Superconducting RF Activities in IHEP

Jiyuan Zhai

IHEP, China

ERL2011, KEK, Oct. 17, 2011

Outline

- BEPCII 500 MHz SCRF Progress
- ILC 1.3 GHz SCRF Progress
- SCRF Infrastructures
- ADS and ERL SCRF Design Study

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- ILC/XFEL 1.3 GHz SCRF Progress
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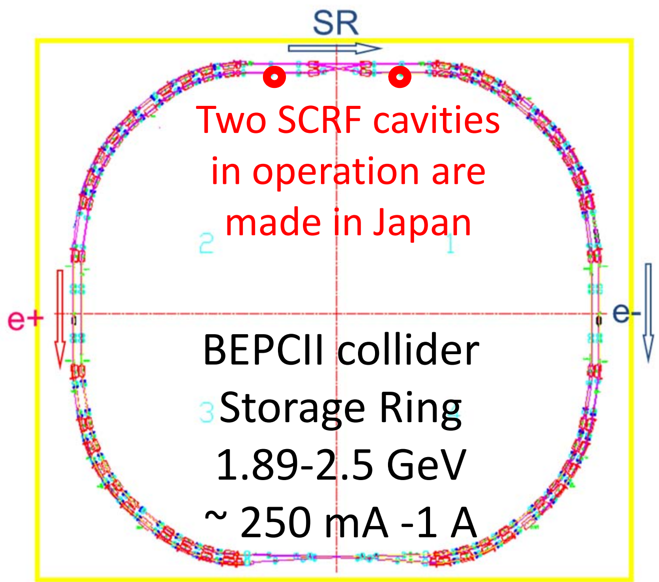
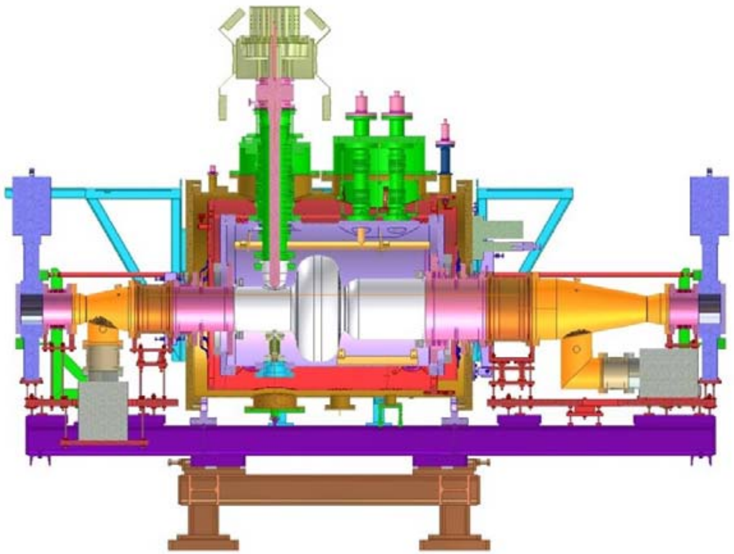
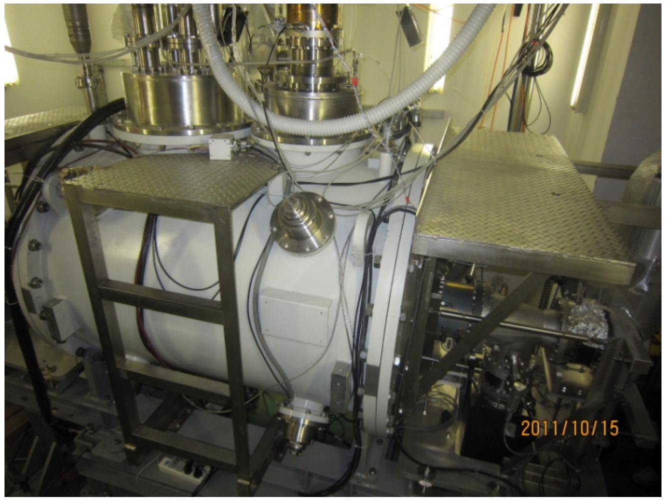


help from T. Furuya etc. of KEK

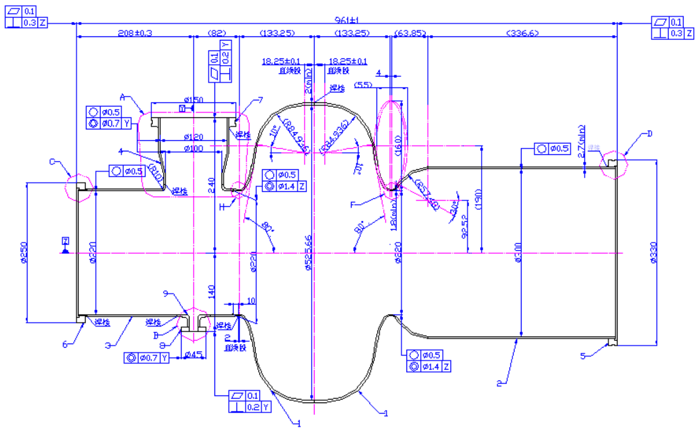


IHEP BEPCII 500 MHz SCRF

- Spare module for BPECII (2008-2011)
- R&D for future SR light source
- Cavity vertical test: Jan.-Jul., 2011
- **Horizontal test: Oct. 13-15, 2011**
  - **V_c = 2.05 MV, Q_0 = 7.7 x 10^8**
  - **V_c = 2.16 MV, Q_0 = 4.1 x 10^8**

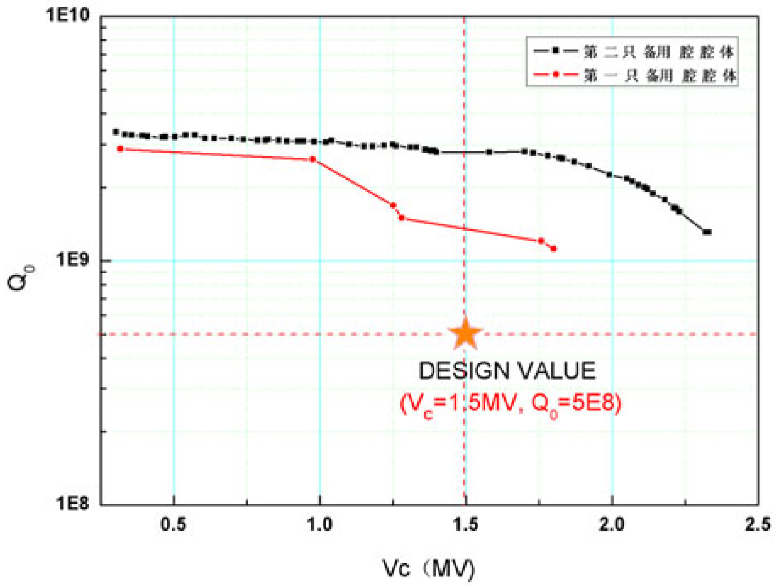


500 MHz Cavity

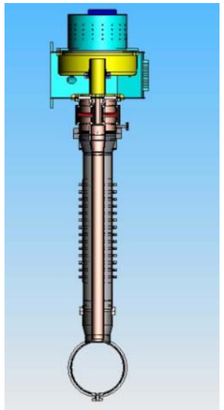


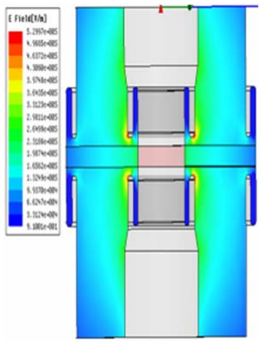
Spinning

BCP & HPR



500 MHz Input Coupler

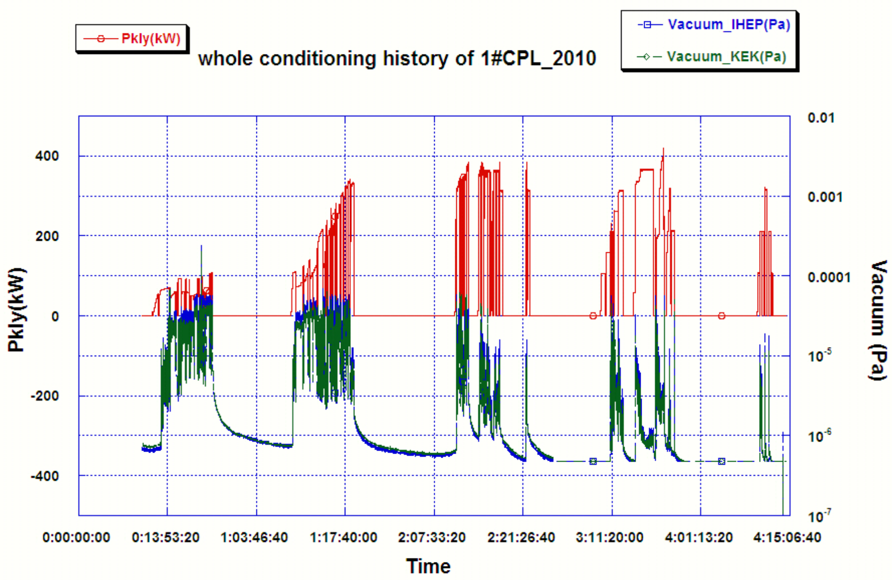




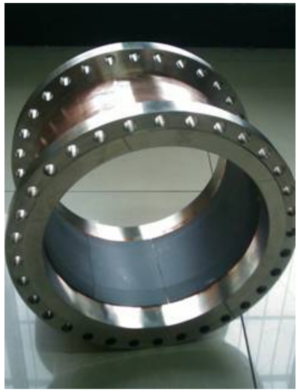
High Power Conditioning:

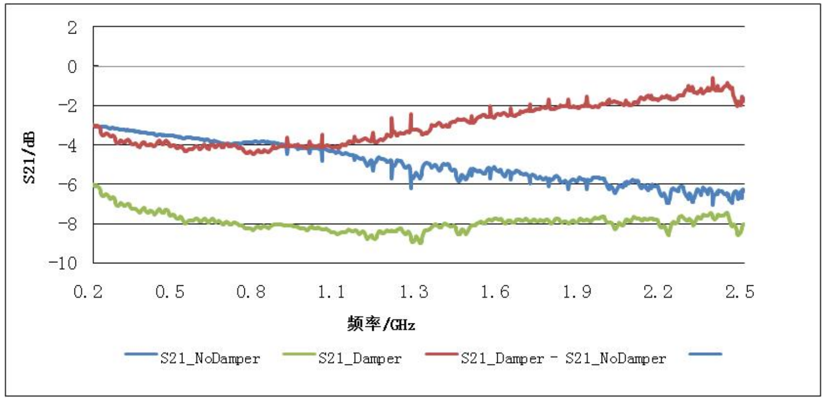
180 kW CW in IHEP test stand (limited by klystron power)

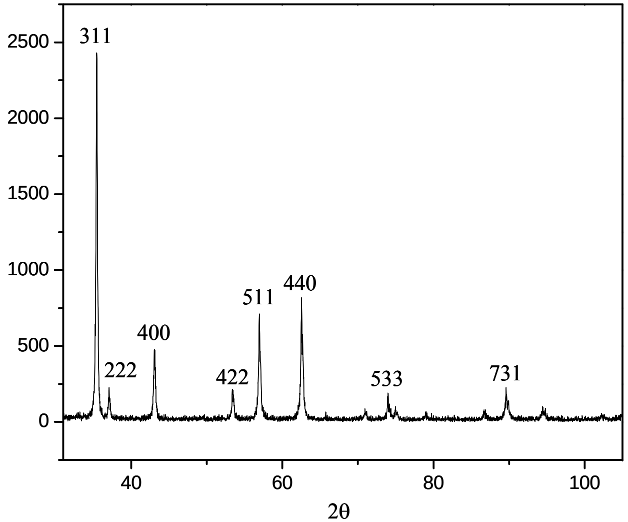
420 kW CW in KEK test stand



HOM Absorber





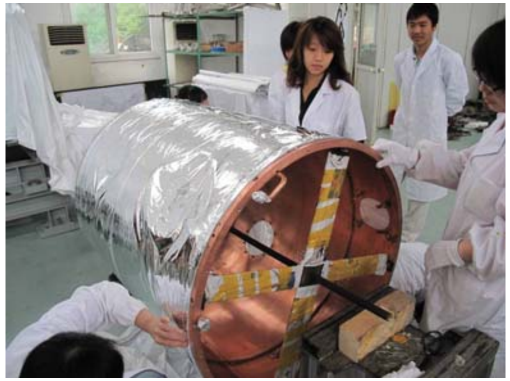


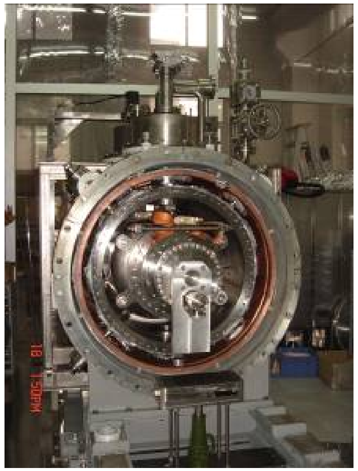
Ni-Zn Ferrite Powder XRD

High Power Test > 4.4 kW at 500 MHz

Cryostat and Assembly



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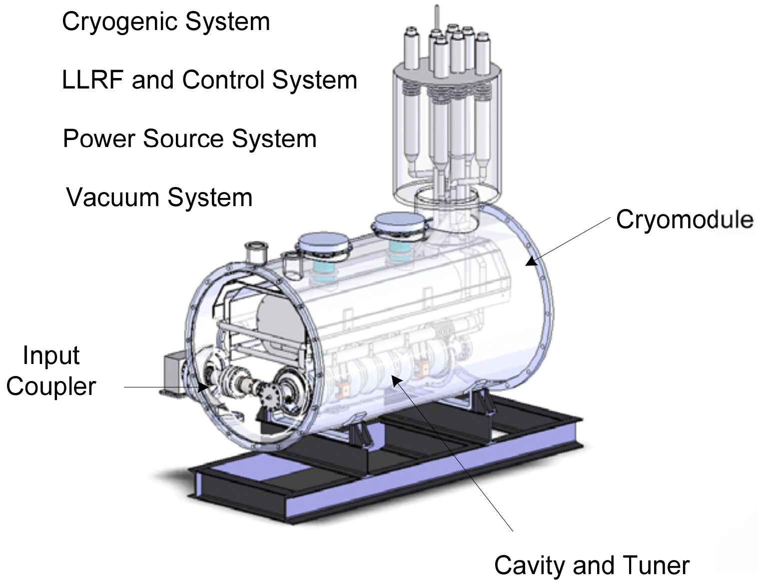
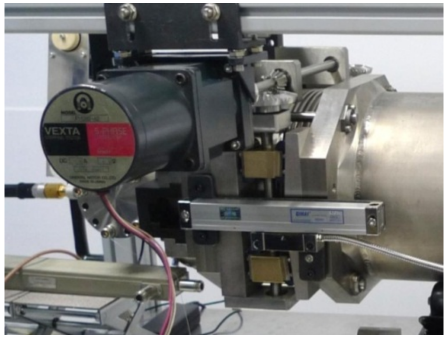


IHEP ILC SCRF R&D Program

- IHEP Innovation Project (2009-2012)
- Primary goals of the program:
  1. key components prototyping (1.3 GHz cavity, input coupler, tuner, LLRF)
  2. SRF infrastructure construction and commissioning
  3. cryomodule integration with one 9-cell cavity (assembly and alignment)
  4. cryomodule test (20-31.5 MV/m, $Q_0 > 8E9$, pulsed 5 Hz, 1 ms flat-top, 1% amplitude and 1 deg phase variation)
  5. horizontal test stand or booster (capture cryomodule) for future SRF test facility

Key Components Prototypes

9-cell cavity (IHEP-01)
Large grain low loss shape



Tuner
KEK slide jack type

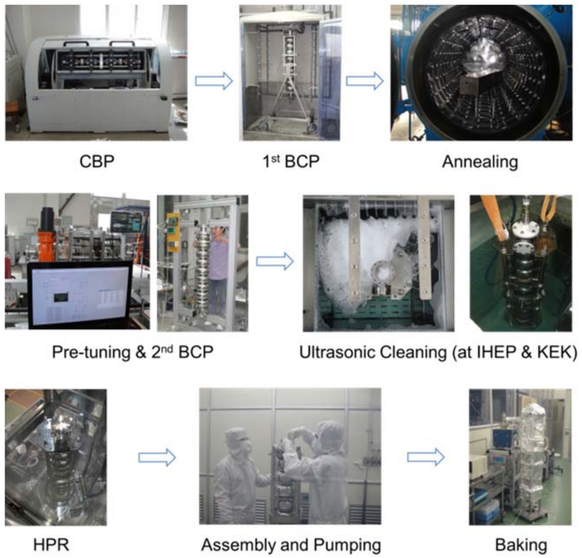
Input coupler
KEK STF type

LLRF

Cryomodule for Euro-XFEL
PXFEL1, 58 more ordered

IHEP-01 9-cell Cavity

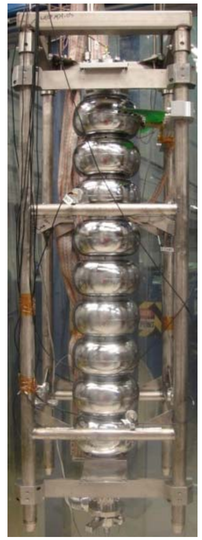
- Low loss shape, without end groups
- fabricated in Beijing with Ningxia OTIC large grain Nb
- processed and RF tuned with SCRF infrastructures in IHEP
- final processing and vertical test in KEK (VT1) and JLAB (VT2)



1st Pass Processing

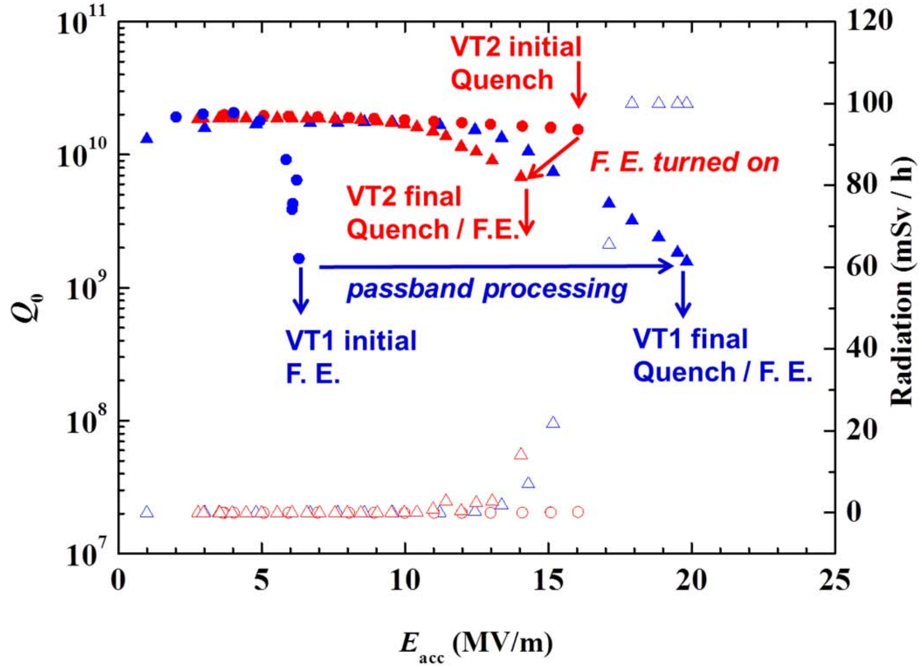
VT1 at KEK
T-mapping

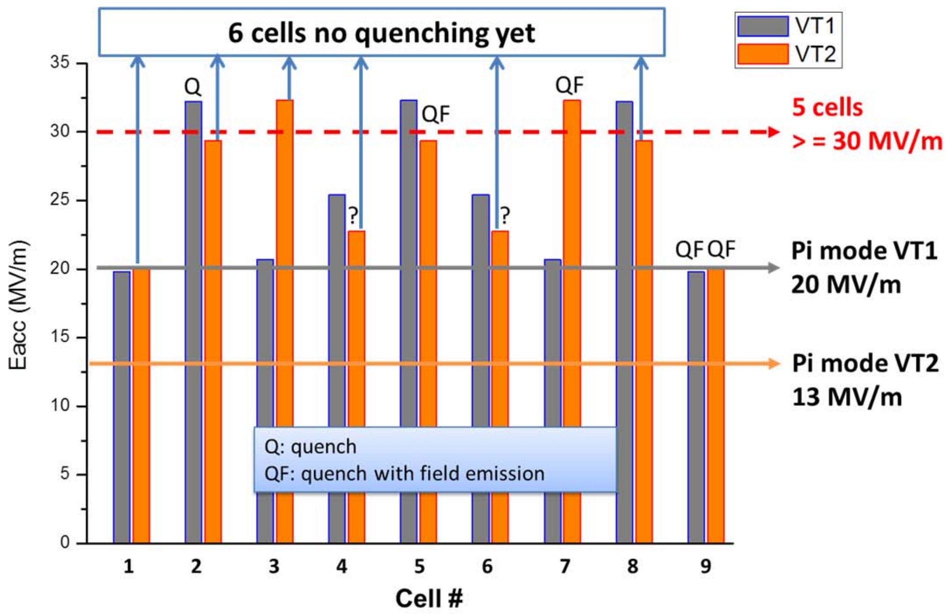
2nd Pass Processing

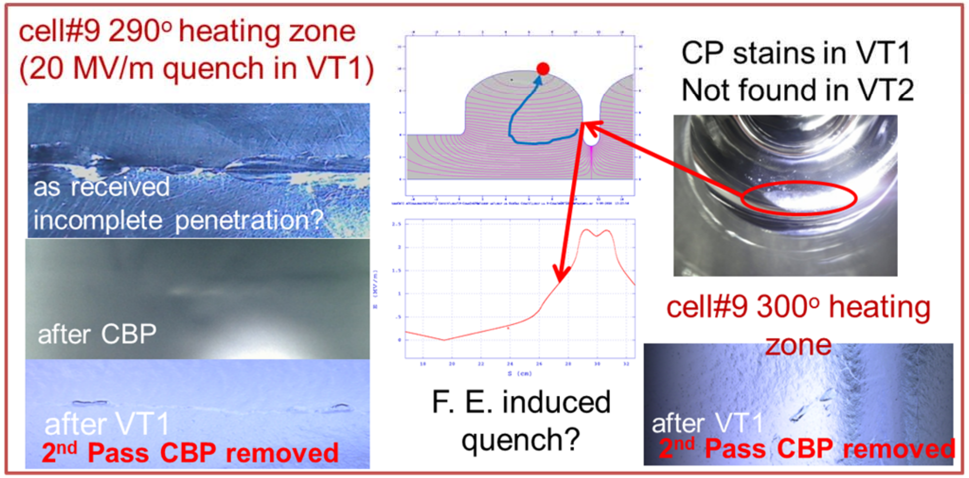


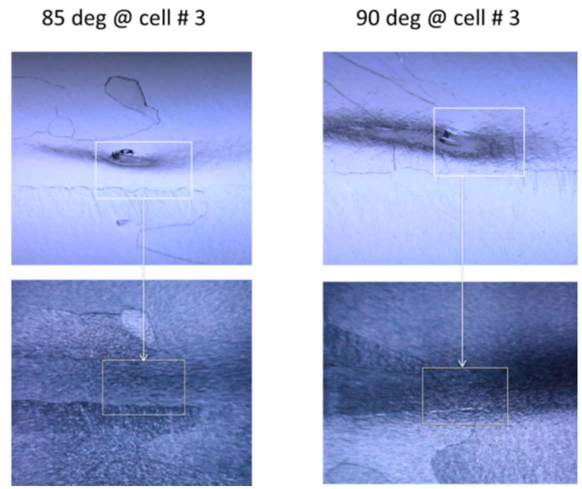
VT2 at JLAB
OST, T-sensor

IHEP-01 Vertical Test Results

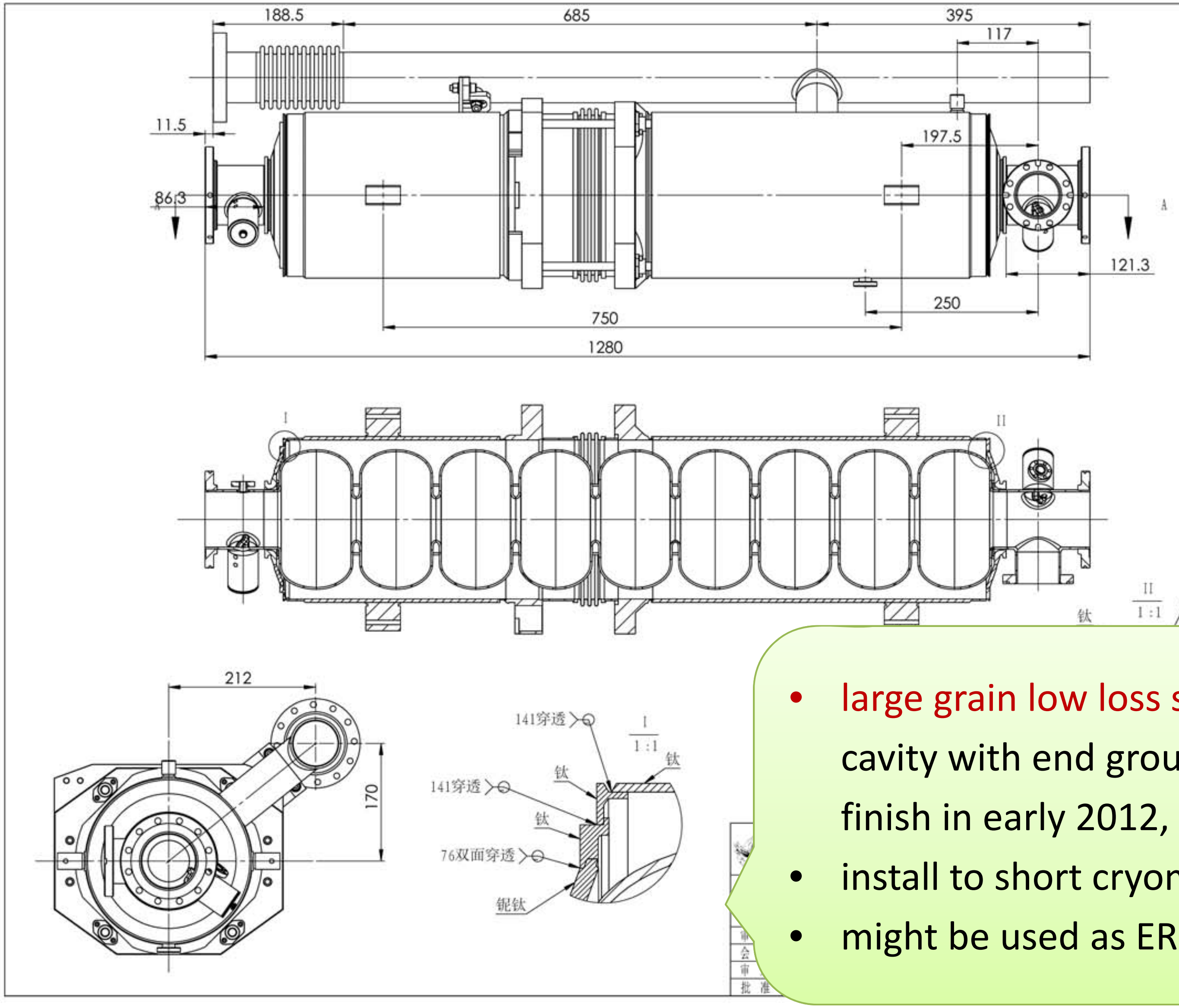






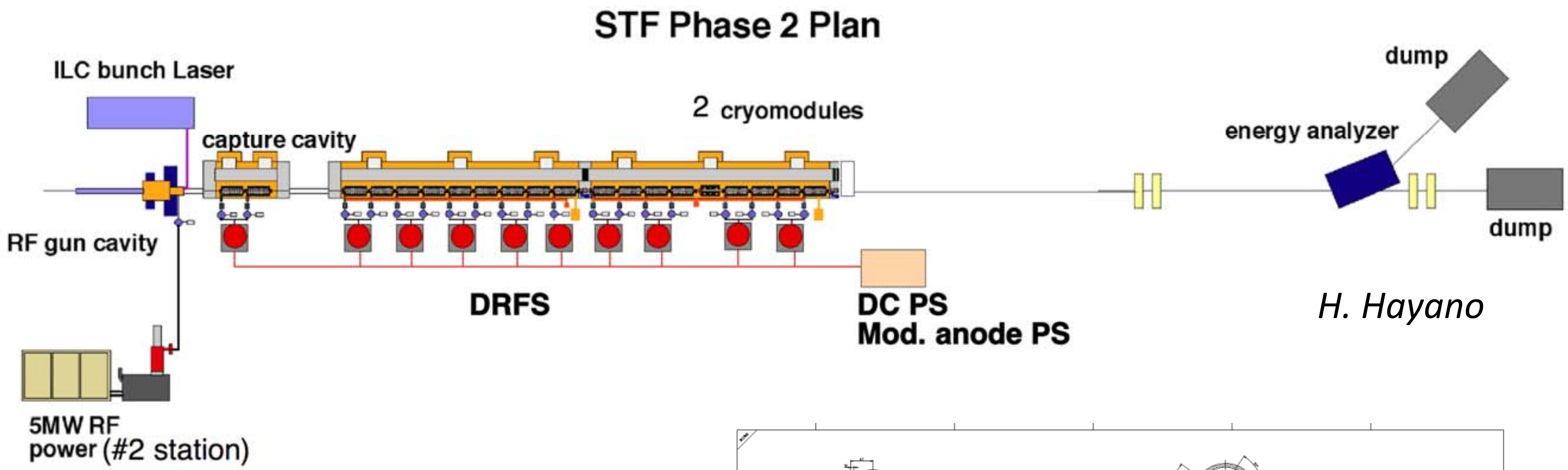


IHEP-02 9-cell Cavity with Helium Vessel



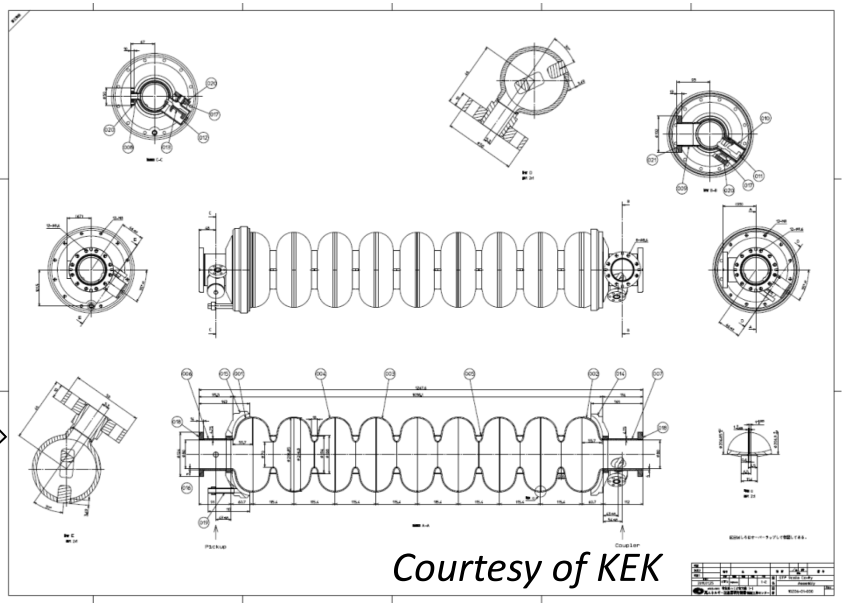
- large grain low loss shape 9-cell cavity with end group, fabrication finish in early 2012, VT at FNAL
- install to short cryomodule
- might be used as ERL booster

IHEP-03 for STF2 Linac



H. Hayano

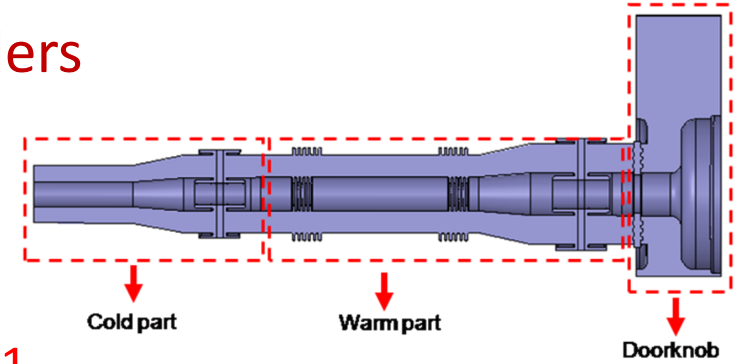
- TESLA-like shape 9-cell fine grain cavity in collaboration with KEK
- small Lorentz detuning
- might install to KEK STF2 for beam test



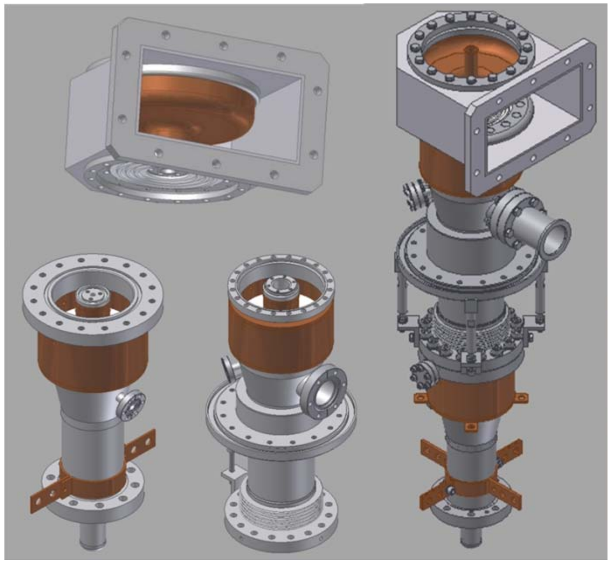
Courtesy of KEK

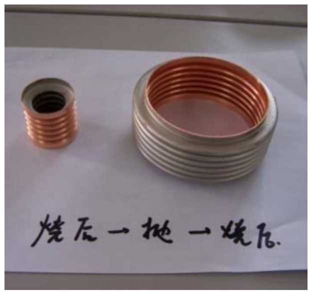
1.3 GHz Input Coupler

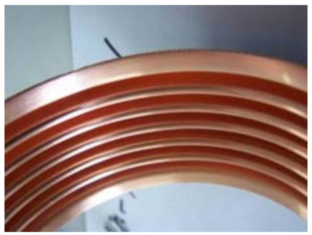
- Two double-choke-window input couplers
  - In-house made (IHEP workshop)
  - TiN coating on ceramics
  - finished fabrication of two couplers
  - high power test at KEK STF: November 2011



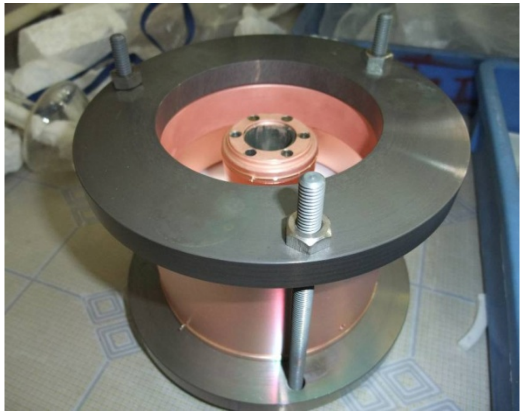
Refer to E. Kako (KEK)

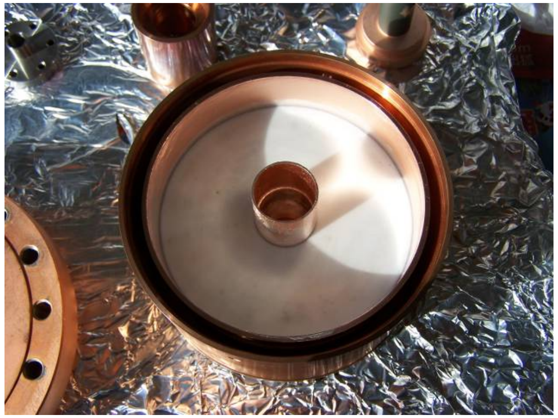






Welded Coupler Parts





Warm and Cold Window

Door knob

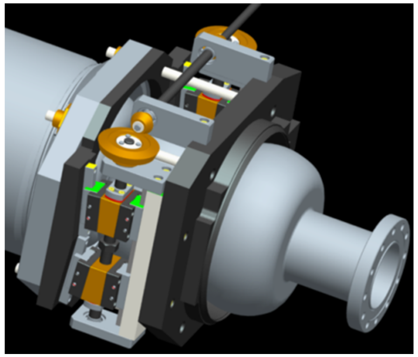
Warm outer part

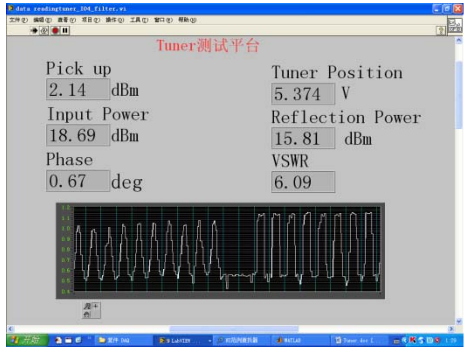
Warm inner part

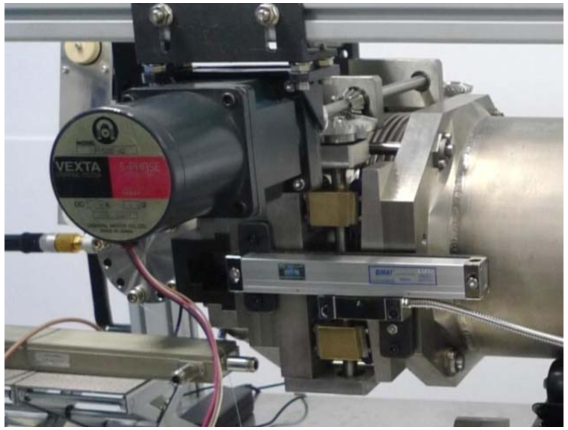
Cold outer and inner parts

Tuner and LLRF

- Home-made slide jack tuner
- Performance test with MHI-04 from KEK
  - Tuner stroke
  - Piezo
  - Stability
- Cold test planned
- Motor inside cryomodule

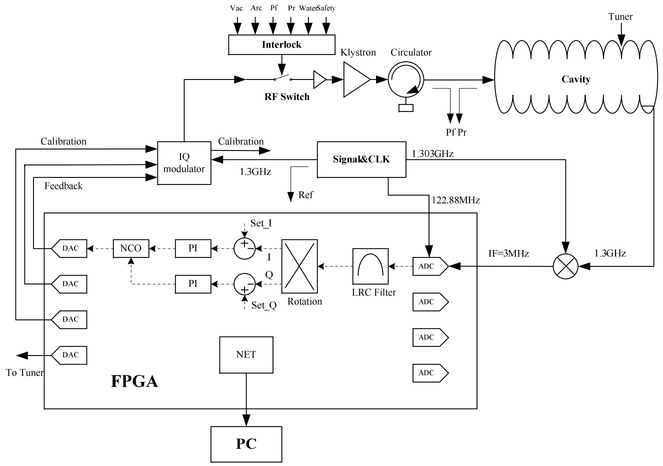


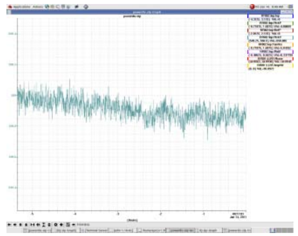


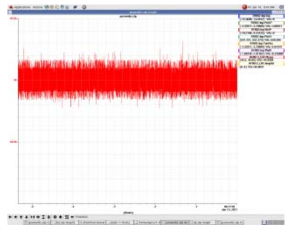


Refer to S. Noguchi (KEK)

LLRF Performance @ RT

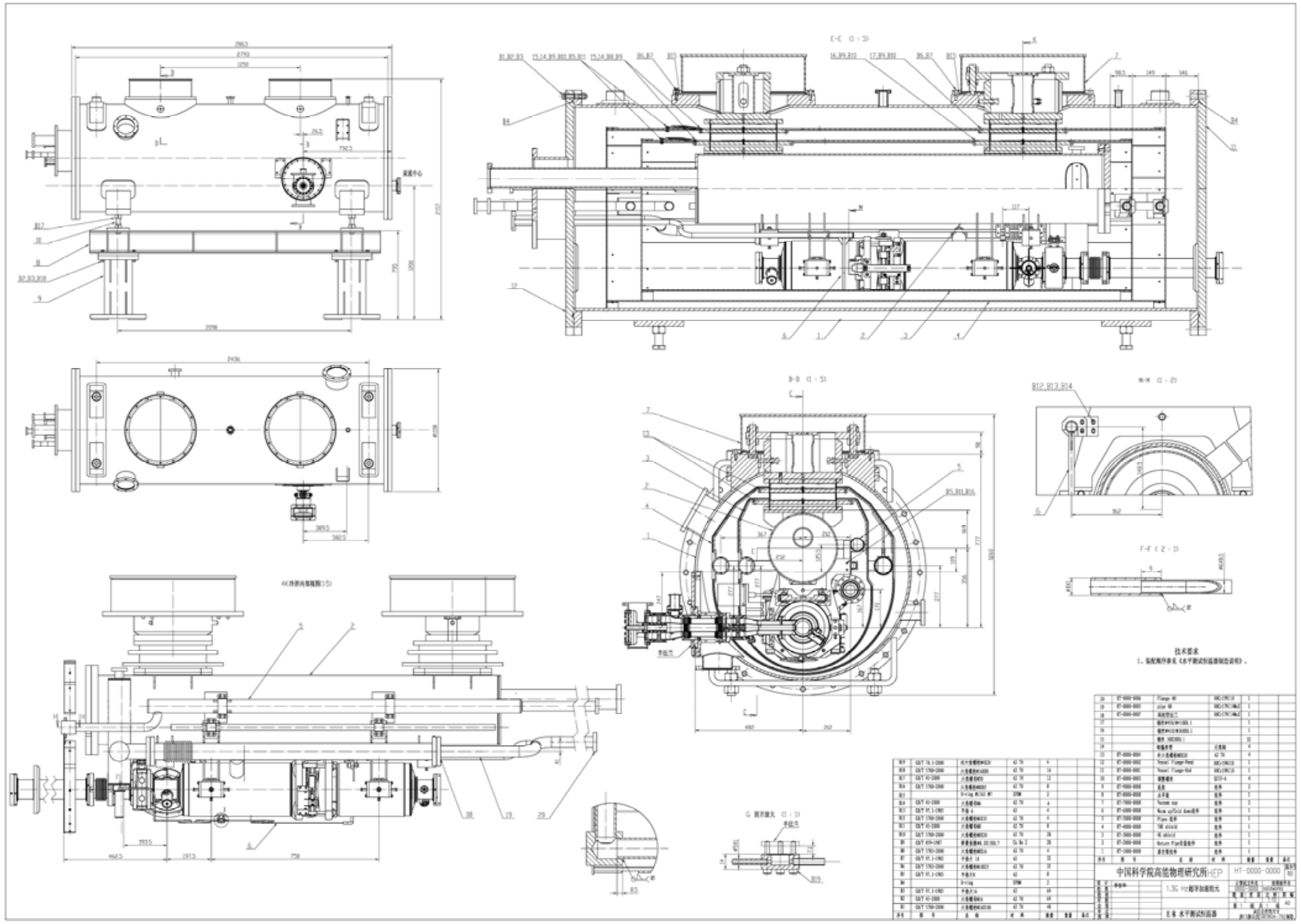






Frequency stability	±1 kHz (room temperature)
Amplitude stability	±0.05 % (peak to peak)
Phase stability	±0.035° (peak to peak)
Response time	70 μs
Dynamic range	20 dB

Cryomodule for the 9-cell Cavity



- Based on PXFEL1 success and XFEL cryomodule mass production
- Design finished, fabricate and assemble in 2011-2012
- Horizontal test with IHEP's new cryogenic system

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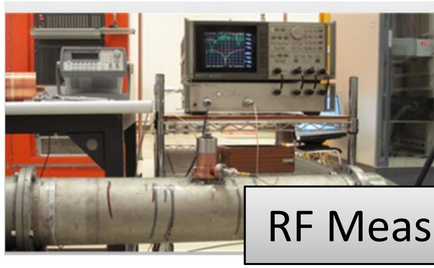
SRF Infrastructures

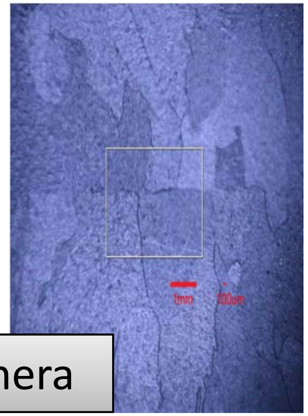
SRF Infrastructures (cont.)

Cavity RF Lab

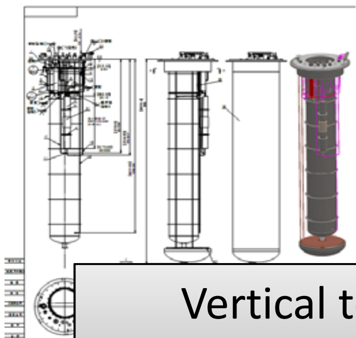
LLRF Lab

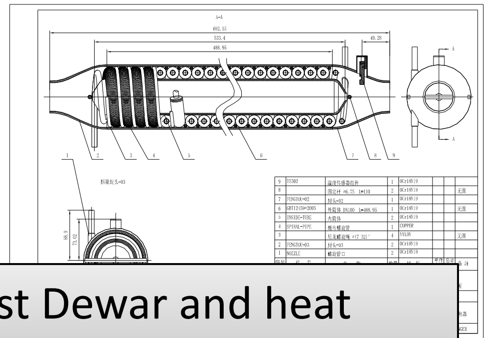


RF Measurement



Inspection Camera





Vertical test Dewar and heat exchanger (in fabrication)

Planned Infrastructures

- EBW machine and cavity fabrication plant
- EP facility, T-mapping
- Dedicated 2K cryogenic system (for ADS, ERL & ILC)
  - cavity vertical test
  - cavity package & module horizontal test
  - test facility operation
- New large SCRF labs outside IHEP campus
  - Huai Rou (future site for *Beijing Advanced Photon Complex*)
  - Erdos (future site for *China ADS*)

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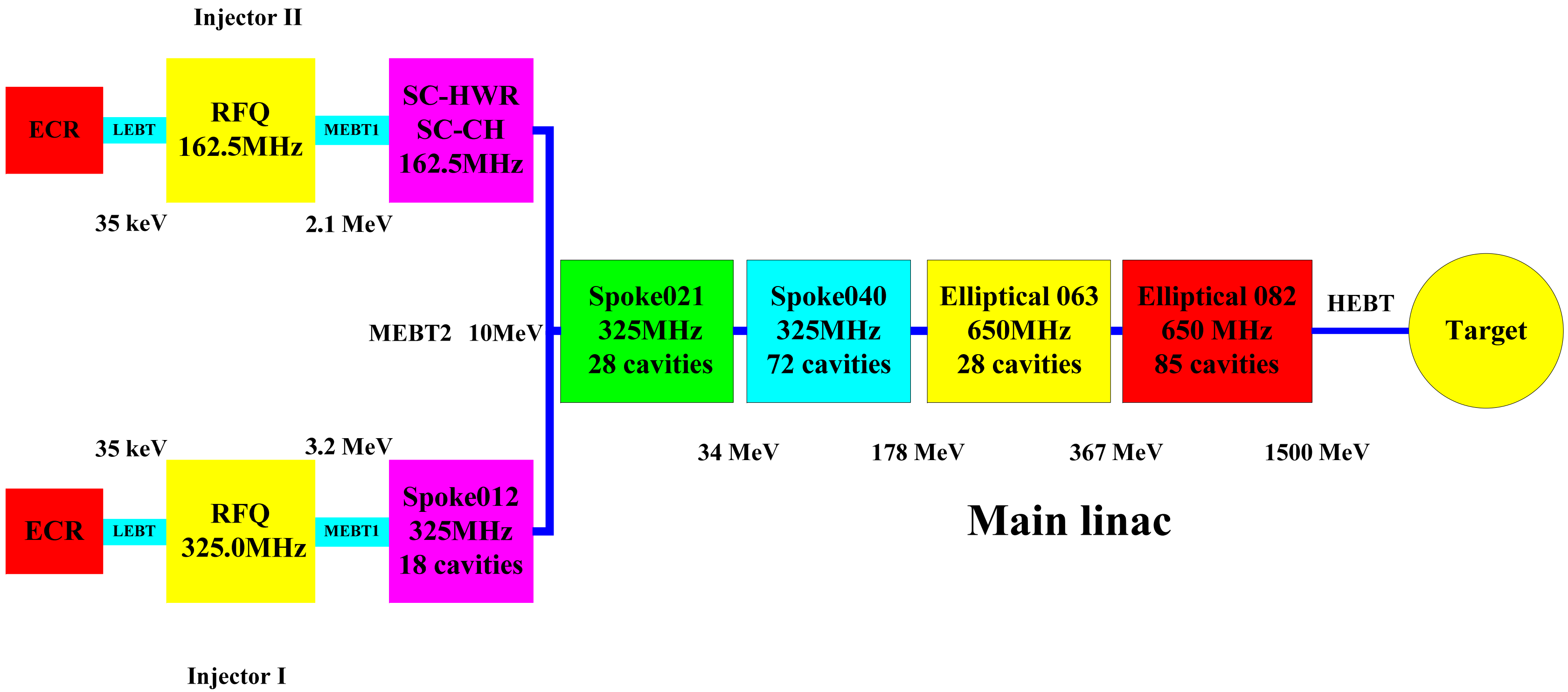
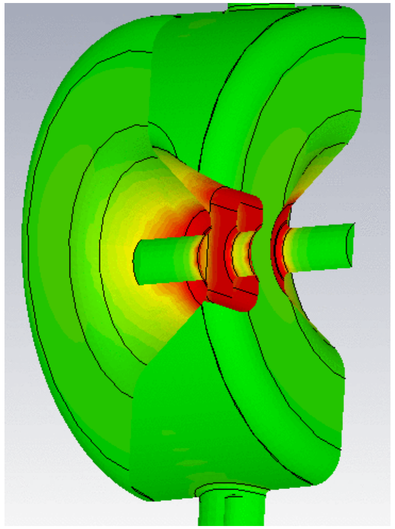
Layout of the China ADS Linac

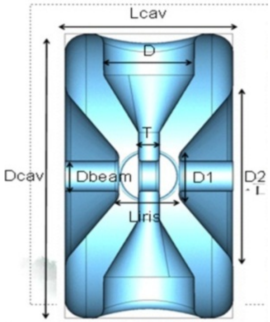


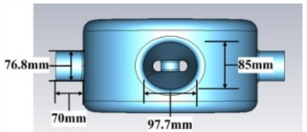
- 3 types of spoke cavities and 2 types of elliptical cavities are needed for China ADS Linac, and the spoke cavity for 3~10 MeV injector is most challenging.
- The collaborations with PKU&HIT were fixed, and collaborations with FNAL/ANL/MSU etc. are expected.

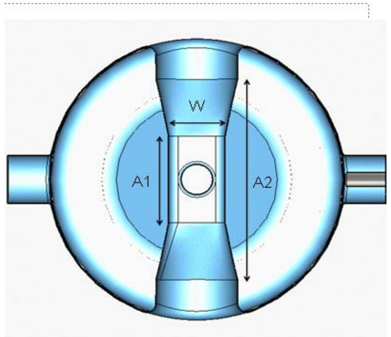
Spoke 0.12 RF Design

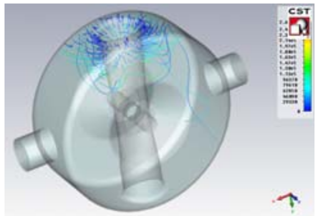
Electric field

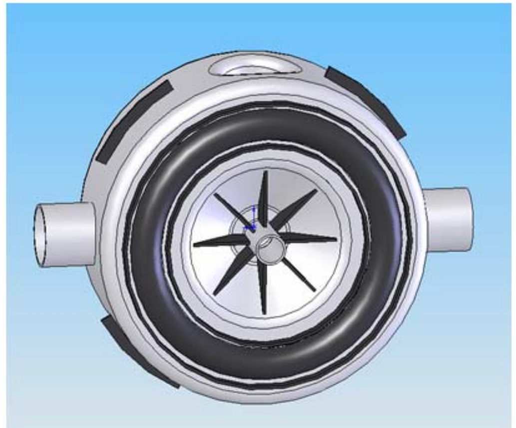








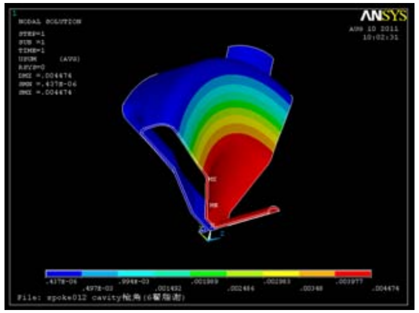


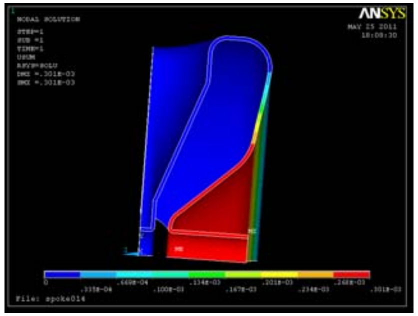


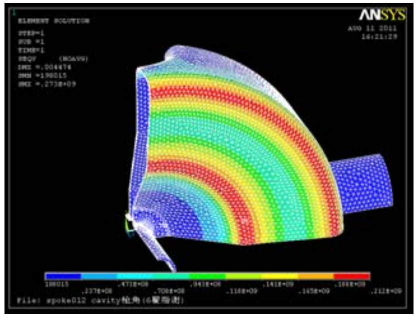
	Lcav	Liris	T	W	Dcav	Dbeam	D1	D2	A1	A2
mm	170	74	29	89	438	35	81	219	110	280

Lcav	f	G	R/Q@βopt	Ep/Eacc	Bp/Eacc	Ttran
170mm	325.0MHz	53Ω	150Ω	3.19	4.66mT/MV/m	0.77

Spoke012 Mechanical Properties



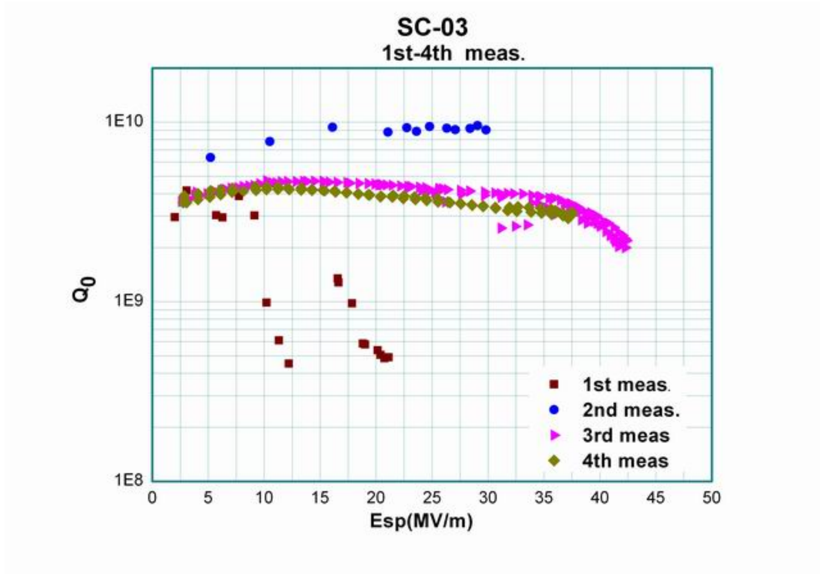




	Without ribs	With ribs
Beam pipe free	4.47 mm/bar -13.7 MHz/bar Von stress=212 MPa Δf/Δp= -18 kHz/torr	0.423 mm/bar -1.04 MHz/bar Von stress=56 MPa Δf/Δp = -1.4 kHz/torr
Beam pipe fixed	0.359 mm/bar -402.29 kHz/bar Von stress=440 MPa Δf/Δp= -530 Hz/torr	0.08 mm/bar +6.5 kHz/bar Von stress=65 MPa Δf/Δp= -8.5 Hz/torr
Tuning sensitivity	0.577 mm/100 kgf 761.3 kHz/100 kgf 1.32 MHz/mm	0.052 mm/100kgf 68.6 kHz/100kgf 1.32 MHz/mm
Lorentz detuning	-25.83 Hz/(MV/m)^2	-3.2 Hz/(MV/m)^2

Elliptical Cavities for ADS

beta=0.45, 1.3 GHz scaled cavity



beta=0.45, 650 MHz cavity half cells

New beta = 0.82 & 0.63

650 MHz 5-cell cavity prototyping

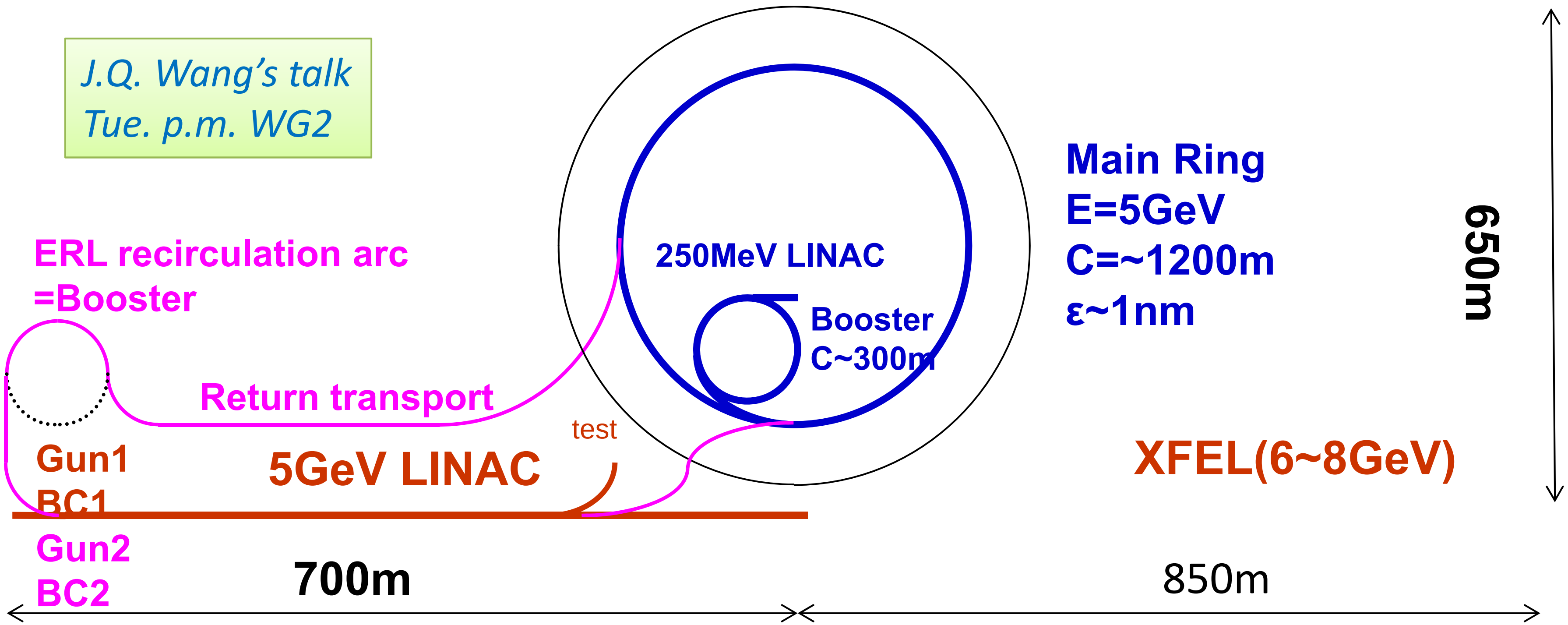
in 2012-2015

Beijing Advanced Photon Complex

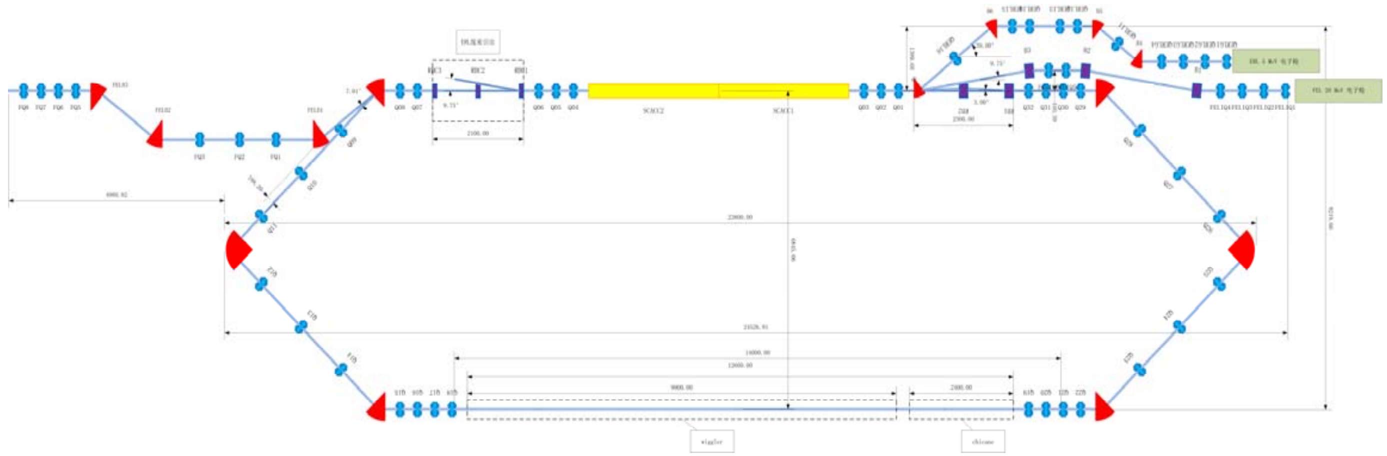
1st Phase: Small emittance synchrotron light source （2015-2020 ?）

2nd Phase : BX-ERL-FEL

J.Q. Wang's talk
Tue. p.m. WG2



Layout of the ERL Test Facility at IHEP



Compact TF-- 35 MeV-10 mA

- DC- and 5 MeV injector (2 x 2-cell CW SC cavity)
- L-band CW SC Linac: E = 15~20 MV/m、35 MeV ~10 mA (2 x 7-cell CW SC cavity)
- ERL ring: 2 TBA arcs , 2 strait section
- ERL-THz beam lines (from CSR or oscillator)

J.Q. Wang's talk
Tue. p.m. WG2

Injector Cryomodule Parameters

Energy gain	5 MeV
RF frequency	1.3 GHz
Number of 2-cell cavities	2
Effective length of 2-cell cavity	23 cm
2-cell cavity R / Q	214 Ω
#1 cavity voltage	1.5 MV（1~3 MV）
#1 cavity gradient	6.5 MV / m
#1 cavity total Q_L	7×10^5
#1 cavity Q_L of each input coupler	1.4×10^6
#1 cavity beam phase	-15° ～-30°
#1 cavity beam power	15 kW
#1 cavity power of each input coupler	7.5 kW（CW）
#2 cavity voltage	3.5 MV（1~3 MV）
#2 cavity gradient	15.2 MV / m
#2 cavity total Q_L	1.6×10^6

Injector Cryomodule Parameters (Cont.)

#2 cavity Q_L of each input coupler	3.2×10^6
#2 cavity beam phase	-10°
#2 cavity beam power	35 kW
#2 cavity power of each input coupler	17.5 kW（CW）
Number of input couplers per cavity	2
Number of input couplers	4
RF power of the input coupler	20 kW（CW）
Input coupler Q_e	2.3×10^6
Variable coupler Q_e range	$10^6 \sim 10^7$
Number of HOM absorbers	3
RF power of a HOM absorber	20 W
Amplitude stability	0.1 %
Phase stability	0.1°
Max beam current	10 mA
2 K/ 5 K / 80 K heat load	12 W / 14 W / 154 W
Total Length	2.4 m

Main Linac Cryomodule Parameters

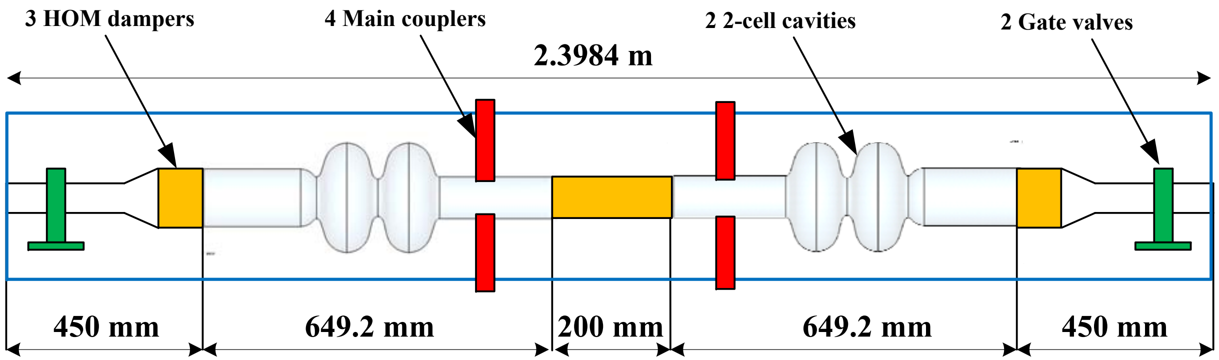
Mode	A	B
Accelerating beam current	10 mA	
Accelerating beam phase	**-10°**	0°
Decelerating beam current	9.7 mA	9.98 mA
Decelerating beam phase	165°	179.5°
Detune	-26.8 Hz	~ 0 Hz
Beam loss	3 %	0.02 %
Bunch charge	77 pC	
Bunch repetition frequency	130 MHz	
Bunch spacing	7.7 ns	
Number of 7-cell cavities	2	
7-cell cavity voltage	15 MV	
7-cell cavity Q_0	1×10^{10}	
7-cell cavity R / Q	800 Ω	
Q_e	2×10^7	
Band width	65 Hz	

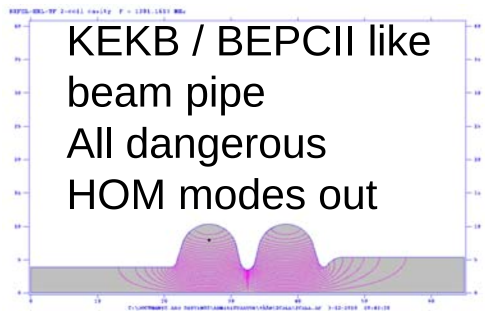
Main Linac Cryomodule Parameters (cont.)

Microphonics (p-p)	50 Hz	10 Hz
RF power	16.3 kW	4 kW
RF Power (30 % abundance)	21.19 kW	5 kW
Number of input couplers per cavity	1	
Number of input couplers	2	
RF Power of input couplers	20 kW (CW)	
Variable coupler Q_e range	$2 \times 10^6 \sim 2 \times 10^7$	
Number of HOM absorbers	3	
RF Power of a HOM absorber	20 W	
Amplitude / phase stability	0.01 % / 0.01°	
2 K/ 5 K / 80 K heat load	60 W / 20 W / 180 W	
Total length	4.8 m	

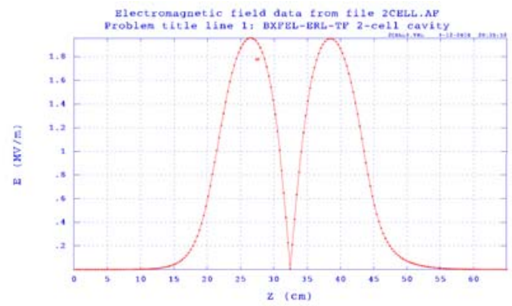
-10 deg was assumed for chicane compressor, now the bunch compression will be performed by TBA1, so the bunch phase should be about 10 deg.

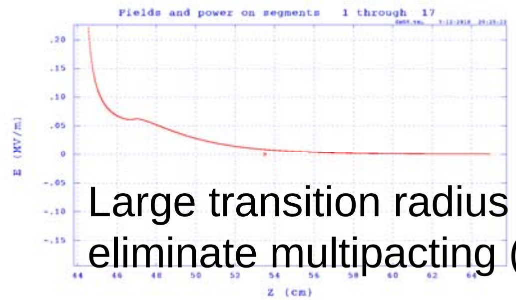
Injector Booster Cavity





Type of accelerating structure	Standing wave
Accelerating mode	TM010, π mode
Fundamental frequency	1301.000 MHz
Design gradient	15 MV / m
Quality factor	1×10^{10}
Active length	0.2292 m
Number of cells	2
Geometry factor (G)	274.5 Ω
R / Q	214.2 Ω
$G \times R / Q$	58776 Ω^2
E_{peak} / E_{acc}	2.02
B_{peak} / E_{acc}	4.2 mT / (MV / m)





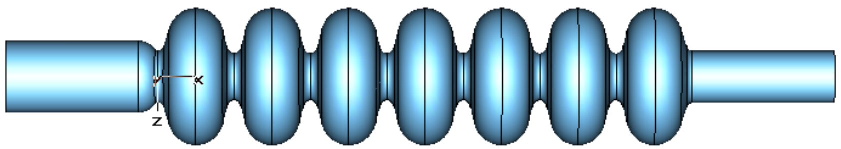
Main Linac Cavity

7-cell , iris 70 mm, based on TESLA cavity

refer to Cornell "HOM-robust" shape

end cell: similar to the 2-cell cavity

CBP (with EP? *C. Cooper SRF2011*) and Large Grain (BCP only or EP, *R. Geng, S. Aderhold SRF2011*) seem to increase the Q value at medium gradient (~ 20 MV/m) 1~2 times higher



	$R/Q \cdot G$	$\frac{E_{pk}}{E_{acc}}$	Wall Angle	Iris Radius	Eq. Horiz.	Eq. Vert.	Iris Horiz.	Iris Vert.
Baseline	15576 Ω	2.00	85°	3.500	4.399	3.506	1.253	2.095
New Design	14837 Ω	2.06	77°	3.598	4.135	3.557	1.235	2.114

Courtesy of Cornell

$$\left(\frac{R}{Q}\right) Q < 5000 \quad [\Omega]$$

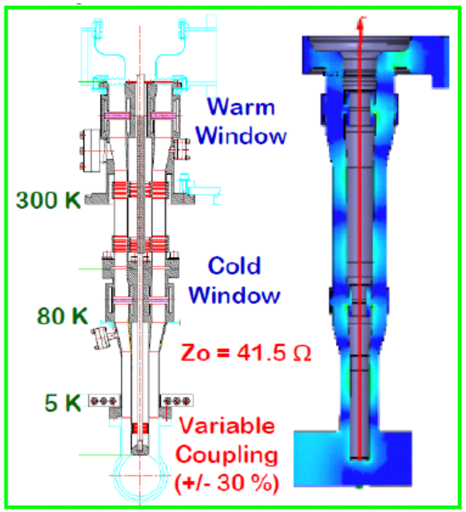
$$\left(\frac{R_t}{Q}\right) \frac{Q}{f} < 2.8 \times 10^5 \quad \left[\frac{\Omega}{\mathrm{cm^2 GHz}}\right]$$

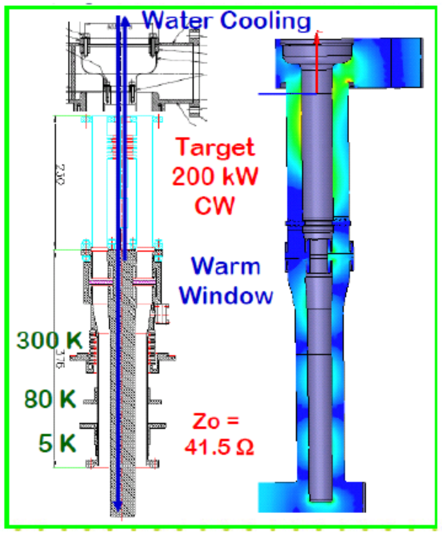
$$\left(\frac{R_q}{Q}\right) \frac{Q}{f} < 8 \times 10^6 \quad \left[\frac{\Omega}{\mathrm{cm^4 GHz}}\right]$$

f_0	1.3 GHz
V_c	15 MV
L_{eff}	0.8 m
E_{acc}	18.8 MV / m
Q_0	10^{10}
R / Q	800 Ω

ERL Input Coupler

- 20 kW CW input coupler for main linac
- same with main linac or 200 kW CW input coupler for injector, if consider 100 mA (if initial power source for the injector is 30 kW, the 200 kW input coupler should be variable)
- Refer to STF-II and KEK ERL Variable Coupler, ERL injector coupler
- IHEP made some of the RF simulation





Courtesy of KEK

RF Power for Cryomodules

	2-cell #1	2-cell #2	7-cell #1	7-cell #2
Cavity Voltage	1.5 / 2.5 MV	2.5 / 3.5 MV	15 MV	15 MV
Q_L （total）	7×10^5 / 1.2×10^6	1.2×10^6 / 1.6×10^6	2×10^7	2×10^7
Bunch phase	-15° ～-30° / 0°	0° / -10°	0° , 180° / -10° , 165°	0° , 180° / -10° , 165°
Power needed	15 kW / 25 kW	25 kW / 35 kW	20 kW	20 kW
Output power	20 kW / 30 kW	30 kW / 45 kW	30 kW	30 kW
Power Source	30 kW	45 kW or 30 kW	30 kW	30 kW

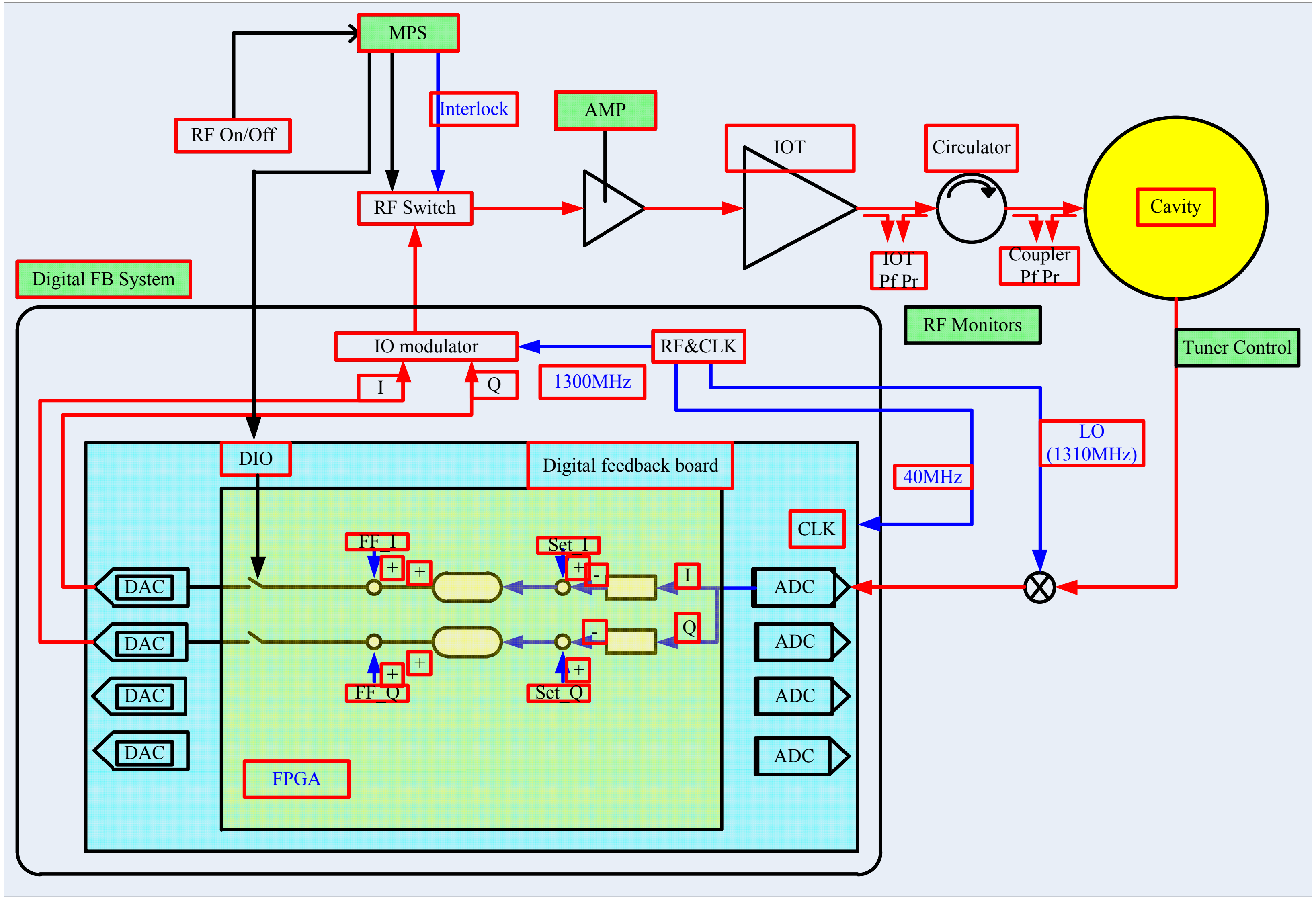
RF Power Source

项目	单位	Buncher	Inj-1	Inj-2	ML-1	ML-2
结构		NC	SC	SC	SC	SC
加速梯度	MV/m	0.14	15	15	15	15
Q_e			8×10^5	2×10^6	2×10^7	2×10^7
束流相位	degree	-90	-15 to -30	-10	0	0
所需功率	kW	4.5	25	25	16.3	16.3
输出功率	kW	6.2	35	35	35	35
功率源类型		IOT	IOT	IOT	IOT	IOT

LLRF

Name	2-cell #1	2-cell #2	7-cell #1	7-cell #2
f_0 (GHz)	1.3	1.3	1.3	1.3
Bandwidth(Hz)	--	--	65	65
V_c (MV)	3	4	15	15
Q_L	$\sim 1\times10^6$	$\sim 1\times10^6$	$\sim 1\times10^7$	$\sim 1\times10^7$
r/Q_0 (Ω)	214	214	800	800
I_b (mA)	10	10	10	10
$\sigma A/A$ (%)	0.1	0.1	0.01	0.01
$\sigma\theta/\theta$ (°)	0.1	0.1	0.01	0.01

LLRF



MPS
RF On/Off
Interlock
AMP
IOT
Circulator
Cavity
RF Switch
IOT Pf Pr
Coupler Pf Pr
Digital FB System
RF Monitors
Tuner Control
IO modulator
RF&CLK
I
Q
1300MHz
LO (1310MHz)
40MHz
DIO
Digital feedback board
CLK
FF_I
Set_I
+
+
+
-
I
Q
-
+
+
+
FF_Q
Set_Q
DAC
DAC
DAC
DAC
ADC
ADC
ADC
ADC
FPGA

Injector CM Heat Load

	Static	**2-cell cavity**	**Input coupler**	**HOM damper**	**Total**
		$R/Q = 214\ \Omega$ $\mathbf{Q_0 = 1 \times 10^{10}}$ $V_c = 2.5$ MV CW	CW 12.5 kW SW	Ferrite (bunch length 2 ps)	
Reference	KEK cERL injector	IHEP ERL	KEK ERL injector coupler	Cornell	
2K	2 W	3 W	1 W	0	12 W
5K	10 W	0	1 W	0	14 W
80K	80 W	0	8 W	14 W	154 W
No.		2	4	3	

Main Linac CM Heat Load

	Static	7-cell cavity	Input coupler	HOM damper	Total
		$R/Q = 800\ \Omega$ $Q_0 = 1\times 10^{10}$ $V_c = 15$ MV CW	CW 20 kW SW	Ferrite (bunch length 2 ps)	
Reference	KEK cERL	Cornell	KEK ERL Linac Coupler	Cornell	
2K	1 W	28 W	1 W	0	60 W
5K	14 W	0	3 W	0	20 W
80K	60 W	0	30 W	20 W	180 W
No.		2	2	3	

Total Heat Load

	2 K	4.5 K	80 K	4.5 K
Two 2-cell (W)	12	14	154	82
Two 7-cell (W)	60	20	180	329
4.5 K valve box (W)		30		30
4.5 K transfer line 100 m, 0.5W / m (W)		50		50
Two 2 K cold box (W)		60		60
2 K transfer line 30 m, 0.5 W / m		15		75
Sum	85	174	334	**626 W**

IHEP ERL TF SCRF Plan

2012-2013: 2-cell and 7-cell cavity, input coupler and HOM absorber prototyping

2013-2014: **injector cryomodule** construction and commissioning with beam (at IHEP campus)

2014-2015: **main linac cryomodule** construction and commissioning with beam (may move to Huai Rou)

Summary

- *IHEP SCRF R&D progressing for many projects*
  - **BEPCII**: spare cavity module meet specs last weekend
  - **ILC**: 1.3 GHz short cryomodule integrated next year
  - **light source** (storage ring, **ERL**), **China ADS**, **CSNS**
- *Infrastructures established and will expand*
- *ERL SCRF R&D based on the above activities*
  - CDR finished
  - key components prototyping in 2012-2015

Acknowledgement

We would like to thank the experts from

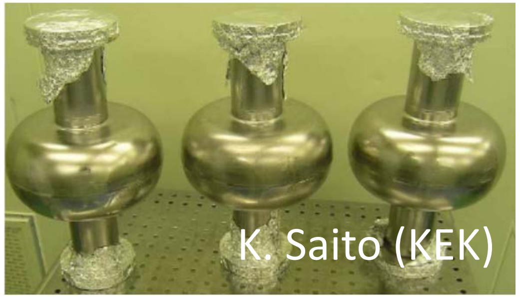
KEK, JLAB, FNAL, ANL & DESY as well as the ILC GDE

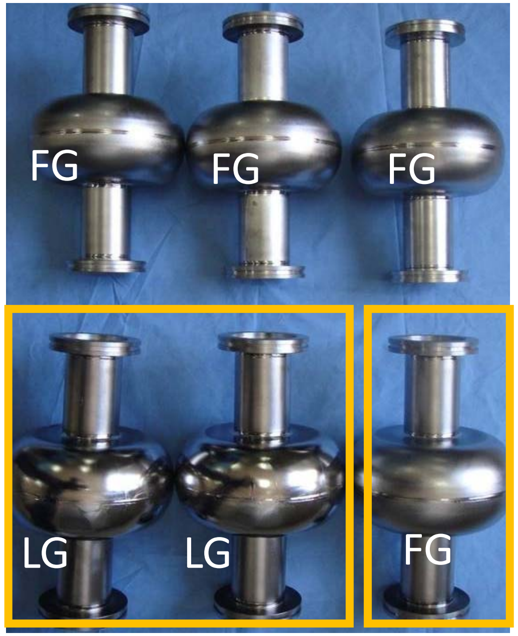
for their kindest cooperation and help.

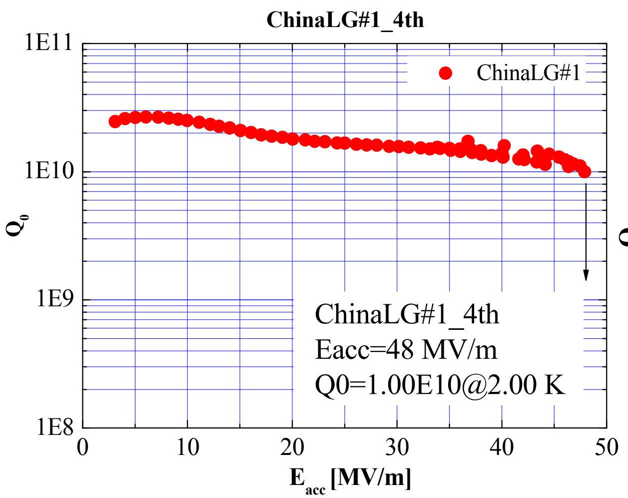
Thank you!

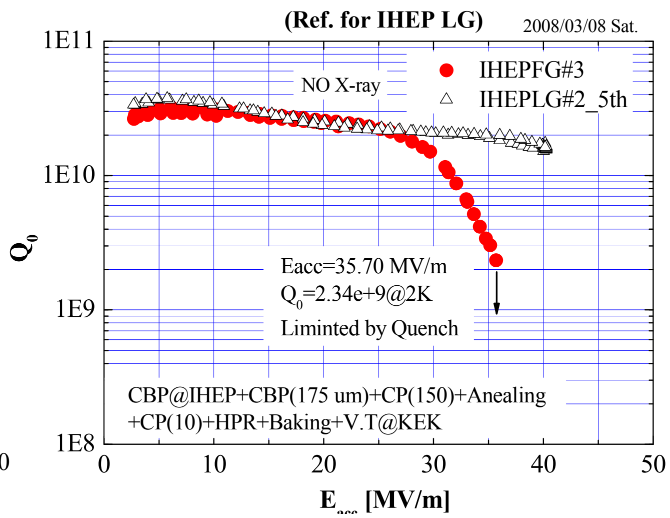
Single Cell Cavities

- 3 Ningxia large grain cavities, made by KEK, in 2007: 48 MV/m (CBP + EP)
- 2 Ningxia large grain cavities, fabricated and processed in IHEP, tested at KEK in 2008
  40 MV/m (CBP + BCP)
- 1 fine grain cavity for reference study

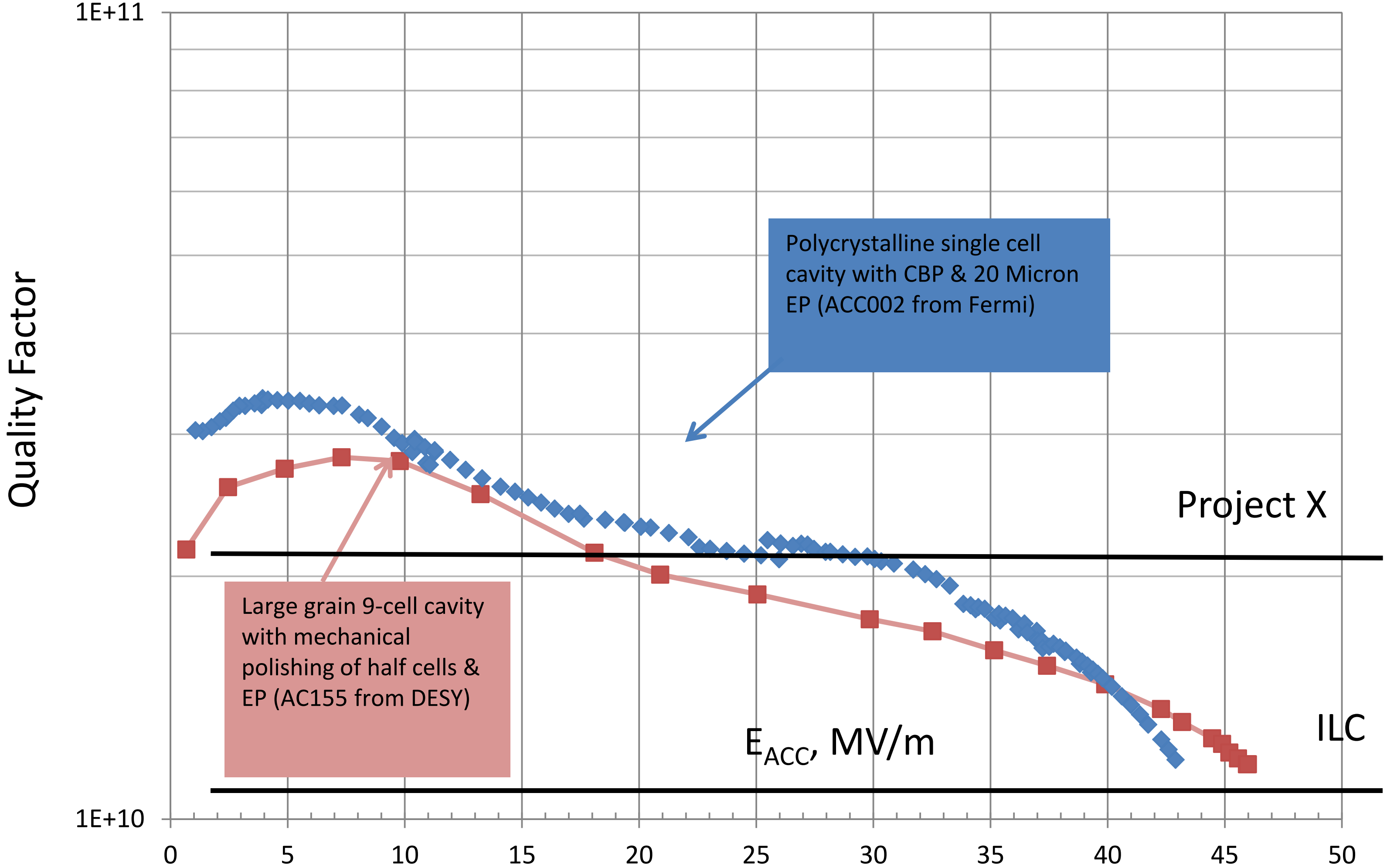






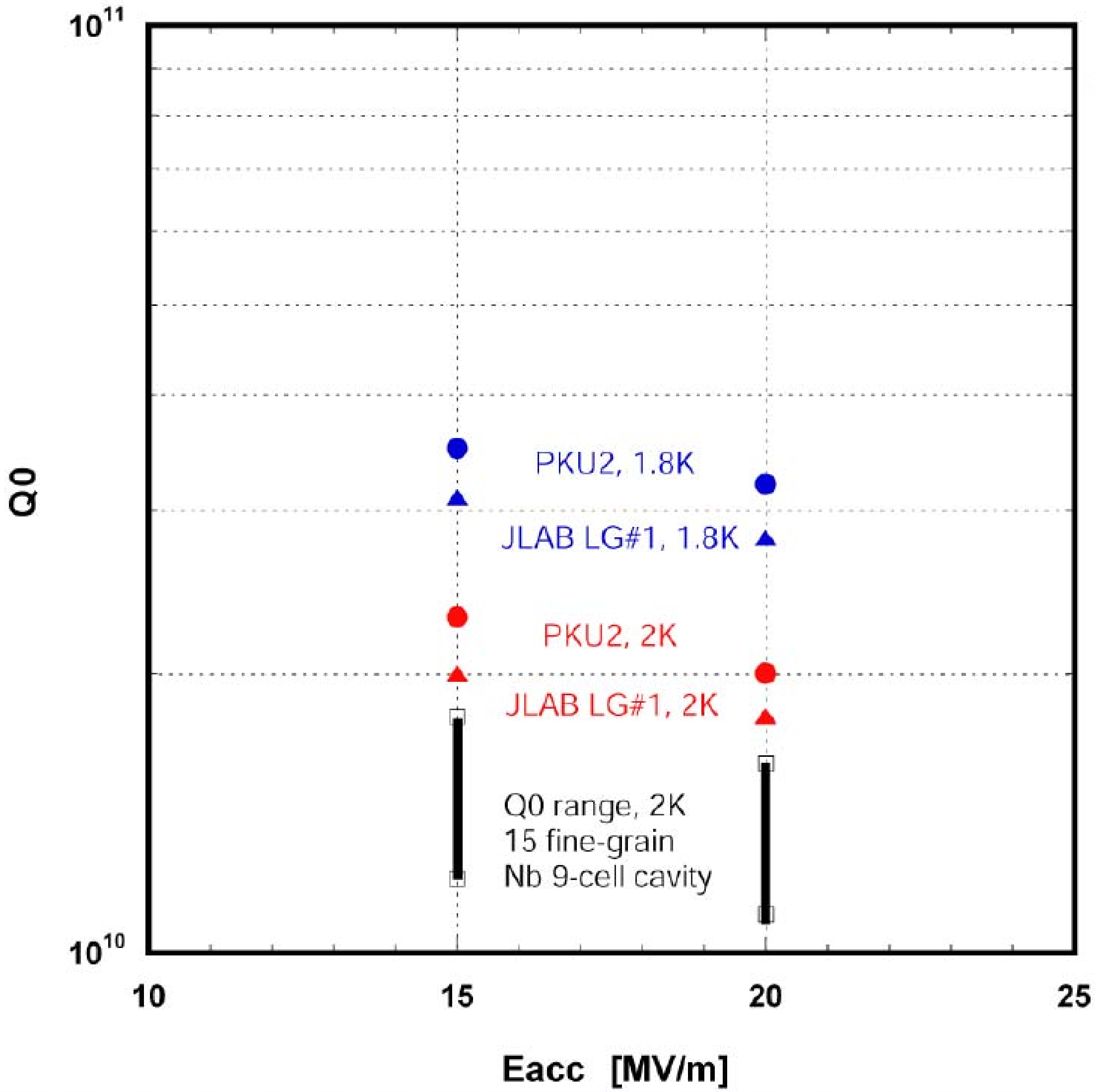


Does Centrifugal Barrel Polishing Affect Q-Slope ?



Recent high Q results on Tesla-Type cavities. Do grain boundaries have a negative effect on Q(Low, Mid, and High)?

Comparison of Q0: LG ↔ FG



Details: R. L. Geng's poster TUPPO049

Comparison of Q0: LG ↔ FG