中国科学院高能物理研究所
Institute of High Energy Physics
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The Development of the High Current Superconducting Cavity at IHEP

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ERL2015

Stony Brook University ICFA U.S. DEPARTMENT OF ENERGY Office of Science BROOKHAVEN NATIONAL LABORATORY

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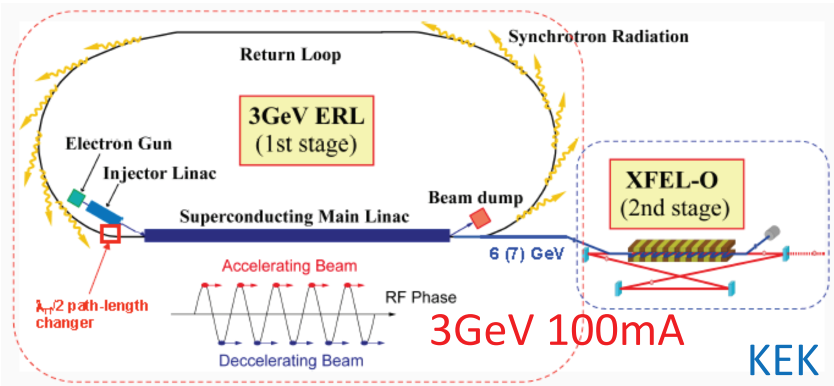
INTRODUCTION

ERL world wide



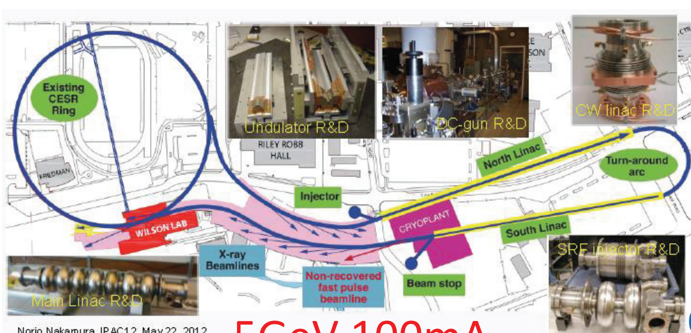
3GeV 100mA

KEK

Schematic view of the ERL light source project at KEK

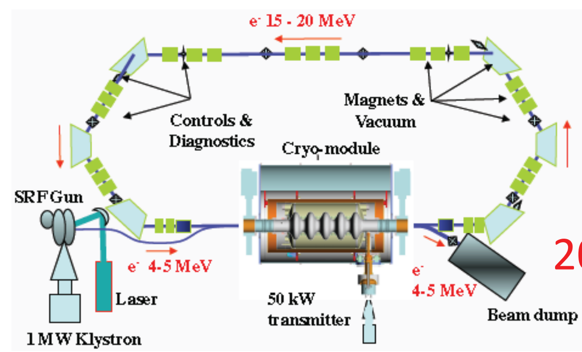
35MeV

KEK cERL



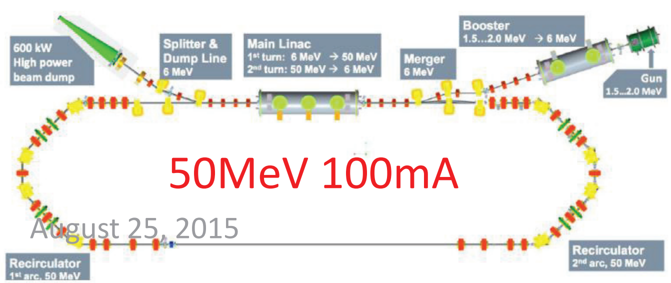
5GeV 100mA

Cornell



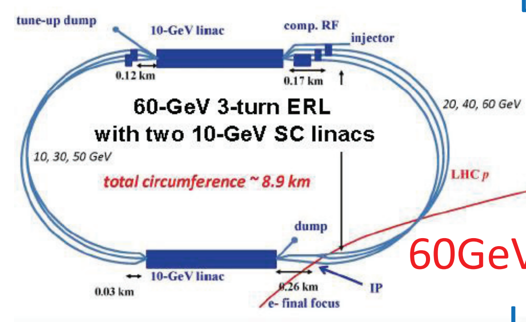
20MeV 500mA

BNL



50MeV 100mA

BERL@HZB

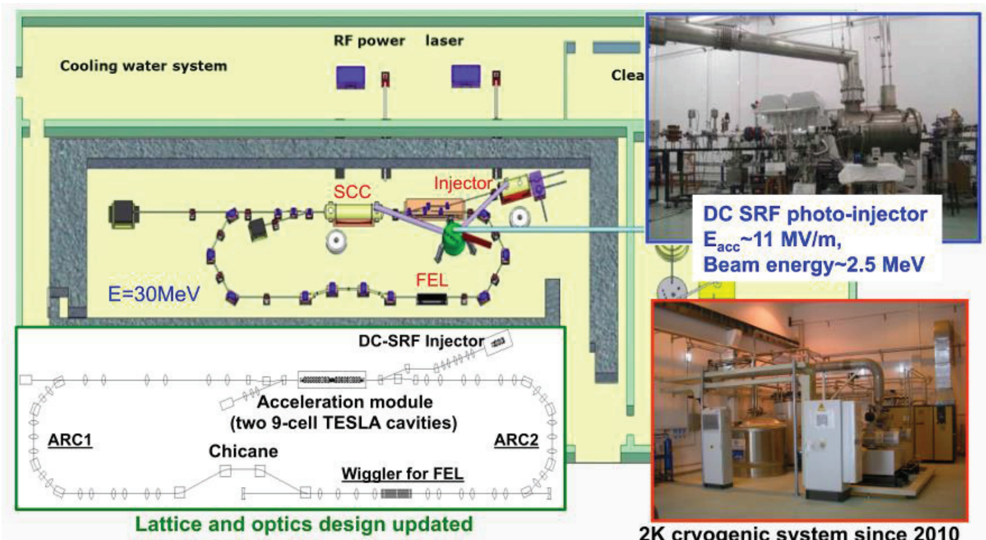


60GeV 50/100mA

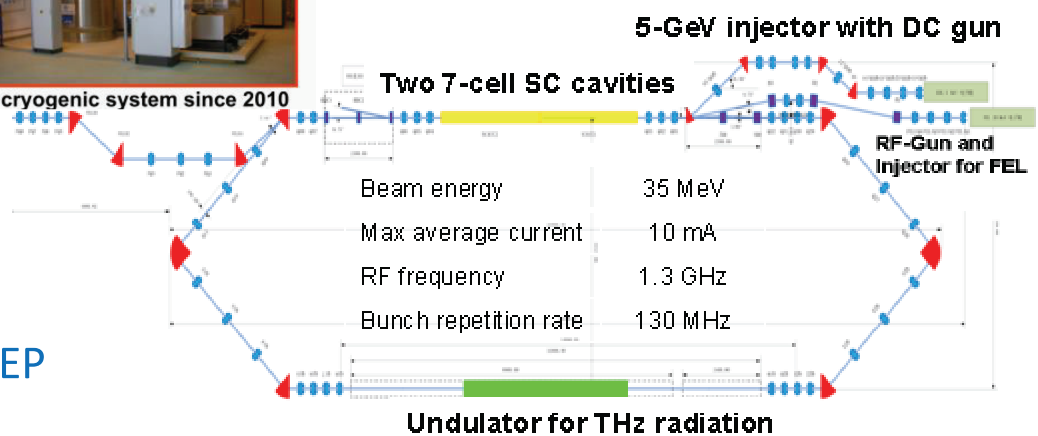
ERL configuration for Linac-Ring option

LHeC@CERN

ERL in China



PKU

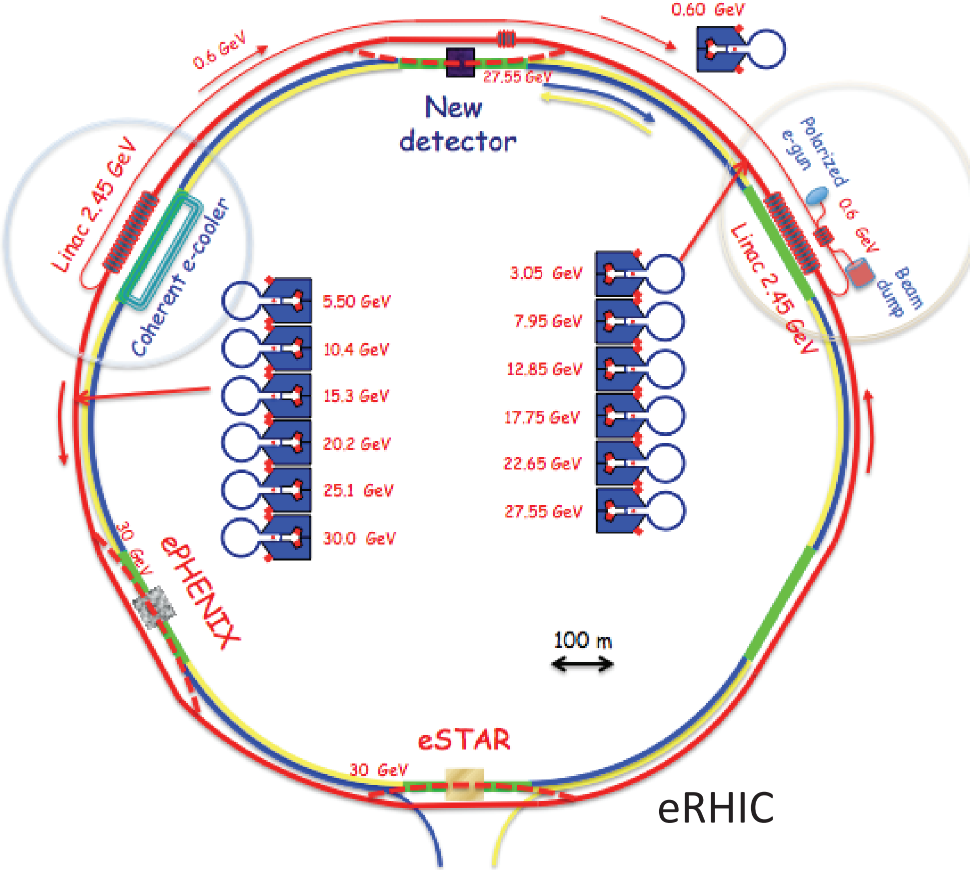


IHEP

Layout of the ERL-FEL Test Facility at IHEP

ERL and e-cooling

Parameters	eRHIC
Bunch charge [nC]	3.5
Beam current [mA]	50
RMS bunch length [mm]	2
Beam energy [GeV]	5-30
Number of passes	6
Operation mode	CW

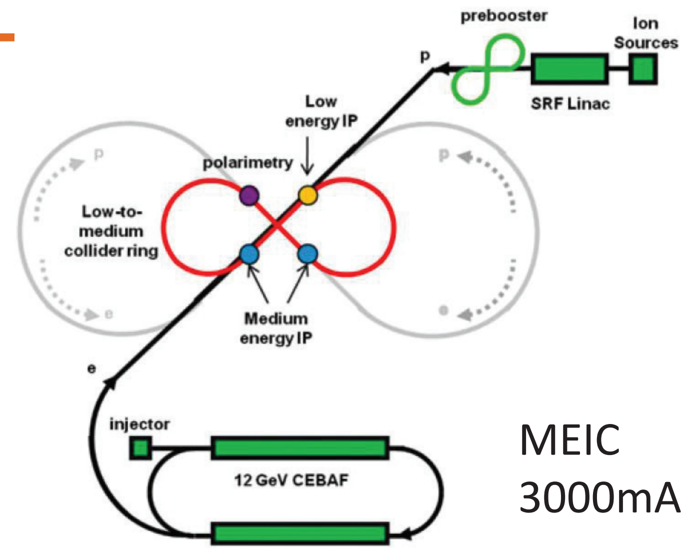


eRHIC

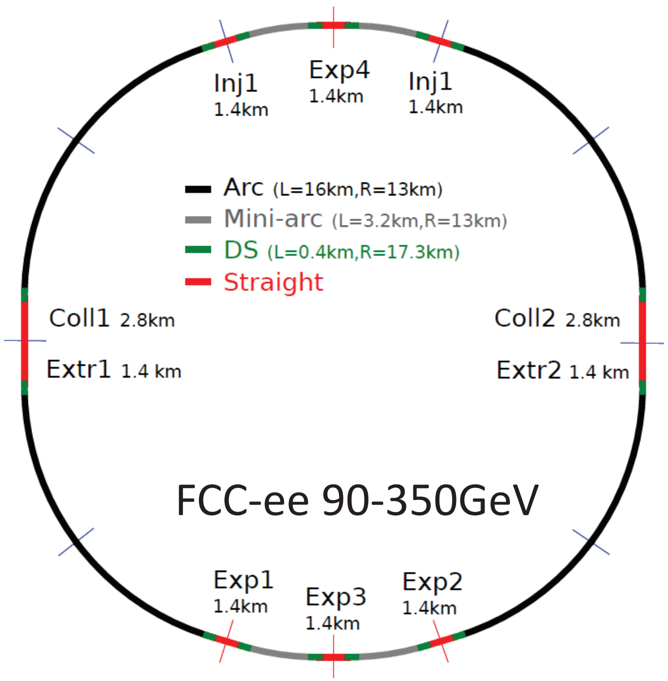
6-turn ERL acceleration
1-turn ERL e cooling

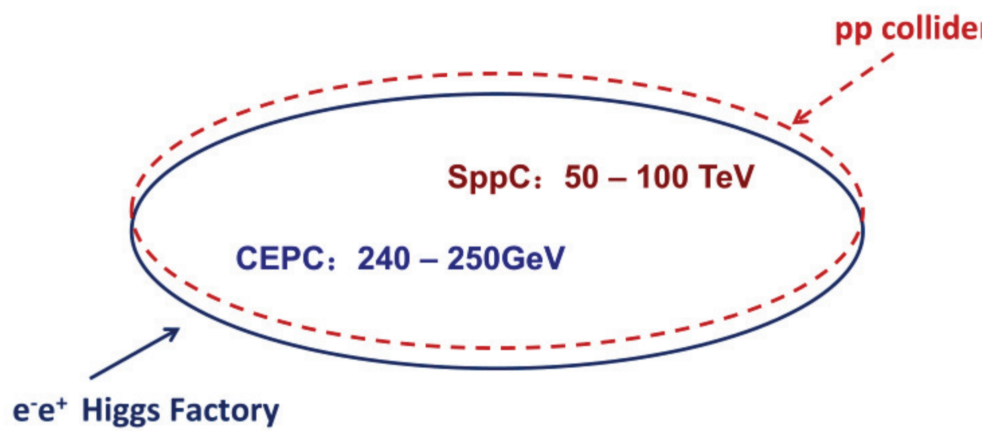
Circular collider

- Several kW HOM power
- Tens to 3000mA beam current



MEIC
3000mA e^-





16.6/33.2mA

Beam parameters for highest luminosity e-p design

	HERA		ENC		MEIC		eRHIC		LHeC linac-ring		LHeC ring-ring	
	p	*e*	*p*	*e*	*p*	*e*	*p*	*e*	*p*	*e*	*p*	*e*
Energy, GeV	920	27.5	15	3	60	5	250	20	7000	60	7000	60
Bunch frequency, MHz	10.4		52 (104)		750		14.1		20		40	
Bunch intensity, 10^{11}	0.72	0.29	0.54(0.36)	2.3	0.042	0.25	2	0.22	1.7	0.02	1.7	0.2
Beam current, mA	100	40	450 (600)	1900	500	3000	420	50	430	6.4	860	100
Normalised rms emittance, x/y, µm	5	1100/ 180	2.3/ 0.8	930/ 320	0.35/ 0.07	54/11	0.18	26.4	3.75	50	3.75	580/ 290
β*, x/y, cm	245/18	63/26	30 (10)	30	4/0.8	4/0.8	5	5	10	12	180/50	18/10
Beam size at IP, x/y, µm	112/30		200/120		15/3		6/6		7/7		30/16	
Bunch length, cm	19	1	30 (20)	10	1	0.75	8	0.2	8	0.03	8	1
Polarization, %	0	45	80	80	>70	80	70	80	0	90	0	40
Peak Luminosity, 10^{33} cm^{-2}s^{-1}	0.04		0.2 (0.6)		14.2		9.7		1.0		1.7	

Vadim Ptitsyn, Overview of asymmetric hadron-electron colliders

Impedance

- ERL BBU threshold:

$$I_{\text{th}} = -\frac{2c^2}{e(\frac{R}{Q})_\lambda Q_\lambda \omega_\lambda} \frac{1}{T_{12} \sin\omega_\lambda t_r},$$

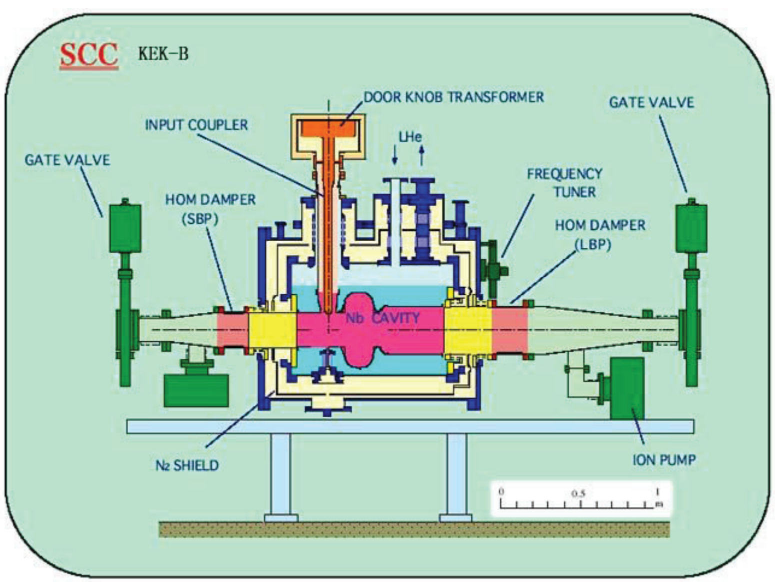
- Circular Collider:

$$R_L^{thresh} = \frac{2(E_0 / e)\upsilon_s}{N_c f_L I_0 \alpha_p \tau_z}$$

$$R_T^{thresh} = \frac{2(E_0 / e)}{N_c f_{rev} I_0 \beta_{x,y} \tau_{x,y}}$$

High current SC cavity

- BEPCII adopted single cell SC cavity to deliver about 1A beam current(from KEK-B, the backup one is made by IHEP).
- Simple, heavy HOM damping, high beam current.
- About 3m long, the efficiency length is about 0.3m, low accelerating efficiency.
- Cost per length for accelerating is high comparing to multi-cell cavity.



No. of cells

- Higher cell numbers, lower the E-H fields at the HOM damper. Also trapped mode may happen.

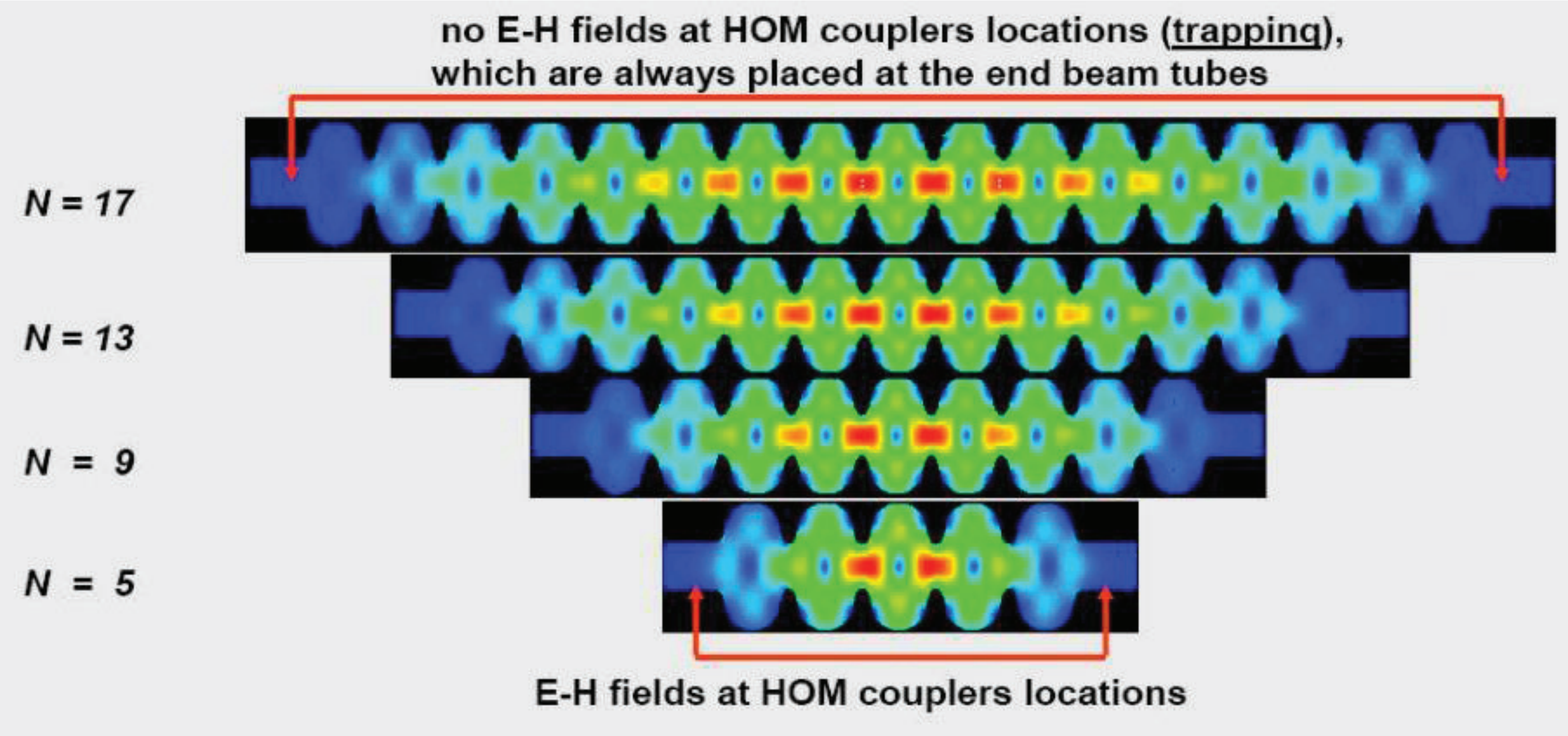
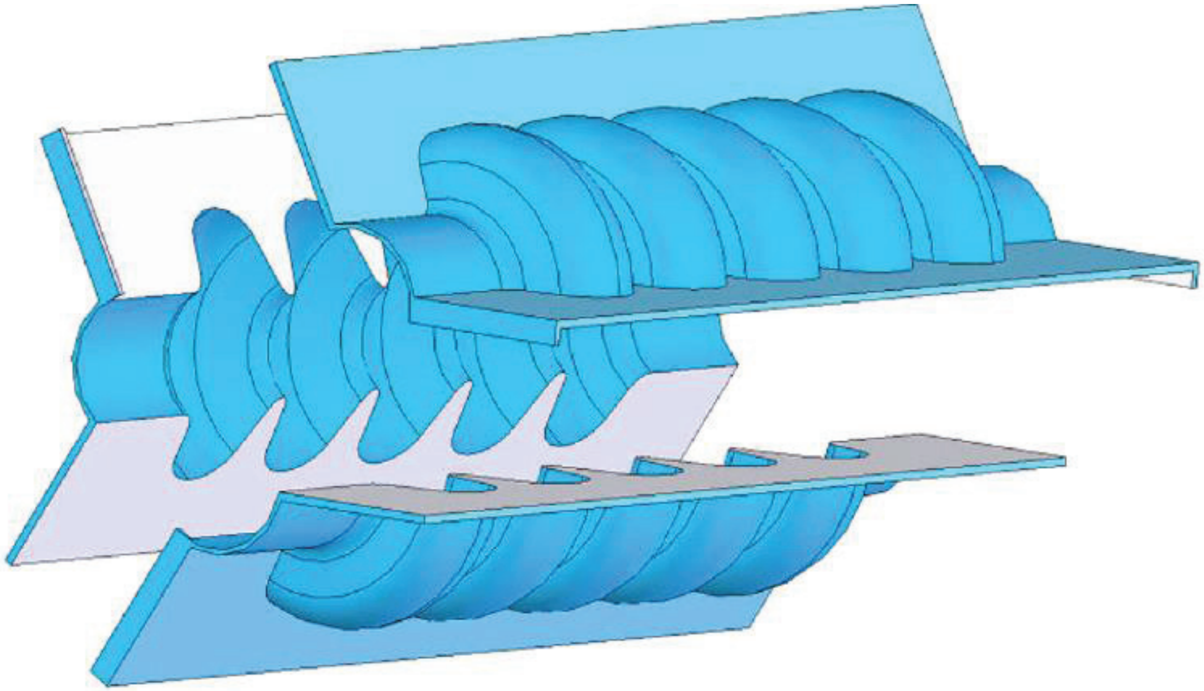
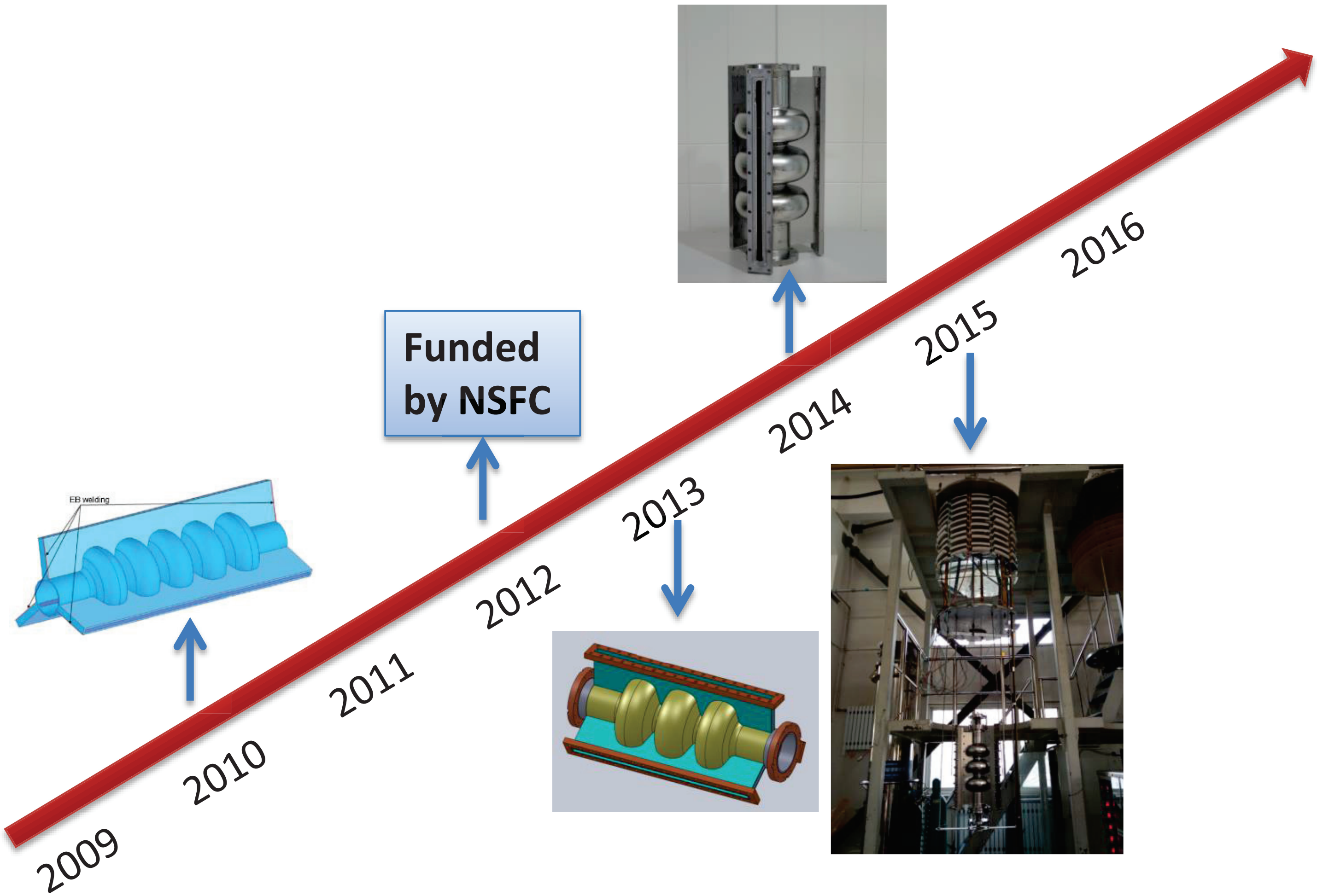


Figure from Mathias Liepe's paper

- Why not open the damping structure on the cell!

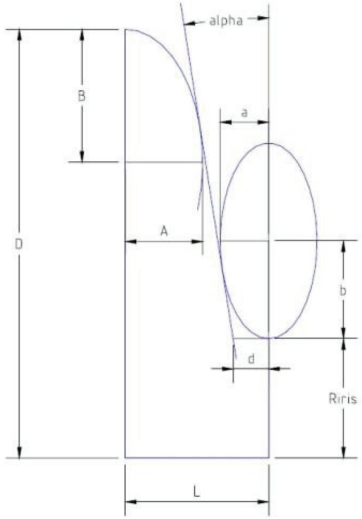


Slotted cavity development time line



Cavity parameters

- Proper cell numbers. For the test cavity, we chose a 3-cell cavity to simplify the fabrication and lower the cost.
- Minimized E_{pk}/E_{acc} and B_{pk}/E_{acc}.
- No hard multipacting barrier caused by cavity shape and the slotted structure.
- Frequency can be easily tuned.
- Easy to fabricate.



	Center cell	End cell
L (mm)	57.7	57.7
Riris (cm)	41.152	48.733
Requator(mm)	103.899	103.899
A(mm)	37.904	35.434
B(mm)	23.825	23.55
a(mm)	10.83	16.786
b(mm)	16.244	16.244
Frequency(GHz)	1.30108	
E_p/E_{acc}	3.57	
H_p/E_{acc}mT/(MV/m)	5.72	
r/Q [Ω]	268.9	
k [%]	2.7%	
Field flatness [%]	>97%	

Why low loss for slotted cavity?

$$Q_0 = \frac{G}{R_s}$$

$$G = \frac{\omega_0 \mu_0 \int_V |\boldsymbol{H}|^2 dv}{\int_S |\boldsymbol{H}|^2 ds}$$

Why low loss for slotted cavity?

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Why low loss for slotted cavity?

$$Q_0 = \frac{G}{R_s}$$

← Constant

$$G = \frac{\omega_0 \mu_0 \int_V |\boldsymbol{H}|^2 dv}{\int_S |\boldsymbol{H}|^2 ds}$$

Why low loss for slotted cavity?

$$Q_0 = \frac{G}{R_s}$$ ← Constant

$$G = \frac{\omega_0 \mu_0 \int_V |\boldsymbol{H}|^2 dv}{\int_S |\boldsymbol{H}|^2 ds}$$

Constant

Why low loss for slotted cavity?

$$Q_0 = \frac{G}{R_s}$$ ← Constant

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$$Q_0 = \frac{G}{R_s}$$

Constant

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Constant

Why low loss for slotted cavity?

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← Constant

$$G = \frac{\omega_0 \mu_0 \int_V |\boldsymbol{H}|^2 dv}{\int_S |\boldsymbol{H}|^2 ds}$$

← Constant

↓

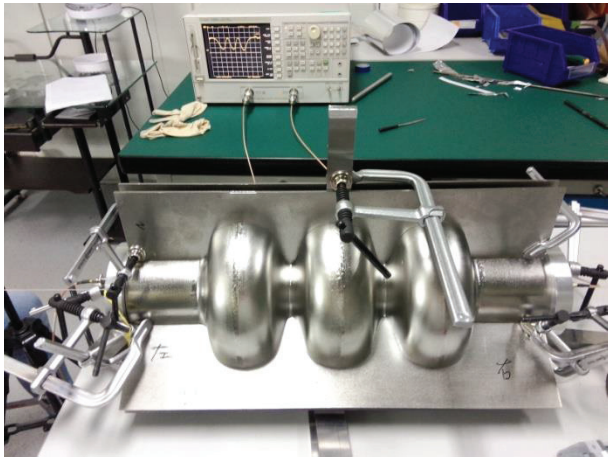
FABRICATION

Fabrication procedure

Fabrication procedure

Fabrication procedure

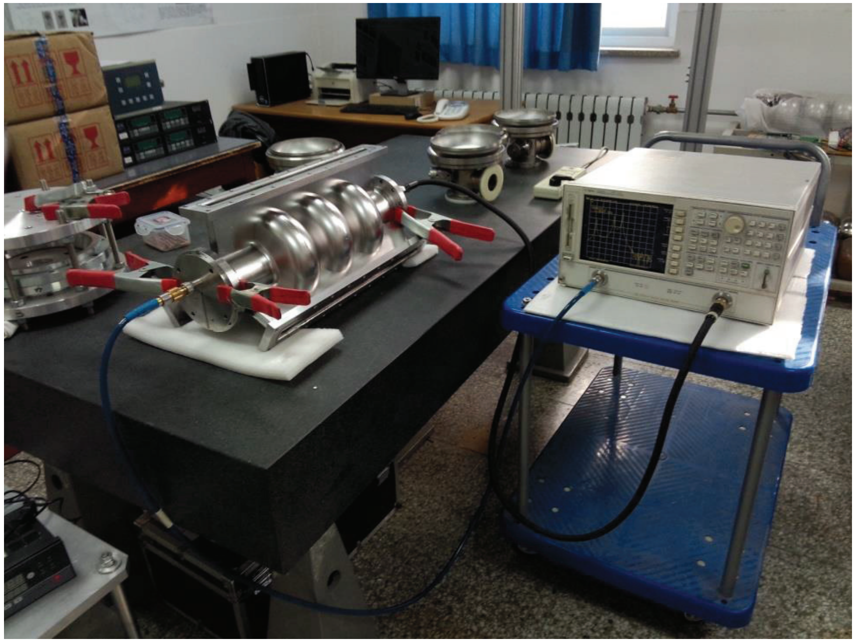
Welding procedure



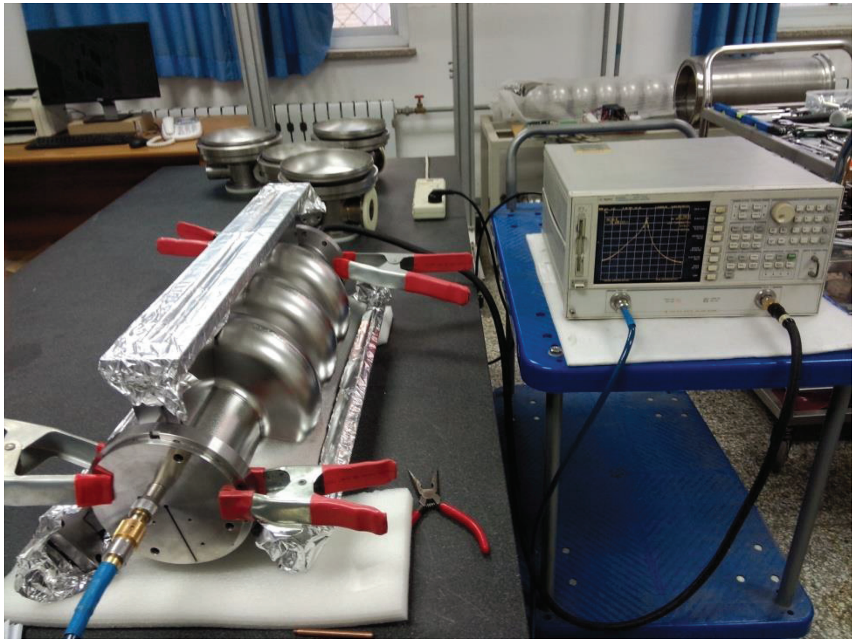
ROOM TEMPERATURE RF TEST

HOM measurement

- ✓ The measured frequency of the π mode of TM_{010} is 1.3013 GHz.
- ✓ The Q_Ls of the fundamental π mode are 6240 and 6110 w/wo covers separately.
- ✓ The Q_L of the main dipole mode decreased obviously when opening the covers, the value changed from 2047 to 344 (the calculation value is 446).



Without covers



With covers

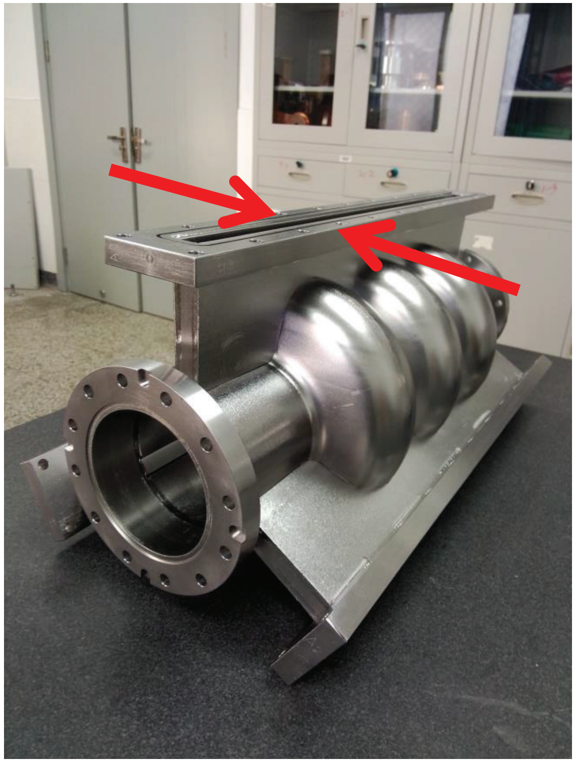
Comparison

Measured Value				Calculated Value	
F (GHz, with covers)	Q_L (with covers, still have field leak)	Q_L ($\approx Q_e$, without covers)	F (GHz, without covers)	Q_e (without covers)	F (GHz)
1.524	560	x	x	5.2	1.525
1.5312	714	x	x	-	-
1.5926	624	x	x	-	-
1.5979	606	100	1.599	2.17	1.599(TE_{111})
1.677	1037	x	x	5.74	1.676
1.68	995	x	x	-	-
1.713	94	x	x	-	-
1.7526	1192	x	x	-	-
1.7492	1280	x	x	20.4/8.8	1.754/1.747
1.794	1312	x	x	-	-
1.8405	2047	344	1.842	446	1.855(TM_{110})
1.9	445	x	x	-	-
1.973	714	x	x	15.9	1.973
2.052	470	x	x	5.43	2.043
2.086	615	x	x	15.2	2.093
2.184	531	172	2.173	14.2	2.175
2.1985	321	x	x	-	-
2.254	1450	x	x	20.7	2.252
2.324	1990	2136	2.324	185961	2.326 *
2.365	1224	x	x	-	-
2.4	1071	630	2.4	-	-
2.437	800	667	2.437	105.1	2.439 *

*Notes on TABLE III: Many HOMs disappeared in the network analyzer when opening the waveguide port as the Q_L of these mode decreased below 10 or so. These modes are depicted by “x”. Since there are several calculated modes around the measured frequency or the frequency shift between measured frequency and calculated frequency is large, we use “-” to depict. * depicts quadruple mode.

Tuning

- The cavity working at a gradient around 15-20 MV/m which is not an issue for today's technology and 90% field flatness is acceptable.
- Squeezing and stretching the long edge of the slot waveguide in circumferential direction can also tune the fundamental mode frequency.
- The *df/ds* is 750 kHz/mm measured on the 1.3 GHz 3-cell prototype cavity
- the squeezing and stretching method is a good option to tune the frequency.



POST PROCESSING

Post processing

- BCP for 120um, BCP for 60 minuets and then upside down for another 60 minuets.
- 10h 650 °C annealing, flanges covered with Nb film with small holes.
- Light BCP of 20um.
- HPR 200 minuets.
- Dried in clean room
- Leak check
- 120 °C bake for about 60 hours.

VERTICAL TEST

Vertical test preparation

LLRF test

cavity

Vertical test

- Established 1.3GHz vertical test system
- Calibrated the coupler probe and pick-up probe
- 4.2K vertical test, limited by power, the accelerating gradient of the cavity reached 2.4MV/m ($Q0=1.4x10^8$)
- Verified the probability of the slotted cavity working at 4.2K
- The cavity will be tested at 2K in future.

Summary

- A 1.3 GHz 3-cell slotted cavity prototype has been fabricated.
- The cavity was processed at the standard procedure for SC cavity at IHEP.
- 4.2K vertical test was carried out and the cavity show great potential on ERL application
- 2K vertical test will be done soon

Thank you!