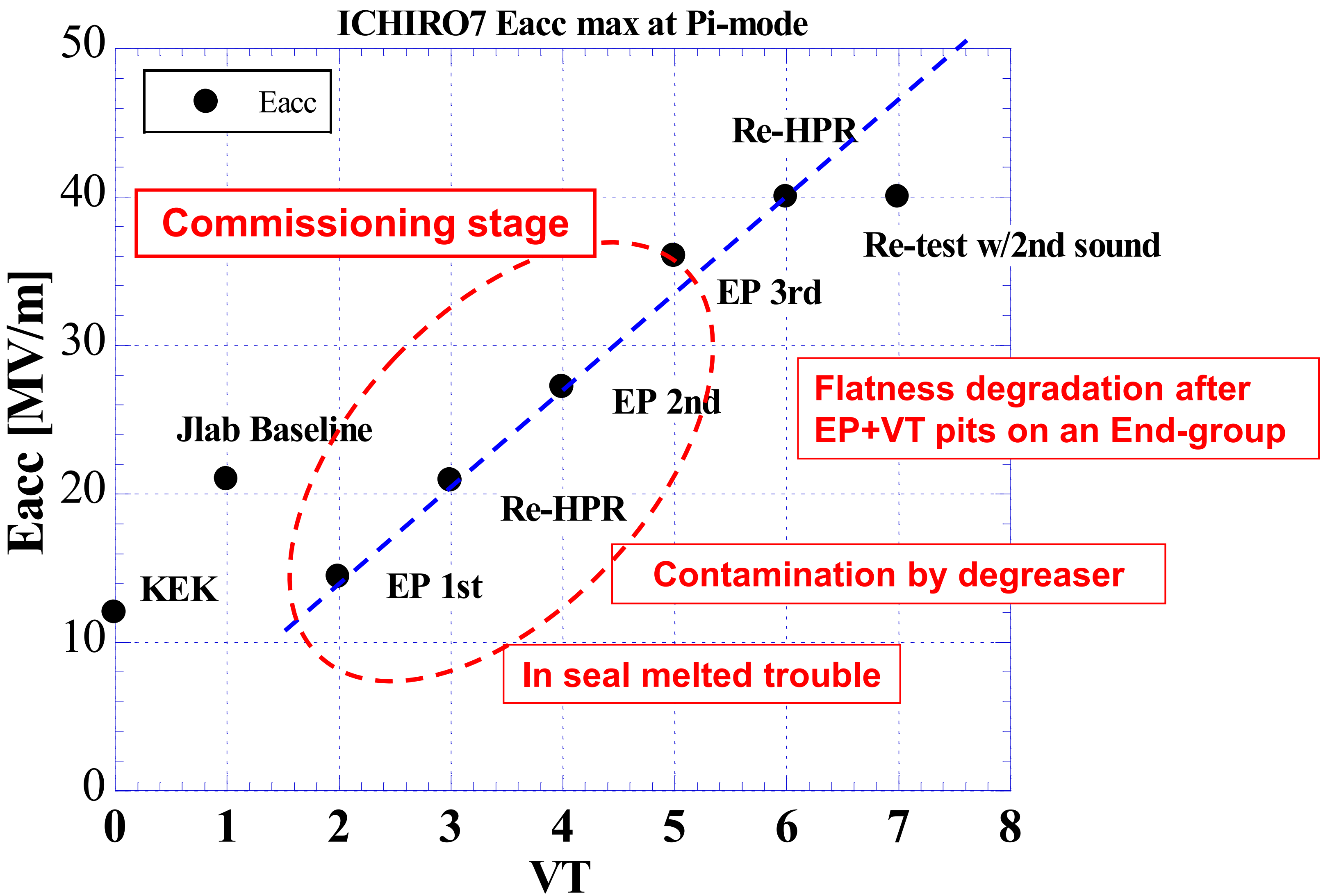
Jan. 19th 2010





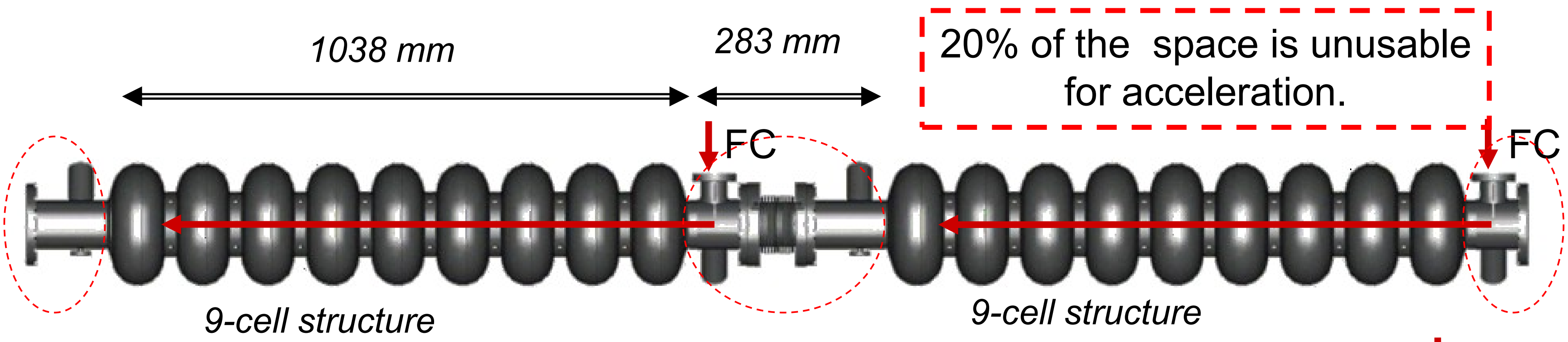


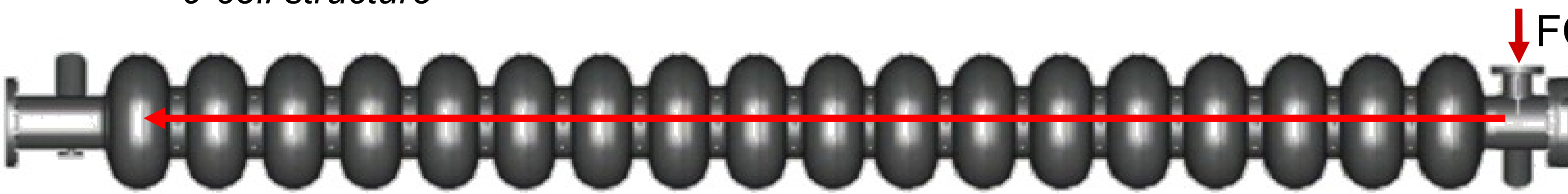
ICHIRO#7 S0-Study @ JLAB Current Summary

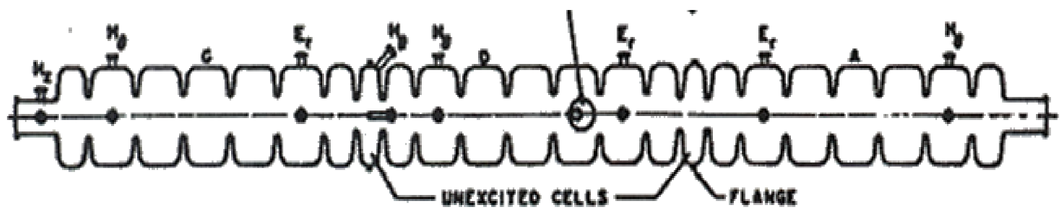


45MV/m is hoped by the next EP, further study will be done very soon.

Configuration : Superstructure







Darmstadt 20-cell *3GHz structures*

SCA at HEPL

There are 2 limitations in number of cells per structure:

1. ***Field unflatness (~ N^2/k_{cc})***
2. ***HOM trapping***

The beam currents of this structure does not exceed 500 µA and are well below ILC current of 9.5 mA.

Conclusion: we could not go this way for ILC (TESLA 1999).

Idea of the Superstructure (SST)

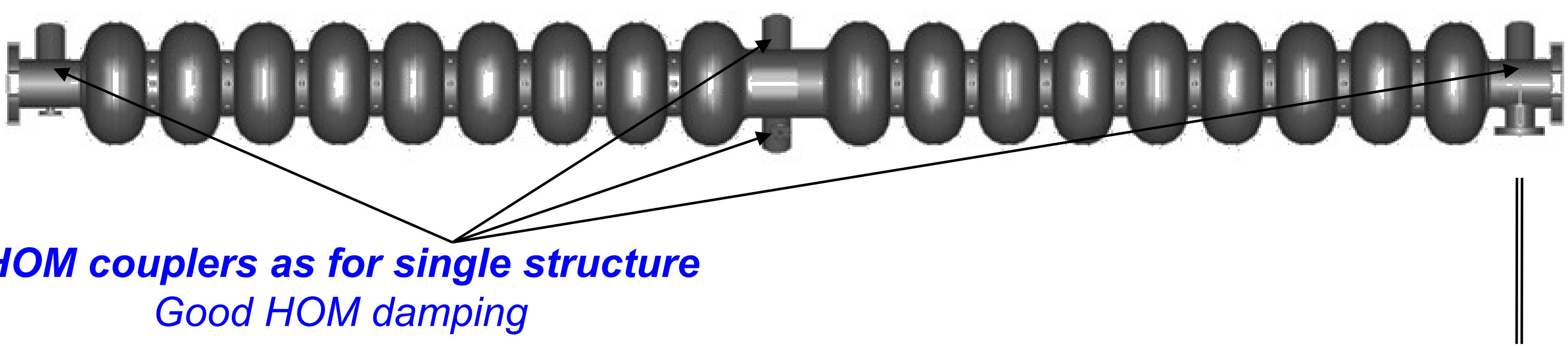
*These **limitations** could be relaxed **by <u>weakly coupled structures</u> (superstructures),** (JS, M. Ferrario, Ch. Tang, PRST-AB, 1999).*

SST layout: *Two (or more) N-cell structures are coupled by λ/2 long tube (synchronization). Each structure has its own cold tuner and HOM couplers.*

λ/2 interconnection
Gain in real estate gradient

Tuner
Partial control of FF

Tuner
Partial control of FF



HOM couplers as for single structure
Good HOM damping

One FPC/(2N) cells
Cost savings

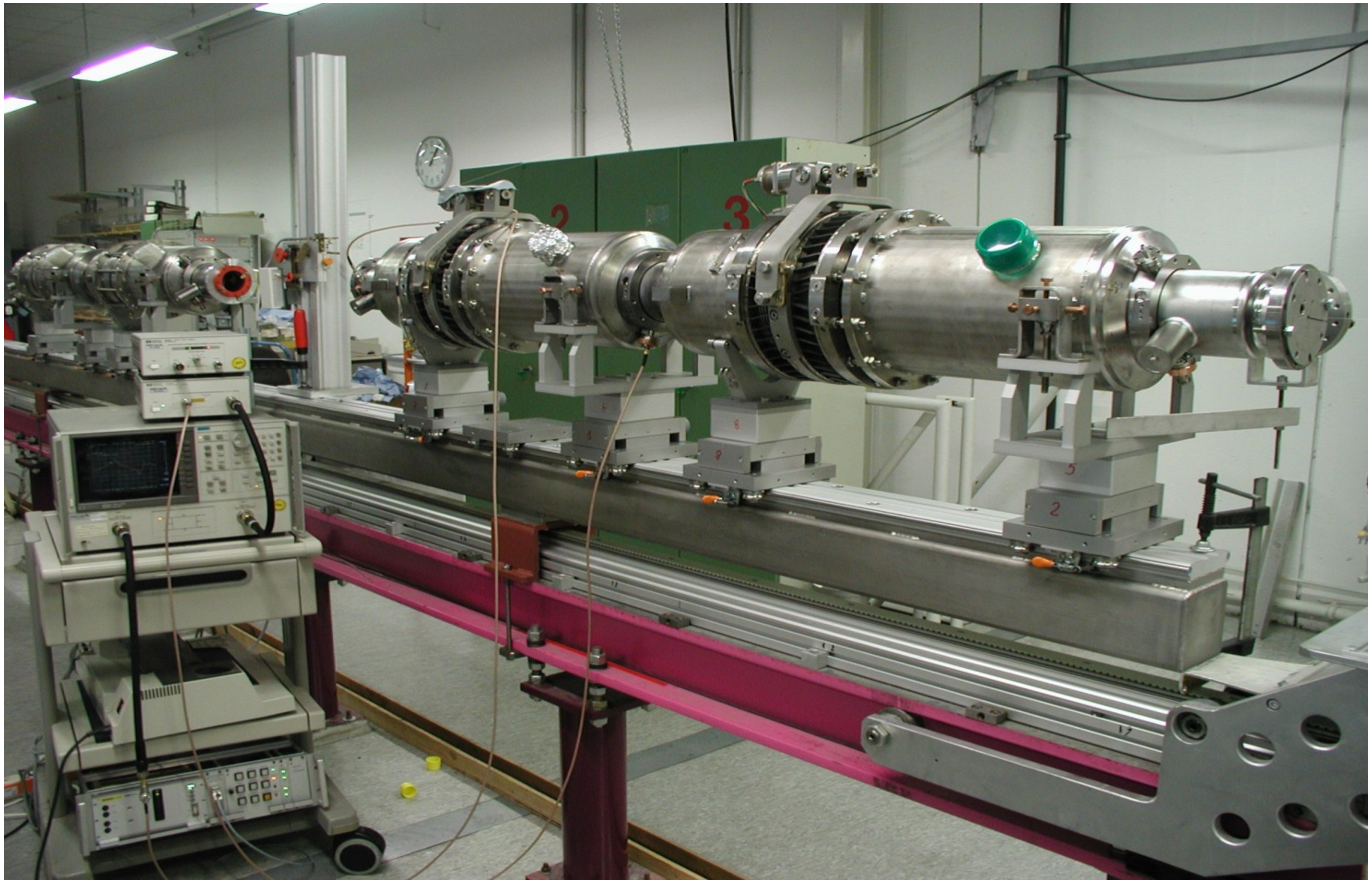
Will the RF power flow via extremely weak coupling to keep energy constant over a train of bunches ???

Pioneer Study of the SST (2x7cell) in TESLA R&D at DESY

Courtesy Jacek Sekutowicz, DESY

The preparation of the experiment begun in 1999.

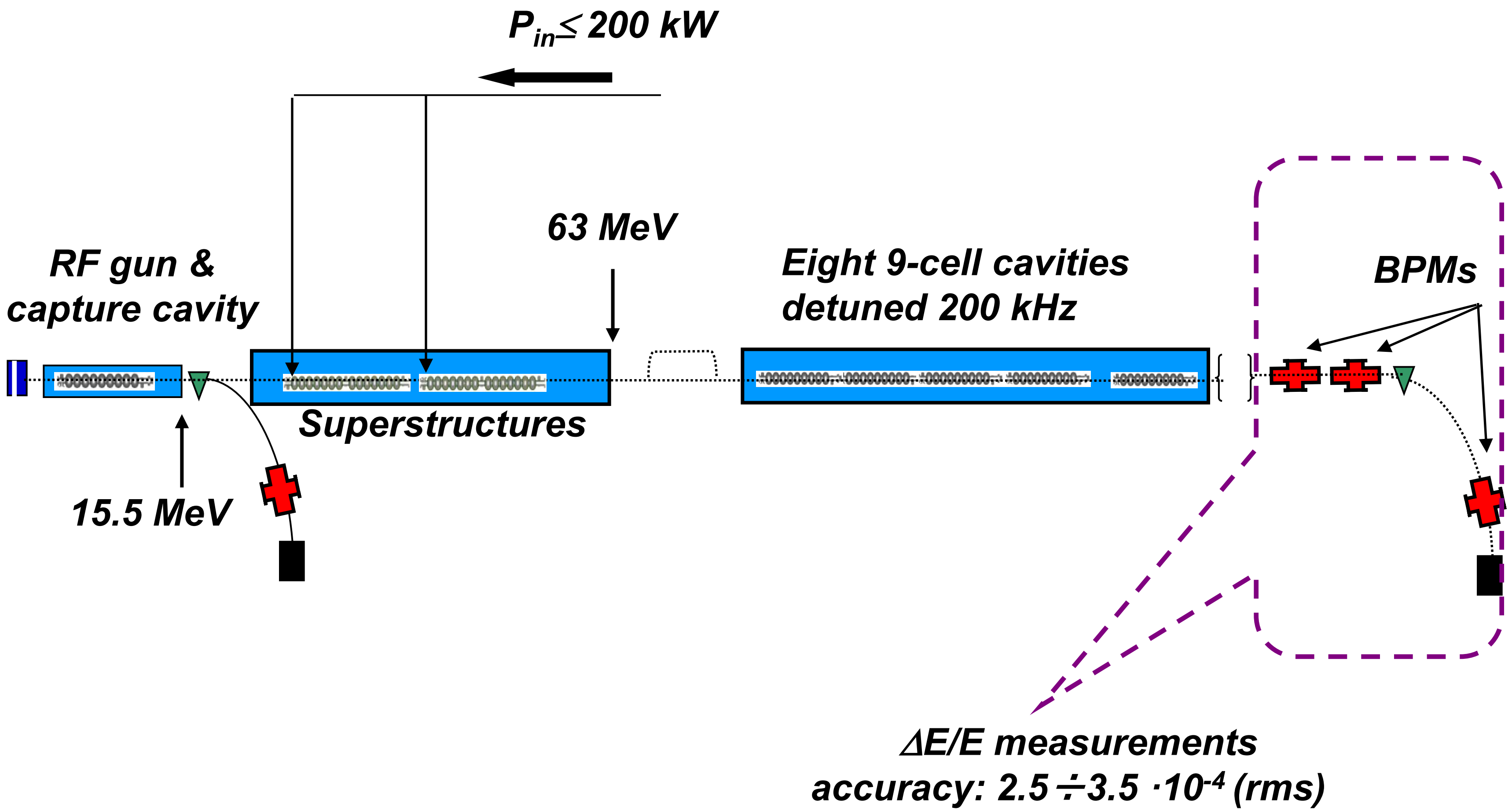
*In 2002, two **2x7-cells SSTs** were assembled in the cryomodule and installed next to the injector in the TTF linac for the test.*



Two 2x7-cell pairs for field profile adjustment and HOM measurements

Beam TEST of the STT(2x7Cell) at DESY

Direct measurements of the energy gain for the whole train

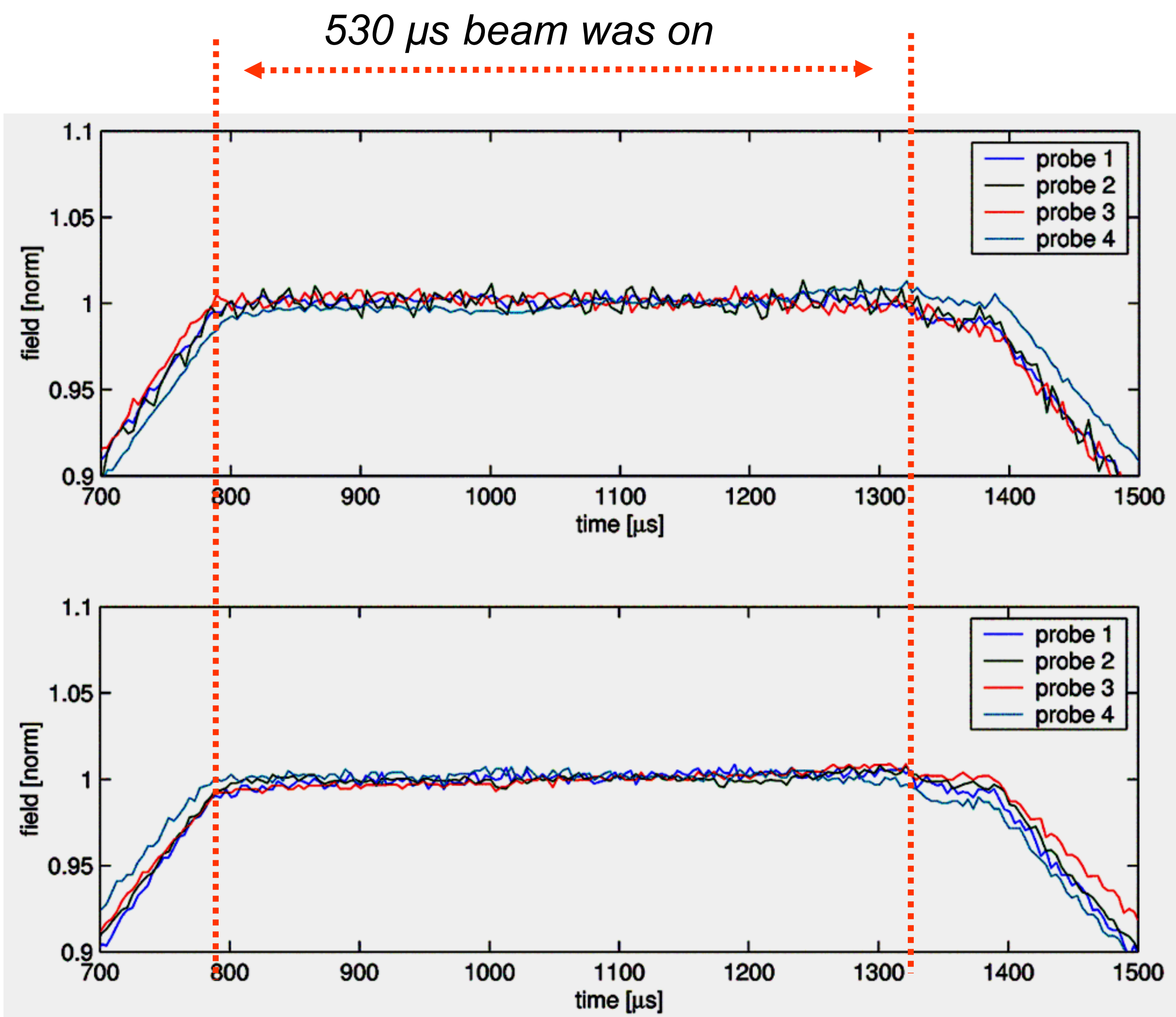


Beam acceleration test was successfully performed at Eacc =14.7MV/m !

Successful Beam acceleration by the SST (2x7cell) at DESY

SST_1

SST_2



No voltage drop was observed.

This was the first hint that SSTs works!!

DESY's Conclusion on the STT

DESY's Conclusions from the experiment

- *The experiment showed that SST concept for acceleration works.*
- *The energy modulation $\Delta E/E$ =3.5 E-4 < the collider spec. $\Delta E/E$ =5 E-4, TESLA*
- *HOM damping is very good (at least for 7-cell units)*

But

- *Handling and preparation are more difficult.* → Demountable structure
- *Subunits should be produced with tighter tolerances.*

Combined Scheme for the ILC 1TeV Upgrade

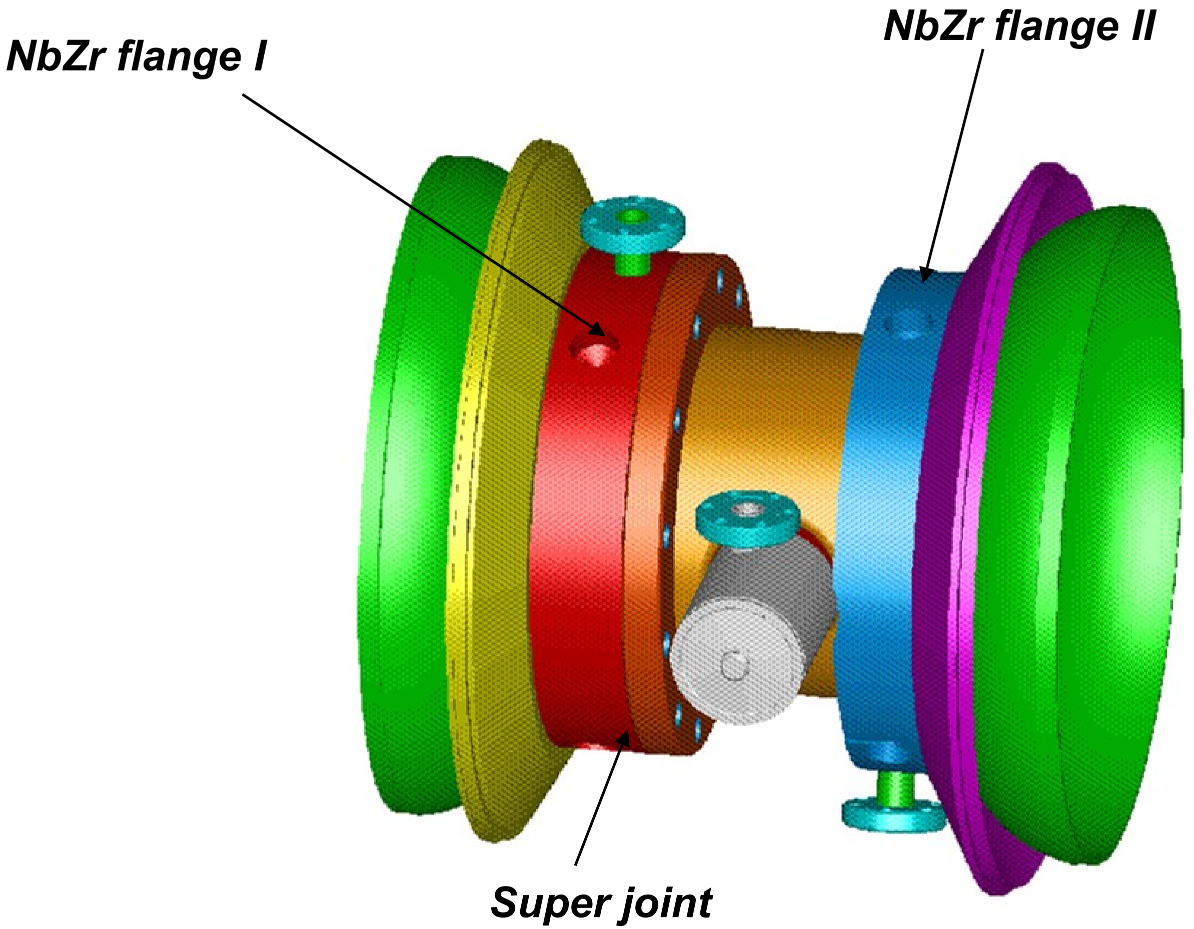
Cavity Operation Gradient	Real Gradient [MV/m] [V/(Structure length+interconnection/2)] 1x9cell	Real Gradient [MV/m] [V/(Structure length+interconnection/2)] 2x9cell SST	Real Gradient [MV/m] [V/(Structure length+interconnection/2)] 4x9cell SST
Eacc=31.5MV/m ILC Baseline	24.7	26.4 (Eacc, eff=33.7)	28.2(Eacc,eff=35.9)
Eacc=36MV/m ILC ACD	28.2	30.2 (Eacc,eff=38.5)	32.1(Eacc,eff=41.0)
Eacc=40MV/m ILC Upgrade	31.4	33.6 (Eacc,eff=42.8)	35.8 (Eacc,eff=45.6)

	Tunnel Length	Input Coupler	RF Distribution	LL Control	Cryogenic load	Gradient Performance	Cavity Fabrication Tolerance
Pros	7-14% shorter	Number reduces to 1/4 max.	Number of parts reduce to 1/4 max.	Station reduces to 1/4 max.	Reduces ~6kW max.@2K		
Cons		Power increases to 4 times max.				SST gradient is limited by the lowest gradient cavity	Becomes tighter

Key Technologies for Superstructure & Ongoing R&D

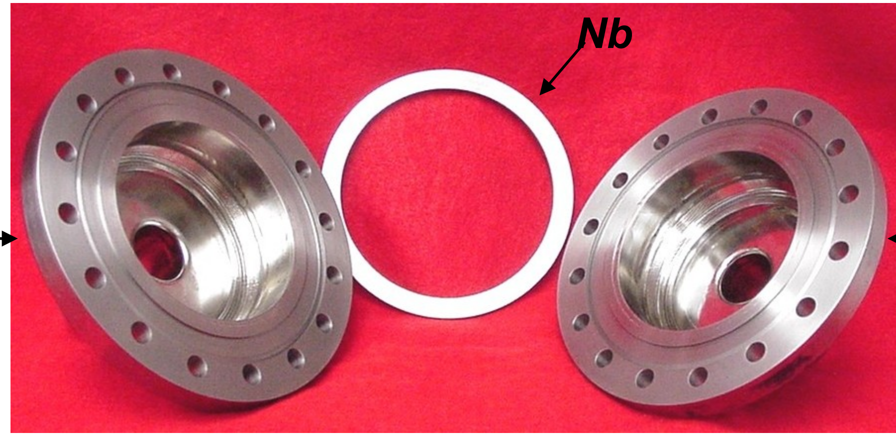
R&D 1 : Super joint

To make SST handling easy, demountable structure is desirable. Super joint is needed for it.



Ongoing R&D on Super-Joint by P. Kneisel at JLab

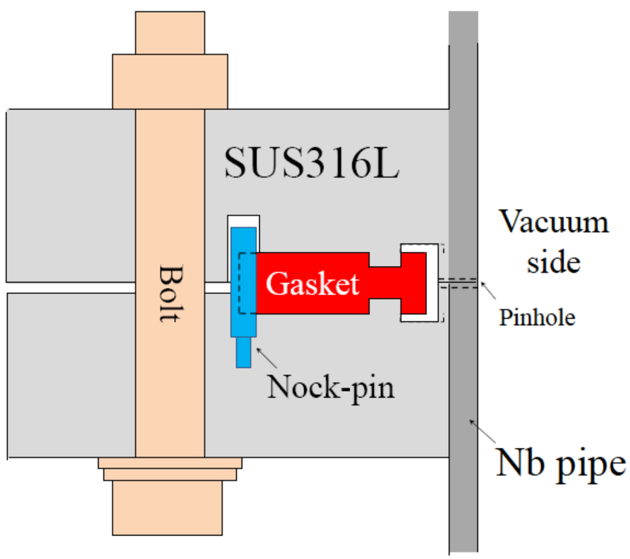
Nb
Reactor grade

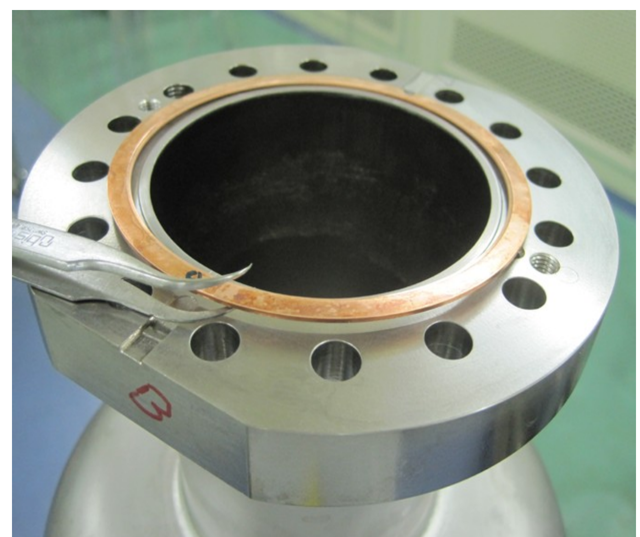


Nb
Reactor grade

2.7 GHz cavity for testing of sc gaskets

Application of MO seal for Super-Joint, to be started soon at KEK



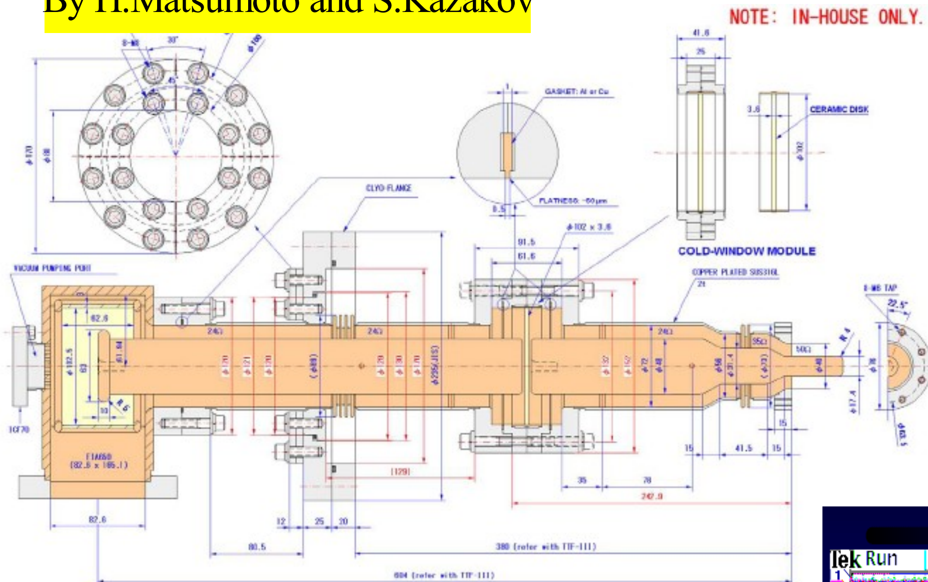


R&D 2 : High Power Coupler

For 4x9cell SST, 2MW coupler is needed but it almost exists.

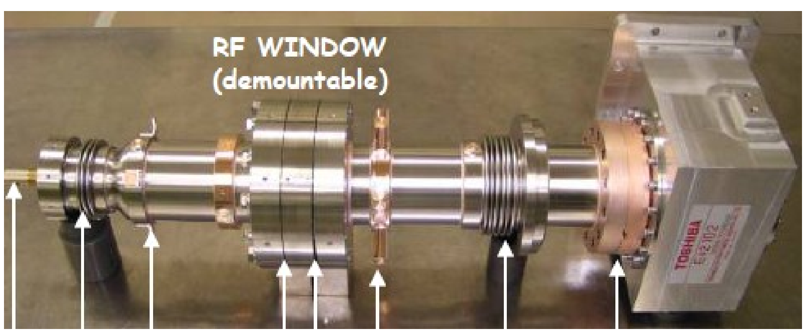
KEK STF 0.5 activity

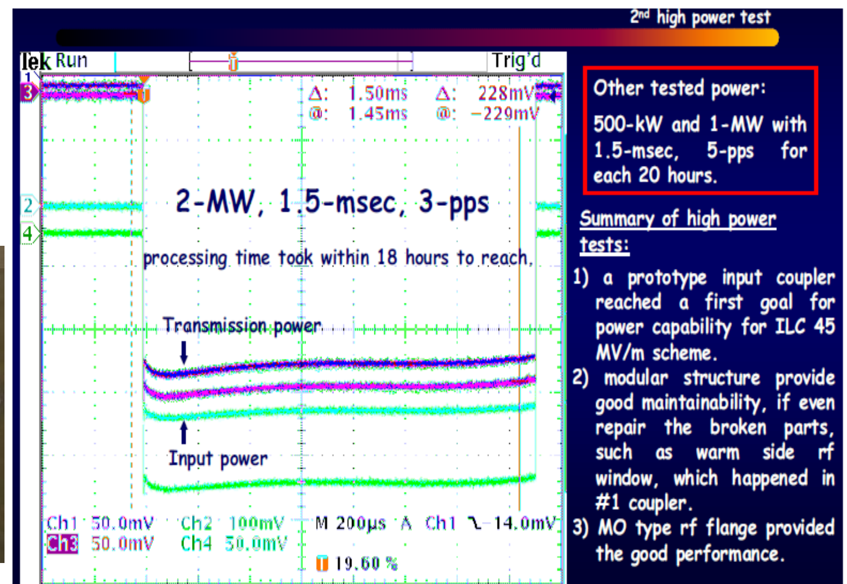
By H.Matsumoto and S.Kazakov



Successfully demonstrated the high power performance up to 2MW!

The specification: 500kW, 1.5msec, 5Hz @ 45MV/m operation





Successfully power loaded at 2MW, 1.5ms, 3pps.

Summary

- LL full 9-cell cavity has reached the ILC alternative specification: Eacc=40MV/m @ Qo=0.8E+10.
- Combined scheme of LL shape and Superstructure will bring big benefit not only on the gradient performance but also on the cost reduction.
- Key R&D issues for this scheme will be the super joint and high power coupler.
- Of course the beam test is essential but it will be done rather easily using the existing SRF module test facility.
- So far the resource is limited very much for the ILC alternative R&D. If GDE takes more concern to this, the realization might be done in the 500GeV phase.

HOM Issues in LL 9-Cell Cavity

Courtesy Jacek Sekutowicz, DESY

LL 9-cell cavity: HOMs

Damping modeling for end-cells I.

End-cell optimization not yet finished !

Mode	f [MHz]	(R/Q)* [Ω/cm^n]	Q_{ext}
M: TM010-9	1300.00	1161	$8 \cdot 10^5$
D: TE111-7a	1717.15	5.0	$4 \cdot 10^4$
D: TE111-7b	1717.21	5.0	$5 \cdot 10^4$
D: TE111-8a	1738.12	3.0	$6 \cdot 10^4$
D: TE111-8b	1738.15	3.0	$8 \cdot 10^4$
D: TM110-2a	1882.15	3.4	$6 \cdot 10^3$
D: TM110-2b	1882.47	3.4	$6 \cdot 10^3$
D: TM110-4a	1912.04	4.6	$9 \cdot 10^3$
D: TM110-4b	1912.21	4.6	$1 \cdot 10^4$
D: TM110-5a	1927.10	15.6	$1.5 \cdot 10^4$
D: TM110-5b	1927.16	15.6	$1.5 \cdot 10^4$
D: TM110-6a	1940.25	12.1	$2 \cdot 10^4$
D: TM110-6b	1940.27	12.1	$2 \cdot 10^4$
M: TM011-6	2177.48	192	10^4
M: TM011-7	2182.81	199	10^4
D: 3-rd-1a	2451.07	31.6	$1 \cdot 10^5$
D: 3-rd -1b	2451.15	31.6	$2 \cdot 10^5$
D: 3-rd 1-2a	2457.04	22.2	$5 \cdot 10^4$
D: 3-rd 1-2b	2457.09	22.2	$5 \cdot 10^4$
D: 5-th – 7a	3057.43	0.5	$3 \cdot 10^5$
D: 5-th – 7b	3057.45	0.5	$3 \cdot 10^5$
D: 5-th – 8a	3060.83	0.4	$8 \cdot 10^5$
D: 5-th – 8b	3060.88	0.4	$9 \cdot 10^5$